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Mr. Steve Tedesco
Tetra Tech
17885 Von Karman
Suite 500
Irvine, CA 92614

April 26, 2012

Subject: Corrosion Engineering Services
West Basin Municipal Water District Wedge Wire Screens

Dear Mr. Tedesco:

Tetra Tech provided Corrpro with a sample of a 90/10 copper-nickel wedge wire screen that was part of a desalinization plant owned and operated by the West Basin Municipal Water District. The screens were reportedly experiencing fouling, which is believed to be a result of corrosion or causing corrosion of the screens themselves. In addition to the sample of wedge wire screen, Tetra Tech provided Corrpro with a chemical analysis of the screens, a water analysis and a number of photographs that demonstrate the issues the screens are having. In order to assess the condition of the screens, Corrpro performed the following tasks:

- Reviewed of all project information supplied to us, that is, the photographs, water analysis report and screen analysis
- Examined the screen sample both visually and analytically using spectrographic and metallographic methods
- Review weld metal usage for its effects on galvanic corrosion
- Prepared this report which summarizes the information provided and analytical testing results and presents conclusions and recommendations

1.0 Conclusions:

1. Visual and metallographic examination of the metal beneath the deposit and measurements of the wedge wire screen did detect corrosion, but not measureable metal loss. This is consistent with 90-10 copper-nickel in seawater.

2. Analytical testing of the deposits on the screen indicates that the deposit contains corrosion products expected of 90/10 copper-nickel immersed in seawater. The deposits were located everywhere on the screen sample we examined and there did not appear to be any localized concentrations. There is nothing in the either the corrosion product analysis or water analysis that suggests pollution to be a factor in the corrosion of the screens.

3. Analytical analysis of the wedge wire shows that the alloy is 90-10 copper-nickel corresponding to UNS 70700.

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4. Cathodic protection can be used to control corrosion of the screens; however, the anti-fouling properties of the metal will be diminished; therefore, because of this and because little corrosion has occurred, cathodic protection is not recommended.

2.0 Recommendations:

1. Monitor the corrosion on the screens both visually and through the use of 90-10 copper-nickel corrosion coupons. This is explained further in the discussion below.

2. Obtain samples of influent water and analyze for pH, oxygen, conductivity, ammonia and sulfide.

3.0 Discussion:

Background

Figure 1 shows a photograph that was supplied by Tetra Tech of the wedge wire screen assembly. The wedge wire screen is fabricated from 90-10 copper-nickel. Copper-nickel (Cu-Ni) alloys were developed specifically for seawater service and contain 9-11 percent nickel, 1-2 percent iron, 0.5-1.0 percent manganese, 0.5 max zinc, 0.05 max carbon, 0.02 max percent lead, 0.02 percent max sulfur and no more than 0.1 percent other elements. The iron and manganese are added to promote resistance to velocity and impingement effects. Various compositions are available for different uses. The alloys are used for offshore, power, desalination industries and Navy and merchant shipping. The alloy has inherent resistance to biofouling. This property is advantageous in avoiding or reducing the necessity for biocide dosing in condensers and seawater systems, and in reducing drag forces and cleaning regimes on offshore platforms and boat hulls. Studies have shown that some corrosion of the alloy (release of copper ions) is required to impart anti-fouling resistance and that the antifouling resistance will be compromised or stopped if corrosion ceases.[1] The initial general corrosion rate of 90-10 Cu-Ni in clean flowing seawater is relatively high initially (about 0.51 mil per year where 1 mil = 0.001 inch) and slowly decreases to about 0.04 mils per year after 14 years. Initial corrosion rates are lower in tidal or quiet or tidal seawater but the long term corrosion rates are about the same in all cases. The good corrosion performance of 90-10 Cu-Ni is adversely affected by pollution, including sulfides and ammonia in aerated seawater. A sulfide concentration of 0.01 ppm is sufficient to cause corrosion of 90-10 Cu-Ni.[2] Pitting and stress corrosion cracking can occur. A characteristic of sulfide corrosion is a black scale on the surface. Copper-nickel alloys have good resistance to pitting and crevice corrosion and are not susceptible to chloride or sulfide stress corrosion cracking. Sustained seawater velocity above about 3.5 m/s can affect corrosion rates because moving seawater removes the protective oxide scale exposing fresh metal to the environment and increases corrosion rates. Galvanic corrosion of the Cu-Ni is possible when the alloy is coupled to stainless steel, nickel alloys and titanium. The Cu-Ni is the cathode (protected) when coupled to zinc, aluminum, steel and aluminum bronze, but this should be avoided as it reduces antifouling as mentioned above.

[1] *ASM Handbook, Vol. 13B Corrosion: Materials*, ASM, Materials Park, OH, 2005, p. 142
[2] *ASM Handbook, Vol. 13C Corrosion: Environments and Industries*, ASM Materials Park, OH, 2006, p.214

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Sample Evaluation

Figure 2 shows an overall view of the sample we received. The sample was about 9-inches long and 12-inches in diameter. It had a deposit on the metal surfaces which appeared green in some areas and brownish in others. Figures 3 and 4 show the different colorations observed.

We were provided with a chemical analysis performed by Camet Research, Inc. Camet Research analyzed the composition of several of the screen components, including the end of screen, nose cone end, center of air burst line, velocity ring and center of adjacent screen. The analyses indicated that all were 90-10 Cu-Ni although different alloys were used, some of which contained iron and manganese and some did not. Iron and manganese are added to improve the velocity and impingement characteristics of the alloy. The analyses of the screens indicated the alloy composition was that of 90-10 Cu-Ni, as follows:

Element	Percent
Nickel	10.463
Manganese	0.236
Iron	0.04
Zinc	0.12
Copper	89.139

We had an outside laboratory (Lehigh Testing Laboratories, New Castle, DE analyze the screen metal to confirm its composition. Appendix A presents their report. The composition measured by Lehigh Testing is as follows:

Element	Percent	UNS 70700
Nickel	10.35	9.5 – 10.5
Manganese	0.22	0.5 max
Iron	0.001	0.05 max
Zinc	Not found	Not specified
Copper	Remainder	Remainder

Based on the Lehigh test results, the composition is consistent with UNS 70700 copper-nickel alloy. We do not know the specified composition of the wedge wire screen, but from a corrosion point of view, 90-10 Cu-Ni alloys are similar.

We mechanically removed the deposit in several areas and examined the metal beneath. The brown deposit was relatively easy to remove but the green colored deposit was better adhered to the metal. The lack of black coloration suggests that sulfides were not present in the influent water. The deposits were located everywhere on the screen sample we examined and there did not appear to be any localized concentrations. The metal substrate appeared relatively unaffected by corrosion - no pitting or significant general corrosion was observed. The greenish deposit was analyzed by Lehigh Testing Laboratories using energy dispersive x-ray analysis (EDXA) and x-ray diffraction (XRD). Appendix B presents their full report. These analyses show that the scale consists of the following:

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Copper Chloride Hydroxide ($CuCl_2 \cdot 3Cu(OH)_2$
Copper-Nickel Chloride Hydroxide $(Cu,Ni)_2Cl(OH)_3$
Copper Oxide (Cu_2O)

These compounds are normally the corrosion products of 90-10 Cu-Ni exposed to seawater. Characteristics of the film are that it is adherent, protective, and generally brown or greenish-brown in color. There is no indication in the corrosion products, such as the presence of sulfur compounds or the color, that sulfides have played any role in corrosion of the screens.

Measurements of wire thickness and width yielded the following:

Thickness, inch	Width, inch
0.048	0.084
0.044	0.087
0.041	0.082
0.043	0.085

These values, while showing differences, are relatively consistent; however, we would need the specification dimensions for a true comparison. We cut specimens of the wire, mounted them in resin and polished and lightly etched the surface for examination in both the longitudinal and transverse directions, then examined them using a metallograph at 300X magnification. The surface was uniformly and very lightly corroded with no pitting, intergranular corrosion, cracking present. The grain structure was as expected for the alloy.

We understand that the weld metal used was a 70-30 copper-nickel alloy. This is recommended practice based on our review of the technical literature.[3] 70-30 Cu-Ni is slightly cathodic to 90-10 Cu-Ni, so the 90-10 Cu-Ni will tend to galvanically corrode when coupled to the 70-30 Cu-Ni. However, the two alloys are very close to each other in the galvanic series and since the weld area is small compared to the area of the screen corrosion should not be a significant issue because the corrosion current would be distributed over a large area (i.e., small cathode - large anode effect), resulting in very low corrosion rates of the anode (the screen and supports). The sample we examined does have some welds between the wire and supports and we did not see any preferential corrosion of the support metal next to the welds which supports the above opinion.

Water Analysis

We were provided with water analyses titled "West Basin Desalination Project, C.I. 9525, Monthly Monitoring Report", Table 1 – Combined Demonstration Facility Discharge to AES RBGS Units 5 & 6 Discharge Tunnel (Location EFF-001) for July 2011, August 2011 and September 2011. The reports are intended to provide information for environmental compliance. We reviewed them for information pertinent to corrosion of the wedge wire screens. Of particular interest are the pH, dissolved oxygen,

[3] C.A. Powell, H.T. Michels, *Copper-Nickel for Seawater Corrosion Resistance and Antifouling – A State of the Art Review*, Copper Development Association, Inc., www.copper.org.

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ammonia, copper values. None of these values indicate a particular concern with respect to the wedge wire screens; however, these are effluent readings. Influent data would be more pertinent, particularly pH, oxygen, conductivity, ammonia and sulfide.

Cathodic Protection

Copper and its alloys can be cathodically protected and with less current than steel. The cathodic protection criterion for copper is a 100 mV polarized potential shift and copper-nickel could be closer to a 50 mV polarized potential shift.[4] The system used needs to be designed based on a clear understanding of the surfaces to be protected, the adjacent structures, seawater velocity and the overall layout of the system. Either a galvanic anode system, such as aluminum-zinc-indium anodes, or a potential controlled impressed current system with dimensionally stable anodes and suitable controls to limit current could be used. The amount of current used must be limited because too much current will result in calcareous deposits that could clog the screen. As previously discussed, some corrosion is necessary to release copper ions so that the antifouling characteristics of the Cu-Ni is maintained, otherwise, the screens will foul with marine growth. According to the literature, the presence of the corrosion products found on the surface appear to be necessary for the Cu-Ni to have its fouling resistance. The copper chloride hydroxide periodically slough off the surface along with the marine organisms that are attached.[1] For that reason, the literature consistently warns against cathodic protection or connections with more active metals, such as steel or aluminum. Consequently, and in light of the lack of significant corrosion found on the wire, we suggest that cathodic protection is not needed or desired.

We recommend that the condition of the screens be monitored both visually and through the use of corrosion coupons immersed along with the screens. Attach a series of pre-weighed coupons, each 1-inch by 2-inches mounted on a rack to one of the screens. Periodically remove a coupon and have it cleaned, weighed and measured to determine the corrosion rate and type of corrosion (the remaining coupons should remain in place for future data collection). We suggest time frames of 6 months, 1 year, 18 months, 2 years, 3 years and so on until a clear steady state corrosion rate is identified. ASTM Test Method G1, *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*, details the procedure to use. Racks and coupons of copper-nickel alloy 70600 are available from Metal Samples Company, Munford, AL. We will be glad to help you design and implement the evaluations.

Please feel free to contact us with any questions.

Very truly yours,

Walter T. Young

Walter T. Young, P.E.
Principal Engineer

[4] L.Berthagen, "The Use of Cathodic Protection for Copper Alloys in Seawater Cooling Systems", Eurocorr 2001, EFC Working Party meeting. Marine Corrosion, Copper Development Association

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Figure 1. Wedge wire screens. Photo courtesy of Tetra Tech.

Figure 2. Wedge wire screen examined by Corrpro.

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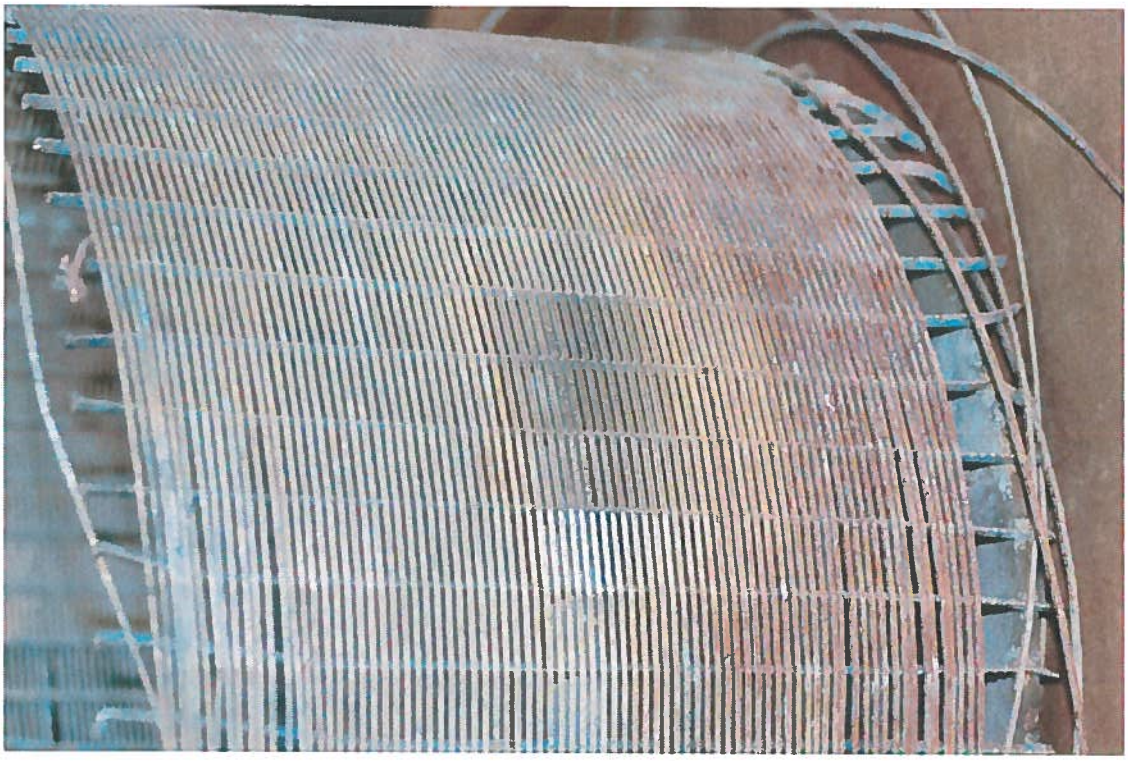

Figure 3. Different colors of deposit on screen.

Figure 4. Screen deposit.

APPENDIX A

METAL ANALYSIS REPORT

Lehigh Testing Laboratories, Inc.
A Subsidiary of THE MMR GROUP, INC.
308 WEST BASIN ROAD • P.O. BOX 903 • NEW CASTLE, DE 19720
(302) 328-0500 • FAX (302) 328-0417

THE MMR GROUP, INC.
an ESOP Company

TEST REPORT

CORRPRO COMPANIES, INC.
ATTENTION: WALTER YOUNG
1380 ENTERPRISE DRIVE
WEST CHESTER, PA 19380

DATE: April 20, 2012

P.O. NO.: **WC 4117**

LEHIGH NO: **N-46-40**

PAGE NO.: 1 of 1

MATERIAL: 90/10 COPPER-NICKEL
SAMPLE DESIGNATION: (1) SAMPLE: WEDGEWIRE SCREEN,
JOB NO. 340160466

CHEMICAL ANALYSIS: BASE METAL (%)

Copper	Remainder
Iron	0.001
Manganese	0.22
Nickel	10.35

Copper + Sum of Named Elements	99.9

Base wire material is consistent with UNS C70700 Copper-Nickel Alloy (90/10).

Results are for information only.

LTL Procedure: *QA-CH-P-124 Rev 1 (ICP)*

Lehigh Testing Laboratories, Inc.

Peter M. Engelgau

Peter M. Engelgau, Principal Chemist

APPENDIX B

CORROSION PRODUCT ANALYSIS

Lehigh Testing Laboratories, Inc.
A Subsidiary of THE MMR GROUP, INC.
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(302) 328-0500 • FAX (302) 328-0417

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TEST REPORT

CORRPRO COMPANIES, INC.
ATTENTION: WALTER YOUNG
1380 ENTERPRISE DRIVE
WEST CHESTER, PA 19380

DATE: April 20, 2012

P.O. NO.: **WC 4117**

LEHIGH NO: **N-46-40**

PAGE NO.: 1 of 1

MATERIAL: DEPOSIT ON SCREEN
SAMPLE DESIGNATION: (1) SAMPLE: WEDGEWIRE SCREEN, JOB NO. 340160466

CHEMICAL ANALYSIS: COMPOUND/PHASE

Copper Chloride Hydroxide
$CuCl_2 \cdot 3Cu(OH)_2$
ICDD Card #18-0439

Copper-Nickel Chloride Hydroxide
$(Cu, Ni)_2\ Cl(OH)_3$
Paratacamite
ICDD Card #50-1560

Copper Oxide
Cu_2O
Cuprite
ICDD Card #5-0667

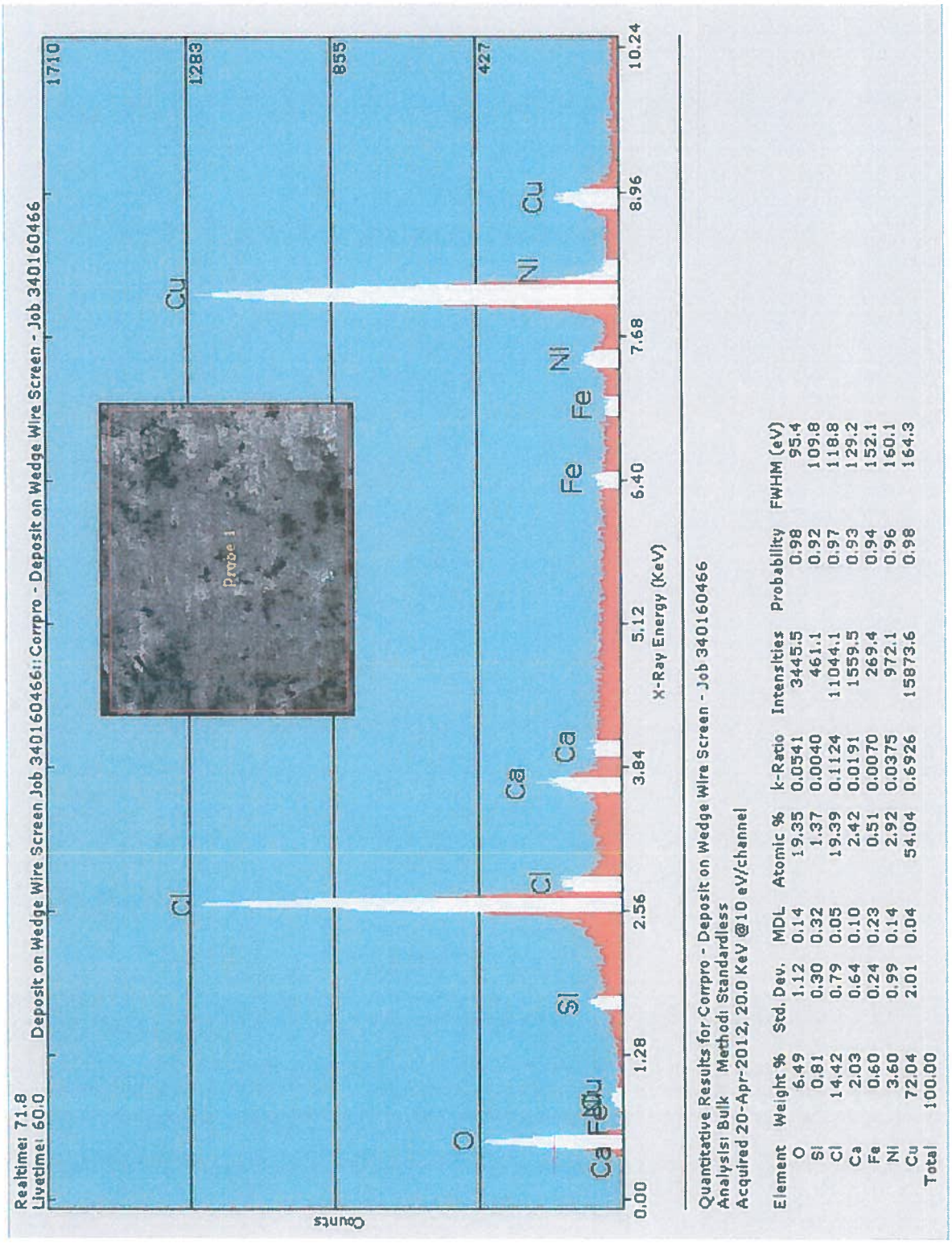
Results are for information only.

LTL Procedure: *QA-CH-P-140 Rev O Shimadzu XRD-6000*

Lehigh Testing Laboratories, Inc.

Peter M. Engelgau

Peter M. Engelgau, Principal Chemist



Quantitative Results for Corrpro - Deposit on Wedge Wire Screen - Job 340160466
Analysis: Bulk Method: Standardless
Acquired 20-Apr-2012, 20.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %	k-Ratio	Intensities	Probability	FWHM (eV)
O	6.49	1.12	0.14	19.35	0.0541	3445.5	0.98	95.4
Si	0.81	0.30	0.32	1.37	0.0040	461.1	0.92	109.8
Cl	14.42	0.79	0.05	19.39	0.1124	11044.1	0.97	118.8
Ca	2.03	0.64	0.10	2.42	0.0191	1559.5	0.93	129.2
Fe	0.60	0.24	0.23	0.51	0.0070	269.4	0.94	152.1
Ni	3.60	0.99	0.14	2.92	0.0375	972.1	0.96	160.1
Cu	72.04	2.01	0.04	54.04	0.6926	15873.6	0.98	164.3
Total	100.00							

*** Basic Data Process ***

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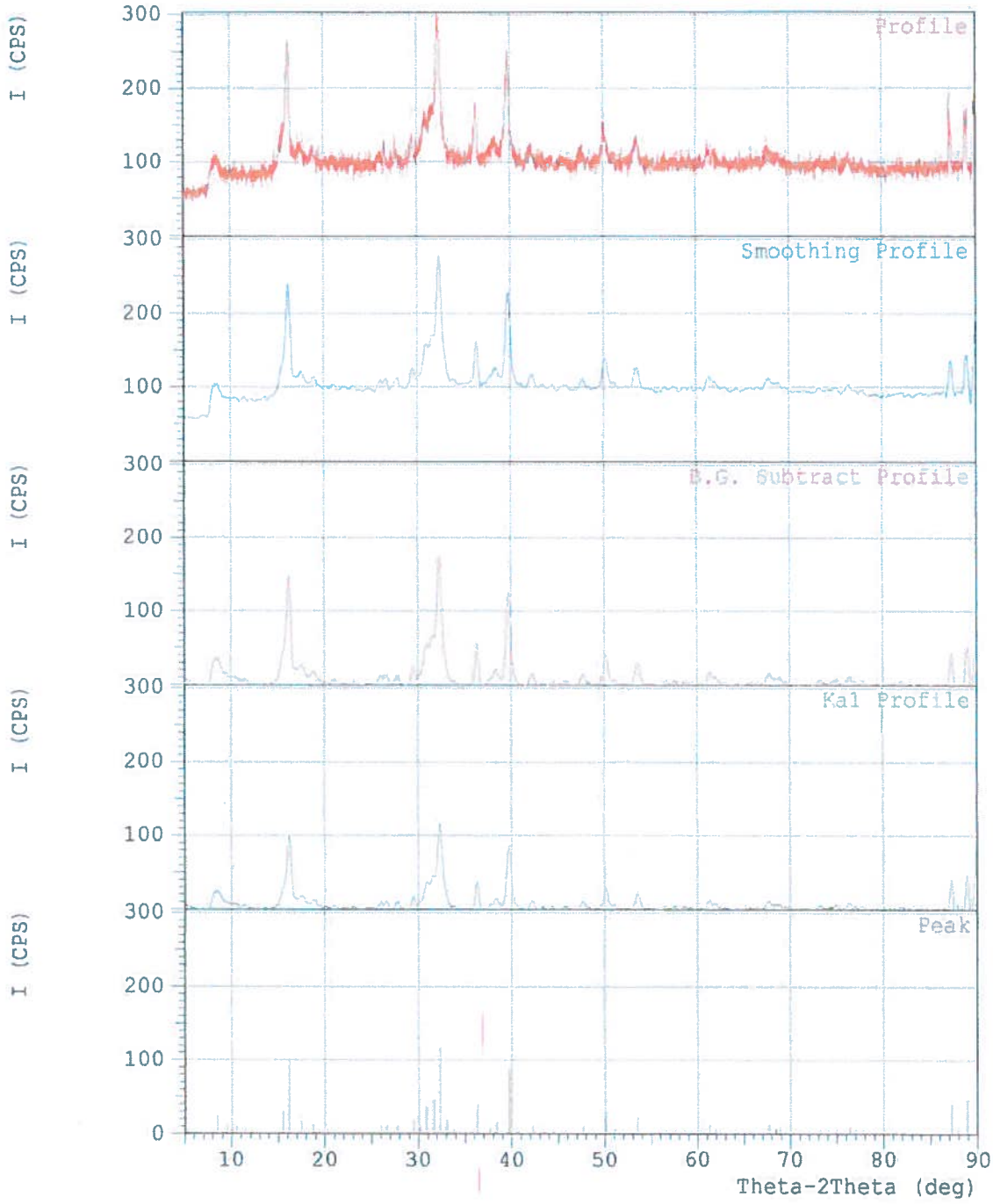
Data Name : N 46-40135623
File Name : N 46-40135623.PKR
Sample Name : Green-Blue Deposit
Comment : Deposit on Wedge Wire Screen



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                *** Basic Data Process ***

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          Data Name             : N 46-40135623
          File Name             : N 46-40135623.RAW
          Sample Name           : Green-Blue Deposit
          Comment               : Deposit on Wedge Wire Screen
          Date & Time           : 04-20-12 11:05:21

# Measurement Condition
    X-ray tube
          target                : Cu
          voltage               : 40.0  (kV)
          current               : 30.0  (mA)
    Slits
          divergence slit       :  1.00 (deg)
          scatter slit          :  1.00 (deg)
          receiving slit        :  0.30 (mm)
    Scanning
          drive axis            : Theta-2Theta
          scan range            :    5.0000 - 90.0000 (deg)
          scan mode             : Continuous Scan
          scan speed            :    0.5000 (deg/min)
          sampling pitch        :    0.0200 (deg)
          preset time           :    2.40 (sec)

# Data Process Condition
    Smoothing                   [ AUTO ]
          smoothing points      : 39
    B.G.Subtraction             [ AUTO ]
          sampling points       : 51
          repeat times          : 30
    Ka1-a2 Separate             [ MANUAL ]
          Ka1 a2 ratio          : 50 (%)
    Peak Search                 [ AUTO ]
          differential points   : 31
          FWHM threshold        : 0.050 (deg)
          intensity threshold   : 30 (par mil)
          FWHM ratio  (n-1)/n   : 2
    System error Correction     [ NO ]
    Precise peak Correction     [ NO ]
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********** SEARCH / MATCH RESULT **********

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File Name : N 46-40135623.PKR
Sample Name : Green-Blue Deposit
Comment : Deposit on Wedge Wire Screen
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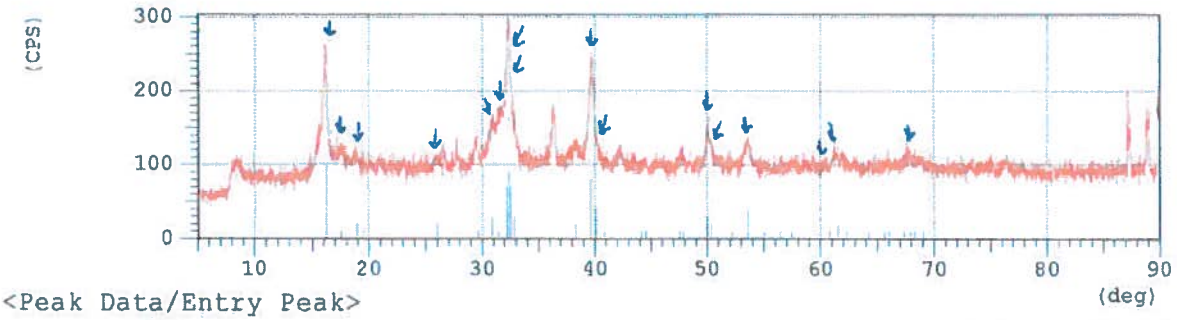

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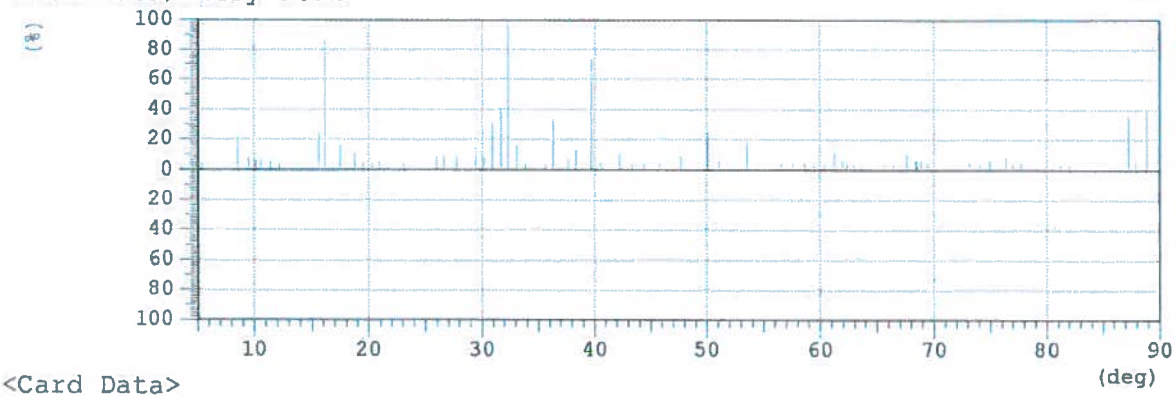

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ICDD CARD # 18-0439
COPPER CHLORIDE HYDROXIDE
$CuCl_2 \cdot 3Cu(OH)_2$

CORRPRO COMPANIES, INC Lehigh Job No.: N-46-40

********** SEARCH / MATCH RESULT **********

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File Name : N 46-40135623.PKR
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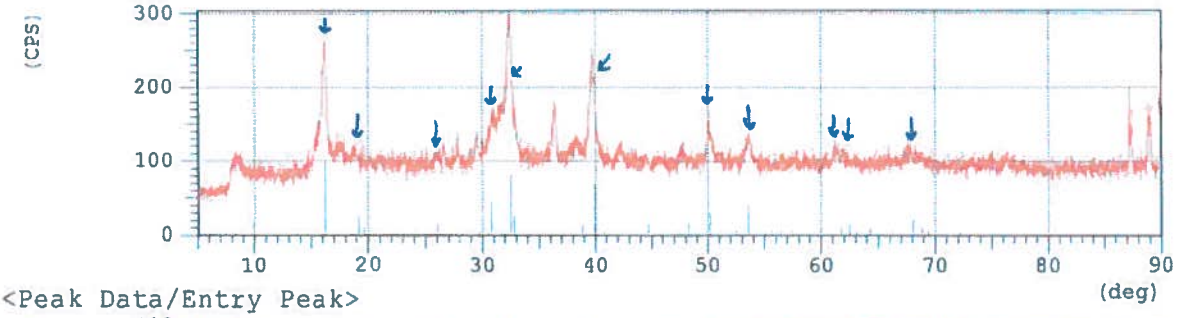

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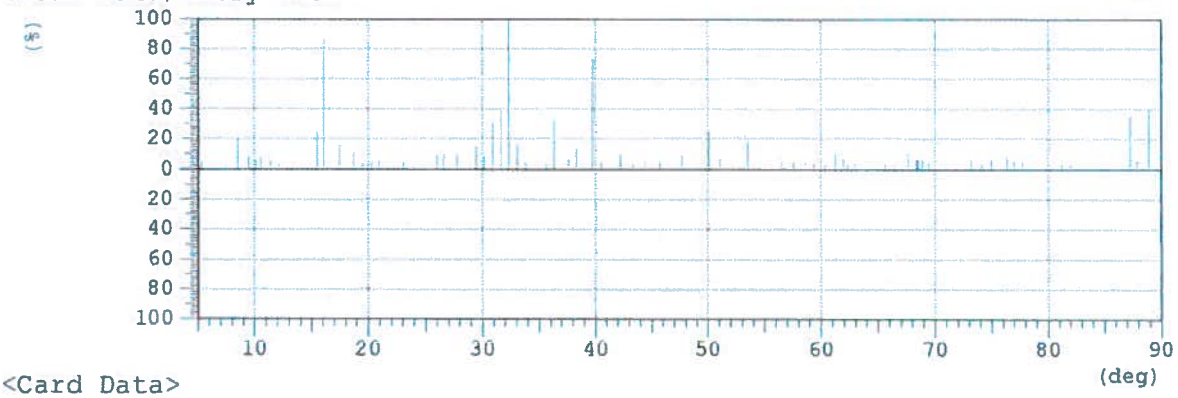

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ICDD CARD # 50-1560

COPPER-NICKEL-CHLORIDE HYDROXIDE

PARATACAMITE

$(Cu, Ni)_2 Cl(OH)_3$

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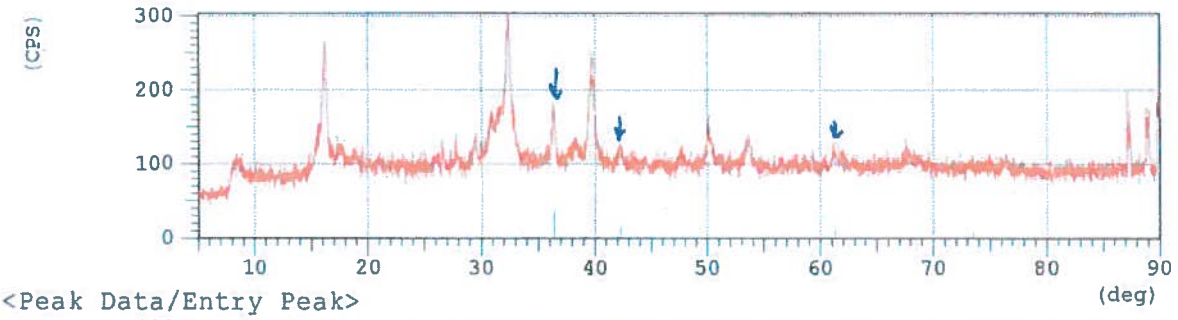

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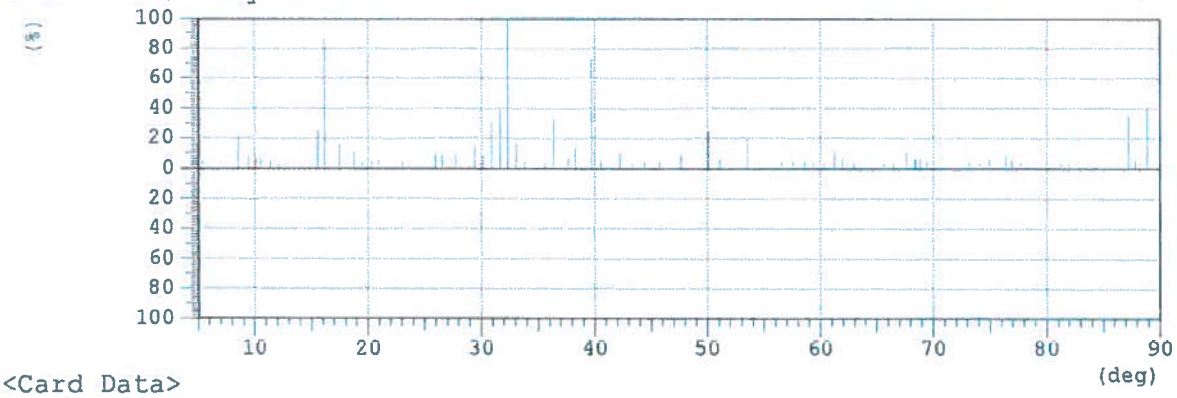

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ICDD CARD # 5-0667

COPPER OXIDE

CUPRITE

Cu_2O