| | |
|---|---|
| AP42 Section: | 13.4 |
| Background Chapter | 4 |
| Reference: | 1 |
| Title: | Cooling Tower Test Report, Typical Drift Test,<br>Kansas City, Missouri, January 12, 1990.<br><br>Midwest Research Institute (l990). |

# Cooling Tower Test Report
## Typical Drift Test

On a 4-Cell, Mechanical-Draft,
Counter-Flow Cooling Tower

For the MRI Cooling Tower Test Group
Internal Drift Research and Development Program

MRI Project No. 9150

**January 12, 1990**

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**January 12, 1990**

## PREFACE

This report was prepared by the MRI Cooling Tower Test Group to document a cooling tower drift test conducted as a part of an internal research and development program. Any contractual questions should be directed to Mr. Dennis Barger, Senior Contract Administrator. Any technical questions regarding this test should be directed to Mr. Nicholas M. Stich, Test Engineer or Mr. Thomas E. Weast, Senior Test Engineer at MRI.

MIDWEST RESEARCH INSTITUTE

Nicholas M. Stich
Test Engineer
Cooling Tower Test Group

Approved:

Chatten Cowherd, Director
Environmental Systems Department

January 12, 1990

## SUMMARY

The Midwest Research Institute (MRI) Cooling Tower Test Group conducted a research and development drift test on one cell of a 4-cell, mechanical-draft, counter-flow cooling tower located at a typical plant.

Cooling tower drift is defined as the percent of circulating water flow which exits from the tower in the form of fine water droplets and aerosols entrained in the exhaust air. The drift from the tower was determined by isokinetically sampling a representative fraction of the tower airflow. The amount of droplets and aerosol leaving the stack was measured by a sampling train consisting of four impingers and a backup filter. The collection media were analyzed for impurities that had been dissolved or suspended in the recirculating water. Drift droplets contain the same impurities as the circulating water.

Inductively coupled argon plasma spectroscopy (ICP), an extremely sensitive detection technique, was then used to measure the concentrations of 32 trace constituents in the basin water and in the sample collected from the airflow exiting the fan stack. Two of the trace elements (Na and Mg) were found to be sufficiently concentrated for selection as representatives of the tower emissions. The drift rate was calculated from the ratio of the selected trace constituent in the isokinetic sampling train to the same trace constituent in the basin water.

The calculated drift rates for the cooling tower cell sampled were 0.00204% and 0.00278%, respectively, for the two tracers selected. When the results are averaged for both tracers, a drift rate of 0.00241% is obtained. The average drift rate for the cell sampled should be representative of the drift rate of the tower, since tower cell geometry and operation parameters were identical.

# SECTION 1

# INTRODUCTION

The Midwest Research Institute (MRI) Cooling Tower Test Group conducted a research and development drift test using modified EPA Method 13A on a mechanical-draft, counter-flow cooling tower. Modified EPA Method 13A is a test procedure to isokinetically sample stack exhaust emissions.

The cooling tower is a 4-cell tower located at a typical plant. Mr. Nicholas M. Stich and Mr. Thomas E. Weast of MRI performed the work. Portions of the test were observed by representatives of the manufacturer and owner of the cooling tower.

## SECTION 2

## DESCRIPTION OF TEST SITE

The cooling tower that was tested provides cooling water to process steam condensers. The cooling tower is located in an unobstructed area adjacent to the plant.

The cooling tower consists of four mechanical-draft, counter-flow cells in a continuous straight line with a common cold water basin beneath the tower. Each cell is equipped with a 28-ft diameter fan driven by an electric motor. Each fan has a 96-in diameter hub seal. The fan stacks were 324 in. in diameter at the sample plane location and constructed of fiberglass.

An underground steel conduit returns hot water from the plant to the cooling tower. The main line then tees off to feed individual cell risers. Pitot taps for water flow measurement were located in the riser lines.

The cold water from the cooling tower basin is collected in the pump forebay adjacent to the tower where two pumps are used to return cold water to the plant. A tap with a temporary standpipe was used for the collection of basin water samples.

## SECTION 3

## SAMPLING SEQUENCE

The test sequence for the drift test was as follows:

1. Water flow and fan horsepower were measured and the tower operations monitored.

2. Drift sample and airflow measurement locations were calculated.

3. A basin water sample was collected.

4. Drift from the selected fan stack was isokinetically sampled.

5. A second basin water sample was collected during the middle of the drift test.

6. Isokinetic drift sampling of the fan was completed.

7. A third basin sample was collected at the conclusion of the test. The three basin samples were composited into one basin water sample.

8. The drift samples were recovered from the sample collection system.

9. The basin composite, a water blank, and the drift impinger samples were each acid stabilized and transported to the laboratory for analysis.

## SECTION 4

## DRIFT TEST EQUIPMENT

### SAMPLE LOCATION

Since drift consists of droplets or aerosols exiting the tower, the drift tests were conducted at the top of the fan stack. The proximity of the sample locations to the fan required that the station locations be adjusted for the hub effect. Sample locations were determined for 10-point radial traverses using the equation for equal annular areas for fan discharge from Chapter 5 of the CTI Manual.[1]

### AIR PITOT-DRIFT PROBE

Since cyclonic flow can affect the drift results, the sampling technique was adjusted to eliminate this bias. A special air pitot-drift probe assembly was developed by MRI to allow unbiased sampling. Airflow, fan discharge temperature, and the angle of cyclonic flow were measured with this probe assembly.

The "alignment approach"[2] was used to ensure isokinetic sampling. If the sample nozzle is oriented in the direction of the stack axis, but is not aligned with the airflow, the effective velocity through the nozzle opening is reduced by the cosine of the angle between the airflow and the stack axis. If the sample nozzle is aligned with the airflow, but is not oriented in the direction of the stack axis, the sample proportionality will be compromised. Isokinetic and proportional sampling needs were satisfied by orienting the sample probe to the direction of the airflow and by adjusting the nominal base sampling time by the cosine of the cyclonic flow angle.

The air pitot-drift probe assembly was equipped with:

1. S-type primary pitot tips which were connected to a manometer to measure air velocity.

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[1] Cooling Tower Institute, Cooling Tower Manual, Houston, Texas, 1983.

[2] Peeler, J.W.; Phoenix, F. J.; and Grove, D. J.; "Characterization of Cyclonic Flow and Analysis of Particulate Sampling Approaches at Asphalt Plants;" Published in Selected Papers on Particulate Sampling in Cyclonic Flow, for USEPA Research Triangle Park, NC; by Entropy Environmentalists, Inc.; March 1980

2. Secondary pitot tips which were positioned at 90° from the primary pitot tips. The secondary set of pitot tips was connected to a separate manometer to align the probe and compensate for any cyclonic flow effects.

3. A temperature sensor that was connected to a digital readout for measurement of the stack temperature.

4. A protractor that was attached to the probe assembly to determine the angle that the probe was rotated during the cyclonic flow determination.

5. A stainless steel sample nozzle and flexible Teflon sample probe, which were connected to the drift collection train.

## DRIFT COLLECTION TRAIN

The drift collection train consisted of four high-capacity impingers and a filter assembly. The first two impingers contained distilled water and were used to scrub out the aerosols and water droplets. The third impinger was used to collect any water droplets that might have been carried over from the previous impingers. The final collection media was a filter placed between the third impinger which was dry and the fourth impinger which contained silica gel. The sampling train was kept iced during testing to help reduce the water vapor pressure and to further improve collection efficiency.

## CONTROL CONSOLE AND PUMP

The control console and pump were a High Volume Sampling System (HVSS) consistent with EPA Method 13A requirements. The impinger train was connected to the console via a sample line through the leak-free vacuum pump capable of up to 4 $ft^3$/min. The modular vacuum pump has two control valves to adjust and maintain the desired sampling rate. The console contains a calibrated dry gas meter, digital temperature readout, manometers, and associated controls.

## SECTION 5

## DRIFT TEST METHODS

Testing was conducted during 1989. The tower circulating water flow was 101.5% of design, and the fan horsepower was 89.2% of design. The test data were acquired in accordance with applicable portions of the CTI ATC-105 (1982) test code and modified EPA Method 13A. The individual parameters were measured as follows:

- Total circulating water flow was measured with two 20-point traverses of the hot water return risers to the tower. A standard Simplex-Leopold type pitot tube was used to measure the velocity at each point. An air-over-water manometer was used for measuring the differential pressure between the impact and reference orifices of the pitot tube.

- Fan motor power was measured with a clamp-on digital-type kilowatt meter using the two-wattmeter method.

- Air velocity was measured with four 10-point radial traverses of the fan stack using the predetermined sampling locations. At each point, the MRI air pitot-drift probe assembly was rotated until the pressure difference across the secondary pitot tips was zero. When this zero differential was obtained, the primary probe was aligned with the flow and the protractor read to determine the cyclonic flow angle. The probe assembly was then used to measure the velocity pressure and temperature at the sample point.

- The isokinetic sampling rate and proportional sample test duration were determined from the previously determined velocity pressure, stack temperature, and cyclonic flow angle. A computer program calculated the required sample volume, isokinetic flow rate, and the adjusted base sample time.

- After the proper sampling rate was determined, sampling at each traverse location was commenced by turning on the sample pump and simultaneously activating the variable timer function of the Epson HX-20 computer. After each sample had been collected, the pump was shut off, the air pitot-probe assembly was relocated to the next sample location, and the above procedure repeated until all 40 points had been sampled.

- The impinger train was sealed and removed from the cooling tower to a sample recovery location where the sample recovery was performed.

The drift sample was recovered by using distilled deionized water to rinse the stainless steel nozzle and flexible Teflon probe into the contents of the first impinger. The impinger volumes and rinse volumes were measured and recorded. The impinger contents and all rinses were transferred to a sample bottle. A water blank was taken from the distilled deionized water supply used for the initial impinger volumes and rinses. Both the drift impinger samples and the water blank were nitric acid stabilized and then returned to MRI for further analysis.

- Basin water samples were taken at the beginning, the midpoint, and the conclusion of the drift sample test. The basin water samples were taken from a thermal well that was installed on the discharge side of the circulating water flow pump. The samples were collected after the thermal well line was purged. The three samples were collected and then combined into one composite basin water sample. The composite basin sample was stabilized with nitric acid in the same manner as the impinger and water blank samples. The composite basin water sample was returned to MRI for further analysis.

## SECTION 6

## SAMPLE ANALYSIS

The samples were returned to MRI where custody of the samples was transferred to the University of Missouri Environmental Trace Substances Research Center (ETSRC) for analysis. Quantitative analysis of selected trace elements in both the tower basin water samples and the collected drift samples was performed by using ICP. Method 3050 was used to prepare the drift and basin water samples for the analysis by Method 6010 as described below. The instrument used for the ICP analysis was a Jarrell-Ash Model 1100 Mark III with 40 analytical channels controlled by a Digital Equipment Company DEC 11/23+ computer system. The instrument was standardized with a series of seven standard solutions containing 36 elements. After the standardization, the detection limit was determined by taking 10 integrations of the zero standard. Three times the standard deviation of the mean was used as the final detection limit. The final detection limit for each element was further increased by 4% of the magnitude of the spectral interferences from the other elements present in the sample.

Instrument quality control samples were analyzed to check the ICP operation. If the values were acceptable, the samples were then analyzed. Standards were run every 10 to 15 samples to check for instrument drift. If the instrument drift was more than 5%, the instrument was restandardized. After the analyses were completed, the data were transferred to a Perkin-Elmer LMIS 2000 computer for calculation of the analytical results. The data were calculated using an ICP calculation program written by the ETSRC personnel to correct for blanks, standard drift, spectral interferences, sample weight, sample volume, and dilution. The data were then checked to correct for possible errors in sample number, weight, volumes, and dilution. After quality control was reviewed, the analysis report was delivered to MRI.

### METHOD 3050

Method 3050 is an acid digestion procedure used to prepare sediments, sludges, and soil samples for analysis by flame or furnace atomic absorption spectroscopy (FLAA and GFAA, respectively) or by ICP.

A representative sample is digested in nitric acid and hydrogen peroxide. The digestate is then refluxed with either nitric acid or hydrochloric acid. Diluted hydrochloric acid is used as the final reflux acid for (1) the ICP analysis of As and Se and (2) the flame AA or ICP analysis of Al, Ba, Ca, Cd, Cr, Co, Cu, Fe, Mo, Pb, Ni, K, Na, Tl, V, and Zn. Diluted nitric acid is employed as the final dilution acid for the furnace AA analysis of As, Be, Cd, Cr, Co, Pb, Mo, Se, Tl, and V.

**METHOD 6010**

Method 6010 describes the procedures for ICP in determining elements including metals in solution. This method is applicable to a large number of metals and wastes. All matrices, including ground water, aqueous samples, EP extracts, industrial wastes, soils, sludges, sediments, and other solid wastes, require digestion prior to analysis.

ICP is used for the simultaneous or sequential, multielemental determination of elements by measuring the element-emitted light with optical spectrometry. Samples are nebulized, and the resulting emission spectra are produced by a radio-frequency inductively coupled plasma. The spectra are dispersed by a grating spectrometer, and the intensities of the lines are monitored by photomultiplier tubes. Background correction is required for trace element determination.

In direct aspiration atomic absorption spectroscopy, a sample is aspirated and atomized in a flame. A light beam from a hollow cathode lamp or an electrodeless discharge lamp is directed through the flame into a monochromator and onto a detector that measures the amount of absorbed light. Absorption depends upon the presence of free unexcited ground-state atoms in the flame. Because the wavelength of the light beam is characteristic of only the metal being determined, the light energy absorbed by the flame is a measure of the concentration of that metal in the sample. This principle is the basis of atomic absorption.

## SECTION 7

## RESULTS AND CONCLUSIONS

The following equation is used by the MRI drift computer program to calculate the drift results:

$$\% \text{ Drift} = 100 \bullet ( NFA / NZA ) * [ NWT / ( WFR * EQT * BTC )]$$

NFA = Net fan area ($ft^2$)
NZA = Nozzle area ($ft^2$)
NWT = Net weight of tracer in the sampling train (µg)
WFR = Water flow rate (g/min)
EQT = Equivalent sample time (240 min)
BTC = Basin tracer concentration (µg/g)

The table below summarizes the results of the laboratory analysis and drift calculations.

| Tracer analyzed | Tracer net wt. (µg) | Basin conc. (µg/g) | % Drift |
|---|---|---|---|
| Mg | 54.11 | 146.0 | 0.00204 |
| Na | 294.7 | 585.0 | 0.00278 |

The results of the research and development drift test conducted by the MRI Cooling Tower Test Group indicate that the cell tested had an average drift rate of 0.00241%. The drift rate of the cell tested should be representative of the average drift rate of the tower, since tower cell geometry and operation parameters were identical.

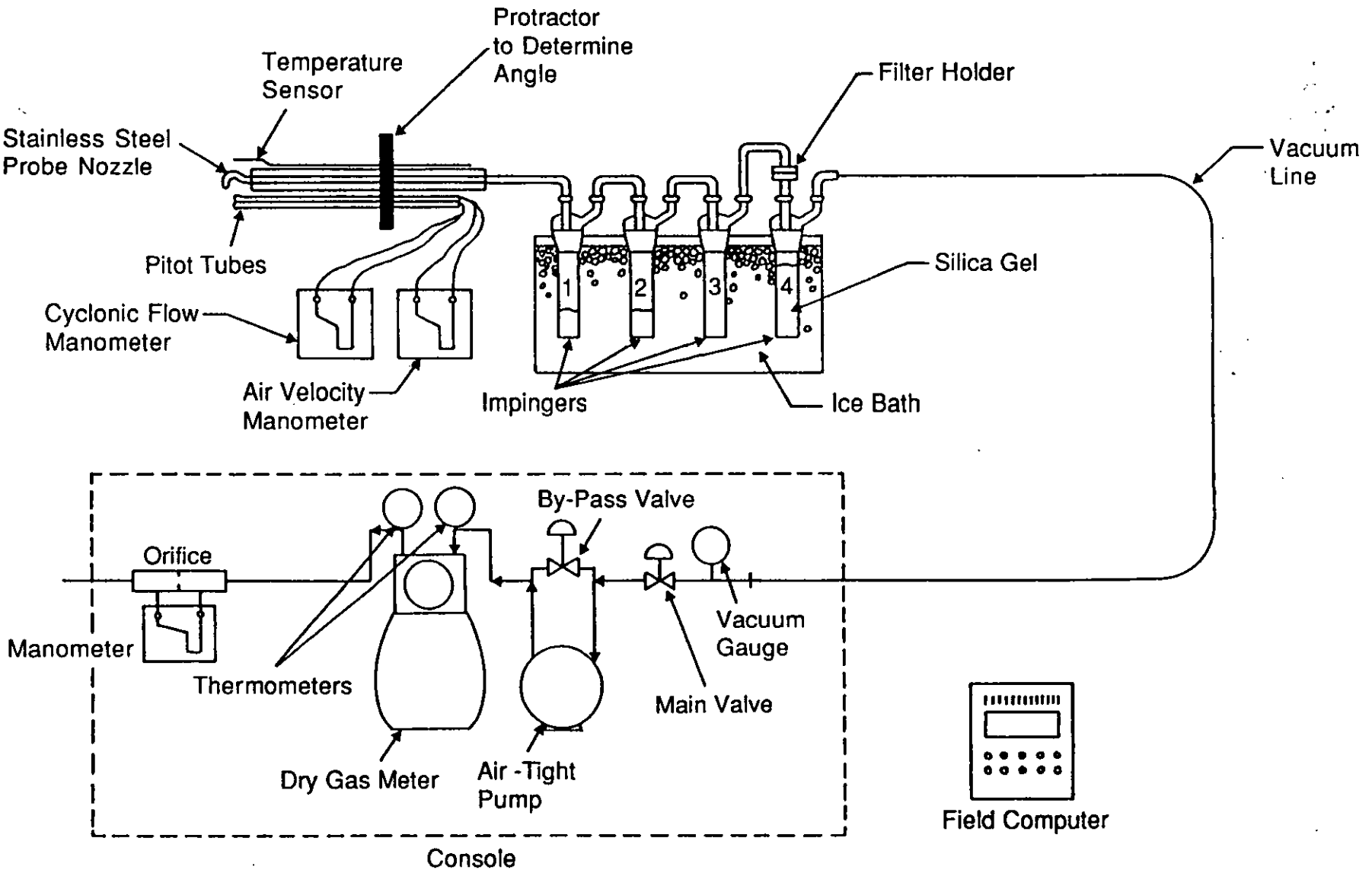


Figure 1. Typical draft collection train.

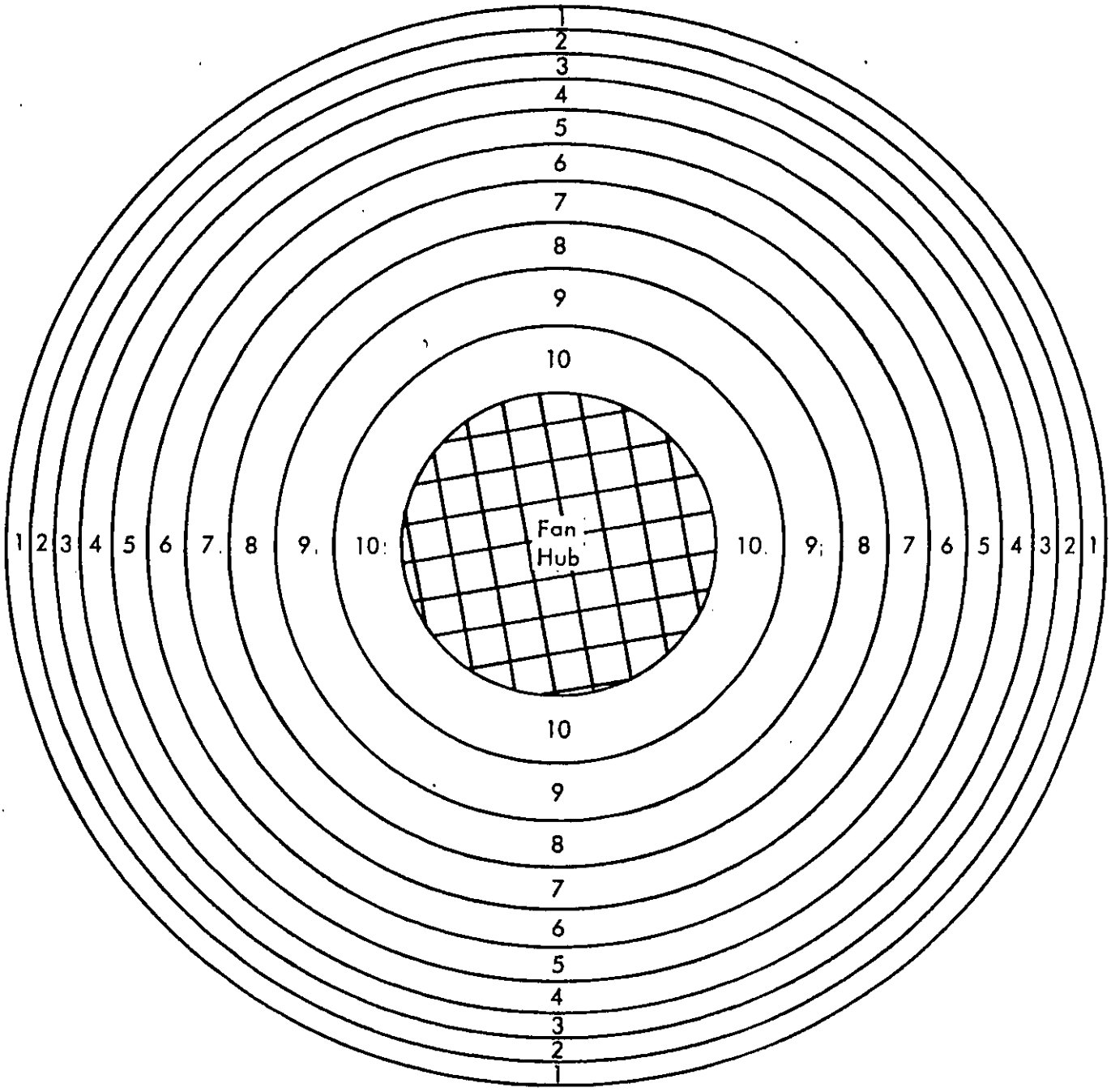


Figure 2 - Sampling Points were Located in the Center of Each of the Equal Area Zones. Numbers 1 to 10 indicate the distances from the fans inside wall to the respective sampling points.

APPENDIX A

SUMMARY OF RESULTS

RESEARCH AND DEVELOPMENT
DRIFT TEST
ON ONE CELL OF A
4-CELL, MECHANICAL-DRAFT, COUNTER-FLOW
COOLING TOWER

1989

FILE NAME :
RUN # :
LOCATION :
DATE :
PROJECT # :

11-26-1989
PROGRAM VER.
04/26/89 V3.3

EQUIVALENT SAMPLING TIME (MINUTES)= 240

NOZZLE DIAMETER (SQUARE FEET)= 0.00106

NET FREE STACK AREA (SQUARE FEET)= 522.29

WATERFLOW RATE PER CELL ( GPM )= 9,818.0

AIRFLOW RATE ( POUNDS DRY AIR/MIN)= 48,299

---------- DRIFT TEST RESULTS ----------

| TRACER ANALYZED | BASIN CONC. (mcg/g) | TRACER NET WT. (mcg) | DRIFT RATE l/min | DRIFT % OF GPM | DRIFT % OF DRY AIR |
|---|---|---|---|---|---|
| Mg | 146.0 | 54.11 | 0.8 | 0.00204 | 0.00347 |
| Na | 585.0 | 294.70 | 1.0 | 0.00278 | 0.00471 |
| AVERAGE DRIFT ALL OF TRACERS | | | 0.9 | 0.00241 | 0.00409 |

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DRIFT DATA REDUCTION

| | | | | | |
|---|---|---|---|---|---|
| Sample Volume | 733 | Rinse Volume | 169 | Filter Sample Volume | 50 |
| Water Blank Volume | 419 | Initial Water Vol. | 250 | | |

| DESCRIPTION | MG | NA | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Basin Water (mcg/g) | 146 | 585 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Impinger (mcg/g) | .073 | .4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Filter (mcg/g) | .032 | .03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water Blank (mcg/g) | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Filter Blank (mcg) | 1.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| CALCULATED VALUES | | | | | | | | | | |
| Impinger Catch (mcg) | 53.51 | 293.20 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| Filter (mcg) | 1.60 | 1.50 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| Water Blank (mcg) | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| Filter Blank (mcg) | 1.00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| Net Sample (mcg) | 54.11 | 294.70 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

MIDWEST RESEARCH INSTITUTE
SUMMARY SHEET

File #: Location: Counter-Flow

Date: 1989

| ELM | DETECTION LIMIT basin | DETECTION LIMIT impinger | BASIN CONC. | IMPG. CONC. | RATIO BASIN vs LIMIT | RATIO IMP vs LIMIT | RATIO IMP vs BASIN | ELEMENT SELECT |
|---|---|---|---|---|---|---|---|---|
| AG | .01 | .01 | NA | NA | NA | NA | NA | |
| AL | .02 | .02 | .26 | NA | 13 | NA | NA | |
| AS | .05 | .05 | NA | NA | NA | NA | NA | |
| B | .03 | .03 | 1.1 | NA | 37 | NA | NA | |
| BA | .0005 | .0005 | .102 | .0007 | 204 | 1 | NA | |
| BE | .0007 | .0006 | NA | NA | NA | NA | NA | |
| BI | .04 | .04 | NA | NA | NA | NA | NA | |
| CA | .4 | .2 | 308 | .3 | 770 | 2 | NA | |
| CD | .006 | .006 | NA | NA | NA | NA | NA | |
| CO | .01 | .01 | NA | NA | NA | NA | NA | |
| CR | .02 | .02 | NA | NA | NA | NA | NA | |
| CU | .003 | .002 | .493 | .006 | 164 | 3 | NA | |
| FE | .009 | .009 | .7 | .2 | 78 | 22 | 28.57 | |
| K | .2 | .2 | 47.1 | NA | 236 | NA | NA | |
| W | .3 | .3 | NA | NA | NA | NA | NA | |
| LI | .002 | .002 | .21 | .027 | 105 | 14 | 12.86 | 12.86 |
| MG | .03 | .001 | 146 | .073 | 4867 | 73 | .05 | .05 |
| MN | .006 | .006 | .01 | .032 | 2 | 5 | NA | |
| MO | .007 | .007 | .059 | NA | 8 | NA | NA | |
| NA | 1 | .01 | 585 | .4 | 585 | 40 | .07 | .07 |
| NI | .02 | .02 | NA | .31 | NA | 16 | NA | |
| P | .3 | .3 | 2.6 | NA | 9 | NA | NA | |
| PB | .04 | .04 | NA | NA | NA | NA | NA | |
| SB | .05 | .04 | .1 | NA | 2 | NA | NA | |
| SE | .1 | .1 | NA | NA | NA | NA | NA | |
| SI | .02 | .02 | .16 | .17 | 8 | 9 | NA | |
| SN | .1 | .1 | NA | NA | NA | NA | NA | |
| SR | .003 | .003 | 3.25 | .003 | 1083 | 1 | NA | |
| TI | .002 | .002 | .01 | .006 | 5 | 3 | NA | |
| TL | .04 | .04 | NA | NA | NA | NA | NA | |
| V | .01 | .01 | NA | NA | NA | NA | NA | |
| ZN | .006 | .006 | .36 | .53 | 60 | 88 | NA | |
| | | | | | | COUNT | 4 | 3 |
| | | | | | | SUM | 41.55 | 12.98 |
| | | | | | | AVG | 10.39 | 4.33 |
| | | | | | | STD | 11.73 | 6.03 |
| | | | | | | U-BOUND | 22.11 | 10.36 |
| | | | | | | L-BOUND | -1.34 | -1.71 |

Elements Eliminated

FE
ZN

Data to date has shown these elements to be inconsistent

| | |
|---|---|
| FILE NAME : | 11-26-1989 |
| RUN # : | PROGRAM VER. |
| LOCATION : | 04/26/89 V3.3 |
| DATE : | |
| PROJECT # : | |

| | |
|---|---|
| INITIAL METER VOLUME (CUBIC FEET)= | 372.000 |
| FINAL METER VOLUME (CUBIC FEET)= | 740.200 |
| METER FACTOR= | 0.9869 |
| FINAL LEAK RATE (CU FT/MIN)= | 0.010 |
| NET METER VOLUME (CUBIC FEET)= | 363.377 |
| GAS VOLUME (DRY STANDARD CUBIC FEET)= | 317.199 |
| BAROMETRIC PRESSURE (IN. HG)= | 28.25 |
| STATIC PRESSURE (INCHES H2O)= | 0.00 |
| PERCENT OXYGEN= | 20.9 |
| PERCENT CARBON DIOXIDE= | 0.0 |
| MOISTURE COLLECTED (ML)= | 0.0 |
| PERCENT WATER= | 5.8 |
| DRY MOLECULAR WEIGHT= | 28.84 |
| WET MOLECULAR WEIGHT= | 28.20 |
| AVERAGE METER TEMPERATURE (F.)= | 113.2 |
| AVERAGE DELTA H (IN. H2O)= | 1.57 |
| WEIGHTED SUM of SQR DELTA P (for % ISOKINETIC)= | 0.4732 |
| % ISOKINETIC= | 101.0 |
| AVERAGE STACK TEMPERATURE (F.)= | 94.8 |
| AVG. SUM of COS ANGLE = | 0.8576 |
| AVG. SUM of SQR DELTA P * COS of ANGLE (IN. H2O)= | 0.4058 |
| PITOT COEFFICIENT= | 0.84 |
| SAMPLING TIME (MINUTES)= | 205.4 |
| NOZZLE DIAMETER (INCHES)= | 0.4413 |
| STACK AXIS (INCHES)= | 324.0 |
| HUB AXIS (INCHES)= | 96.0 |
| CIRCULAR STACK | |
| NET FREE STACK AREA (SQUARE FEET)= | 522.29 |
| STACK VELOCITY (ACTUAL, FEET/MIN)= | 1,459 |
| FLOW RATE (ACTUAL, CUBIC FT/MIN)= | 761,935 |
| FLOW RATE (STANDARD, WET, CUBIC FT/MIN)= | 684,717 |
| FLOW RATE (STANDARD, DRY, CUBIC FT/MIN)= | 644,776 |
| SPECIFIC VOLUME @ STACK (CUBIC FT MIX/LB DRY AIR) | 15.7752 |
| AIRFLOW RATE ( POUNDS DRY AIR/MIN)= | 48,299 |

FILE NAME :
RUN # :
LOCATION :
DATE :
PROJECT # :

11-26-1989
PROGRAM VER.
04/26/89 V3.3

* * METRIC UNITS * *

| | |
|---|---|
| INITIAL METER VOLUME (CUBIC METERS)= | 10.534 |
| FINAL METER VOLUME (CUBIC METERS)= | 20.960 |
| METER FACTOR= | 0.9869 |
| FINAL LEAK RATE (CU M/MIN)= | 0.0003 |
| NET METER VOLUME (CUBIC METERS)= | 10.289 |
| GAS VOLUME (DRY STANDARD CUBIC METERS)= | 8.982 |
| BAROMETRIC PRESSURE (MM HG)= | 718 |
| STATIC PRESSURE (MM H2O)= | 0 |
| PERCENT OXYGEN= | 20.9 |
| PERCENT CARBON DIOXIDE= | 0.0 |
| MOISTURE COLLECTED (ML)= | 0.0 |
| PERCENT WATER= | 5.8 |
| DRY MOLECULAR WEIGHT= | 28.84 |
| WET MOLECULAR WEIGHT= | 28.20 |
| AVERAGE METER TEMPERATURE (C.)= | 45.1 |
| AVERAGE DELTA H (MM H2O)= | 39.9 |
| WEIGHTED SUM of SQR DELTA P (for % ISOKINETIC)= | 2.38 |
| % ISOKINETIC= | 101.0 |
| AVERAGE STACK TEMPERATURE (C.)= | 34.9 |
| AVG. SUM of SQR DELTA P * COS of ANGLE (MM H2O)= | 2.05 |
| PITOT COEFFICIENT= | 0.84 |
| SAMPLING TIME (MINUTES)= | 205.4 |
| NOZZLE DIAMETER (MM)= | 11.21 |
| STACK AXIS #1 (METERS)= | 8.230 |
| STACK AXIS #2 (METERS)= | 2.438 |
| CIRCULAR STACK | |
| STACK AREA (SQUARE METERS)= | 48.522 |
| STACK VELOCITY (ACTUAL, M/MIN)= | 445 |
| FLOW RATE (ACTUAL, CUBIC M/MIN)= | 21,576 |
| FLOW RATE (STANDARD, WET, CUBIC M/MIN)= | 19,389 |
| FLOW RATE (STANDARD, DRY, CUBIC M/MIN)= | 18,258 |

FILE NAME :
RUN # :
LOCATION :
DATE :
PROJECT # :

11-26-1989
PROGRAM VER.
04/26/89 V3.3

| POINT # | DELTA P (IN. H2O) | DELTA H (IN. H2O) | STACK T (F.) | METER T. IN(F.) | METER T. OUT(F.) | ANGLE (DEG) |
|---|---|---|---|---|---|---|
| 1 | 0.021 | 0.150 | 90 | 111 | 111 | 55 |
| 2 | 0.050 | 0.350 | 90 | 112 | 111 | 50 |
| 3 | 0.100 | 0.700 | 84 | 112 | 111 | 25 |
| 4 | 0.090 | 0.650 | 79 | 113 | 112 | 10 |
| 5 | 0.150 | 1.000 | 78 | 112 | 111 | 7 |
| 6 | 0.230 | 1.600 | 78 | 112 | 111 | 22 |
| 7 | 0.210 | 1.500 | 78 | 111 | 110 | 18 |
| 8 | 0.240 | 1.700 | 79 | 110 | 109 | 20 |
| 9 | 0.200 | 1.400 | 81 | 109 | 107 | 25 |
| 10 | 0.140 | 1.000 | 83 | 108 | 106 | 40 |
| 11 | 0.140 | 1.000 | 96 | 104 | 103 | 40 |
| 12 | 0.150 | 1.000 | 97 | 104 | 104 | 32 |
| 13 | 0.180 | 1.200 | 97 | 104 | 104 | 25 |
| 14 | 0.230 | 1.600 | 97 | 105 | 104 | 15 |
| 15 | 0.300 | 2.000 | 96 | 105 | 104 | 7 |
| 16 | 0.310 | 2.100 | 98 | 101 | 101 | 10 |
| 17 | 0.420 | 2.900 | 99 | 114 | 114 | 10 |
| 18 | 0.390 | 2.700 | 99 | 116 | 115 | 22 |
| 19 | 0.260 | 1.800 | 100 | 117 | 116 | 32 |
| 20 | 0.210 | 1.700 | 99 | 117 | 116 | 60 |
| 21 | 0.140 | 1.000 | 99 | 115 | 115 | 50 |
| 22 | 0.180 | 1.200 | 100 | 117 | 116 | 32 |
| 23 | 0.120 | 0.800 | 100 | 119 | 117 | 30 |
| 24 | 0.210 | 1.500 | 99 | 118 | 117 | 15 |
| 25 | 0.350 | 2.400 | 100 | 120 | 118 | 10 |
| 26 | 0.360 | 2.500 | 100 | 122 | 120 | 10 |
| 27 | 0.390 | 2.700 | 98 | 123 | 121 | 10 |
| 28 | 0.370 | 2.600 | 99 | 127 | 123 | 22 |
| 29 | 0.250 | 1.800 | 100 | 129 | 125 | 28 |
| 30 | 0.240 | 1.700 | 101 | 129 | 126 | 40 |
| 31 | 0.050 | 0.350 | 105 | 114 | 113 | 65 |
| 32 | 0.150 | 1.000 | 101 | 113 | 114 | 40 |
| 33 | 0.160 | 1.100 | 102 | 112 | 113 | 35 |
| 34 | 0.240 | 1.600 | 100 | 112 | 112 | 30 |
| 35 | 0.280 | 1.900 | 99 | 112 | 112 | 23 |
| 36 | 0.260 | 1.800 | 99 | 113 | 112 | 25 |
| 37 | 0.380 | 2.600 | 97 | 114 | 112 | 25 |
| 38 | 0.370 | 2.500 | 98 | 114 | 112 | 20 |
| 39 | 0.310 | 2.100 | 97 | 116 | 114 | 28 |
| 40 | 0.240 | 1.700 | 98 | 115 | 114 | 45 |

APPENDIX B

FIELD DATA SHEETS

RESEARCH AND DEVELOPMENT
DRIFT TEST
ON ONE CELL OF A
4-CELL, MECHANICAL-DRAFT, COUNTER-FLOW
COOLING TOWER

1989

MIDWEST RESEARCH INSTITUTE

Run Number 1 Project Number _____

Date _____

Plant _____

Sampling Location _____

**FIELD CREW**

Crew Chief T. Wenst

Testing Engineer N - Stich

Assistant Testing Engineer

Process Engineer

Other

## DRIFT SAMPLE LOCATIONS

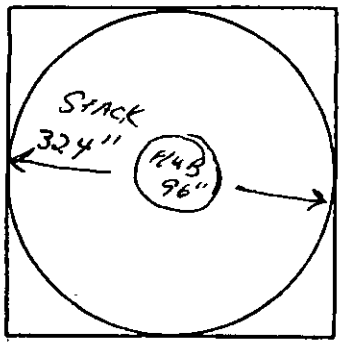
| Station # | Distance (inches) |
|---|---|
| 1 | 3 3/4 |
| 2 | 11 1/2 |
| 3 | 19 5/8 |
| 4 | 28 3/8 |
| 5 | 37 5/8 |
| 6 | 47 5/8 |
| 7 | 58 5/8 |
| 8 | 71 — |
| 9 | 85 1/4 |
| 10 | 102 7/8 |

# FIELD DATA

RUN NO. 1
PROJECT NO. -RED
PLANT
DATE
SAMPLING LOCATION
SAMPLE TYPE Drift
OPERATOR Stich/WEAST
FILTER NO. Drift
RECORD DATA EVERY VAR MIN. 6 min Basis
UMBILICAL/SAMPLER HOOKUP Drift

PROBE NO. Drift
PROBE LENGTH AND TYPE teflon -
SAMPLE BOX NO. Drift
METER BOX NO. Drift
TEMP. CONTROLLER NO. —
TEMP. METER NO. —
THERMOCOUPLE I.D. NO. —
UMBILICAL CORD I.D. NO. —
UMBILICAL CORD I.D. NO. —
NOZZLE NO. 7-1

NOZZLE DIA. .4413
ASSUMED MOISTURE % Sat.
METER ΔH@ 2.293
METER CORRECTION .9869
PITOT NO. Drift.
PITOT COEFFICIENT .84
BAROMETRIC PRESSURE 28.25
SITE TO BARO. ELEVATION (ft.) -0-
CORRECTED B.P. (0.1 in./100 ft.) 28.25
STATIC PRESSURE



SCHEMATIC OF TRAVERSE POINT LAYOUT

PITOT LEAK CHECK ≥3" $H_2O$

| | INITIAL | FINAL | INITIAL | FINAL | INITIAL | FINAL |
|---|---|---|---|---|---|---|
| TIME (24 hr) | | | | | | |
| PASS/FAIL | | | | | | |

PITOT LEAK CHECK ≥3" $H_2O$

| | INITIAL | FINAL | INITIAL | FINAL | INITIAL | FINAL |
|---|---|---|---|---|---|---|
| TIME (24 hr) | | | | | | |
| PASS/FAIL | | | | | | |

B-4

SAMPLE TRAIN LEAK CHECKS

| | INITIAL | FINAL | INITIAL | FINAL | INITIAL |
|---|---|---|---|---|---|
| TIME (24 hr) | 10:00 | 19:35 | | | |
| VACUUM, In. Hg | ≥15" | 10" | ≥15" | | ≥15" |
| CFM | .018 | .01 | | | |
| VOLUMES | | | | | |
| FINAL | | | | | |
| INITIAL | | | | | |
| DIFFERENCE | | | | | |

Background OGM
Stop 1020.6
Start 887.00 | 104 | 110

SAMPLE TRAIN LEAK CHECKS

Total Sample Time 529.2 min

| | FINAL | INITIAL | FINAL | INITIAL | FINAL |
|---|---|---|---|---|---|
| TIME (24 hr) | | | | | |
| VACUUM, In. Hg | | ≥15" | | ≥15" | |
| CFM | | | | | |
| VOLUMES | | | | | |
| FINAL | | | | | |
| INITIAL | | | | | |
| DIFFERENCE | | | | | |

Stopped at 19:42

INITIAL VOLUME
FINAL VOLUME
LEAK CHECK VOLUME
ADJUSTED FINAL VOLUME

COMMENTS

Revision 11/18/86

1

RUN NO. 1 | SAMPLING LOCATION | p. 1 of 2

DATE | PROJECT NO. R90 | OPERATOR Stich / Grant

| TRAVERSE POINT NUMBER | CLOCK TIME (24-hr.) / SAMPLING TIME, min | GAS METER READING ($V_m$), ft³ INITIAL 372.0 DESIRED | GAS METER READING ACTUAL | VELOCITY HEAD ($\Delta p_s$), in. $H_2O$ | ORIFICE PRESSURE DIFFERENTIAL ($\Delta H$), in $H_2O$ DESIRED | ORIFICE PRESSURE DIFFERENTIAL ACTUAL | STACK TEMP. ($T_s$), °F | DRY GAS METER TEMPERATURE INLET ($T_{m\,in}$), °F | DRY GAS METER TEMPERATURE OUTLET ($T_{m\,out}$), °F | PUMP VAC., in. Hg | IMPINGER TEMP., °F | SAMPLE BOX TEMP., °F | PROBE TEMP., °F | FILTER TEMP., °F | ANGLE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E-1 | 206 | 373.68 | 373.70 | .021 | .14 | .15 | 90 | 111 | 111 | 1 | — | — | — | — | 55 | |
| E-2 | 437 | 377.12 | 377.17 | .05 | .34 | .35 | 90 | 112 | 111 | 2 | — | — | — | — | 50 | |
| E-3 | 763 | 383.66 | 383.69 | .10 | .70 | .70 | 84 | 112 | 111 | 2 | — | — | — | — | 25 | |
| E-4 | 1117 | 389.44 | 390.41 | .09 | .64 | .65 | 79 | 113 | 112 | 3 | — | — | — | — | 10 | |
| E-5 | 1474 | 399.26 | 399.24 | .15 | 1.0 | 1.0 | 78 | 112 | 111 | 4 | — | — | — | — | 7 | |
| E-6 | 1807 | 409.46 | 409.40 | .23 | 1.6 | 1.6 | 78 | 112 | 111 | 5 | — | — | — | — | 22 | |
| E-7 | 2149 | 419.43 | 419.39 | .21 | 1.5 | 1.5 | 78 | 111 | 110 | 6 | — | — | — | — | 18 | |
| E-8 | 2487 | 429.96 | 430.05 | .24 | 1.7 | 1.7 | 79 | 110 | 109 | 6 | — | — | — | — | 20 | |
| E-9 | 2813 | 439.17 | 439.20 | .20 | 1.4 | 1.4 | 81 | 109 | 107 | 5 | — | — | — | — | 25 | |
| E-10 | 3088 12:36 | 445.66 | 445.82 | .14 | .97 | 1.0 | 83 | 108 | 106 | 4 | — | — | — | — | 40 | |
| | PORT CHANGE | | | | | | | | | | | | | | | |
| N-1 | 3363 13:08 | 452.02 | 451.90 | .14 | .95 | 1.0 | 96 | 104 | 103 | 3 | — | — | — | — | 40 | |
| N-2 | 3668 | 459.34 | 459.31 | .15 | 1.0 | 1.0 | 97 | 104 | 104 | 5 | — | — | — | — | 32 | |
| N-3 | 3994 | 467.89 | 468.01 | .18 | 1.2 | 1.2 | 97 | 104 | 104 | 5 | — | — | — | — | 25 | |
| N-4 | 4341 | 478.21 | 478.19 | .23 | 1.55 | 1.6 | 97 | 105 | 104 | 6 | — | — | — | — | 15 | |
| N-5 | 4698 | 490.32 | 490.30 | .30 | 2.0 | 2.0 | 96 | 105 | 104 | 7 | — | — | — | — | 7 | |
| N-6 | 5052 | 502.56 | 502.49 | .31 | 2.1 | 2.1 | 98 | 101 | 101 | 7 | — | — | — | — | 10 | |
| * N-7 | 354 1520 | 516.98 | 516.93 | .42 | 2.9 | 2.9 | 99 | 104 | 104 | 8 | — | — | — | — | 10 | |
| N-8 | 687 | 530.09 | 530.10 | .39 | 2.7 | 2.7 | 99 | 116 | 115 | 8 | — | — | — | — | 22 | |
| N-9 | 992 | 539.90 | 539.7 | .26 | 1.8 | 1.8 | 100 | 117 | 116 | 7 | — | — | — | — | 32 | |
| N-10 | 1171 1552 | 545.56 | 546.56 | .21 | 1.7 | 1.7 | 99 | 117 | 116 | 6 | — | — | — | — | 60 | |
| | | Change of Ports | | | | | | | | | | | | | | |

COMMENTS

* Restarted Computer 5052 Sample Time

B-5

Revision 9-4-88

RUN NO. 1 | SAMPLING LOCATION | p. 2 of 3

DATE | PROJECT NO. | OPERATOR Stick/Wead

| TRAVERSE POINT NUMBER | CLOCK TIME (24-hr.) / SAMPLING TIME, min (1171 / 6:38) | GAS METER READING ($V_m$), ft³ INITIAL 545.55 — DESIRED | GAS METER READING — ACTUAL | VELOCITY HEAD ($\Delta p_s$), in. $H_2O$ | ORIFICE PRESSURE DIFFERENTIAL ($\Delta H$), in $H_2O$ — DESIRED | ORIFICE PRESSURE DIFFERENTIAL — ACTUAL | STACK TEMP. ($T_s$), °F | DRY GAS METER TEMPERATURE — INLET ($T_{m\,in}$), °F | DRY GAS METER TEMPERATURE — OUTLET ($T_{m\,out}$), °F | PUMP VAC., in. Hg | IMPINGER TEMP., °F | SAMPLE BOX TEMP., °F | PROBE TEMP., °F | FILTER TEMP., °F | ANGLE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-1 | 1402 | 550.99 | 551.05 | .14 | .96 | 1.0 | 99 | 115 | 115 | 5 | — | — | — | — | 50 |
| * W-2 | 1707 | 559.16 | 559.15 | .18 | 1.2 | 1.2 | 100 | 117 | 116 | 5 | — | — | — | — | 32 |
| W-3 | 305 | 565.84 | 565.91 | .12 | .82 | .8 | 100 | 119 | 117 | 4 | — | — | — | — | 30 |
| W-4 | 652 | 575.90 | 575.98 | .21 | 1.44 | 1.5 | 99 | 118 | 117 | 6 | — | — | — | — | 15 |
| W-5 | 1006 | 589.17 | 589.20 | .35 | 2.4 | 2.4 | 100 | 120 | 118 | 7 | — | — | — | — | 10 |
| W-6 | 1360 | 602.67 | 602.65 | .36 | 2.5 | 2.5 | 100 | 122 | 120 | 8 | — | — | — | — | 10 |
| W-7 | 1714 | 616.78 | 616.70 | .39 | 2.7 | 2.7 | 98 | 123 | 121 | 9 | — | — | — | — | 10 |
| W-8 | 2047 | 629.75 | 629.71 | .37 | 2.6 | 2.6 | 99 | 127 | 123 | 9 | — | — | — | — | 22 |
| W-9 | 2364 | 639.93 | 639.95 | .25 | 1.75 | 1.8 | 100 | 129 | 125 | 6 | — | — | — | — | 28 |
| W-10 | 2639 17:48 | 648.95 | 648.65 | .24 | 1.67 | 1.7 | 101 | 129 | 126 | 6 | — | — | — | — | 40 |
| | PORT | CHANGE | | | | | | | | | | | | | |
| S-1 | 2791 18:17 | 650.71 | 650.72 | .05 | .34 | .35 | 105 | 114 | 113 | 3 | — | — | — | — | 65 |
| S-2 | 3066 | 657.39 | 657.38 | .15 | 1.0 | 1.0 | 101 | 113 | 114 | 4 | — | — | — | — | 40 |
| S-3 | 3360 | 664.74 | 664.78 | .16 | 1.0 | 1.0 | 102 | 112 | 113 | 5 | — | — | — | — | 35 |
| S-4 | 3671 | 674.28 | 674.31 | .24 | 1.6 | 1.6 | 100 | 112 | 112 | 6 | — | — | — | — | 30 |
| S-5 | 4002 | 685.25 | 685.21 | .28 | 1.9 | 1.9 | 99 | 112 | 112 | 7 | — | — | — | — | 23 |
| S-6 | 4328 | 695.68 | 695.68 | .26 | 1.8 | 1.8 | 99 | 113 | 112 | 7 | — | — | — | — | 25 |
| S-7 | 4654 | 708.31 | 708.33 | .38 | 2.6 | 2.6 | 97 | 114 | 112 | 8 | — | — | — | — | 25 |
| S-8 | 4992 | 721.22 | 721.19 | .37 | 2.5 | 2.5 | 98 | 114 | 112 | 8 | — | — | — | — | 20 |
| S-9 | 5309 | 732.35 | 732.31 | .31 | 2.1 | 2.1 | 97 | 116 | 114 | 7 | — | — | — | — | 28 |
| S-10 | 5563 19:20 | 740.20 | 740.10 | .24 | 1.7 | 1.7 | 98 | 115 | 114 | 6 | — | — | — | — | 45 |

B-6

COMMENTS

* Restarted Computer Total Sample Time 5052 + 1707 Total Sample Time 5052 / 1707 / 5563 / 12322 seconds

or 205.37 minutes

Revision 9-4-96

MIDWEST RESEARCH INSTITUTE
Cooling Tower Test Group
Drift Recovery Sheet

Project #: _____ Date : _____

Location : _____ Run # : 1

| | 1st Imp. | 2nd Imp. | 3rd Imp. | Silica Gel |
|---|---|---|---|---|
| Initial Volume | 150 | 100 | Dry | — |
| Final Volume | 910.5 | 785.5 | 678.9 | 653.2 |
| Initial Volume | 745.0 | 689.5 | 626.4 | 627.9 |
| Difference | 165.5 | 96.0 | 52.5 | 25.3 |

| | |
|---|---|
| Liquid Weight Gain | 314 |
| Silica Gel Wt. Gain | 25.3 |
| Total Weight Gain | 339.3 |

| | | |
|---|---|---|
| Total Sample Volume (including all rinses) | | 733 |
| Initial Impinger Volume | - | 250 |
| Liquid Weight Gain | - | 314 |
| Sample Rinse Volume | = | 169 |

# MIDWEST RESEARCH INSTITUTE

FILE NO.: _____ DATA SHEET "C" TEST DATE: _____

MEAS OF: FAN DRIVER INPUT HORSEPOWER — UNIT: HP

INSTRUMENT IDENTIFICATION: _____ DATE CALIBR.: _____

TIME. START _____ END _____

| FAN NO. | VOLTS | AMPS | P.F. | $KW_1$ | $KW_2$ | $KW_T$ | MOTOR EFF | HP |
|---|---|---|---|---|---|---|---|---|
| 1-1 | 470 | 90.6 | | 43.2 | 22.3 | 65.5 | .95 | 83.41 |
| | 470 | 89.9 | | | | | | |
| 1-2 | 470 | 85.9 | | 41.6 | 20.9 | 62.5 | .95 | 79.59 |
| | 470 | 87.6 | | | | | | |
| 1-3 | 470 | 87.6 | | 41.7 | 21.2 | 62.9 | .95 | 80.10 |
| | 470 | 89.1 | | | | | | |
| 1-4 | 471 | 85.9 | | 41.6 | 20.6 | 62.2 | .95 | 79.20 |
| | 471 | 86.8 | | | | | | |
| Ave | | 87.92 | | | | 63.28 | .95 | 80.58 |
| Loss | | | | | | .58 | | .74 |
| TEST AVERAGE INPUT HP | | | | | | 62.70 | | 79.84 |

MEAS. OF: _____ UNIT: _____

INSTRUMENT IDENTIFICATION: _____

| TIME | | | WIND, MPH | WIND DIREC. |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

TEST AVERAGE: _____

MEAS. OF: _____ UNIT: _____

INSTRUMENT IDENTIFICATION: _____ DATE CALIBR.: _____

| RUN | TIME | | Making Starts | | | |
|---|---|---|---|---|---|---|
| 1 | 12:00 | | OFF | | | |
| 2 | 1405 | | ON | | | |
| 3 | 1505 | | OFF | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |
| 11 | | | | | | |
| 12 | | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | | | | | | |
| TEST AVERAGE | | | | | | |

MEAS. OF: _____ UNIT: _____

INSTRUMENT IDENTIFICATION: _____ DATE CALIBR.: _____

| RUN | TIME | | | | | |
|---|---|---|---|---|---|---|
| 1 | wire size 2/0 | | | | | |
| 2 | | | | | | |
| 3 | wire length = 300 | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |
| 11 | | | | | | |
| 12 | | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | | | | | | |
| TEST AVERAGE: | | | | | | |

# MIDWEST RESEARCH INSTITUTE

FILE NO.: _____

**DATA SHEET "E"**
**WATER FLOW MEASUREMENT**
**PITOT TUBE**

TEST DATE: _____

| PITOT TUBE MAKE, MODEL | SERIAL NO. | PIPE SIZE, INCHES |
|---|---|---|
| Simplex | MRI 8842 | NOM = 30 I.D. = 29 1/4 |
| DATE CALIBR. | TUBE COEFFICIENT | AREA = .00545 ID², SQ FT |
| May '88 | c = .7948 | A = 4.6664 |

| PIPE I.D. | | | | | West | | | | East | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RDG NO. | DIA. X | RDG NO. | DIA. X | LOCATION DECIMAL INCHES CALCULATED | CORRECTED* | STA. DESC. 29½ø E d, in. | √d | TIME 29-ø S d, in. | √d | STA. DESC. 29 1/16 - E d, in. | √d | TIME 29½ø S d, in. | √d |
| 1 | .013 | | | .373 | 367 | 21- | | 20½ | .368 | 26½ | | 22¼ | |
| 2 | .039 | | | 1.151 | 1.132 | 22½ | | 23- | 1.134 | 28¼ | | 24¾ | |
| 3 | .067 | | | 1.976 | 1.943 | 23- | | 24- | 1.947 | 30½ | | 25½ | |
| 4 | .097 | | | 2.858 | 2810 | 23½ | | 24½ | 2.846 | 31½ | | 27- | |
| 5 | .129 | | | 3.811 | 3.747 | 22½ | | 25- | 3.765 | 31½ | | 28¼ | |
| 6 | .165 | 1 | .026 | 4.855 | 4.773 | 23- | | 25- | 4.783 | 32- | | 29¼ | |
| 7 | .204 | 2 | .082 | 6.024 | 5.922 | 23½ | | 25- | 5.934 | 32¼ | | 29¾ | |
| 8 | 250 | 3 | .146 | 7.375 | 7.250 | 23- | | 25- | 7.266 | 32- | | 30- | |
| 9 | .306 | 4 | .226 | 9.037 | 8.884 | 23½ | | 24½ | 8.903 | 33- | | 30- | |
| 10 | .388 | 5 | .342 | 11.452 | 11.258 | 24- | | 24½ | 11.287 | 32½ | | 30- | |
| 11 | .812 | 6 | .658 | 18.048 | 17.742 | 27½ | | 24½ | 17.781 | 30½ | | 30- | |
| 12 | .694 | 7 | .774 | 20.463 | 20.116 | 28½ | | 26- | 20.159 | 29¾ | | 29- | |
| 13 | .750 | 8 | .854 | 22.125 | 21.750 | 28½ | | 27- | 21.792 | 29½ | | 28½ | |
| 14 | .796 | 9 | .918 | 23.476 | 23.078 | 28½ | | 27- | 23.138 | 28- | | 27½ | |
| 15 | .835 | 10 | .974 | 24.645 | 24.227 | 28- | | 26- | 24.289 | 27½ | | 26¼ | |
| 16 | .871 | | | 25.689 | 25.253 | 27½ | | 26- | 25.308 | 26¼ | | 26- | |
| 17 | .903 | | | 26.642 | 26.190 | 25½ | | 25½ | 25.241 | 24¾ | | 25½ | |
| 18 | .933 | | | 27.524 | 27.057 | 24- | | 24- | 27.116 | 23- | | 23- | |
| 19 | .961 | | | 28.349 | 27.868 | 22- | | 22½ | 27.928 | 20½ | | 21½ | |
| 20 | .987 | | | 29.127 | 28.633 | 19½ | | 22- | 28.695 | 19¼ | | 20½ | |
| | | | | | | TOTAL | 98.749 | TOTAL | 99.093 | TOTAL | 106.402 | TOTAL | 103.225 |
| | | | | | | AVG | 4.9375 | AVG | 4.9547 | AVG | 5.3201 | AVG | 5.1612 |
| | | | | | | TRAVERSE AVG √d | | | 4.9461 | TRAVERSE AVG √d | | | 5.2407 |

(18 IN. DIAM AND OVER / UNDER 18 IN. DIAM)

| RDG NO | TIME | d |
|---|---|---|
| A | | |
| B | | |
| C | | |

Q, gpm = $\sqrt{d}\left(1040 \times C \times A\right) = \sqrt{d}\left(\frac{3857.2}{}\right)$

US GPM 19078

US GPM 20214

BASIS: AIR/WATER MANOMETER

Total = 39292 gpm

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF PITOT TUBE TO CENTER LINE OF IMPACT HOLE.

9818 gpm AVG/CELL

APPENDIX C

LABORATORY ANALYSIS

RESEARCH AND DEVELOPMENT
DRIFT TEST
ON ONE CELL OF A
4-CELL, MECHANICAL-DRAFT, COUNTER-FLOW
COOLING TOWER

1989

Environmental Trace Substances Research Center
ICP Scan - Sample Analysis Report

Project: MIDWEST RESEARCH INST. Units: MCG
Batch #:

Customer ID: BACKGROUND BLANK FILTER
Description: FILTER
ETSRC ID:

| Elm | Result | Estimated Sample Detection Limit |
|---|---|---|
| AG | <0.5 | 0.5 |
| AL | 614. | 1. |
| AS | 12. | 2. |
| B | 1140. | 1. |
| BA | 1620. | 0.02 |
| BE | <0.02 | 0.02 |
| BI | <2. | 2. |
| CA | 790. | 8. |
| CD | <0.2 | 0.2 |
| CO | <0.5 | 0.5 |
| CR | 0.9 | 0.8 |
| CU | 0.39 | 0.1 |
| FE | 17. | 0.5 |
| K | 900. | 10. |
| W | 140. | 10. |
| LI | 0.59 | 0.03 |
| MG | 121. | 0.03 |
| MN | 0.53 | 0.1 |
| MO | 0.3 | 0.3 |
| NA | 3320. | 0.5 |
| NI | <2. | 2. |
| P | <7. | 7. |
| PB | 5. | 2. |
| SB | <2. | 2. |
| SE | <3. | 3. |
| SI | 18. | 0.8 |
| SN | <3. | 3. |
| SR | 21.7 | 0.06 |
| TI | 0.3 | 0.1 |
| TL | <2. | 2. |
| V | <0.5 | 0.5 |
| ZN | 1100. | 0.1 |

Environmental Trace Substances Research Center
ICP Scan - Sample Analysis Report

Project: MIDWEST RESEARCH INST. Units: MCG
Batch #:

Customer ID: FILTER BLANK 13A
Description: FILTER
ETSRC ID:

| Elm | Result | Estimated Sample Detection Limit |
|---|---|---|
| AG | <0.5 | 0.5 |
| AL | 2. | 1. |
| AS | <2. | 2. |
| B | 2. | 1. |
| BA | 0.093 | 0.02 |
| BE | <0.02 | 0.02 |
| BI | <2. | 2. |
| CA | <8. | 8. |
| CD | <0.2 | 0.2 |
| CO | <0.5 | 0.5 |
| CR | <0.8 | 0.8 |
| CU | <0.1 | 0.1 |
| FE | <0.5 | 0.5 |
| K | <10. | 10. |
| W | <10. | 10. |
| LI | <0.03 | 0.03 |
| MG | 1.0 | 0.02 |
| MN | <0.1 | 0.1 |
| MO | <0.3 | 0.3 |
| NA | <0.5 | 0.5 |
| NI | <2. | 2. |
| P | <7. | 7. |
| PB | <2. | 2. |
| SB | <2. | 2. |
| SE | <3. | 3. |
| SI | 7.5 | 0.8 |
| SN | <3. | 3. |
| SR | <0.06 | 0.06 |
| TI | 0.2 | 0.1 |
| TL | <2. | 2. |
| V | <0.5 | 0.5 |
| ZN | 0.3 | 0.1 |

Environmental Trace Substances Research Center
ICP Scan - Sample Analysis Report

Project: MIDWEST RESEARCH INST. Units: MCG
Batch #:

Customer ID: TEST FILTER BACKGROUND
Description: FILTER
ETSRC ID:

| Elm | Result | Estimated Sample Detection Limit |
|---|---|---|
| AG | <0.5 | 0.5 |
| AL | 602. | 1. |
| AS | <2. | 2. |
| B | 1110. | 1. |
| BA | 1590. | 0.02 |
| BE | <0.02 | 0.02 |
| BI | <2. | 2. |
| CA | 760. | 8. |
| CD | <0.2 | 0.2 |
| CO | <0.5 | 0.5 |
| CR | <0.8 | 0.8 |
| CU | 0.73 | 0.1 |
| FE | 15. | 0.5 |
| K | 850. | 10. |
| W | 140. | 10. |
| LI | 0.58 | 0.03 |
| MG | 117. | 0.02 |
| MN | 0.47 | 0.1 |
| MO | <0.3 | 0.3 |
| NA | 3220. | 0.5 |
| NI | <2. | 2. |
| P | <7. | 7. |
| PB | <2. | 2. |
| SB | <2. | 2. |
| SE | <3. | 3. |
| SI | 29. | 0.8 |
| SN | <3. | 3. |
| SR | 21.3 | 0.06 |
| TI | 0.2 | 0.1 |
| TL | <2. | 2. |
| V | <0.5 | 0.5 |
| ZN | 1050. | 0.1 |

Environmental Trace Substances Research Center
ICP Scan - Sample Analysis Report

Project: MIDWEST RESEARCH INST. Units: MCG
Batch #:

Customer ID: TEST FILTER 13A
Description: FILTER
ETSRC ID:

| Elm | Result | Estimated Sample Detection Limit |
|---|---|---|
| AG | <0.5 | 0.5 |
| AL | 2. | 1. |
| AS | <2. | 2. |
| B | 5.7 | 1. |
| BA | 0.21 | 0.02 |
| BE | <0.02 | 0.02 |
| BI | <2. | 2. |
| CA | 9. | 8. |
| CD | <0.2 | 0.2 |
| CO | <0.5 | 0.5 |
| CR | <0.8 | 0.8 |
| CU | <0.1 | 0.1 |
| FE | 1. | 0.5 |
| K | <10. | 10. |
| W | <10. | 10. |
| LI | <0.03 | 0.03 |
| MG | 1.6 | 0.02 |
| MN | <0.1 | 0.1 |
| MO | <0.3 | 0.3 |
| NA | 1.5 | 0.5 |
| NI | <2. | 2. |
| P | <7. | 7. |
| PB | <2. | 2. |
| SB | <2. | 2. |
| SE | <3. | 3. |
| SI | 6.0 | 0.8 |
| SN | <3. | 3. |
| SR | <0.06 | 0.06 |
| TI | <0.1 | 0.1 |
| TL | <2. | 2. |
| V | <0.5 | 0.5 |
| ZN | 1.2 | 0.1 |

Environmental Trace Substances Research Center
ICP Scan - Sample Analysis Report

Project: MRI
Units: MCG/ML
Batch #:

Customer ID: MILL Q H20 BLANK CLARK
Description: WATER
ETSRC ID:

| Elm | Result | Estimated Sample Detection Limit |
|---|---|---|
| AG | <0.01 | 0.01 |
| AL | <0.02 | 0.02 |
| AS | <0.05 | 0.05 |
| B | <0.03 | 0.03 |
| BA | <0.0005 | 0.0005 |
| BE | <0.0006 | 0.0006 |
| BI | <0.04 | 0.04 |
| CA | <0.2 | 0.2 |
| CD | <0.006 | 0.006 |
| CO | <0.01 | 0.01 |
| CR | <0.02 | 0.02 |
| CU | <0.002 | 0.002 |
| FE | <0.009 | 0.009 |
| K | <0.2 | 0.2 |
| W | <0.3 | 0.3 |
| LI | <0.002 | 0.002 |
| MG | <0.001 | 0.001 |
| MN | <0.006 | 0.006 |
| MO | <0.007 | 0.007 |
| NA | <0.01 | 0.01 |
| NI | <0.02 | 0.02 |
| P | <0.3 | 0.3 |
| PB | <0.04 | 0.04 |
| SB | <0.04 | 0.04 |
| SE | <0.1 | 0.1 |
| SI | 0.24 | 0.02 |
| SN | <0.1 | 0.1 |
| SR | <0.003 | 0.003 |
| TI | <0.002 | 0.002 |
| TL | <0.04 | 0.04 |
| V | <0.01 | 0.01 |
| ZN | <0.006 | 0.006 |

Quality Control Report
Environmental Trace Substances Research Center
ICP Scan - Blind QC Report

Project: MRI Units: MCG/ML

Batch #:

Customer ID: ERA9911TM
Description: WATER-TRACE METALS
ETSRC ID:

| Elm | Result | Expected Value | +/- STD.DEV. | Estimated Sample Detection Limit |
|---|---|---|---|---|
| AG | 0.04 | 0.044 | 0.009 | 0.02 |
| AL | 0.1 | 0.176 | 0.035 | 0.04 |
| AS | <0.1 | 0.026 | 0.005 | 0.1 |
| B | 0.23 | 0.290 | 0.058 | 0.07 |
| BA | 0.149 | 0.108 | 0.022 | 0.001 |
| BE | 0.069 | 0.068 | 0.014 | 0.001 |
| BI | <0.09 | | | 0.09 |
| CA | 10. | | | 0.3 |
| CD | 0.073 | 0.094 | 0.019 | 0.01 |
| CO | 0.14 | 0.172 | 0.034 | 0.02 |
| CR | 0.17 | 0.185 | 0.037 | 0.04 |
| CU | 0.11 | 0.139 | 0.028 | 0.005 |
| FE | 0.34 | 0.231 | 0.046 | 0.02 |
| K | 0.7 | | | 0.5 |
| W | <0.7 | | | 0.7 |
| LI | 0.17 | | | 0.004 |
| MG | 2.25 | | | 0.002 |
| MN | 0.25 | 0.130 | 0.026 | 0.01 |
| MO | 0.18 | 0.202 | 0.040 | 0.01 |
| NA | 6.52 | | | 0.02 |
| NI | 0.30 | 0.343 | 0.069 | 0.03 |
| P | <0.7 | | | 0.7 |
| PB | 0.1 | 0.139 | 0.028 | 0.08 |
| SB | <0.09 | 0.032 | 0.006 | 0.09 |
| SE | <0.2 | 0.042 | 0.008 | 0.2 |
| SI | 0.32 | | | 0.03 |
| SN | <0.2 | | | 0.2 |
| SR | 0.092 | | | 0.006 |
| TI | 0.059 | 0.068 | 0.014 | 0.004 |
| TL | <0.08 | 0.046 | 0.009 | 0.08 |
| V | 0.14 | 0.179 | 0.036 | 0.02 |
| ZN | 0.13 | 0.175 | 0.035 | 0.01 |

Environmental Trace Substances Research Center
ICP Scan - Sample Analysis Report

Project: MRI
Units: MCG/ML
Batch #:

Customer ID: CLARK 1 DRIFT BASIN SMPL
Description: WATER
ETSRC ID:

| Elm | Result | Estimated Sample Detection Limit |
|---|---|---|
| AG | <0.01 | 0.01 |
| AL | 0.26 | 0.02 |
| AS | <0.05 | 0.05 |
| B | 1.1 | 0.03 |
| BA | 0.102 | 0.0005 |
| BE | <0.0007 | 0.0007 |
| BI | <0.04 | 0.04 |
| CA | 308. | 0.4 |
| CD | <0.006 | 0.006 |
| CO | <0.01 | 0.01 |
| CR | <0.02 | 0.02 |
| CU | 0.493 | 0.003 |
| FE | 0.70 | 0.009 |
| K | 47.1 | 0.2 |
| W | <0.3 | 0.3 |
| LI | 0.210 | 0.002 |
| MG | 146. | 0.03 |
| MN | 0.01 | 0.006 |
| MO | 0.059 | 0.007 |
| NA | 585. | 1. |
| NI | <0.02 | 0.02 |
| P | 2.6 | 0.3 |
| PB | <0.04 | 0.04 |
| SB | 0.1 | 0.05 |
| SE | <0.1 | 0.1 |
| SI | 0.16 | 0.02 |
| SN | <0.1 | 0.1 |
| SR | 3.25 | 0.003 |
| TI | 0.010 | 0.002 |
| TL | <0.04 | 0.04 |
| V | <0.01 | 0.01 |
| ZN | 0.36 | 0.006 |

Environmental Trace Substances Research Center
ICP Scan - Sample Analysis Report

Project: MRI  Units: MCG/ML

Batch #:

Customer ID: DRIFT IMPINGERS & RINSES
Description: WATER
ETSRC ID:

| Elm | Result | Estimated Sample Detection Limit |
|---|---|---|
| AG | <0.01 | 0.01 |
| AL | <0.02 | 0.02 |
| AS | <0.05 | 0.05 |
| B | <0.03 | 0.03 |
| BA | 0.0007 | 0.0005 |
| BE | <0.0006 | 0.0006 |
| BI | <0.04 | 0.04 |
| CA | 0.3 | 0.2 |
| CD | <0.006 | 0.006 |
| CO | <0.01 | 0.01 |
| CR | <0.02 | 0.02 |
| CU | 0.006 | 0.002 |
| FE | 0.20 | 0.009 |
| K | <0.2 | 0.2 |
| W | <0.3 | 0.3 |
| LI | 0.027 | 0.002 |
| MG | 0.073 | 0.001 |
| MN | 0.032 | 0.006 |
| MO | <0.007 | 0.007 |
| NA | 0.40 | 0.01 |
| NI | 0.31 | 0.02 |
| P | <0.3 | 0.3 |
| PB | <0.04 | 0.04 |
| SB | <0.04 | 0.04 |
| SE | <0.1 | 0.1 |
| SI | 0.17 | 0.02 |
| SN | <0.1 | 0.1 |
| SR | 0.003 | 0.003 |
| TI | 0.006 | 0.002 |
| TL | <0.04 | 0.04 |
| V | <0.01 | 0.01 |
| ZN | 0.53 | 0.006 |

Quality Control Report
Environmental Trace Substances Research Center
ICP Scan - Duplicate Report

Project: MRI  Units: MCG/ML

Batch #:

Customer ID: MILL Q H20 BLANK CLARK
Description: WATER
ETSRC ID:

| Elm | Result | Duplicate | % Deviation | Estimated Sample Detection Limit |
|---|---|---|---|---|
| AG | <0.01 | <0.01 | 0.0 | 0.01 |
| AL | <0.02 | <0.02 | 0.0 | 0.02 |
| AS | <0.05 | <0.05 | 0.0 | 0.05 |
| B | <0.03 | <0.03 | 0.0 | 0.03 |
| BA | <0.0005 | <0.0005 | 0.0 | 0.0005 |
| BE | <0.0006 | <0.0006 | 0.0 | 0.0006 |
| BI | <0.04 | <0.04 | 0.0 | 0.04 |
| CA | <0.2 | <0.2 | 0.0 | 0.2 |
| CD | <0.006 | <0.006 | 0.0 | 0.006 |
| CO | <0.01 | <0.01 | 0.0 | 0.01 |
| CR | <0.02 | <0.02 | 0.0 | 0.02 |
| CU | <0.002 | <0.002 | 0.0 | 0.002 |
| FE | <0.009 | <0.009 | 0.0 | 0.009 |
| K | <0.2 | <0.2 | 0.0 | 0.2 |
| W | <0.3 | <0.3 | 0.0 | 0.3 |
| LI | <0.002 | <0.002 | 0.0 | 0.002 |
| MG | <0.001 | <0.001 | 0.0 | 0.001 |
| MN | <0.006 | <0.006 | 0.0 | 0.006 |
| MO | <0.007 | <0.007 | 0.0 | 0.007 |
| NA | <0.01 | <0.01 | 0.0 | 0.01 |
| NI | <0.02 | <0.02 | 0.0 | 0.02 |
| P | <0.3 | <0.3 | 0.0 | 0.3 |
| PB | <0.04 | <0.04 | 0.0 | 0.04 |
| SB | <0.04 | <0.04 | 0.0 | 0.04 |
| SE | <0.1 | <0.1 | 0.0 | 0.1 |
| SI | 0.35 | 0.14 | 85.7 | 0.02 |
| SN | <0.1 | <0.1 | 0.0 | 0.1 |
| SR | <0.003 | <0.003 | 0.0 | 0.003 |
| TI | <0.002 | <0.002 | 0.0 | 0.002 |
| TL | <0.04 | <0.04 | 0.0 | 0.04 |
| V | <0.01 | <0.01 | 0.0 | 0.01 |
| ZN | <0.006 | <0.006 | 0.0 | 0.006 |

Average % Deviation 2.7

Quality Control Report
Environmental Trace Substances Research Center
ICP Scan - Duplicate Report

Project: MRI  Units: MCG/ML

Batch #:

Customer ID: CLARK 1 DRIFT BASIN SMPL
Description: WATER
ETSRC ID:

| Elm | Result | Duplicate | % Deviation | Estimated Sample Detection Limit |
|---|---|---|---|---|
| AG | <0.01 | <0.01 | 0.0 | 0.01 |
| AL | 0.27 | 0.26 | 3.8 | 0.02 |
| AS | <0.05 | <0.05 | 0.0 | 0.05 |
| B | 1.1 | 1.2 | 8.7 | 0.03 |
| BA | 0.100 | 0.103 | 3.0 | 0.0005 |
| BE | <0.0006 | 0.0009 | *** | 0.0006 |
| BI | <0.04 | <0.04 | 0.0 | 0.04 |
| CA | 340. | 276. | 20.8 | 0.4 |
| CD | <0.006 | <0.006 | 0.0 | 0.006 |
| CO | <0.01 | <0.01 | 0.0 | 0.01 |
| CR | <0.02 | <0.02 | 0.0 | 0.02 |
| CU | 0.485 | 0.502 | 3.4 | 0.003 |
| FE | 0.69 | 0.71 | 2.9 | 0.009 |
| K | 46.4 | 47.8 | 3.0 | 0.2 |
| W | <0.3 | <0.3 | 0.0 | 0.3 |
| LI | 0.206 | 0.213 | 3.3 | 0.002 |
| MG | 144. | 148. | 2.7 | 0.03 |
| MN | 0.01 | 0.01 | 0.0 | 0.006 |
| MO | 0.058 | 0.061 | 5.0 | 0.007 |
| NA | 577. | 594. | 2.9 | 1. |
| NI | <0.02 | 0.02 | *** | 0.02 |
| P | 2.5 | 2.8 | 11.3 | 0.3 |
| PB | <0.04 | <0.04 | 0.0 | 0.04 |
| SB | 0.1 | 0.1 | 0.0 | 0.05 |
| SE | <0.1 | <0.1 | 0.0 | 0.1 |
| SI | 0.079 | 0.24 | 100.9 | 0.02 |
| SN | <0.1 | <0.1 | 0.0 | 0.1 |
| SR | 3.45 | 3.04 | 12.6 | 0.003 |
| TI | 0.011 | 0.0087 | 23.4 | 0.002 |
| TL | <0.04 | <0.04 | 0.0 | 0.04 |
| V | <0.01 | <0.01 | 0.0 | 0.01 |
| ZN | 0.39 | 0.34 | 13.7 | 0.006 |

Average % Deviation  7.4

Quality Control Report
Environmental Trace Substances Research Center
ICP Scan - Spike Report

Project: MRI
Units: MCG/ML

Batch #:

Customer ID: DRIFT IMPINGERS & RINSES
Description: WATER
ETSRC ID:

| Elm | Result | MCG Added | Spiked Sample | % Recovery | Estimated Sample Detection Limit |
|---|---|---|---|---|---|
| AG | <0.01 | 20.0 | 0.54 | 135. | 0.01 |
| AL | <0.02 | 100.0 | 2.17 | 109. | 0.02 |
| AS | <0.05 | 50.0 | 1.1 | 110. | 0.05 |
| B | <0.03 | 100.0 | 2.0 | 100. | 0.03 |
| BA | 0.0007 | 10.0 | 0.214 | 107. | 0.0005 |
| BE | <0.0006 | 5.0 | 0.109 | 109. | 0.0006 |
| BI | <0.04 | 0.0 | <0.04 | - | 0.04 |
| CA | 0.3 | 0.0 | 0.2 | - | 0.2 |
| CD | <0.006 | 10.0 | 0.21 | 105. | 0.006 |
| CO | <0.01 | 0.0 | 0.01 | - | 0.01 |
| CR | <0.02 | 50.0 | 1.0 | 100. | 0.02 |
| CU | 0.006 | 100.0 | 1.98 | 99. | 0.003 |
| FE | 0.20 | 1000.0 | 22.7 | 113. | 0.009 |
| K | <0.2 | 0.0 | 0.3 | - | 0.2 |
| W | <0.3 | 0.0 | 0.9 | - | 0.3 |
| LI | 0.027 | 0.0 | 0.027 | - | 0.002 |
| MG | 0.073 | 500.0 | 9.87 | 98. | 0.001 |
| MN | 0.032 | 50.0 | 1.04 | 101. | 0.006 |
| MO | <0.007 | 50.0 | 1.11 | 111. | 0.008 |
| NA | 0.40 | 0.0 | 0.32 | - | 0.01 |
| NI | 0.31 | 50.0 | 1.4 | 109. | 0.02 |
| P | <0.3 | 0.0 | <0.4 | - | 0.3 |
| PB | <0.04 | 50.0 | 1.0 | 100. | 0.04 |
| SB | <0.04 | 0.0 | <0.05 | - | 0.04 |
| SE | <0.1 | 50.0 | 1.0 | 100. | 0.1 |
| SI | 0.17 | 0.0 | 0.31 | - | 0.02 |
| SN | <0.1 | 0.0 | <0.1 | - | 0.1 |
| SR | 0.003 | 10.0 | 0.21 | 103. | 0.003 |
| TI | 0.006 | 0.0 | <0.002 | - | 0.002 |
| TL | <0.04 | 50.0 | 1.1 | 110. | 0.04 |
| V | <0.01 | 10.0 | 0.21 | 105. | 0.01 |
| ZN | 0.53 | 200.0 | 4.53 | 100. | 0.007 |

Average % Recovery 106.

- Not Spiked
* Possibly Not Spiked - Not in Average
*** Spike Too Low

UNIVERSITY OF MISSOURI-COLUMBIA

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SEP- 1-89 FRI 12:56 

ETSRC Sample Report

MIDWEST RESEARCH INST.
89080352

| Submitter's ID Number | ETSRC ID | Test | Final Concen. | Units of Fin.Conc. | Description |
|---|---|---|---|---|---|
| BASIN SAMP | | TDS | 3840 | MG/L | WATER |