199306.15 Salt Kill Study

Norlite Corporation

Norlite

628 SO. SARATOGA ST.
P.O. BOX 694
COHOES, N.Y. 12047
TEL.: (518) 235-0401
FAX.: (518) 235-0233

June 15, 1993

WJZ-114-93

JUN 21 1993

Mr. William Clarke
Regional Permit Administrator
New York State Department of
Environmental Conservation
Region 4
2176 Guilderland Ave.
Schenectady, NY 12306

Dear Mr. Clarke:

Submitted with this letter is a report on the study of the source of the precipitate observed in the Salt Kill Creek under certain conditions. This study was performed in accordance with a Work Plan submitted to NYSDEC on October 15, 1992. The study concludes that control of scrubber blowdown pH to a range of 8.0 to 8.5 will prevent the formation of the precipitate. This range is also consistent with the optimum pH range for acid gas removal efficiency by the APC system demonstrated in the October 1992 Trial Burn.

If you have any questions, please contact Richard Schlauch or myself at 803/329-9690.

Sincerely,

William J. Ziegler

William J. Ziegler
Vice President of Health,
Safety and Environmental Affairs

WJZ:ncm

Attachment

cc: Carol Lamb-LaFay
William Voshell
Dallas Robinson

JUN 21 1993

STUDY OF PRECIPITATE IN THE SALT KILL CREEK AT NORLITE CORPORATION

COHOES, NEW YORK

JUNE 10, 1993

Prepared by:
Richard Schlauch
Richard Schlauch
Environmental Systems Manager
Norlite Corporation

Operator Certification by:
William Ziegler
William J. Ziegler
Vice President of Health,
Safety & Environmental Affairs
Norlite Corporation

STUDY OF PRECIPITATE OBSERVED IN THE SALT KILL CREEK AT NORLITE CORPORATION, COHOES, NEW YORK

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1. INTRODUCTION

1.1 Scope of Salt Kill Precipitation Study

To understand the magnitude of the Salt Kill precipitation (or siltation) phenomenon, as well as the cause and sources of the deposited material, an analytical evaluation of both the natural Salt Kill water as well as the Norlite wet scrubber blowdown discharge was performed. The analytical results were then used to accurately predict the chemical composition of an admixture of the natural Salt Kill water with the scrubber blowdown as well as the chemical reactions that will occur (if any) upon mixing.

1.2 Natural Water Characteristics

Reference to any text or published information on natural water supply characteristics (eg. Refs. 1 and 2) indicate that all natural water sources, either in the raw state or after treatment, contain dissolved mineral matter. The most abundant of these dissolved minerals are the bicarbonates, sulfates and chlorides of calcium, magnesium and sodium. Silica (SiO_2) is also a common dissolved constituent of natural water ranging in concentration from about 1 ppm to over 100 ppm. Iron and manganese are also typically present, but in dissolved concentrations of less than 1.0 ppm.

In natural streams such as the Salt Kill, these dissolved minerals enter into the water through the solvent properties of the water acting on soil and rock constituents. For instance, the primary mechanism for calcium and bicarbonate presence in the water is through a natural process where organic matter and carbonaceous materials deposited in the soil (in contact with the water) are decomposed by soil bacteria. The decomposition of carbonaceous matter generates carbon dioxide gas as a by-product, which is absorbed in the water. The dissolved carbon dioxide (CO_2) forms carbonic acid (H_2CO_3) in the water which then dissolves naturally occurring limestone ($CaCO_3$) that the water comes in contact with. The limestone constituents, when dissolved, form the calcium ion (Ca++) and bicarbonate ion (HCO_3^-) concentrations analyzed in the water. The more decomposing carbonaceous material the water contacts, the more CO_2 can be absorbed (more at cooler temperature than at warm temperature) and the more limestone that can be dissolved into the water.

A water that has become "saturated" with dissolved calcium and bicarbonate in this way, can initially appear crystal clear and colorless without any sign of suspended solids (i.e., the calcium and bicarbonate are completely dissolved in the form of ions in water). To remain in the saturated ionic calcium bicarbonate condition, the water must remain within a specific range of pH value, temperature and total solids concentration. A significant change in any one or more of these conditions can trigger a reaction between calcium and bicarbonate ions that will precipitate some or most of these constituents, thus forming solid calcium carbonate either as a soft, voluminous precipitate or a hard rock-like (crystalline) material.

The significant changes triggering these precipitation reactions can be the result of either natural or un-natural environmental changes or a combination of both. Environmental changes that cause calcium carbonate precipitation are heating, evaporation and pH increases due to loss of $C0_2$ content or other influences.

An example of a common natural display of the phenomenon is when groundwater saturated with calcium bicarbonate percolates through the rocks and soil before reaching a cavern or cavity underground. If percolation is slow enough for water droplets to form on an elevated surface of the cavern, some of the droplet will evaporate causing calcium carbonate to crystalize on the surface from which the drop is suspended. When another droplet percolates through to join the first, a portion of the droplet falls to the floor of the cavern where it continues to evaporate and crystallize more calcium carbonate on that surface. As this process continues over many hundreds and thousands of years, gigantic pillars of limestone (i.e., $CaC0_3$) are formed hanging from the ceiling (stalagtites) and growing up from the floor (stalagmites).

1.3 Scrubber Blowdown Characteristics

The same parameters that cause calcium carbonate to precipitate in natural water will cause calcium carbonate to precipitate in an industrial wastewater discharge such as wet scrubber blowdown. The primary parameters are the calcium and carbonate/bicarbonate concentrations as well as the pH, temperature and total solids concentration of the discharges. Even if no calcium or carbonate concentrations are present in the industrial discharge, mixing the discharge with a natural water can trigger calcium carbonate precipitation due to a shift in the resultant temperature and/or pH of the combined flows.

1.4 Conventional Calcium Carbonate Chemistry Terminology

The study and evaluation of water systems involving calcium carbonate chemistry uses terminology that is almost exclusively limited to the water treatment technology field. Thus, such terms may not be familiar to chemists and engineers who have discipline in more general chemical process or analytical fields. A brief description of the following terms are relevant to understanding the results, discussion and conclusions of this study:

1.4.1 Hardness

The dissolved calcium concentration of a water is not of particular concern from an environmental or health point-of-view. Most naturally occurring calcium compounds are non-toxic substances that make up a large fraction of the earths crust as well as many living organisms. For example, exoskeletons of many marine and aquatic invertebrates are made of calcium carbonate assimilated from the surrounding water. The skeletons and teeth of higher animals are comprised of calcium phosphate.

From an industrial use point-of-view however, the calcium content of a water is a major concern. For example, because of the tendency of calcium carbonate (and calcium sulfate) to "scale out" of water when it is used for either cooling or steam generating purposes, its analyses in the water source is always essential and treatment for its removal is typically required.

Historically, the term "hardness" was initiated by the laundry and cleaning products industries. The term hardness applies to the natural cationic components of water that cause soap to precipitate and thus, make a water "hard" to wash with. Normally, calcium and magnesium are the most abundant cations in natural water that cause soap to precipitate. Together, the calcium and magnesium concentrations are generally considered the "total hardness" of natural water. Alone, the calcium ion concentration is considered the "calcium hardness" and magnesium ion concentration is the "magnesium hardness".

1.4.2 Alkalinity

Whenever a natural mineral, such as calcium carbonate or sodium chloride dissolve in water, ions of opposite charge called cations (i.e., Ca++, Na+, etc.) and anions (i.e., $CO_3^=$, Cl^-, etc.) are formed in chemically equivalent (stoichiometric) concentrations.

Thus, whenever calcium ion is found dissolved in natural water, there must be a chemically equivalent balance with one or more anions (such as bicarbonate, carbonate, sulfate or chloride) present that came from the dissociation of the same dissolved mineral(s).

Certain of the anions have the ability to neutralize mineral acids (i.e., HCl, H_2SO_4, HNO_3) forming salt and water as the products of the neutralization reaction. Together, the combined concentration of all the acid neutralizing anions is called the "total alkalinity" of the water. In natural water, bicarbonate (HCO_3^-), carbonate ($CO_3^=$) and hydroxide (OH^-) ions make up the "total alkalinity" of the water. The HCO_3^- concentration is the "bicarbonate alkalinity", $CO_3^=$ concentration is the "carbonate alkalinity" and the OH^- concentration is the "hydroxyl alkalinity" (also referred to as "causticity") of the water. Since most natural water has pH values less than 9.0, and very little OH^- concentration is present at this pH, "total alkalinity" is typically comprised of just HCO_3^- and $CO_3^=$ concentration.

Since $SO_4^=$ and Cl^- are already the anions of salts of these acids, they don't neutralize the acids and do not constitute alkalinity in the water.

Therefore, hardness may be associated with an equivalent concentration of alkalinity or may be associated only with non-alkaline anions or may be associated with some of each. That portion of hardness associated with (or equivalent to) the alkalinity (i.e., HCO_3^- and $CO_3^=$) of the water is known as "carbonate hardness" and the portion associated with (or equivalent to) the non-alkaline anions (i.e., $SO_4^=$, Cl^-, NO_3^-) is known as "non-carbonate hardness".

1.4.3 Calcium Carbonate Units or Equivalents

Historically, the conventional water treatment process for removal of calcium hardness involves precipitation with carbonate to form solid calcium carbonate. If not enough carbonate or bicarbonate ion is naturally present, a soluble salt such as soda ash (Na_2CO_3) is added stoichiometrically to maximize the removal of dissolved calcium as much as possible.

Even though ion exchange softening has largely replaced these conventional water treatment methods (that involve treating for dissolved calcium by precipitation of solid calcium carbonate), it is still the convention in both analysis reporting and calculation of treatment dosages to express both hardness and alkalinity constituents in terms of calcium carbonate equivalents (i.e., mg/l as $CaCO_3$). Therefore, upon glancing at a water analysis it is readily apparent whether or not all the calcium present is associated with (or equivalent to) all the alkalinity present or vice-versa. Also, this convention helps in calculating the dosages of treatment chemicals (such as $Ca(OH)_2$ and Na_2CO_3) needed to remove either excess calcium or excess alkalinity since they would also be converted to their $CaCO_3$ equivalents.

Another reason for use of $CaCO_3$ equivalents is that it is a convenient mechanism with which to put each of the reacting hardness and alkalinity components on the same molar (i.e., chemically equivalent or stoichiometric) basis. Since each chemical species must react with the stoichiometric equivalent of another species, the molecular weight of $CaCO_3$ (being 100 grams/mole) makes a convenient denominator to divide the molecular weight of the other reacting species by to determine their multiplication factors for calculating concentrations as $CaCO_3$ equivalents.

The use of $CaCO_3$ equivalents was a system devised in the early days of water treatment technology since many water treatment operators had no formal training or knowledge of chemical reactions, molar equivalents or stoichiometric balances between reacting species. Therefore, tables were prepared, such as shown in Tables 126 through 134 in Ref. 1, pp 488-489, to allow quick calculation of various chemical species concentrations as calcium carbonate equivalents (i.e., mg/L as $CaCO_3$).

2. SUMMARY

2.1 Objective

The first objective of this study is to determine the source, quantity and composition of the precipitate observed in the Salt Kill Creek downstream of Norlite's scrubber blowdown outfall.

The second objective is to determine and recommend measures that can be taken to eliminate or minimize the precipitate formation and subsequent deposition in the creek.

2.2 Scope

The results of this study including its conclusions and recommendations are based on data from sampling, measurements and analysis compiled from a 5-day study period representing typical facility operating and creek flow conditions during November 9 to 13, 1992.

These sampling procedures involved compositing five individual daily grab samples (both liquids and solid sediments from upstream Salt Kill, scrubber blowdown and downstream Salt Kill sample points) into 5-day composites to determine average stream compositions during this study period.

The sampling program was carried out by qualified Norlite personnel. Sample analysis were conducted by outside New York State certified laboratories.

2.3 Results

Results of the stream sampling and laboratory testing and analysis studies show that the majority of the precipitate observed in the Salt Kill downstream of the Norlite scrubber blowdown outfall is calcium carbonate. About 80 percent of the precipitate is composed of calcium carbonate while the majority of the remaining 20 percent is attributed to silica (i.e., SiO_2) and water with minor amounts of calcium, magnesium, aluminum and iron silicates, oxides and hydrates.

Mass balance calculations show the majority of the downstream sample point precipitate during the study (i.e., 84%) came from the Salt Kill water flow itself as naturally occurring carbonate hardness. The remaining 16% of the precipitate at the downstream Salt Kill sample point originates from the scrubber blowdown discharge due to calcium carbonate hardness in the scrubber recycle water.

Excess carbonate/bicarbonate alkalinity in the scrubber blowdown, during this study period, was the key factor in initiating calcium carbonate precipitation at the downstream sampling point.

This excess total alkalinity was sufficient to raise the pH of the Salt Kill to about 9.2 at the downstream sample point. At this pH value, the naturally dissolved calcium carbonate hardness in the Salt Kill becomes "mostly" insoluble and the majority precipitates and settles to the bottom of the creek as sediment.

2.4 Recommendations

Recommendations are made considering several options to reduce the pH and "buffering" characteristics of the total alkalinity in the scrubber blowdown stream. Lowering the excess concentration of carbonate buffer in the blowdown by reducing the scrubber recycle pH value from 9.2 to about 8.5 or less is an option that can be immediately taken to reduce the amount of precipitation that was observed during this study. The zero discharge option, if implemented, will also eliminate this source of precipitation. A final effluent pH adjustment system is also an option that could be added to ensure that precipitation of the natural hardness in the Salt Kill is not increased by the blowdown discharge.

The most effective interim option, from an effectiveness and implementation standpoint, is to substitute sodium hydroxide for sodium carbonate as the alkali source for acid neutralization in the scrubber system. This would eliminate excess carbonate buffer in the blowdown and the need for a final effluent pH adjustment system (assuming the blowdown pH value is maintained at a maximum of 9.0). A major reduction in downstream calcium carbonate suspended solids (i.e., precipitate) could be obtained immediately even prior to implementation of the zero discharge option.

3. SAMPLING PROGRAM

3.1 Objective

The sampling and evaluation program was proposed in a letter submitted by Norlite to NYSDEC dated October 15, 1992.

Collection of representative samples during typical kiln operation and Salt Kill Creek flow was performed to determine the composition and quantity of precipitate found settling in the creek bed downstream of Norlite's Outfall 005 discharge. This outfall flow is comprised of blowdown from the wet scrubber process of the expanded lightweight aggregate kiln APC systems.

Based on the typical Salt Kill Creek flow rate and scrubber blowdown rates, the mass of precipitated material was calculated from sample analysis. Recommendations are made in section 10 of this report, proposing alternative measures that will prevent or reduce the mass of precipitated material that has been demonstrated to be formed by admixing of APC wet scrubber blowdown discharge with upstream Salt Kill Creek Water.

3.2 Estimated Representative Conditions

The sampling program was carried out during a period of estimated typical Kiln #1 and #2 operating conditions, Salt Kill flow and weather conditions. The sampling was started on November 9, 1992 and completed on November 13, 1992. Each daily grab sample was combined with the others into a 5-day composite sample to determine average sample source composition over the 5-day period.

In addition to analyzing the composite samples of scrubber blowdown and Salt Kill Creek upstream and downstream locations, a 5-day composite of blowdown (at 1-part by volume) mixed with upstream Salt Kill water (at 7.3 parts by volume) was prepared and studied for precipitate formation. This volume ratio represents the average combined scrubber blowdown flows (at 60 gpm) with Salt Kill flow (at 1 ft^3/sec). (The calculated average Salt Kill flow during this study turned out to be 0.94 ft^3/sec based on results of the sample analysis).

Salt Kill bottom sediment sample compositions were also compared with the composition of the precipitate formed by mixing of the blowdown water samples with the upstream Salt Kill water samples.

Sample point locations where the grab samples were collected are shown in Figure 3-1. The definition of each sample collected at these sampling locations is included in Table 3-1.

3.3 Sample Collection Procedure

During the period of November 9, 1992 to November 13, 1992, grab samples of the Outfall 005 discharge; the upstream and downstream Salt Kill waters; and upstream and downstream Salt Kill bottom sediments were collected daily for the period of 5 consecutive days. The samples were collected and combined (i.e., mixed) as follows:

SAMPLE POINT A. Each day a 2-liter grab sample of 005 discharge was split into various portions as follows;

Sample A.1 - A 750-ml portion of the Outfall 005 grab sample was composited each day into a 1-gallon 5-day composite and preserved only by refrigeration. A 200-ml portion of this grab sample was added daily to a 1-liter glass jar, preserved with HNO_3, to form a 5-day composite. The non-acidified portions were designated Sample A-1 and the HNO_3 preserved portion were designated Sample A.1 (HNO_3 preserved).

Sample A.2 - A one-liter portion of each daily 005 grab sample was measured for pH and temperature and then settled in an Imhoff cone for 60-minutes to measure settleable solids concentrations. Then, 90-ml of the supernatant in the Imhoff cone was saved each day for preparing composite sample C and 750 mls were combined into a 1-gallon 5-day composite designated Sample A.2. Also, a 50-ml portion of each daily supernatant was combined in a 250-ml glass jar preserved with HNO_3. The non-acidified 1-gallon composite was designated Sample A.2 and the 250-ml acidified composite was designated Sample A.2 (HNO_3 preserved).

SAMPLE POINT B. Each daily 2-liter grab sample of upstream Salt Kill water was split into various portions as follows;

Sample B.1 - A 750-ml sample of upstream water was composited each day into a 1-gallon 5-day composite of the daily grab samples and preserved by refrigeration. A 200-ml portion was composited in a 1-liter glass jar preserved with HNO_3. These were designated composite Sample B.1 (i.e., 1-gallon non-acidified) and B.1 (HNO_3 preserved).

Sample B.2 - A 1-liter portion of each daily upstream creek sample was measured for pH, temperature and settled in an Imhoff cone for 60-minutes to measure settleable solids concentration. A 660-ml portion of this supernatant sample was saved each day for preparing composite Sample C.

Also, a 200-ml portion of each daily supernatant was combined into a 1-liter non-acidified 5-day composite designated as composite Sample B.2. Additionally, a 50-ml portion of each daily supernatant was combined into a 250-ml glass jar preserved with HNO_3 and designated composite Sample B.2 (HNO_3 preserved).

SAMPLE POINT C. Each day, a 90-ml sample of Imhoff cone supernatant saved from Outfall 005 (i.e., Sample A.2) was combined with a 660-ml portion of supernatant saved from the upstream grab sample (i.e., Sample B.2) in a 1-gallon non-acidified 5-day composite designated composite Sample C.

SAMPLE POINT D. Each daily grab sample of downstream creek water was split into various portions as follows;

Sample D.1 - A 750-ml portion of the downstream creek daily grab was composited daily into a 5-day 1-gallon composite and preserved by refrigeration. Also, a 200-ml portion of this sample was combined daily in a 1-liter glass jar preserved with $HN0_3$. The non-acidified 1-gallon sample was designated composite Sample D.1 and the 1-liter acid preserved sample was designated composite Sample D.1 ($HN0_3$ preserved).

Sample D.2 - A 1-liter portion of each daily downstream creek sample was measured for pH, temperature and settled in an Imhoff cone for 60-minutes to measure settleable solids concentration. A 200-ml portion of this supernatant sample was combined into a 1-liter non-acidified 5-day composite designated as Sample D-2. A 200-ml portion of this supernatant was also combined into a 1-liter $HN0_3$ preserved sample designated D.2 ($HN0_3$ preserved)

SAMPLE POINT E. Each day a 750-ml sample of the bottom mud and sediment was collected from the upstream creek bed (consisting of liquid and settled solids) by scooping the sediment off the bottom and measuring in a 1-liter graduated cylinder. Sand and pebbles were avoided in collecting this sediment sample. The daily 750-ml bottom sediment samples were combined into a 1-gallon 5-day composite designated composite Sample E. Note: Due to a limited amount of non-sandy (i.e., muddy) sediment at sample point E, only a small fraction of Sample E was solid sediment.

SAMPLE POINT F. Each day a 750-ml sample of bottom mud and sediment was collected from the downstream creek bed (consisting of approximately 50% by volume liquid and 50% by volume settled solids) by scooping the sediment off the bottom and measuring in a 1-liter graduated cylinder. Sand and pebbles were avoided with this sediment sample. The daily 750-ml bottom sediment samples were combined into a 1-gallon 5-day composite designated composite Sample F.

3.4 Sample Analysis Procedure

3.4.1 - At the completion of the 5-day sampling procedure, all composite samples designated A.1, B.1, D.1, A.2, B.2 and D.2 (including both the 1-gallon non-acidified samples, as well as the $HN0_3$ preserved portions) were sent directly to AnalytiKEM Inc. in Cherry Hill, New Jersey for the following analyses:

3.4.1.1 - All the 1-gallon (non-acidified) composites were shaken well prior to analysis and analyzed by standard wet chemical analysis for the following parameters;

- o Total hardness
- o Total alkalinity

- Carbonate alkalinity
- Bicarbonate alkalinity
- Hydroxide alkalinity
- Total sulfate
- Total suspended solids
- Total dissolved solids
- pH value

All the above parameters were determined using procedures described in "Standard Methods for Analysis of Water and Wastewater."

3.4.1.2 - All the HNO_3 preserved portions of these composite samples were analyzed by New York State approved ICP methods for the following metals;

- Total calcium
- Total magnesium
- Total iron
- Total manganese
- Total aluminum

3.4.2 <u>Step 1. Laboratory Separations</u>

At the completion of the 5-day sampling period, all composite samples designated C., E. and F. were sent to ThermalKEM Inc. Wastewater Treatment Laboratory in Rock Hill, S.C. for liquid-solid separation by bench test procedures as follows;

3.4.2.1 - Each composite sample (i.e., C., E. and F.) was well shaken, measured for pH, temperature and conductivity and then strained through a U.S. Standard 100-mesh (i.e., 0.15 mm open~~ing~~) stainless steel sieve. The retained solids (if any) were collected, dried at 104°C, weighed and placed in separate glass jars (unpreserved) and designated Sample C.1, E.1 and F.1 to correspond with the original composite sample.

3.4.2.2 - The portion of each composite sample that passed through the 100-mesh sieve was then individually filtered through a pre-weighed and pre-rinsed filter pad by vacuum flask fitted with a buchner funnel. The vacuum was applied until the free liquid stopped flowing from the solids residue cake on the filter pad. Each filter cake was then dried at 104°C and weighed with the filter pad and the filter pad weight subtracted from the total. The filter pads were removed and each solids residue was placed in a separate glass jar designated Sample C.2, E.2 and F.2.

3.4.3 **Step 2. Sample Residue Analysis**

Solid residues including Samples F.1, C.2, E.2 and F.2 , were analyzed by x-ray diffraction methods for compounds containing the following elements:

- calcium
- Iron
- manganese
- aluminum
- carbon
- oxygen
- silicon
- sulfur

Samples C.1 and E.1 were not of significant quantity to measure or analyze.

TABLE 3-1

NORLITE FACILITY

SALT KILL CREEK SEDIMENT STUDY SAMPLE DESIGNATION/DESCRIPTION MATRIX

A.1 Outfall 005 Wastewater Discharge	**B.1** Upstream Salt Kill Creek Water	**C.** Blend of 1-Part A.2 + 7.3 Parts B.2	**D.1** Downstream Salt Kill Creek Water	**E.** Sediment Upstream Salt Kill Creek Bed	**F.** Sediment Downstream Salt Kill Creek Bed
A.2 Supernatant of Outfall 005 Discharge	**B.2** Supernatant of Upstream Salt Kill Water	**C.1** Coarse Solids + 100 Mesh From Sample C.	**D.2** Supernatant of Downstream Salt Kill Water	**E.1** +100 Mesh Solids Strained From Sample E.	**F.1** +100 Mesh Solids Strained From Sample F.
		C.2 Fine Solids - 100 Mesh Filter Cake From Sample C.		**E.2** -100 Mesh Solids Residue Filtered From Sample E.	**F.2** -100 Mesh Solids Residue Filtered From Sample F.

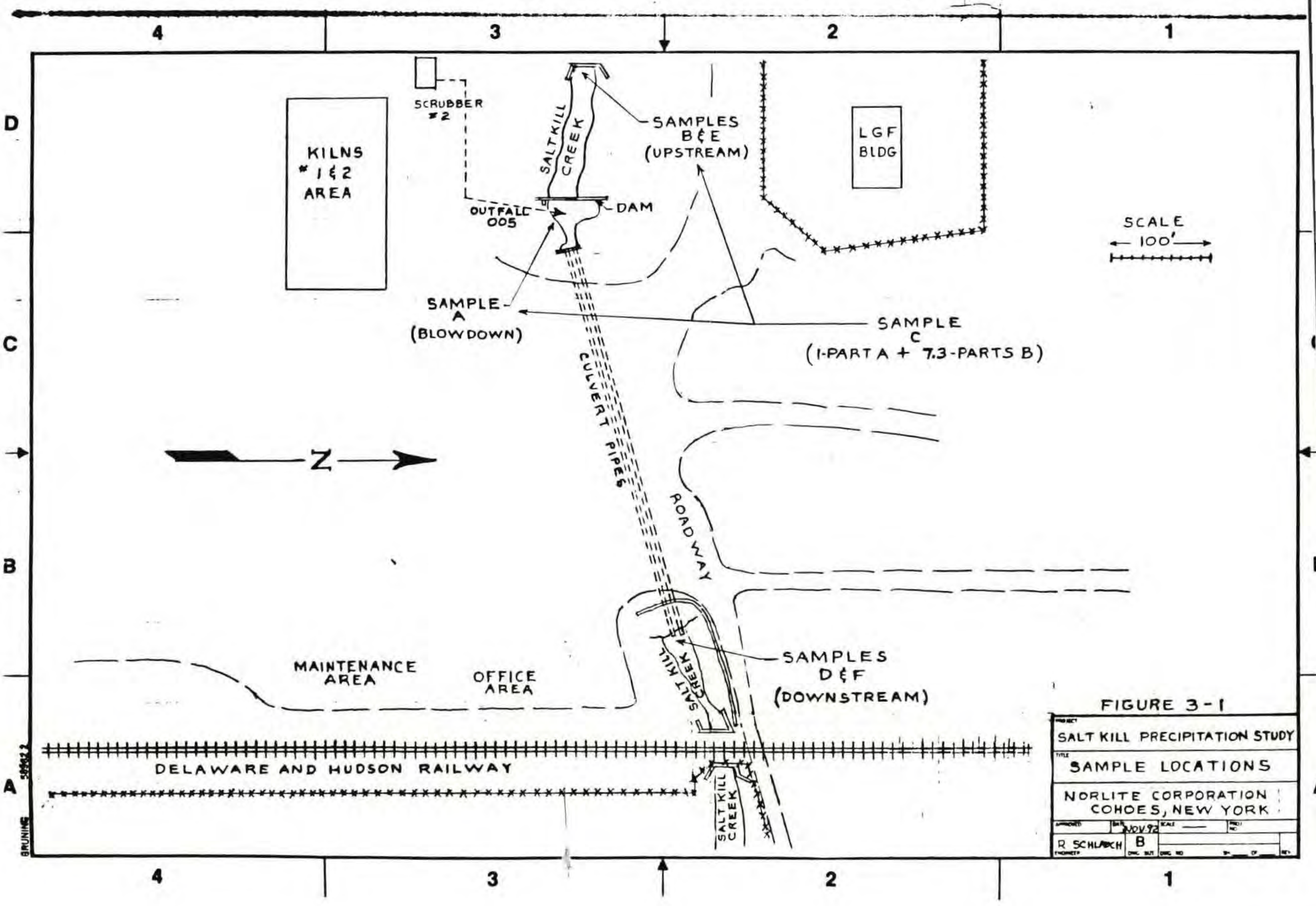

FIGURE 3-1

SALT KILL PRECIPITATION STUDY

SAMPLE LOCATIONS

NORLITE CORPORATION
COHOES, NEW YORK

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4. LABORATORY LIQUID-SOLIDS SEPARATIONS AND JAR TESTS

4.1 Laboratory Bench Measurements

One gallon samples (sent in a refrigerated cooler) were received at the ThermalKEM, Rock Hill, SC wastewater treatment laboratory on November 17, 1992 for liquid-solids separations and jar tests.

The following bench measurements were made upon receipt of the samples:

Sample	Temperature (°F)	pH Value	Conductivity (micro S/cm
B-1	51	8.46	750
C	51	8.82	2,870
E	51	8.30	675
F	52	8.88	3,590

4.2 Liquid-Solids Separations

4.2.1 Coarse Solids Fraction

The one-gallon samples of C, E and F were strained through a stainless steel U.S. Standard 100 mesh sieve (i.e., 0.15 mm opening) and solids retained on the sieve were dried at 104°C and weighed to give the following results:

Sample	Settled Solids Vol (ml/L)	Supernatant Vol (L)	Dry Solids (grams)
C.1	0.35	3.65	none
E.1	<0.1	3.60	0.007
F.1	950	3.20*	345.426

* Filtrate volume

4.2.2 Fine Solids Fraction

The supension passing through the 100-mesh sieve was then filtered through a Whatman GF/A (0.0016 mm pore diameter) filter pad to capture and retain the fine solids fraction. The retained solids on the filter pad were dried at 104°C and weighed to give the following results:

Sample	Settled Solids Vol (ml/L)	Supernatant Vol (L)	Dry Solids (grams)
C.2	NA	3.65	0.368
E.2	NA	3.60	0.106
F.2	NA	3.20	196.625

These results indicate that the total suspended solids resulting from admixing 1-part of scrubber blowdown with 7.3 parts of Salt Kill water (i.e., Sample C) are equal to 101 mg/L (i.e., 368 mg/3.65 liters).

One duplicate of Sample B.1 was initially sent to Rock Hill with samples C.2, E.2 and F.2 for jar tests to study the precipitation potential of the upstream Salt Kill water itself. However, it was reported that the other duplicate B.1 sample was not received at AnalytiKEM in Cherry Hill, New Jersey for general chemical and metals analysis. Therefore, a 500-ml portion of B.1 was used with 3600-ml of Sample E filtrate to represent the upstream Salt Kill water in these jar tests. The remainder of Sample B.1 (about 3-liters) was sent to AnalytiKEM, Cherry Hill, New Jersey for general chemical and metals analyses.

4.3 <u>Upstream Salt Kill Water Jar Tests</u>

Jar tests were performed at varied temperatures, soda ash dosages and pH values to evaluate the potential for calcium carbonate to precipitate from the upstream Salt Kill water. The results of three jar tests are summarized in Table 4-1.

The results of Jar Test #1 show that, at room temperature (71°F) and variable increasing soda ash dosages at pH value above 10.0, an almost constant concentration of calcium hardness will precipitate from the Salt Kill water. This concentration is determined at 134 to 139 mg/L (as $CaCO_3$).

The results of Jar Test #2 show that at elevated temperature (comparable to the scrubber blowdown temperature at 110°F) the constant minimum dosage of soda ash (i.e., 588 mg/L Na_2CO_3) will generate increasing concentrations of calcium carbonate precipitate in the Salt Kill proportional to increase in pH value between 8.1 and 9.9. This variable range in pH value is the result of adjusting the equilibrium pH to lower values with hydrochloric acid solution.

The results of Jar Test #3 show that at elevated temperature and increasing pH value (i.e., from pH 8.2 to 10.1) increasing concentrations of calcium carbonate precipitated from the Salt Kill. All but about 5 mg/L of the calcium hardness can be precipitated from the Salt Kill as the result of only pH and temperature increases. No soda ash addition is required to precipitate the calcium hardness in the Salt Kill. Also, a modest increase in pH from 8.2 to 8.6 (without carbonate addition) results in 101 mg/L of $CaCO_3$ precipitated. However, raising the temperature alone, without adding soda ash or increasing the pH, results in only a slight amount of calcium carbonate precipitation.

The results of these three jar tests demonstrate that a filtered Salt Kill sample is naturally saturated with calcium carbonate hardness and that the total suspended solids precipitated by either soda ash addition, temperature increase and/or pH increase (i.e., by sodium hydroxide addition) is virtually 100 percent calcium carbonate precipitate.

4.4 Laboratory Comparison of NaOH vs. Na_2CO_3 for Acid Neutralization in Wet Scrubber

Bench neutralization titrations were performed on a laboratory prepared sample of 1.1 weight percent hydrochloric acid (HCl) solution. The 1.1% HCl solution is calculated to be at least as great as the maximum instantaneous acid concentration absorbed in the wet scrubber solution under average operating conditions. The results of the laboratory titrations comparing sodium hydroxide neutralization efficiency with soda ash neutralization efficiency are shown in Figure 4-1.

These results show clearly that in order to neutralize the HCl solution to a scrubber operating pH value of 9.0, about 12,000 mg/L of NaOH or about 19,200 mg/L of Na_2CO_3 are required. It is also shown that, on a dry weight basis, 60 percent more Na_2CO_3 is required than NaOH to perform the same degree of acid neutralization to pH 7.0.

The results also demonstrate that, where as no carbonate or bicarbonate alkalinity is added to the neutralized solution when using NaOH, use of Na_2CO_3 requires that an excess of about 2000 mg/L Na_2CO_3 are needed to raise the pH from 4.3 to 9.0. Below pH 4.3, essentially no bicarbonate or carbonate alkalinity is present as all the remaining carbonate added exists as carbonic acid. Therefore, about 17,200 mg/L of Na_2CO_3 were used in neutralizing the HCl and the additional 2000 mg/L Na_2CO_3 (i.e., 1880 mg/L as $CaCO_3$) are required to raise the pH from 4.3 to 9.0 in the neutralized acid solution. Since about 99% of all the acid was neutralized as the pH was raised to 4.3, the excess residual of 1880 mg/L carbonate alkalinity (as $CaCO_3$) is the minimum required excess existing in the scrubber blowdown at pH 9.0 when using soda ash. Even at acid concentrations of only 1% of the demonstrated 1.1% HCl case (i.e., 0.011% HCl) the required excess of Na_2CO_3 is still about 2000 mg/L Na_2CO_3 to maintain the equilibrium pH at 9.0.

STUDY OF PRECIPITATE OBSERVED IN THE SALT KILL CREEK AT NORLITE CORP. COHOES, NY

TABLE 4-1

JAR TEST RESULTS

Upstream Salt Kill Sample Pre-Filtered - Calcium Hardness = 175 ppm $CaCO_3$

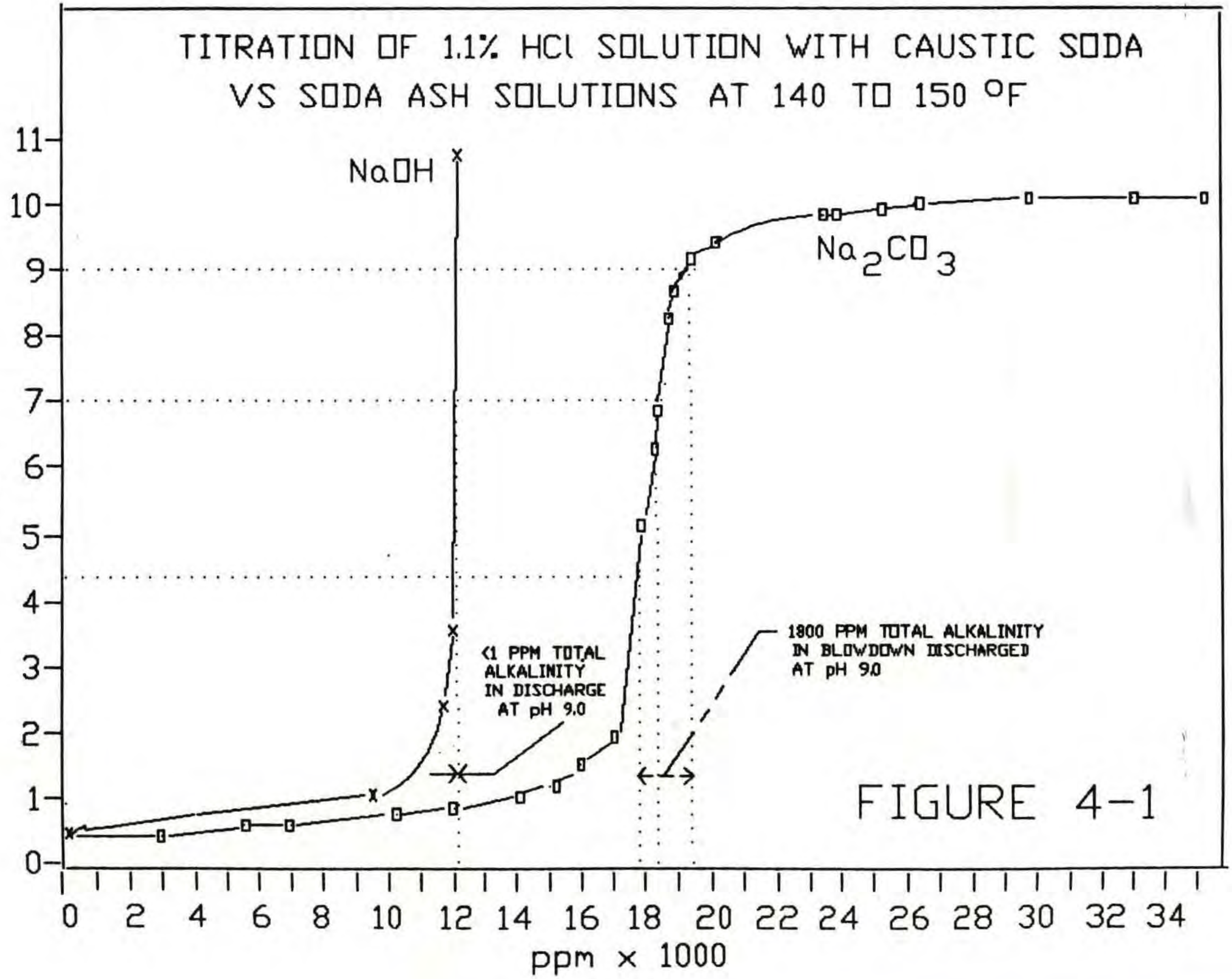
TREATMENT		RESULTS	
DOSAGE	pH	TSS (ppm)*	Ca pptd as $CaCO_3$ (ppm)** (Prefilt.Ca-Postfilt.Ca=Pptd.Ca)
Jar Test #1 - 71° Reaction Temp. w/Variable Soda Ash Dosage - Reagent Dilution Factor = 0.88 x 175 ppm $CaCO_3$ = 154 ppm $CaCO_3$			
588 ppm Na_2CO_3***	10.21	127	154 - 20 = 134
2350 ppm Na_2CO_3	10.76	152	154 - 15 = 139
5880 ppm Na_2CO_3	10.96	159	154 - 16 = 138
Jar Test #2 - 110°F Reaction Temp. w/Constant Soda Ash & Variable pH - Reagent Dilution Factor = 0.88 x 175 ppm $CaCO_3$ = 154 ppm $CaCO_3$			
588 ppm Na_2CO_3 +HCl	8.14	107	154 - 52 = 102
588 ppm Na_2CO_3 +HCl	8.96	148	154 - 15 = 139
588 ppm Na_2CO_3 +HCl	9.88	157	154 - 5 = 149
Jar Test #3 - 110°F Reaction Temp. w/Variable pH Only			
~ 0.1 ppm NaOH	8.61	100	175 - 74 = 101
~ 5 ppm NaOH	10.13	170	175 - 5 = 170
0	8.15	5	175 -170 = 5

NOTES:

* Total Suspended Solids by gravimetric determination, accuracy = ± 3 ppm

** Calcium determination by ICP spectrophotometry, accuracy = ± 4.5%

*** Typical soda ash purity = 99.2% Na_2CO_3



TITRATION OF 1.1% HCl SOLUTION WITH CAUSTIC SODA VS SODA ASH SOLUTIONS AT 140 TO 150 °F

<1 PPM TOTAL ALKALINITY IN DISCHARGE AT pH 9.0

1800 PPM TOTAL ALKALINITY IN BLOWDOWN DISCHARGED AT pH 9.0

FIGURE 4-1

5. AQUEOUS STREAM SAMPLE ANALYSIS

5.1 Field Measurement Data

On a daily basis, during the sampling period, measurements of pH, temperature and settleable solids were made for each aqueous grab sample. Table 5-1 shows the results recorded for these sample measurements. For the purpose of using this grab sample data to represent average study period conditions in conjunction with the 5-day composite samples, the data values are averaged to obtain a 5-day average of the field data. Therefore, the 5-day averaged field data is used with the 5-day composite sample analysis to define average sample point conditions for calculating precipitation material balances in Section 7 of this report.

The results of these measurements for settleable solids indicate that the average value was 3.1 ml/L for this study period. This increase from the average value of 1.3 ml/L, measured during the 3-month period of July to September 1992, is attributed to an increase in the rate of dry lime feed, i.e., $Ca(OH)_2$, to the baghouses instituted during October 1992. The increase in lime feed was made to improve the removal of HCl and SO_2 in the baghouses and therefore reduce the amount of soda ash feed required for the wet scrubber operation.

However, the increased rate of lime feed allows more lime fines to pass into the wet scrubber solution, therefore contributing calcium which precipitates (eventually) with the carbonate alkalinity of the scrubber solution to form calcium carbonate precipitate in the scrubber blowdown.

5.2 Analytical Laboratory Results for Composite Samples

The daily grab samples from each sample point were composited each day to generate a 5-day composite of each sample source. The analytical results for the aqueous samples from points A, B and D are shown in Table 5-2. The raw sample fractions are labelled A.1, B.1 and D.1, respectively. The corresponding supernatant liquids, after sedimentation in the "Imhoff" settling cone, are designated Samples A.2, B.2 and D.2.

The analysis of scrubber blowdown Samples A.1 and A.2 actually represent final chemical equilibrium conditions rather than conditions at time of blowdown discharge. Since the unpreserved composite samples had opportunity to continue reactions during the 5-day sample collection, in addition to several days elapsed time from sample shipment to laboratory analysis, the average concentration of total suspended solids at the time of sample collection is estimated to be about 2 times lower than the indicated value of 630 mg/L TSS. That is, considering the differences in total concentrations of preserved metals (such as Ca, Al and Fe) observed in Sample A-1 vs. A-2, only about one half of the metal cations were in precipitated form at the time the grab samples were collected and settled in the Imhoff cone.

The presence of 630 mg/L TSS in the raw composite blowdown sample (A.1) is primarily the result of calcium contributed to the wet scrubber solution by passage of small amounts of lime through the baghouses. Because the lime is in dry particulate form as it contacts the hot wet scrubber solution it does not completely dissolve quickly and some remains suspended as a fine dispersion in the blowdown. Due to the alkaline pH of the scrubber solution (i.e., pH 9.4) the residual lime dissolves very slowly even though the dissolved fraction of calcium ions immediately form calcium carbonate precipitate. Therefore, at the time of grab sample collection and settleable solids testing, a minimum of 1-hour had elapsed before the supernatant sample was collected and preserved for metals analysis. Since 44 mg/L of calcium remained in the supernatant sample following this test, it is evident that portion of the total calcium concentration was not yet precipitated as $CaC0_3$ but remained as dispersed $Ca(0H)_2$. With compositing, plus shipping time, this lime eventually dissolved and was then precipitated as calcium carbonate.

Calculations show that the 90 mg/L of total calcium in the scrubber blowdown can be eventually precipitated as 457 mg/L of a hydrated form of calcium carbonate (i.e., $CaC0_3.6H_20$). (See Ref #3, pg B-79). Instead of forming the anhydrous crystalline calcite or aragonite (i.e., $CaC0_3$) as is typically formed in natural waters that are saturated with approximately equivalent concentrations of calcium hardness and carbonate alkalinity, the scrubber solution is saturated with a 15-fold excess of carbonate alkalinity (above the calcium hardness requirement). This causes a high percentage of the water associated with the calcium ions to be included in the crystals of calcium carbonate that are rapidly precipitated. This form of calcium carbonate is not the typical hard scale or dense particle, but a light voluminous precipitate. In addition to the six molecules of water precipitated with each molecule of calcium carbonate formed, significant percentages of dissolved salts (including NaCl, Na_2C0_3 and Na_2S0_4) are also incorporated in the hydrated calcium carbonate precipitate.

The precipitation of calcium therefore, accounts for the majority of TSS in the blowdown sample. The following composition has been calculated for the 630 mg/L of TSS resulting in the scrubber blowdown:

Compound Precipitated	**Percent of TSS**
$CaCO_3 \cdot 6H_2O$	72.5
$Fe(OH)_3$	4.3
$Al(OH)_3$	3.0
$Mg(OH)_2$	1.0
Misc. inclusions;	19.2
o SiO_2	
o H_2O	
o NaCl	
o $Na_2CO_3 \cdot 10H_2O$	
o $Na_2SO_4 \cdot 10H_2O$	

The analysis of the scrubber solution supernatant (i.e., A-2) also indicates that the TSS is comprised mostly of hydrated calcium carbonate with high percentages of entrained water and salts in the precipitate. The increase in dissolved solids in the supernatant has to be attributed to the absorbtion of CO_2 from the atmosphere as the scrubber water stands in the settling cone during the settleable solids test. As the liquid cools, CO_2 is absorbed from the air forming an increase in the bicarbonate concentration by 850 mg/L (as $CaCO_3$).

The following equation describes the ambient reaction taking place:

$$\underset{\text{Sodium carbonate}}{Na_2CO_3} + \underset{\text{atmospheric carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \xrightarrow{\text{cooling}} \underset{\text{sodium bicarbonate}}{2\ NaHCO_3}$$

Absorbtion of atmospheric CO_2 plus a considerable degree of evaporation of hot water from the settling cone surface accounts for the increase in dissolved solids concentrations in the blowdown supernatant sample vs. the raw blowdown sample.

The individual analysis of total calcium and total magnesium (by ICP) in Table 5-2 should be considered more accurate than the total hardness concentrations reported since the total hardness is a titration to a change in color endpoint which is subject to the optical interferences of the TSS in the sample. However, in all three sample sources (A, B and D) there is reasonable agreement between the total hardness by titration and the combined calcium and magnesium concentrations (analyzed by ICP in the acid preserved samples) after converting to $CaCO_3$ equivalent concentrations.

The analysis of Sample B.1 shows that the upstream Salt Kill is near saturation with carbonate hardness in solution. The calcium hardness is 77 mg/L (as Ca) x 2.5 = 193 mg/L (as $CaCO_3$). Therefore, 89% of the hardness present in the upstream Salt Kill is carbonate hardness.

STUDY OF PRECIPITATE OBSERVED IN THE SALT KILL CREEK AT NORLITE CORPORATION, COHOES, NEW YORK

TABLE 5-1

FIELD MEASUREMENT DATA FOR DAILY GRAB SAMPLES COLLECTED FOR 5-DAY COMPOSITE ANALYSIS

DATE	PARAMETER MEASURED	SAMPLE POINT A OUTFALL 005 DISCHARGE	SAMPLE POINT B UPSTREAM SALT KILL	SAMPLE POINT D DOWNSTREAM SALT KILL
Nov. 9, 1992	Time Hrs	1435	1437	1439
	pH	9.09	8.37	9.32
	Temp °F	102	43	52
	Set.Solids ml/l	0.3	<0.1	<0.1
Nov. 10, 1992	Time Hrs	1510	1512	1515
	pH	9.44	8.43	9.22
	Temp °F	102	66	55
	Set.Solids ml/l	4.0	<0.1	0.2
Nov. 11, 1992	Time Hrs	1545	1547	1549
	pH	8.89	8.44	9.09
	Temp °F	99	52	52
	Set.Solids ml/l	5.0	<0.1	<0.1
Nov. 12, 1992	Time Hrs	1545	1547	1555
	pH	9.26	8.43	9.39
	Temp °F	99	55	54
	Set.Solids ml/l	3.0	<0.1	<0.1
Nov. 13, 1992	Time Hrs	1100	1102	1106
	pH	9.34	8.42	9.28
	Temp °F	100	55	54
	Set.Solids ml/l	3.0	<0.1	<0.1
5-Day Average	Time Hrs	1427	1429	1433
	pH	9.20	8.42	9.26
	Temp °F	100	54	53
	Set.Solids ml/l	3.1	<0.1	<0.12

STUDY OF PRECIPITATE OBSERVED IN THE SALT KILL CREEK AT NORLITE CORPORATION, COHOES, NEW YORK

TABLE 5-2

ANALYTICAL LABORATORY RESULTS FOR 5-DAY COMPOSITE AQUEOUS SAMPLES

	A-1	B-1	D-1
pH	9.4	8.5	8.8
TSS mg/l	630	19	77
TDS mg/l	12000	470	2500
T-Hardness mg/l as $CaCO_3$	200	240	190
SO_4	3300	71	740
HCO_3 mg/l as $CaCO_3$	3300	170	1100
CO_3 mg/l as $CaCO_3$	410	2	25
OH mg/l as $CaCO_3$	<1	<1	<1
Al mg/l	6.6	0.72	1.1
Ca mg/l	90	77	47
Fe mg/l	14	1.3	1.6
Mg mg/l	10	20	15
Mn mg/l	0.37	0.044	0.061
	A-2	B-2	D-2
pH	9.4	7.7	8.5
TSS mg/l	730	<10	<10
TDS mg/l	17,000	450	2500
T-Hardness mg/l as $CaCO_3$	160	250	180
SO_4	4700	63	700
HCO_3 mg/l as $CaCO_3$	4000	170	480
CO_3 mg/l as $CaCO_3$	560	1.2	13
OH mg/l as $CaCO_3$	<1	<1	<1
Al mg/l	2.6	0.73	0.88
Ca mg/l	44	67	40
Fe mg/l	4.8	1.1	1.5
Mg mg/l	6.6	16	14
Mn mg/l	0.11	0.046	0.052

In the downstream Salt Kill (i.e., Sample D.1) 100% of the calcium hardness is present as carbonate hardness. That is, the total carbonate alkalinity is in excess of the total calcium hardness (i.e., 118 mg/L as $CaCO_3$). This is attributed to the excess carbonate contributed by the discharge of blowdown which precipitates and settles about 30 ppm of calcium hardness (as $CaCO_3$) by the time the Salt Kill flow reaches downstream sample point D.

The analytical laboratory report shows the results of Samples D.1 and D.2 in reverse order from those shown in Table 5-2. This is concluded to be a sample switch or identification error since it is impossible for the total suspended solids in the raw sample to be less than its supernatant after settling, while at the same time the total alkalinity and total hardness also increase in the supernatant fraction after settling. Due to the temperature of the downstream sample (i.e., 53°F) evaporation would not be a significant factor in this case as is indicated by the constant total dissolved solids in the raw and supernatant fractions of the downstream sample.

However, besides the moderate differences in TSS and bicarbonate (HCO_3^-) alkalinity, there is no significant difference between the raw and supernatant fractions of the downstream Salt Kill (i.e., Samples D.1 and D.2). These modest differences, no matter if the results are reversed or not, do not affect the conclusions of this study in any way.

6. PRECIPITATE AND BOTTOM SEDIMENT ANALYSIS

General inorganic and metals analysis of total constituents in the aqueous stream samples are used to calculate the composition of the precipitates that will form using known solubility values at the measured temperature, pH and concentration conditions. Analysis of the dried solid residues of precipitation and the bottom sediments is an alternative means of determining the composition of the precipitate. Typically, x-ray diffraction (and similar methods) are useful for determining approximate percentages of various suspected compounds in the solid samples.

6.1 Source and Description of Solid Residues Analyzed

Sample C was generated and composited daily by combining of supernatants of grab samples collected from the blowdown source (Sample Point A) and upstream Salt Kill source (Sample Point B). These supernatant samples were blended together at the volume ratio of the average Salt Kill flow to the average blowdown flow (i.e., 7.3 to 1). Since only the supernatants (i.e., liquid after settleable solids are removed) of these samples were blended, it demonstrates that the resulting TSS in the blend is the result of a precipitation reaction between the blowdown and Salt Kill sources and not due to pre-existing settleable solids from either source.

Since the liquid-solids separations test of Sample C (i.e., Section 4) showed that the TSS of this blend was 101 mg/L, it demonstrates that dissolved constituents from the Salt Kill are reacting with the blowdown to form a precipitate (i.e., 101 mg/L as TSS) in the combined streams. It is also important to note that 101 mg/L is precisely the concentration of calcium carbonate precipitated from the "filtered" upstream Salt Kill sample after raising the pH and temperature of the sample without addition of any carbonate alkalinity or calcium hardness. These results are shown for Jar Test #3 in Table 4-1 of Section 4.

After filtering and drying the resulting fine precipitate from Sample C, the solid residue, designated Sample C.2, was submitted for identification and quantification of specific chemical compounds by X-ray diffraction techniques.

The bottom sediment samples from Sample Points E and F were separated from the liquid by U.S. Standard 100-mesh sieve and, then, laboratory vacuum filtration to separately collect the coarse and fine sediment fractions for X-ray diffraction analysis. Sample E, from the upstream Salt Kill Creek bed, contained no observable solids larger than 0.15 mm diameter. Therefore, only a fine fraction, designated Sample E.2, was submitted for X-ray diffraction analysis.

Unlike the upstream bottom sediment Sample E, the downstream bottom sediment Sample F contained a high percentage of solids larger than 0.15 mm diameter. Therefore, a coarse fraction designated Sample F.1 was collected from the 100-mesh sieve and dried at 104°C for X-ray diffraction analysis. The fine fraction was filtered on Whatman GF filter pad (0.0016 mm pore), dried at 104°C and designated Sample F.2 for X-ray diffraction analysis.

6.2 Results of X-Ray Diffraction Analysis

Samples C.2, E.2, F.1 and F.2 were submitted to Adirondack Environmental Services in Albany, New York for X-ray diffraction analysis to target eleven possible inorganic compounds as follows:

calcium carbonate	$CaCO_3$
magnesium oxide	MgO
manganese dioxide	MnO_2
aluminum oxide	Al_2O_3
ferric oxide	Fe_2O_3
calcium sulfite	$CaSO_3.1/2\ H_2O$
calcium sulfate	$CaSO_4.2H_2O$
magnesium silicate	$MgSiO_3$
manganese silicate	$MnSiO_3$
iron orthosilicate	Fe_2SiO_4
aluminum silicate	$Al_2O_3.SiO_2$

Because of the limited quantities of most of the solid residue samples recovered, the composition could only be quantified for the major constituents, calcium carbonate and silicon dioxide. The following percentages of calcium carbonate and silicon dioxide were determined to be present in each of these samples by the Adirondack Environmental Laboratory:

Sample	Description	Percent by wt.	
		$CaCO_3$	SiO_2
C.2	Solids precipitated by blending A.2 and B.2	78.73	12.29
E.2	Solids sediment collected from upstream creek bed	7.83	58.32
F.1	Coarse solid sediment collected from downstream creek bed	52.14	26.25
F.2	Fine solid sediment collected from downstream creek bed	31.82	43.12

The high percentage of calcium carbonate (i.e., almost 80%) found in the precipitated solids (i.e., Sample C.2), resulting from blending of scrubber blowdown supernatant with upstream Salt Kill supernatant, confirms the conclusion made from the aqueous sample analysis that the majority of precipitate observed in the Salt Kill downstream of Outfall 005 is calcium carbonate.

The lower percentage of calcium carbonate in the sediment of the upstream creek bed (i.e., 7.83%) indicates that there is not a high percentage of calcium hardness in the upstream creek water in a precipitated form. The remaining composition of the sediment in the upstream creek bed is assumed to be natural clay, mud and organic matter.

The increased concentrations of calcium carbonate analyzed in both the coarse and fine fractions of the downstream creek bed (i.e., F.1 and F.2) indicate that the rate of calcium carbonate precipitation and sedimentation is increased at the downstream Sample Point F as compared to the upstream Sample Point E.

7. PRECIPITATE FORMATION AND MATERIAL BALANCE CALCULATIONS

7.1 Average Blowdown, Salt Kill and Combined Stream Conditions During Sampling Period

7.1.1 Stream Flow Rates

7.1.1.1 Scrubber Blowdown Rate

The average combined blowdown rate for Kilns #1 and #2 APC system scrubbers = 60 gpm

$$\frac{60 \text{ gal}}{\text{min}} \times \frac{3.785 \text{ Liters}}{\text{gal}} = 227 \text{ L/min}$$

7.1.1.2 Calculation of Salt Kill and Combined Blowdown - Salt Kill Stream (i.e., Downstream) Flow Rate

The flow rates of the combined Salt Kill and blowdown flows, as well as the estimated Salt Kill flow itself, during the sampling period of this study can be calculated from the analyzed total dissolved solids concentrations in each stream as follows:

Sample A-2 - Blowdown total dissolved solids = C_{BD} = 17,000 mg/L
- Blowdown total flow rate = V_{BD} = 227 L/min

Sample B-2 - Upstream Salt Kill total dissolved solids =C=450 mg/L
- Upstream Salt Kill flow rate = V_{US}

Sample D-2 - Downstream total dissolved solids = C_{DS} = 2500 mg/L
- Downstream flow rate = V_{DS} = 227 L/min + V_{US}

$$(V_{BD})(C_{BD})+(V_{US})(C_{US}) = (V_{DS})(C_{DS})$$
$$(227 \text{ L/min})(17{,}000 \text{ mg/L})+(V_{US})(450 \text{ mg/L})=(V_{US}+227 \text{ L/min})(2500 \text{ mg/L})$$
$$3{,}859{,}000 \text{ mg/min} + 450\ V_{US} \text{ mg/min} = 2500\ V_{US} \text{ mg/min}+567{,}500 \text{ mg/min}$$
$$2050\ V_{US} = 3{,}291{,}500$$
$$V_{US} = 1606 \text{ L/min} = 424 \text{ gpm}$$

$V_{DS} = V_{US}+227$ L/min = 1606+227 = 1833 L/min = 484 gpm

Therefore, stream volume ratio = Salt Kill : Blowdown = 7.1:1

7.2 Calculation of Calcium Carbonate Saturation Indices for Upstream Salt Kill and Downstream Salt Kill Sample Points

The precipitation of calcium carbonate from water is dependent upon the concentrations of calcium hardness and carbonate alkalinity (i.e., carbonate/bicarbonate concentrations) as well as certain other existing conditions of the water source in question, including;

A. The total solids (primarily TDS) concentration
B. Temperature of the water, at equilibrium conditions
C. Calcium concentration
D. Methyl Orange (i.e., Total) Alkalinity concentration
E. Solution pH, at equilibrium conditions

References #1 (pg 223), #4 (pg 150) and #5 (pg 111) describe formula tables and equations that are used to calculate the pH at which a water in question will be saturated with calcium carbonate based on the other existing conditions listed above. This relationship (known as the Langelier Index for calcium carbonate saturation) is often used by chemists and engineers to determine if calcium carbonate scaling or precipitation will take place in piping systems, cooling towers and other equipment based on a given or predicted water quality.

The Langelier calcium carbonate saturation pH (or pHs) is determined by the following equation:

pHs = (9.3+A+B) - (C+D) where;
A = total solids concentration in ppm or mg/L
B = water temperature in °F
C = calcium concentration in ppm or mg/L as $CaC0_3$
D = methyl orange (total) alkalinity in ppm or mg/L as $CaC0_3$

The precipitation (or saturation) index is calculated by:

Saturation Index = pH - pHs where;
pH = the measured or predicted pH of the water in question
pHs = the saturation pH as calculated above and, as a result;

- if pH - pHs = 0, the water is considered to be in a stable (no potential to scale, precipitate or corrode) condition

- If pH - pHs = greater than 0, the water has a potential to induce precipitation of calcium carbonate which increases relative to the magnitude of the positive pH - pHs value.

- o If pH - pHs is less than 0, there is an increasing potential for the water to be corrosive which increases relative to the magnitude of the negative pH - pHs value.

7.2.1 Calcium Carbonate Precipitation Potential in Existing Upstream Salt Kill Water

Existing Water Conditions	**Formula Value from Langelier Index Tables**
A = Total solids concentration = 470 mg/L =	0.2
B = Temperature during sampling = 54°F =	2.3
C = Calcium hardness (as $CaCO_3$) = 193 mg/L =	1.9
D = Total alkalinity (as $CaCO_3$) = 172 mg/L =	2.2

and, average measured pH during sampling = 8.4

$pHs = (9.3+A+B) - (C+D)$
$pHs = 9.3+0.2+2.3 - 1.9-2.2$
$pHs = 7.7$ = pH at which $CaCO_3$ is at the saturation concentration in upstream Salt Kill and so,

Saturation Index = $pH - pHs = 8.4-7.7 = +0.7$

Therefore, the existing upstream Salt Kill flow has a positive potential (saturation index = +0.7) to precipitate $CaCO_3$ naturally without any influence from Norlite's outfall discharges. This fact is clearly demonstrated by the experimental results in Table 4-1 showing that 5 ppm as $CaCO_3$ are precipitated from a presettled sample (from upstream Salt Kill sample point B) just by increasing the temperature from 71°F to 110°F. Also, the analytical results shown in Tables 5-1 and 5-2 indicate that by raising the upstream Salt Kill sample temperature from 54°F to about 70°F and setting for 1-hour, 25 ppm of $CaCO_3$ are precipitated from the raw water sample. Raising the temperature of the water has the effect of approximately doubling the reaction rate for every 10°F rise in temperature (Ref #1, pg 442). The total of 30 ppm $CaCO_3$ precipitated represents the potential amount of hardness deposited as sediment between sample point B and the Salt Kill's confluence with the Hudson River without any influence from Norlite's outfalls or other downstream point source discharges. This amount of hardness deposition is also increased by introduction of even a slight amount of additional alkalinity due to stormwater runoff and other natural sources.

7.2.2 Calcium Carbonate Precipitation Potential in Existing Downstream Salt Kill Water

Existing Water Conditions	Formula Value from Langelier Index Tables
A = Total solids concentration = 2500 mg/L =	0.2
B = Temperature during sampling = 53°F =	2.3
C = Calcium hardness (as $CaCO_3$) = 221 mg/L =	1.9
D = Total alkalinity (as $CaCO_3$) = 1125 mg/L =	3.1 (est)

and, average measured pH during sampling = 9.26

pHs = (9.3+A+B) - (C+D)
pHs = 9.3+0.2+2.3 - 1.9-3.1
pHs = 6.8 = pH at which $CaCO_3$ is at the saturation concentration at downstream Salt Kill Sample Point D

Saturation Index = pH - pHs = 9.26-6.8 = +2.46

Therefore, the existing downstream Salt Kill flow has a positive potential to precipitate $CaCO_3$ that is 3.5 times the upstream saturation index.

7.3 Calculation of Theoretical and Experimental Calcium/ Carbonate Mass Quantities Precipitated Downstream of Norlite Outfall 005

7.3.1 Calculation of Calcium Hardness at the Saturation Concentration at Downstream Salt Kill Sample Point D

Existing Water Conditions	Formula Value from Langelier Index Tables
A = Total solids concentration = 2500 mg/L =	0.2
B = Temperature during sampling = 53°F =	2.3
C = Calcium hardness (as $CaCO_3$) at saturation =	C
D = Total alkalinity (as $CaCO_3$) = 1125 mg/L =	3.1 (est)

pHs = (9.3+A+B) - (C+D)
7.1 = 9.3+0.2+2.3 - C-3.1
7.1 = 8.7-C
C = 8.7-7.1 = 1.6

Therefore, from Table C in Ref #5 (pg 111) Ca hardness at saturation at downstream sample point = <u>99 ppm as $CaCO_3$</u>

7.3.2 Calculation of Theoretical Excess Calcium Hardness Above Saturation from Upstream Salt Kill at the Downstream Sample Point D

$C_{US} - C_{DS}(sat.) = C_{US}(XS)$ where;

C_{US} = calcium hardness as $CaC0_3$ in upstream Salt Kill
$C_{DS}(sat.)$ = calcium hardness at saturation in downstream Salt Kill
$C_{US}(XS)$ = calcium hardness concentration of upstream Salt Kill in excess of downstream saturation concentration

193 mg/L Ca(as $CaC0_3$)-99 mg/L Ca(as $CaC0_3$)=94 mg/L excess $CaC0_3$

7.3.3 Calculation of Excess Calcium Hardness Above Saturation from Scrubber Blowdown at Downtown Sample Point D

$C_{BD} - C_{DS}(sat.) = C_{BD}(XS)$ where;

C_{BD} = calcium hardness as $CaC0_3$ in blowdown stream
$C_{DS}(sat.)$ = calcium hardness at saturation in downstream Salt Kill
$C_{BD}(XS)$ = calcium hardness concentration of blowdown stream in excess of downstream saturation concentration

225 mg/L Ca(as $CaC0_3$)-99 mg/L Ca(as $CaC0_3$)=126 mg/L excess $CaC0_3$

7.3.4 Relative Theoretical Quantities of Calcium Carbonate Precipitated from Upper Salt Kill and Blowdown Streams

Although the concentration of calcium carbonate precipitate originating in the blowdown is somewhat higher than the concentration originating in the upstream Salt Kill, the flow of the Salt Kill is 7.1 times greater than the blowdown flow rate. This means that the theoretical quantity of calcium carbonate precipitated in the Salt Kill originating in the scrubber blowdown is only 16 percent of the total calcium carbonate precipitated in the downstream Salt Kill. The remaining 84 percent $CaC0_3$ precipitated originates from the upstream Salt Kill itself.

7.3.5 Calculation of Experimental $CaC0_3$ Concentration Precipitated from Upper Salt Kill After Mixing with the Scrubber Blowdown Flow

Table 5-1 shows, from the analysis of the upstream Salt Kill raw sample (i.e., Sample B-1), that calcium hardness = 77 mg/L (as Ca). It is also shown that the residual calcium hardness (at equilibrium) remaining in solution after discharge of the scrubber blowdown stream (i.e., Sample D-2) = 40 mg/L (as Ca).

Therefore, the concentration of calcium hardness (as $CaC0_3$) actually precipitated from the upper Salt Kill can be calculated as follows:

$C_{US} - C_{CS} = C_{PPT}$ where;

C_{US} = Upstream Salt Kill Ca hardness=77 mg/L x 2.5 = 192.5 mg/L (as $CaC0_3$)
C_{DS} = Downstream Salt Kill Ca hardness=40 mg/L x 2.5 = 100 mg/L (as $CaC0_3$)
C_{PPT} = Calcium hardness precipitated from upstream Salt Kill (as mg/L $CaC0_3$)
therefore;

192.5 mg/L $CaC0_3$ - 100 mg/L $CaC0_3$ = 92.5 mg/L $CaC0_3$ precipitated

Note; The 92.5 mg/L $CaC0_3$ actually precipitated from upstream Salt Kill as demonstrated by these sample analyses is in very close agreement with the theoretical excess of calcium hardness calculated in 7.3.2. That is,

$$\frac{92.5 \text{ mg/L } CaC0_3}{94 \text{ mg/L } CaC0_3} = 0.984 \text{ or at } 98.4\% \text{ agreement}$$

7.3.6 Calculation of Experimental $CaC0_3$ Concentration Precipitated from Scrubber Blowdown After Mixing with the Upstream Salt Kill Flow

Table 5-1 shows that, from the analysis of the scrubber blowdown (i.e., Sample A-1), the calcium hardness = 90 mg/L (as Ca). Again, considering that the residual calcium hardness (at equilibrium) remaining in solution after mixing with the upstream Salt Kill (i.e., Sample D-2) = 40 mg/L (as Ca), the concentration of calcium hardness (as $CaC0_3$) actually precipitated from the scrubber blowdown can be calculated as follows:

$C_{BD} - C_{DS} = C_{PPT}$ where;

C_{BD} = Blowdown calcium hardness = 90 mg/L x 2.5 = 225 mg/L (as $CaC0_3$)
C_{DS} = Downstream Salt Kill calcium hardness = 40 mg/L x 2.5 = 100 mg/L (as $CaC0_3$)
C_{PPT} = Calcium hardness precipitated from blowdown (as mg/L $CaC0_3$)
therefore;

225 mg/L $CaC0_3$ - 100 mg/L $CaC0_3$ = 125 mg/L $CaC0_3$ precipitated

Again, there is very close agreement between the demonstrated experimental concentration of calcium hardness precipitated from the scrubber blowdown and the theoretical excess calcium hardness concentration calculated for the scrubber blowdown. That is;

$$\frac{125 \text{ mg/L } CaC0_3}{126 \text{ mg/L } CaC0_3} = 0.992 \text{ or at } 99.2\% \text{ agreement}$$

Because of this very close agreement with demonstrated experimental results, the theoretical $CaC0_3$ saturation index formula (as cited above in 7.2 and references #1,4 and 5) can be used with confidence to predict what the effect will be of changing any given scrubber blowdown condition on precipitation of $CaC0_3$ in the downstream Salt Kill.

8. OPTIONS CONSIDERED FOR CONTROL OF PRECIPITATION IN SALT KILL

An observation of the relationship between parameters used to calculate the Langelier Saturation Index shows the three most significant parameters causing calcium carbonate to precipitate in any given aqueous stream are as follows:

- The stream pH at equilibrium compared to the $CaC0_3$ saturation pH of the stream (i.e., the Saturation Index value)
- The total alkalinity concentration of the stream
- The total calcium hardness concentration of the stream

If any one of these parameters is maintained at (or controlled at) a non-significant value, $CaC0_3$ precipitation cannot occur.

If all three of these parameters are simultaneously present at significant levels, then the Saturation Index value (i.e., pH-pHs) is the most critical parameter to control. The total alkalinity concentration is the second most critical control parameter followed by the actual dissolved calcium (i.e., hardness) concentration.

8.1 Calculation of Blowdown pH Required to Control Downstream Saturation Index at Zero

In order to control the Saturation Index at 0 in the downstream Salt Kill, the existing downstream Salt Kill pH must he reduced to 7.1. That is, for the existing downstream pHs = 7.1:

$$\begin{aligned} pH - pHs &= 0 \\ pH - 7.1 &= 0 \\ pH &= 7.1 \end{aligned}$$

For the given upstream and downstream Salt Kill conditions, calculate the blowdown pH value required if total blowdown flow = 60 gpm:
where;

V_{US} = Upstream Average Flow Volume = 1606 liters/min
pH_{US} = Upstream Average pH Value = 8.4
V_{DS} = Downstream Average Flow Volume = 1833 liters/min
pH_{DS} = Downstream Target pH Value = 7.1
V_{BD} = Scrubber Blowdown Average Flow Volume = 227 liters/min
pH_{BD} = Scrubber Blowdown Required pH Value = C_{BD} $\frac{\text{moles H+}}{\text{liter}}$

Since pH = Negative log of hydrogen ion concentration in $\frac{\text{moles}}{\text{liter}}$

$$= - \text{Log } [H^+]$$

then;

$pH_{US} = 8.4 = -\ (\text{Log}\ [H+]_{US})$

$[H+]_{US} = 10^{-8.4} = 4x10^{-9}\ \frac{\underline{\text{moles H+}}}{\text{liter}}$

$C_{US} = 4x10^{-9}\ \frac{\underline{\text{moles H+}}}{\text{liter}}$

$pH_{DS} = 7.1 = -(\text{Log}\ [H+]_{DS})$

$C_{DS} = 10^{-7.1} = 7.9x10^{-8}\ \frac{\underline{\text{moles H+}}}{\text{liter}}$

$pH_{BD} = -\ (\text{Log}\ [H+]_{BD})$

$C_{BD} = 10^{-pHBD}\ \frac{\underline{\text{moles H+}}}{\text{liter}}$

$(V_{BD})(C_{BD})+(V_{US})(C_{US}) = (V_{DS})(C_{DS})$
$(227\ \text{L/min})(C_{BD})+(1606\ \text{L/min})(4x10^{-9}\ \text{moles/L})=(1833\ \text{L/min})(7.9x10^{-8}\ \text{moles/L})$

$227\ \text{L/min}\ (C_{BD}\ \text{moles/L})+6.42x10^{-6}\ \text{moles/min} = 1.45x10^{-4}\ \text{moles/min}$

$C_{BD}\ \text{moles/L} = 4.39x10^{-4}\ \text{moles/min x 1 min/227 L} = 6.12x10^{-7}\ \text{moles/L}$
therefore;
Blowdown pH = $-(\text{Log}\ 6.12x10^{-7}\ \frac{\underline{\text{moles H+}}}{\text{L}}) = -(-6.21) = 6.21$

Controlling the scrubber water pH value at 6.21 is not a feasible option since the scrubber pH value must be kept at a pH value of about 8.5 or higher to ensure adequate removal of acid gases from the kiln in the wet scrubber system.

In order to adjust the blowdown pH to 6.2, most of the excess bicarbonate and carbonate alkalinity in the blowdown would have to be neutralized with acid. This would require an average of 1950 lbs/day of 100% HCl or 551 gallons per day of 36% concentrated hydrochloric acid.

8.2 Calculation of Blowdown pH Required to Control Downstream Saturation Index at Upstream Value

In order to control the Saturation Index of the downstream at the same value as the upstream Salt Kill (i.e., 0.7) the pH value downstream must be lowered. Although this would not completely eliminate the potential for $CaCO_3$ to precipitate, the degree of precipitation that would occur would be equal to the existing potential (i.e., Saturation Index) of the upstream Salt Kill. That is, for the downstream Saturation Index = upstream Saturation Index;

$$\mathrm{pH_{DS}}\ (\text{existing}) - 0.7 = \mathrm{pH_{DS}}\ (\text{target})$$
$$\mathrm{pH_{DS}}\ (\text{target}) = 9.2 - 0.7 = 8.5$$

For the given upstream and downstream Salt Kill conditions, the blowdown pH value required to control the downstream pH at 8.5 can be calculated as in Section 8.5 above. However, to maintain the pH of the downstream at 8.5, (while the upstream pH = 8.4) it is self evident that the scrubber blowdown pH must also be at a maximum of 8.5 to ensure a combined stream pH greater than 8.5 will not occur.

On the other hand, to adjust the scrubber blowdown from the existing discharge pH of 9.2 to 8.5, a quantity of about 551 gallons per day of 36% HCl is again required. The same daily quantity of acid that would be required to reduce the blowdown pH from 9.2 to 6.2 is required to reduce the pH from 9.2 to 8.5 because essentially 100% of this acid is required to neutralize the existing average 3710 mg/L (as $CaCO_3$) of total carbonate-bicarbonate alkalinity in the blowdown.

After all this alkalinity is neutralized, only minimal amounts of acid are then required to reduce the pH values to 8.5 or 6.2 as these differences in hydrogen ion concentration are extremely small. The differences in the existing blowdown stream hydrogen ion concentration, i.e., $[H+]_{BD}$ at 9.2 and the $[H+]_{BD}$ at either target pH value of 8.5 or 6.2 is calculated as follows:

$$\text{pH } 9.2 = -(\text{Log } [H+]_{BD})\ \text{existing}$$
$$\text{existing } [H+]_{BD} = 10^{-9.2} = 6.31\text{x}10^{-10}\ \frac{\text{moles H+}}{\text{liter}}$$

$$\text{pH } 8.5 = -(\text{Log } [H+]_{BD})\ \text{target}$$
$$\text{target } [H+]_{BD} = 10^{-8.5} = 3\text{x}10^{-9}\ \frac{\text{moles H+}}{\text{liter}}$$

$$\text{pH } 6.2 = -(\text{Log } [H+]_{BD})\ \text{target}$$
$$\text{target } [H+]_{BD} = 10^{-6.2} = 6.31\text{x}10^{-7}\ \frac{\text{moles H+}}{\text{liter}}$$

Acid requirements to establish either target pH from the existing pH 9.2, after neutralization of existing total alkalinity would be:

$$\text{pH } 9.2 \text{ to pH } 8.5 = 3\text{x}10^{-9}\ \frac{\text{moles H+}}{\text{L}} - 6.31\text{x}10^{-10}\ \frac{\text{moles H+}}{\text{L}}$$

$$\text{pH } 9.2 \text{ to pH } 8.5 = 2.4\text{x}10^{-9}\ \frac{\text{moles H+}}{\text{L}}$$

$$2.4\text{x}10^{-9}\ \frac{\text{moles H+}}{\text{L}} \text{ x } \frac{36.5 \text{ grams HCl}}{\text{mole H+}} = 8.76\text{x}10^{-8}\ \frac{\text{grams HCl}}{\text{L}}$$

$$8.76\times10^{-8}\ \frac{\text{grams HCl}}{\text{L}} \times \frac{227\ \text{L}}{\text{min}} \times \frac{1440\ \text{min}}{\text{day}} = 2.9\times10^{-2}\ \frac{\text{grams HCl}}{\text{day}}$$

$$2.9\times10^{-2}\ \frac{\text{grams HCl}}{\text{day}} \times \frac{100}{36} = \frac{0.08\ \text{grams 36\% HCl}}{\text{day}}$$

$$\frac{0.08\ \text{grams 36\% HCl}}{\text{day}} \times \frac{1\ \text{lb}}{454\ \text{gr}} \times \frac{1\ \text{gal}}{9.83\ \text{lb}} = \frac{0.000018\ \text{gal 36\% HCl}}{\text{day}}$$

$$\text{pH 9.2 to pH 6.2} = 6.31\times10^{-7}\ \frac{\text{moles H+}}{\text{L}} - 6.31\times10^{-10}\ \frac{\text{moles H+}}{\text{L}}$$

$$\text{pH 9.2 to pH 6.2} = 6.30\times10^{-7}\ \frac{\text{moles H+}}{\text{L}}$$

$$6.30\times10^{-7}\ \frac{\text{moles H+}}{\text{L}} \times \frac{36.5\ \text{grams HCl}}{\text{mole H+}} = 2.3\times10^{-5}\ \frac{\text{grams HCl}}{\text{L}}$$

$$2.3\times10^{-5}\ \frac{\text{grams HCl}}{\text{L}} \times \frac{227\ \text{L}}{\text{min}} \times \frac{1440\ \text{min}}{\text{day}} = \frac{7.5\ \text{grams HCl}}{\text{day}}$$

$$\frac{7.5\ \text{grams HCl}}{\text{day}} \times \frac{100}{36} = \frac{20.8\ \text{grams 36\% HCl}}{\text{day}}$$

$$\frac{20.8\ \text{grams 36\% HCl}}{\text{day}} \times \frac{1\ \text{lb}}{454\ \text{gr}} \times \frac{1\ \text{gal}}{9.83\ \text{lb}} = \frac{0.005\ \text{gal 36\% HCl}}{\text{day}}$$

Therefore, although about 280 times more HCl is required to reduce the unbuffered pH to 6.2 than to 8.5, these quantities are insignificant compared to the 551 gallons/day of 36% HCl required to neutralize the carbonate buffer in the existing blowdown.

8.3 Calculation of Blowdown Total Alkalinity Required to Control Downstream Saturation Index at Zero

Anticipated Downstream Conditions	**Formula Value from Langelier Index Tables**
A = Total solids concentration = 2500 mg/L	0.2
B = Temperature = 53°F	2.3
C = Calcium hardness (as $CaCO_3$)= 221 mg/L	1.9
D = Total alkalinity (as $CaCO_3$)= (to be calculated)	

Assume scrubber blowdown is controlled at pH = 9.0. Then, the theoretical (unbuffered) downstream pH is calculated as follows:

V_{US} = Upstream average flow volume = 1606 L/min
pH_{US} = Upstream average pH value = 8.4 = $4\times10^{-9}\ \frac{\text{moles H+}}{\text{L}}$
V_{DS} = Downstream average flow volume = 1833 L/min
pH_{DS} = Downstream average pH value = $pH_{DS} = -\ (\text{Log}\ [H+]_{DS})$

V_{BD} = Scrubber blowdown average flow = 227 L/min

pH_{BD} = Scrubber blowdown average pH value = 9.0 = $1\text{x}10^{-9}\ \frac{\text{moles H+}}{\text{L}}$

$$(V_{BD})(C_{BD})+(V_{US})(C_{US}) = (V_{DS})(C_{DS})$$

$$(227\ \text{L/min})(1\text{x}10^{-9}\frac{\text{moles H+}}{\text{L}})+(1606\ \text{L/min})(4\text{x}10^{-9}\frac{\text{moles}}{\text{L}})=1833\ \text{L/min}(C_{DS}\ \frac{\text{mole}}{\text{L}})$$

$$2.27\text{x}10^{-7}\ \frac{\text{moles H+}}{\text{min}} + 6.42\text{x}10^{-6}\ \frac{\text{moles H+}}{\text{L}} = 1833\ \text{L/min}\ (C_{DS}\ \frac{\text{moles}}{\text{L}})$$

$$6.65\text{x}10^{-6}\ \frac{\text{moles H+}}{\text{L}} = 1833\ \text{L/min}\ (C_{DS}\ \frac{\text{moles H+}}{\text{L}})$$

$$C_{DS}\ \frac{\text{moles H+}}{\text{L}} = 6.65\text{x}10^{-6}\ \frac{\text{moles H+}}{\text{min}} \text{ x } \frac{1\ \text{min}}{1833\ \text{L}}$$

$$C_{DS}\ \frac{\text{moles H+}}{\text{L}} = 3.63\text{x}10^{-9}\ \frac{\text{moles H+}}{\text{L}}$$

$$pH_{DS} = -\ (\text{Log } 3.63\text{x}10^{-9}) = -\ (-8.44) = 8.44$$

If Saturation Index = 0 and pH_{DS} = 8.44 then,

$$\begin{aligned} &pH - pHs = 0 \\ &8.44 - pHs = 0 \\ &pHs = 8.44 \text{ and,} \end{aligned}$$

$$\begin{aligned} pHs &= (9.3+A+B) - (C+D) \\ 8.44 &= 9.3+0.2+2.3 - 1.9 - D \\ 8.44 &= 9.9 - D \\ D &= 9.9 - 8.44 = 1.46 \end{aligned}$$

From tables (Ref. 5 pg 111) the total alkalinity would = 29 mg/L (as $CaCO_3$) in downstream Salt Kill.

The relative calculated total alkalinity of the blowdown would be:

V_{BD} = Volume blowdown = 227 L/min

C_{BD} = Total Alkalinity of blowdown = C_{BD}

V_{US} = Volume upstream Salt Kill = 1606 L/min

C_{US} = Total Alkalinity of upstream = 172 mg/L (as $CaCO_3$

V_{DS} = Volume downstream Salt Kill = 1833 L/min

C_{DS} = Target Alkalinity of downstream = 29 mg/L (as $CaCO_3$)

$$(V_{BD})(C_{BD})+(V_{US}(C_{US}) = (V_{DS})(C_{DS})$$

$$227\ \text{L/min}\ (C_{BD}\ \text{mg/L})+(1606\ \text{L/min})(172\ \text{mg/L})=(1833\ \text{L/min})(29\ \text{mg/L})$$

$$227\ \text{L/min}\ (C_{BD}\ \text{mg/L}) + 276232\ \text{mg/min} = 53157\ \text{mg/min}$$

$$227\ \text{L/min}\ (C_{BD}\ \text{mg/L}) = 53157-276232\ \text{mg/min}$$

$$C_{BD} = \frac{-223075}{227} = -983\ \text{mg/L (as } CaCO_3)$$

Since the total alkalinity of the blowdown cannot be negative at pH = 8.5 to 9.0, control of blowdown alkalinity alone will not reduce the downstream Salt Kill Saturation Index to zero.

8.4 Calculation of Blowdown Total Alkalinity Required to Control Downstream Saturation Index at Upstream Value

Anticipated Downstream Conditions	Formula Value from Langelier Index Tables
A = Total solids concentration = 2500 mg/L	0.2
B = Temperature = 53°F	2.3
C = Calcium hardness (as $CaC0_3$)= 221 mg/L	1.9
D = Total alkalinity (as $CaC0_3$)= (to be calculated)	

Assume the scrubber blowdown is controlled at pH = 9.0. Then, the theoretical (unbuffered) downstream pH = 8.44. If the downstream Saturation Index = upstream Saturation Index then, downstream Saturation Index = 0.7.

$$
\begin{aligned}
&\text{Since, Saturation Index} = pH - pHs = 0.7 \\
&\text{then,} \quad 8.44 - pHs = 0.7 \quad \text{and,} \\
&\qquad pHs = 7.74
\end{aligned}
$$

$$
\begin{aligned}
pHs &= (9.3+A+B) - (C+D) \\
7.74 &= 9.3 + 0.2 + 2.3 - 1.9 - D \\
7.74 &= 9.9 - D \\
D &= 9.9 - 7.74 = 2.16
\end{aligned}
$$

From Langelier Tables (Ref 5, pg 111) total alkalinity should = 146 mg/L (as $CaC0_3$) in the downstream Salt Kill. Then, total alkalinity of the blowdown must be:

V_{BD} = Volume blowdown = 227 L/min
C_{BD} = Total alkalinity of blowdown (as $CaC0_3$) = C_{BD}
V_{US} = Volume upstream Salt Kill = 1606 L/min
C_{US} = Total alkalinity of upstream (as $CaC0_3$) = 172 mg/L
V_{DS} = Volume downstream Salt Kill = 1833 L/min
C_{DS} = Target alkalinity of downstream = 146 mg/L (as $CaC0_3$)

$$
\begin{aligned}
&(V_{BD})(C_{BD})+(V_{US})(C_{US}) = (V_{DS})(C_{DS}) \\
&227\ \text{L/min}\ (C_{BD}\ \text{mg/L})+(1606\ \text{L/min})(172\ \text{mg/L})=(1833\ \text{L/min})(146\ \text{mg/L}) \\
&227\ \text{L/min}\ (C_{BD}\ \text{mg/L})+276232\ \text{mg/min} = 267618\ \text{mg/min} \\
&227\ \text{L/min}\ (C_{BD}\ \text{mg/L})=267618-276232\ \text{mg/min} \\
&C_{BD}\ \text{mg/L} = -8614\ \text{mg/min} \times \frac{1\ \text{min}}{227\text{L}} \\
&C_{BD}\ \text{mg/L} = -38\ \text{mg/L (as } CaC0_3)
\end{aligned}
$$

Therefore, in order to maintain the existing upstream Salt Kill Saturation Index "unchanged" at the downstream Salt Kill sample point, the total alkalinity of the scrubber blowdown would have to be approximately 0 mg/L (as $CaC0_3$).

Observation of the data and results from this study show that, during the study period, the average total alkalinity was 3710 mg/L (as $CaCO_3$). Since this total alkalinity concentration is the result of average "real time" blowdown pH value measured at 9.2, it is expected that more accurate control of pH, to remain in the range of 8.5 to 9.0, will reduce the blowdown total alkalinity concentration as follows:

Figure 4-1 shows that titrations of 1.1% HCl solution with soda ash (Na_2CO_3) solution requires 19,200 mg/L (as Na_2CO_3) to reach pH 9.0 and 18,900 mg/L (as Na_2CO_3) to reach pH 8.5. To reach pH 4.0, the required Na_2CO_3 dosage is 17,400 mg/L (as Na_2CO_3). Below pH 4.0, it is expected that all but a solubility limited amount of alkalinity introduced into the acid stream is lost to the atmosphere by generation and evolution of carbon dioxide gas (i.e., CO_2). CO_2 has limited solubility in the scrubber water solution (i.e., about 576 mg/L at 140°F) as described in Ref. #5 pg 18 and Ref. # 2 pg 130.

From this titration data, the excess concentration of combined carbonate and bicarbonate alkalinity can be calculated as follows;

Excess total alkalinity in solution in raising pH from 4.0 to 9.0 =
19,200 mg/L (as Na_2CO_3)-17,400 mg/L (as Na_2CO_3)=1800 mg/L (as Na_2CO_3)
1800 mg/L (as Na_2CO_3)x0.94=1692 mg/L (as $CaCO_3$)
1692 mg/L (as $CaCO_3$)+ residual CO_2 at 657 mg/L (as $CaCO_3$)=2349 mg/L (as $CaCO_3$)

Excess total alkalinity in solution in raising pH from 4.0 to 8.5 =
18,800 mg/L (as Na_2CO_3)-17,400 mg/L (as Na_2CO_3)=1400 mg/L (as Na_2CO_3)
1400 mg/L (as Na_2CO_3)x0.94=1316 mg/L (as $CaCO_3$)
1316 mg/L (as $CaCO_3$)+ residual CO_2 at 657 mg/L (as $CaCO_3$)=1973 mg/L (as $CaCO_3$)

Even with precise control of the scrubber blowdown pH within the range of 8.5 to 9.0, the total alkalinity concentration in the blowdown will range from 2000 mg/L (as $CaCO_3$) to 2400 mg/L (as $CaCO_3$) which is in excess of the zero alkalinity concentration required to maintain the existing upstream Saturation Index of 0.7. Performing the required calculations shows that, at the 2400 mg/L (as $CaCO_3$) blowdown alkalinity, the resultant downstream Salt Kill Saturation Index will be 1.6. This is significantly lower than the +2.46 Saturation Index value measured during this study (i.e, it is about 65% of the present downstream Saturation Index).

8.5 <u>Calculation of Downstream Saturation Index Resulting from Replacement of Soda Ash with Sodium Hydroxide for Scrubber Water pH Control</u>

As indicated above, use of soda ash (Na_2CO_3) for pH control in the wet scrubber leaves an excess of carbonate and bicarbonate alkalinity in the blowdown (at pH value between 8.5 and 9.0) due to the necessary formation of bicarbonate ion (HCO_3^-) from neutralization of acid (H^+) as represented by the following equation:

$$\underset{\text{soda ash}}{Na_2CO_3} + \underset{\text{hydrochloric acid}}{HCl} = \underset{\text{salt}}{NaCl} + \underset{\text{sodium bicarbonate}}{NaHCO_3}$$

Thus, in neutralizing 1 mg/L of HCl, 2.9 mg/L of Na_2CO_3 are required, generating 3.9 mg/L of total dissolved solids (TDS). The relative concentration of bicarbonate ion remaining in solution is, therefore, dependent upon the concentration of acid being neutralized while maintaining the pH over 8.5 in the scrubber water. Between pH values 4.0 and 8.5, some of the bicarbonate ion generated is lost due to evolution of CO_2. Below pH 4.0, all bicarbonate concentration is lost but some alkalinity will remain in solution due to the solubility of CO_2 in water as carbonic acid (H_2CO_3). This residual CO_2 concentration (in form of H_2CO_3) will form bicarbonate ion (HCO_3^-) as the pH is raised above 4.0. The portion of CO_2 converted to bicarbonate ion is proportional to the increase in pH value between pH 4.0 and 8.5 (see the graphical relationship in Ref #2. pg 130).

If relatively pure sodium hydroxide (i.e. NaOH) solution is used instead of soda ash, the source of carbonate and bicarbonate addition to the scrubber solution caused by acid neutralization would be eliminated. The following equation represents this reaction;

$$\underset{\text{sodium hydroxide}}{NaOH} + \underset{\text{hydrochloric acid}}{HCl} = \underset{\text{salt}}{NaCl} + \underset{\text{water}}{H_2O}$$

Thus, in neutralizing 1 mg/L of HCl, 1.1 mg/L of NaOH is required in generating only 1.6 mg/L of TDS. So, besides the elimination of the addition of carbonate-bicarbonate alkalinity when using sodium hydroxide, only 41% of the TDS would be generated in the neutralization reaction.

Reducing the TDS generated in the blowdown will have little if any effect on increasing the downstream Saturation Index, but eliminating the addition of the carbonate-bicarbonate alkalinity to the blowdown shows a marked reduction in the value of the downstream Saturation Index.

However, although essentially no total alkalinity is added by adjusting the pH with sodium hydroxide, some total alkalinity will be present from the carbon dioxide gas (CO_2) which is absorbed by the wet scrubber solution from the kiln off-gas stream. At a scrubber recirculation solution temperature of 140°F (i.e., 60°C) the anticipated absorbed CO_2 concentration in the blowdown stream would be 576 mg/L (as CO_2) x 1.14 = 657 mg/L (as $CaCO_3$).

Therefore, the calculated downstream total alkalinity would be:

V_{BD} = Volume blowdown = 227 L/min
C_{BD} = Total alkalinity of blowdown = 657 mg/L (as $CaC0_3$)
V_{US} = Volume upstream Salt Kill = 1606 L/min
C_{US} = Total alkalinity upstream = 172 mg/L (as $CaC0_3$)
V_{DS} = Volume downstream Salt Kill = 1833 L/min
C_{DS} = Resultant alkalinity downstream = to be calculated

$(V_{BD})(C_{BD})+(V_{US})(C_{US}) = (V_{DS})(C_{DS})$
227 L/min (657 mg/L)+(1606 L/min)(172 mg/L)=(1833 L/min)(C_{DS} mg/L)
149,139 mg/min + 276232 mg/min = 1833 L/min (C_{DS} mg/L)

$$C_{DS}\ \text{mg/L} = 425{,}371\ \text{mg/min} \times \frac{1\ \text{min}}{1833\text{L}}$$

$$C_{DS}\ \text{mg/L} = 232\ \text{mg/L (as } CaC0_3)$$

Anticipated Downstream Conditions	**Formula Value from Langelier Index Tables**
A = Total solids concentration = 1225 mg/L	0.2
B = Temperature = 53°F	2.3
C = Calcium hardness (as $CaC0_3$)= 221 mg/L	1.9
D = Total alkalinity (as $CaC0_3$)= 232 mg/L	2.4

pH_{DS} = 8.44 at blowdown pH = 9.0

pHs = (9.3+A+B)-(C+D)
pHs = 9.3+0.2+2.3-1.9-2.4
pHs = 7.5

Saturation Index = pH - pHs
= 8.44 - 7.5
= 0.94

Therefore, the resultant Saturation Index would be only 34% higher than the existing value of the upstream Salt Kill (i.e., 0.7).

8.6 Calculation of Downstream Saturation Index Resulting from Replacement of Soda Ash with Sodium Hydroxide and Pretreatment of the Blowdown for TSS Removal Before Discharge

As indicated in Section 8.5, replacement of the soda ash used for pH control of the wet scrubber solution with sodium hydroxide will reduce the total alkalinity of the blowdown from 3710 mg/L (as $CaC0_3$) to 657 mg/L (as $CaC0_3$). This, along with controlling the pH of the blowdown at 8.5 to 9.0 would have the effect of lowering the downstream Salt Kill Saturation Index to a value of 0.94.

Pretreatment of the blowdown stream for TSS removal would further reduce the downstream Saturation Index due to removal of existing blowdown calcium hardness. The expected total alkalinity of the blowdown would be about 550 mg/L (as $CaCO_3$) due to CO_2 absorbtion and neutralization, if soda ash is not used in the wet scrubber pH control process. The expected residual calcium hardness discharged in the effluent would be expected to be about 15 mg/L (as $CaCO_3$). This expected calcium hardness concentration is confirmed by the observed results of Jar Test #2, shown in Table 4-1.

Under these anticipated blowdown conditions, the downstream Saturation Index is calculated as follows:

Downstream calcium hardness (as $CaCO_3$) = ;

V_{BD} = Volume blowdown = 227 L/min
C_{BD} = Blowdown calcium hardness = 15 mg/L (as $CaCO_3$)
V_{US} = Upstream volume = 1606 L/min
C_{US} = Upstream calcium hardness = 193 mg/L (as $CaCO_3$)
V_{DS} = Downstream volume = 1833 L/min
C_{DS} = Downstream calcium hardness = to be calculated

$(V_{BD})(C_{BD})+(V_{US})(C_{US}) = (V_{DS})(C_{DS})$
227 L/min (15 mg/L)+(1606 L/min)(193 mg/L)=(1833 L/min)(C_{DS} mg/L)
3405 mg/min + 309958 mg/min = 1833 L/min (C_{DS} mg/L)
C_{DS} mg/L = 313,363 mg/min x $\frac{\underline{1\text{ min}}}{1833\text{L}}$ = 171 mg/L (as $CaCO_3$)

Downstream total alkalinity (as $CaCO_3$) = ;

V_{BD} = Blowdown volume = 227 L/min
C_{BD} = Blowdown total alkalinity = 325 mg/L (as $CaCO_3$)
V_{US} = Upstream volume = 1606 L/min
C_{US} = Upstream total alkalinity = 172 mg/L (as $CaCO_3$)
V_{DS} = Downstream volume = 1833 L/min
C_{DS} = Downstream total alkalinity = to be calculated

$(V_{BD})(C_{BD})+(V_{US})(C_{US}) = (V_{DS})(C_{DS})$
(227 L/min)(325 mg/L)+(1606 L/min)(172 mg/L)=(1833 L/min)(C_{DS} mg/L)
73,775 mg/min + 276,232 mg/min = 1833 L/min (C_{DS} mg/L)
C_{DS} mg/L = 350,007 mg/min x $\frac{\underline{1\text{ min}}}{1833\text{L}}$ = 191 mg/L (as $CaCO_3$)

Anticipated Downstream Conditions	**Formula Value from Langelier Index Tables**
A = Total solids concentration = 1225 mg/L	0.2
B = Temperature = 53°F	2.3
C = Calcium hardness (as $CaC0_3$)= 171 mg/L	1.8
D = Total alkalinity (as $CaC0_3$)= 191 mg/L	2.3

pH_{DS} = 8.44 at blowdown pH = 9.0

pHs = (9.3+A+B)-(C+D)
pHs = 9.3+0.2+2.3-1.8-2.3
pHs = 7.7

Saturation Index = pH - pHs
= 8.44 - 7.7 = 0.74

Therefore, the resultant Saturation Index would be only 5.7% higher than the existing value of the upstream Salt Kill. This is not expected to cause a noticeable or measurable difference in the concentration of calcium hardness precipitating at the downstream sampling points in comparison with the upstream sampling points.

8.7 Calculation of Downstream Saturation Index Resulting from Pretreatment for TSS Removal without Replacing Soda Ash used in Wet Scrubber

If soda ash is used to adjust pH in the wet scrubber system in combination with TSS removal, most of the existing calcium hardness would be removed, and most of the existing alkalinity would remain in the treated effluent. In other words, the existing total alkalinity in the blowdown would be reduced by the value of the existing blowdown calcium hardness (i.e., about 210 mg/L as insoluble $CaC0_3$), leaving about 3500 mg/L (as $CaC0_3$) total alkalinity remaining. The anticipated blowdown and Salt Kill conditions would be calculated as follows:

V_{BD} = Blowdown volume = 227 L/min
C_{BD} = Blowdown alkalinity = 3500 mg/L (as $CaC0_3$)
V_{US} = Upstream volume = 1606 L/min
C_{US} = Upstream alkalinity = 172 mg/L (as $CaC0_3$)
V_{DS} = Downstream volume = 1833 L/min
C_{DS} = Downstream alkalinity = to be calculated

$$(V_{BD})(C_{BD})+(V_{US})(C_{US}) = (V_{DS})(C_{DS})$$
$$(227\ \text{L/min})(3500\ \text{mg/L})+(1606\ \text{L/min})(172\ \text{mg/L})=(1833\ \text{L/min})(C_{DS}\ \text{mg/L})$$
$$794{,}500\ \text{mg/min} + 276{,}232\ \text{mg/min} = 1833\ \text{L/min}\ (C_{DS}\ \text{mg/L})$$
$$C_{DS}\ \text{mg/L} = 1{,}070{,}732\ \text{mg/min} \times \frac{1\ \text{min}}{1833\text{L}} = 584\ \text{mg/L (as } CaC0_3)$$

Therefore;

Anticipated Downstream Conditions	**Formula Value from Langelier Index Tables**
A = Total solids concentration = 1700 mg/L	0.2
B = Temperature = 53°F	2.3
C = Calcium hardness (as $CaCO_3$)= 171 mg/L	1.8
D = Total alkalinity (as $CaCO_3$)= 584 mg/L	2.8

pH_{DS} = 8.9 at blowdown pH = 9.0

$$\begin{aligned} pHs &= (9.3+A+B)-(C+D) \\ pHs &= 9.3+0.2+2.3-1.8-2.8 \\ pHs &= 7.2 \end{aligned}$$

$$\begin{aligned} \text{Saturation Index} &= pH - pHs \\ &= 8.9 - 7.2 \\ \text{Saturation Index} &= 1.7 \end{aligned}$$

Therefore, pretreatment for total suspended solids removal will not significantly reduce the existing downstream Saturation Index unless the blowdown pH is also reduced to less than pH 9.0. However, it is more effective to replace the use of soda ash in the wet scrubber system with sodium hydroxide since even without pretreatment for total suspended solids removal, soda ash replacement with sodium hydroxide will reduce the Saturation Index to 0.94.

9. **CONCLUSIONS**

9.1 The Salt Kill water, upstream of the Norlite facility scrubber blowdown outfalls, is very close to the limit of saturation possible for calcium carbonate concentration. This degree of saturation is indicated by the average carbonate hardness concentration and pH value analyzed during this study.

The relatively low temperature measured for the Salt Kill (i.e., <56°F) is the major condition keeping the natural hardness from precipitating in the Salt Kill upstream of the Norlite scrubber blowdown outfalls.

9.2 The primary cause for precipitation of suspended solids in the Salt Kill downstream of the Norlite scrubber blowdown outfall location, is the increase in measured stream pH value (during this study) from about 8.4 to 9.2. This causes calcium carbonate to become less soluble and to precipitate in the downstream Salt Kill.

9.3 The secondary cause contributing to the precipitation of suspended solids in the Salt Kill downstream of the Norlite scrubber blowdown outfall is the concentration of calcium carbonate hardness in the scrubber blowdown. About 84 percent of the calcium carbonate precipitated during this study was observed to be from the Salt Kill water source itself and the remaining 16 percent of calcium carbonate precipitated was due to the scrubber blowdown carbonate hardness concentration .

9.4 The characteristics of the scrubber wastewater itself, which cause "settleable solids" to occur in the blowdown samples, is attributed to a slow reaction between excess carbonate alkalinity and residual lime (calcium hydroxide) fines from the baghouses. Even though the scrubber blowdown is relatively clear and low in settleable solids at the time of discharge, residual lime in suspension slowly dissolves due to solution cooling and absorbtion of $C0_2$ from the atmosphere during the settling test. These conditions cause the blowdown solution to become saturated with calcium carbonate upon standing and increased concentrations of settleable solids then form.

9.5 Under natural conditions, the concentration of calcium carbonate hardness in the upstream Salt Kill is high enough for calcium carbonate precipitation to be taking place. This is especially more feasible in summer months when sunlight warms the creek bed rocks and substrata in slower moving pools of water. As the cool creek water runs over these warmed solid surfaces, the stoichiometric balance of calcium and carbonate in the stream causes calcium carbonate ($CaC0_3$) to uniformly "scale-out" on these solid surfaces (as hard crystalline layers) without visible silting or precipitation taking place.

However, under the influence of excess carbonate alkalinity introduced from the scrubber blowdown, a more voluminous hydrated precipitate form of calcium carbonate (i.e., $CaC0_3.6H_20$) forms which visibly settles to the bottom as a light to tan colored precipitate.

9.6 Combined analysis of the aqueous stream samples and the solid precipitate and sediment samples collected during this study confirm that about 80 percent by weight of the precipitate forming and settling at downstream Sample Points D and F is a form of calcium carbonate. The remaining 20 percent of the weight of the precipitate is attributed to mostly silica and silicates, hydrates and oxides of calcium, iron, aluminum and magnesium.

9.7 Material balance calculations using the aqueous sample analyses show that the Salt Kill flow conditions were in a typical range for this study. The reported average flow conditions for the Salt Kill drainage area are about 1-cubic foot of water per second. The material balance calculations show the upstream Salt Kill flow rate averaged about 0.94 cu ft/sec during this study period.

9.8 Adjusting the composition of the present scrubber blowdown in order to induce less increase in pH value of the downstream Salt Kill will have the greatest effect on reducing the amount of calcium carbonate precipitation in the Salt Kill.

9.9 Eliminating the excess carbonate and bicarbonate buffer concentration in the present scrubber blowdown discharges will enable both a minimal increase in Salt Kill pH value as well as a substantial reduction in carbonate hardness concentration. The minimum pH increase and reduced carbonate hardness in the resulting Salt Kill flow will significantly reduce the potential for calcium carbonate to precipitate.

It is calculated that the calcium carbonate Saturation Index of the downstream Salt Kill can be reduced from + 2.46 to + 0.94 (i.e., 2.6 times lower precipitation potential) by operating the scrubber at a blowdown discharge pH of 9.0 using sodium hydroxide (NaOH) instead of sodium carbonate (Na_2CO_3) as the alkali source for acid neutralization. This resulting Saturation Index of 0.94 is only 34% higher than the existing value of the upstream Salt Kill Saturation Index of + 0.7 which will give a relative reduction in downstream calcium carbonate precipitation.

9.10 Reducing the scrubber blowdown pH (by minimizing Na_2CO_3 dosage) could result in some significant improvement in reducing calcium carbonate precipitation in the Salt Kill. Since, with Na_2CO_3, an excess carbonate alkalinity is required to maintain pH above 8.5 in the blowdown, the degree of improvement would depend on whether or not a significant increase in the pH value above 8.5 in the Salt Kill would still occur.

However, sodium carbonate usage can be significantly reduced (minimized) by changing the injection points into the wet scrubber system from the recycle tank to a direct connection into the recycle pump suction lines. Less unused soda ash would be lost to the blowdown with this modified system.

Results of the December 1992 Trial Burn on Kiln #1 show that optimum SO_2 and HCl removal are obtained with a scrubber water pH value in the range of 7.9 to 8.3. Operating in this pH range will ensure the blowdown will not increase the pH of the Salt Kill while at the same time it will reduce the concentration of excess carbonate alkalinity in the downstream Salt Kill. Both of these effects would significantly decrease the concentration of calcium carbonate precipitation in the downstream Salt Kill.

9.11 Adjusting the pH of the scrubber recycle solution to 8.3 to 9.0 with sodium hydroxide (NaOH), and pretreatment for TSS removal is another approach to reducing the mass of calcium carbonate precipitation in the downstream Salt Kill to a value essentially equal to the natural upstream Salt Kill. That is, the Saturation Index of the downstream Salt Kill would be increased to only 0.74 from the upstream value of 0.70. This is not expected to be a difference that will result in any measurable increase in precipitated calcium carbonate from the upstream sample points to the downstream sample points.

Replacement of sodium carbonate with sodium hydroxide is expected to have an NaOH requirement that is about 30 percent less than Na_2CO_3 on a delivered dry weight basis.

10. **RECOMMENDATIONS**

Although several recommendations can be made as to measures that can be taken to improve or relieve the observed problem of calcium carbonate precipitation in the Salt Kill, there is a definite order of preference based on consideration of effectiveness, cost and dependability. The following recommendations are made in order of most preferable measures first:

10.1 Substituting sodium hydroxide solution (25% W/W NaOH) for sodium carbonate solution (5% W/W Na_2CO_3) as the alkali for neutralization of acid gases in the wet scrubber system is the most direct measure to control blowdown discharges from causing Salt Kill precipitation from the standpoint of effectiveness, cost and long range dependability.

Although this measure will require some initial costs for facility retrofitting including, installation of insulation and heat tracing of chemical holding tanks, transfer pump and lines and possible installation of a 20,000 to 25,000 gallon sodium hydroxide solution storage tank, the following benefits will be immediately gained;

10.1.1 No final effluent pH adjustment with acid would be required, with use of sodium hydroxide, even at a blowdown pH value of 9.0, since carbonate concentration increases in the Salt Kill would be eliminated.

10.1.2 The chemical operating cost for sodium hydroxide would be approximately equal to the present cost of using sodium carbonate without any additional controls for limiting downstream Salt Kill precipitation.

10.1.3 The resultant immediate effect of sodium hydroxide use will be a substantial improvement in suspended solids generated in the downstream Salt Kill due to discharge of the scrubber blowdowns. This is even without pretreatment for suspended solid removal. About a 75% reduction in existing downstream TSS is estimated.

10.1.4 The resultant long-term effect of sodium hydroxide use will be a restoration of the Salt Kill TSS precipitation to a condition essentially equivalent to the upstream Salt Kill TSS concentration. A 90% reduction in existing TSS is estimated with pretreatment for TSS removal. Note; It is not possible to achieve 100% reduction in Salt Kill TSS since the upstream flow already contains 10 to 20 ppm of natural TSS.

10.1.5 The resultant immediate and long-term effect of sodium hydroxide usage would be to reduce the relative total dissolved solids (TDS) loading to the Salt Kill by a factor of up to 50% or more.

10.2 Changing existing sodium carbonate solution injection points (from the recycle tanks) to the recycle pump suction lines, while also reducing the scrubber blowdown pH value to less than 9.0 (eg. pH 8.0 to 8.5) on a continuous basis, would minimize use of sodium carbonate feed to the wet scrubber systems. While this measure is expected to achieve at least 25 to 35% reduction in existing downstream Salt Kill TSS, it would also have the following immediate benefits;

10.2.1 The resulting downstream Salt Kill pH value would be reduced to a value less than 9.0.

10.2.2 No additional or new operating or capital costs would be incurred.

10.2.3 Immediate short-term improvement will be realized until the point at which the zero discharge option is implemented.

10.3 Norlite has proposed a zero discharge option to wastewater management, in which the scrubber blowdown is injected into the kiln. This option will eliminate the blowdown discharge to the Salt Kill creek. Norlite is scheduled to install this system by July 15, 1993.

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12. APPENDIX

12.1 Reference Citations

12.2 AnalytiKEM Laboratory Report

12.3 Adirondack Environmental Laboratory Report

12.4 Laboratory Bench and Jar Test Data

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12.1 Reference Citations

1. Nordell
2. Betz
3. CRC Handbook
4. NACE
5. Permutit

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12.2 ANALYTIKEM LABORATORY REPORT

Supplemental, December 29, 1992

Original, December 4, 1992

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12.3 Adirondack Environmental Laboratory Report

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12.4 Laboratory Bench Test and Jar Test Data
TK Wastewater Treatment Laboratory, Rock Hill, SC

APPENDIX A

12.1 Reference Citations

1. Nordell
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WATER TREATMENT

FOR INDUSTRIAL AND OTHER USES

by

Eskel Nordell

Administrator, Analytical Laboratories,
Research and Pilot Plant Divisions,
The Permutit Company

Formerly W. O. C. Consultant Water Treatment,
War Production Board, General Machinery
Section, General Industrial Equipment Branch;
General Manager, Water Softening Division,
The Wayne Company

REINHOLD PUBLISHING CORPORATION
330 WEST FORTY-SECOND STREET
NEW YORK 18, U. S. A.
1951

Lange's "Handbook of Chemistry," Zimmerman and Lavine's "Conversion Factors and Tables," Hering's "Conversion Tables," and The Chemical Rubber Publishing Company's "Handbook of Chemistry and Physics."

I extend my thanks to The Permutit Company for permitting me to engage in this work and allowing me to use company photographs, drawings, and other material; to Henry W. Foulds, President, and Eric Pick for their kindly encouragement; to the Research, Pilot Plant, Analytical Laboratories. Engineering, and other divisions of The Permutit Company for their interest; to my family for their patience during my five years of labor; and to my daughter for typing the manuscript. Some twenty of the illustrations were made from photographs which I took in the field. Credit for these and most of the remaining illustrations is due The Permutit Company. In other cases, a proper courtesy line has been attached.

ESKEL NORDELL

Mount Holly, N.J.
January, 1951

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Second Printing, 1951
Third Printing, 1956

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Lithoprinted in U.S.A.
EDWARDS BROTHERS, INC.
Ann Arbor, Michigan

PREFACE

THIS BOOK was written to provide a comprehensive work on industrial waters that would be of practical value to executives, consultants, engineers, chemists, operating personnel and students, and that would eliminate tedious search through a mass of scattered literature. Every effort has been made to present the material as simply and clearly as possible, and although chemical reactions are included, a chemical training is not necessary in order to understand the basic principles involved.

The first four chapters are devoted chiefly to impurities in water supplies and how they can be eliminated or reduced to allowable tolerances. To illustrate the amounts of impurities in ground and surface waters and the possible variations in the latter, over one-thousand analyses were calculated to a uniform method of expression and concisely tabulated. Chapter 5 concerns the water requirements for industrial uses, and current water-treatment practices in various industries are discussed. Chapters 6 and 7 describe the problems and practices relating to boiler feed waters and cooling waters, respectively. The different processes and equipment used in treating (conditioning) water are covered in detail in Chapters 8 through 18. Duplication of descriptive matter in the text is eliminated, for the most part, by cross references to the chapters in which specific processes are described. The appendix section contains forty-three tables of conversion factors and equivalents and three curves which will be found useful in making calculations.

No attempt has been made to include lists of patents or complete bibliographies of publications on water-treating materials, processes or equipment. Instead, a selected list of publications is presented in the chapter bibliographies. For the reader who wishes to make a thorough search of the literature, the references in the publications listed are probably sufficient to start a chain reaction in that direction.

Solubilities have been largely taken from Seidell's "Solubilities of Inorganic and Metal Organic Compounds" and E. P. Partridge's "Formation and Properties of Boiler Scale," University of Michigan Engineering Research Bulletin No. 15. Handbooks which have been used include

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TABLE 4. ANALYSES OF NINETY-EIGHT RIVER WATERS—ONE-YEAR AVERAGES

Name of River	Sampled at or near	(expressed as ppm of $CaCO_3$)								(ppm) Fe	(ppm) SiO_2
		Hardness	Ca	Mg	Na + K	HCO_3	Cl	SO_4	NO_3		
Alabama	Selma, Ala.	45	33	12	15	40	3	9	0.6	0.5	21
Allegheny	Kittaning, Pa.	47	35	12	24	32	20	17	0.6	1.2	8
Arkansas	Arkansas City, Kans.	336	238	98	529	207	412	201	1.5	1.6	31
Big Blue	Manhattan, Kans.	225	168	57	96	212	29	46	1.9	3.0	34
Brazos	Waco, Tex.	381	303	78	553	130	477	290	1.8	0.3	22
Cache	Mounds, Ill.	73	48	25	33	70	10	19	1.7	2.5	22
Cahaba	Birmingham, Ala.	43	33	10	20	43	3	9	0.5	0.4	16
Cedar	Cedar Rapids, Ia.	186	120	66	26	171	5	31	2.5	0.1	14
Chattahoochee	West Point, Ga.	15	12	3	17	18	3	5	0.6	0.5	20
Chikaskia	Argonia, Kans.	209	160	49	82	228	21	35	0.9	1.3	28
Chippewa	Eau Claire, Wisc.	52	33	19	18	40	2	14	0.5	0.2	12
Cimarron	Englewood, Kans.	352	213	139	774	253	702	163	1.4	1.4	38
Clackamas	Cazadero, Ore.	19	13	6	4	21	2	4	0.2	0.05	17
Columbia	Cascade Locks, Wash.	57	40	17	15	55	3	13	0.4	0.04	13
Columbia	Northport, Wash.	64	45	19	9	59	1	12	0.2	0.02	9
Cottonwood	Emporia, Kans.	353	255	98	61	256	15	136	2.4	0.9	21
Crooked	Prineville, Ore.	110	65	45	89	165	15	17	0.3	0.1	34
Cumberland	Nashville, Tenn.	80	65	15	21	76	3	14	1.0	0.4	20
Delaware	Lambertville, N.J.	44	30	14	12	38	4	12	0.9	0.07	9
Deschutes	Moody, Ore.	32	21	11	27	47	3	5	0.5	0.05	28
Des Moines	Keosauqua, Ia.	231	145	86	37	177	7	74	2.7	0.4	22
Embarrass	Charleston, Ill.	226	128	98	29	204	7	32	6.1	0.3	17
Fall	Neodesha, Kans.	222	165	57	65	199	18	30	1.5	0.6	28
Flint	Albany, Ga.	28	22	6	15	26	4	6	0.5	0.9	24
Fox	Ottawa, Ill.	281	150	131	31	225	11	63	4.0	0.2	11

TABLE 4. ANALYSES OF NINETY-EIGHT RIVER WATERS—ONE-YEAR AVERAGES *(Continued)*

Name of River	Sampled at or near	(expressed as ppm of $CaCO_3$)								(ppm) Fe	(ppm) SiO_2
		Hardness	Ca	Mg	Na + K	HCO_3	Cl	SO_4	NO_3		
Grand	Grand Rapids, Mich.	218	140	78	22	189	11	34	1.9	0.07	14
Grande Ronde	Elgin, Ore.	31	25	6	20	44	2	6	0.6	0.25	30
Hudson	Hudson, N.Y.	69	53	16	17	59	6	16	0.6	0.15	11
Illinois	LaSalle, Ill.	215	125	90	35	166	18	52	9.0	0.2	12
Iowa	Iowa City, Ia.	193	123	70	31	172	5	37	2.3	0.25	19
James	Richmond, Va.	47	35	12	15	49	3	7	0.2	0.5	18
Kalamazoo	Kalamazoo, Mich.	212	138	74	18	190	5	24	1.5	0.05	17
Kankakee	Kankakee, Ill.	231	145	86	24	176	7	59	3.3	0.27	15
Kansas	Holliday, Kans.	249	183	66	111	214	57	63	1.9	1.1	29
Kaskaskia	Carlyle, Ill.	200	118	82	31	174	10	35	3.9	0.4	17
Kentucky	Frankfort, Ky.	68	53	15	15	63	3	9	2.0	0.5	16
Klickitat	Klickitat, Wash.	31	18	13	14	36	2	7	0.1	0.13	27
Lehigh	So. Bethlehem, Pa.	59	35	24	16	33	7	31	1.8	0.1	9
Marmaton	Fort Scott, Kans.	239	203	36	51	206	7	36	1.5	1.1	14
Maumee	Toledo, O.	210	143	67	53	145	56	50	3.6	0.27	17
Medicine Lodge	Kiowa, Kans.	589	408	181	228	185	138	473	2.7	1.6	27
Miami	Dayton, O.	246	148	98	20	210	6	42	6.9	0.15	17
Mississippi	Memphis, Tenn.	139	90	49	42	105	12	45	1.4	0.6	24
Mississippi	Minneapolis, Minn.	157	100	57	22	155	2	19	1.1	0.07	15
Missouri	Kansas City, Kans.	229	155	74	96	166	18	140	1.8	0.7	37
Monongahela	Elizabeth, Pa.	39	30	9	16	15	5	34	1.5	0.5	8
Muddy	Murphysboro, Ill.	112	63	49	44	59	18	75	1.6	2.1	24
Muskingum	Zanesville, O.	147	108	39	51	96	56	45	1.3	0.18	14
Okanogan	Okanogan, Wash.	72	53	19	19	67	1	16	0.2	0.02	14
Oostanaula	Rome, Ga.	41	30	11	20	44	3	4	0.3	0.7	24

TABLE 4. ANALYSES OF NINETY-EIGHT RIVER WATERS—ONE-YEAR AVERAGES *(Continued)*

Name of River	Sampled at or near	(expressed as ppm of $CaCO_3$)								(ppm) Fe	(ppm) SiO_2
		Hardness	Ca	Mg	Na + K	HCO_3	Cl	SO_4	NO_3		
Osage	Boicourt, Kans.	217	168	49	61	182	14	37	2.8	2.2	24
Oswegatchie	Ogdensburg, N.Y.	47	33	14	12	43	1	9	0.3	0.2	9
Pearl	Jackson, Miss.	23	18	5	19	27	5	7	0.6	0.37	18
Peedee	Peedee, S.C.	21	17	4	19	27	4	4	0.5	0.3	26
Platte	Columbus, Nebr.	232	158	74	104	153	20	158	1.1	0.2	32
Platte, North	North Platte, Nebr.	164	115	49	69	135	10	79	1.0	0.26	40
Potomac	Cumberland, Md.	79	60	19	20	30	9	60	0.7	0.14	8
Powder	North Powder, Ore.	85	58	27	64	112	9	25	0.5	0.08	26
Raritan	Bound Brook, N.J.	46	30	16	20	42	7	12	1.5	0.15	16
Red	Shreveport, La.	255	185	70	196	111	170	146	0.3	1.1	30
Republican	Junction, Kans.	230	173	57	124	242	42	55	2.4	2.2	48
Rock	Rockford, Ill.	215	113	102	22	207	7	23	3.3	0.44	15
Rogue	Tolo, Ore.	25	18	7	15	32	2	4	0.2	0.07	24
Sacramento	Sacramento, Calif.	61	33	28	29	60	8	17	0.5	0.43	28
Salinas	Paso Robles, Calif.	265	150	115	129	232	55	101	0.6	0.15	31
Saluda	Columbia, S.C.	26	21	5	13	27	5	5	0.4	0.38	21
San Antonio	Bradley, Calif.	244	158	86	82	187	34	98	0.8	0.16	37
San Gabriel	Azusa, Calif.	162	113	49	39	150	6	33	0.9	0.16	21
Sangamon	Decatur, Ill.	245	138	107	31	220	8	36	6.8	0.27	19
San Joaquin	Lathrop, Calif.	91	50	41	78	60	66	40	0.8	0.3	19
Santa Ana	Corona, Calif.	89	65	24	39	84	10	14		0.15	16
Shenandoah	Millville, W. Va.	114	80	34	15	111	4	6	2.1	0.08	15
Siletz	Siletz, Ore.	15	11	4	13	14	6	5	1.3	0.03	9
Skagit	Sedro Woolley, Wash.	27	20	7	8	23	1	8	0.2	0.08	9
Smoky Hill	Lindsborg, Kans.	375	285	90	349	210	269	246	1.5	0.86	28

TABLE 4. ANALYSES OF NINETY-EIGHT RIVER WATERS—ONE-YEAR AVERAGES *(Continued)*

Name of River	Sampled at or near	(expressed as ppm of $CaCO_3$)								(ppm) Fe	(ppm) SiO_2
		Hardness	Ca	Mg	Na + K	HCO_3	Cl	SO_4	NO_3		
Snake	Weiser, Idaho	123	83	40	53	107	24	36	0.5	0.04	26
Solomon	Beloit, Kans.	296	230	66	187	241	95	112	2.4	1.4	35
Spokane	Spokane, Wash.	43	28	15	12	40	1	9	0.2	0.02	11
Spring	Baxter Springs, Kans.	199	165	34	51	114	10	87	4.3	1.1	13
Susquehanna	West Pittston, Pa.	59	45	14	14	51	6	14	1.2	0.12	10
Tennessee	Knoxville, Tenn.	73	55	18	18	71	14	7	0.6	0.54	25
Tombigbee	Epes, Ala.	52	45	7	22	55	4	7	0.5	0.63	25
Umatilla	Umatilla, Ore.	85	58	27	54	95	13	24	1.0	0.07	34
Umpqua	Elkton, Ore.	29	20	9	13	30	4	5	0.2	0.1	18
Ventura	Ventura, Calif.	388	265	123	102	192	28	261	0.6	0.14	23
Verdigris	Coffeyville, Kans.	223	178	45	72	214	32	32	2.6	1.4	24
Vermilion	Streator, Ill.	257	138	119	39	198	10	70	1.0	0.22	14
Wabash	Logansport, Ind.	348	205	143	308	192	412	82	4.8	0.23	14
Wabash, Little	Carmi, Ill.	87	50	37	33	73	11	33	1.7	2.0	26
Wallowa	Joseph, Ore.	41	38	3	9	39	1	9	0.2	0.02	10
Walnut	Winfield, Kans.	299	225	74	69	240	21	90	3.0	1.2	23
Wateree	Camden, S.C.	23	16	7	18	28	4	4	0.3	0.28	25
Wenatchee	Cashmere, Wash.	23	14	9	9	23	1	7	0.3	0.08	12
White, E. Fork	Azalia, Ind.	247	153	94	21	226	4	31	4.5	0.14	15
White, W. Fork	Indianapolis, Ind.	304	185	119	104	239	110	60	4.9	0.15	14
Willamette	Salem, Ore.	19	13	6	9	21	3	4	0.3	0.1	15
Wisconsin	Portage, Wisc.	63	35	28	18	48	3	18	0.7	0.22	13
Youghiogeny	McKeesport, Pa.	86	58	28	20	acid	6	128	0.9	0.7	9
Yakima	Prosser, Wash.	65	40	25	31	66	7	22	0.3	0.1	19
Yukon	Anvik, Alaska	120	90	30	14	110	2	15		0.07	12

Table 6. Analyses of Fifty Lake Waters

Name of Lake	State or Province	(expressed as ppm of CaCO₃)								(ppm) Fe	(ppm) SiO_2
		Hardness	Ca	Mg	Na + K	HCO_3	Cl	SO_4	NO_3		
Angela	California	15	13	2	5	15	4	1			
Bass	Wisconsin	7	2	5	1	3	4	1			5
Bigstone	Minnesota	312	111	201	87	192	13	198		1.1	107
Cedar	Washington	23	17	6	8	23	3	6	0.2	0.02	13
Center	Indiana	253	218	33	20	183	21	68			10
Champlain	New York	48	36	12	13	51	1	7			4
Clear	California	87	41	46	12	93	3	4			7
Crater	Oregon	30	18	12	27	28	15	11	0.3	0.1	18
Crystal	California	9	6	3	2	9	1	1			
Eagle	Texas	326	274	52	189	120	318	58	20.0		28
Echo	New Hampshire	12	6	6	5	5	2	9	0.2	0.01	4
Erie	New York	109	78	31	15	94	13	13	0.2	0.07	6
Geneva	Wisconsin	179	68	111	9	154	6	13			10
Goose	California	53	45	8	804	687	141	47	1.2	0.02	50
Hemlock	New York	71	50	21	7	54	3	18	0.3		2
Humboldt	Nevada	104	32	72	685	335	418	32			33
Huron	Michigan	89	60	29	9	85	4	6	0.3	0.04	12
Kampeska	South Dakota	256	138	118	29	216	7	54			4
Kester	West Virginia	36	28	8	3	28	4	8			
Long	Wisconsin	82	46	36	11	82	11	2			8
Massabesic	New Hampshire	12	7	5	6	7	4	7	0.1	0.04	22
Mead	Nevada	305	203	102	189	150	85	253	2.3	0.25	19
Mendota	Wisconsin	139	50	89	11	129	4	15			15
Michigan	Illinois	125	80	45	7	122	3	7		0.03	5
Mille Lacs	Minnesota	118	55	63	25	142	1	1			4

Table 6. Analyses of Fifty Lake Waters (*Continued*)

Name of Lake	State or Province	(expressed as ppm of CaCO₃)								(ppm) Fe	(ppm) SiO_2
		Hardness	Ca	Mg	Na + K	HCO_3	Cl	SO_4	NO_3		
Minnetonka	Minnesota	103	70	33	6	108	1				5
Moosehead	Maine	7	6	1	5	9	3	2	tr.	0.1	1
Nipissing	Ontario, Can.	34	22	12	2	20	3	10	1.1	0.08	6
North	Colorado	48	43	5	29	74	1	tr.			2
North Watuppa	Massachusetts	10	7	3	10	7	9			0.14	2
Okeechobee	Florida	107	78	29	39	93	39	7	0.1	0.1	8
Ontario	Ontario, Can.	123	89	34	17	94	23	23	1.1	0.05	8
Penacook	New Hampshire	12	8	4	8	12	3	4			
St. Johns	Quebec, Can.	19	12	7		6	1		tr.	tr.	4
St. Marys	Ohio	176	119	57	35	120	35	56			
Sebago	Maine	12	7	5	2	3	2	7	0.7	0.05	2
Silver	Massachusetts	9	5	4	10	7	10	6		0.07	4
Silver	Montana	104	75	29	31	122	1	9		tr.	
Simcoe	Ontario, Can.	119	102	17	26	112	8	17	0.5	0.05	11
Skaneateles	New York	113	85	28	5	95	2	15	1.2	0.02	6
Spavinaw	Oklahoma	80	75	5	10	76	6	8	tr.	0.1	4
Superior	Michigan	46	33	13	7	46	1	2	0.4	0.06	7
Tahoe	California	36	24	12	20	47	3	6		0.1	14
Washington	Washington	33	16	17		38	11	9		0.5	15
Whatcom	Washington	19	12	7	14	17	8	9	0.6	0.16	7
Winnebago	Wisconsin	162	87	75	4	168	4	10			14
Winnepesaukee	New Hampshire	10	7	3	6	8	2	4	tr.	0.02	1
Winnipeg	Manitoba, Can.	100	63	37	19	77	9	22	4.8	0.4	19
Worth	Texas	164	128	36	57	129	55	36	0.1	0.1	5
Yellowstone	Nevada	23	22	1	44	42	13	8			42

NOTE: Great Lakes sampled at following points: Erie at Buffalo; Huron at Port Huron; Michigan at Chicago; Ontario at Toronto, and Superior at Sault Ste. Marie

2. *DISSOLVED MINERAL MATTER*

THE ORDER in which water impurities are discussed in Chapters 2, 3, and 4 is according to the group classification given in Chapter 1, namely: (1) dissolved mineral matter; (2) dissolved gases; (3) turbidity and sediment; (4) color and organic matter; (5) tastes and odors; and (6) microorganisms. Dissolved mineral matter is the subject taken up in this chapter. Chapter 3 is devoted to dissolved gases, while turbidity, sediment, color, organic matter, tastes, odors, and microorganisms are discussed in Chapter 4.

All natural water supplies, either in their raw state or after treatment by a municipality, contain dissolved mineral matter. As shown in the analyses listed in Chapter 1, these mineral constituents differ greatly in the amounts and relative proportions present in various water supplies. The most abundant are the bicarbonates, sulfates, and chlorides of calcium, magnesium and sodium. Silica also is a common constituent of waters and may be present in amounts ranging from as little as 1 ppm to over 100 ppm.

Iron is present in most water supplies in small amounts, and if present to the extent of 0.1 ppm or less, may be considered as negligible for most industrial uses. If present in greater amounts than 0.2 or 0.3 ppm, it is usually very objectionable. Manganese is a rarer constituent but is even more objectionable, and tolerances for special uses may be even lower than the tolerances for iron.

Nitrates are usually absent or present only as traces, but there are exceptions, and if appreciable amounts are present, nitrates are determined. Nitrites are either absent or present in such minute amounts that they are rarely determined in industrial water analyses. Ammonia, which possibly might more appropriately be considered under gases, is also usually such a minor constituent that it is seldom determined in industrial water analyses. There are exceptional cases, however, where heavily contaminated waters have given off enough ammonia in the boilers to have an effect on brass valves and fittings.

NOTE: From a health standpoint and then only in the case of very young babies, nitrates above some 10 to 20 ppm in the drinking water can cause methemoglobinemia.

Bosch, H. M., *et al.*, "Methemoglobinemia and Minnesota Well Supplies," *J. Am. Water Works Assoc.*, 42, 161 (1950) and references in same.

Potassium, because it is usually present in such small amounts and is so much like sodium in most of its properties, is usually grouped with the sodium. Fluorides, which may occur in the waters in certain localities in amounts of from less than 1 to 8 ppm, are of importance from a health angle but are probably of little significance for most industrial uses. A few of the waters in certain western areas contain borates in sufficient amounts to be of importance when used for irrigation. Small amounts of alumina are also commonly found in water supplies, but usually they are of little significance.

Small quantities of carbonate alkalinity may be found, at times, in both natural surface waters and well waters, and objectionable amounts may be present in the so-called alkali waters. Caustic alkalinity is practically never found except in treated waters.

Mineral acidity, usually caused by sulfuric acid, is found in many mine waters and some surface waters which have been contaminated by trade wastes or seepage from mines.

NOTE: Bromine, in commercially extractable amounts, is found in seawater and some connate waters or oil-field brines. Iodine is also present in small amounts in seawater and some connate waters and oil-field brines. In fresh waters, while the amounts of iodine present are extremely small—they are measured in parts per billion instead of in ppm—they are of importance in reducing the prevalence of goiter. For industrial uses, its presence or absence is of no importance. There are also a few very unusual waters which contain

TABLE 15A. MINERAL CONSTITUENTS USUALLY DETERMINED IN WATER ANALYSIS

Name	Formula	Expressed as	Commonly Known as	
Calcium	Ca	$CaCO_3$	Calcium hardness +	= Total hardness
Magnesium	Mg	$CaCO_3$	Magnesium hardness	
Sodium	Na	$CaCO_3$	—	
Bicarbonate	HCO_3	$CaCO_3$	Bicarbonate alkalinity	
Carbonate	CO_3	$CaCO_3$	Carbonate alkalinity	
Hydroxide	OH	$CaCO_3$	Caustic alkalinity	
Chloride	Cl	$CaCO_3$	—	
Sulfate	SO_4	$CaCO_3$	—	
Nitrate	NO_3	$CaCO_3$	—	
Mineral acid*	—	$CaCO_3$	Mineral acidity	
Fluoride	F	F	—	
Silica	SiO_2	SiO_2	—	
Iron	Fe	Fe	—	
Manganese	Mn	Mn	—	

* Mineral acidity may be due to sulfuric acid or sulfates of iron, alumina, or manganese. In the effluent from hydrogen-cation exchangers, both sulfuric and hydrochloric acids may be present, plus, with some waters, small amounts of nitric acid.

measurable amounts of such unusual constituents as arsenic, selenium and strontium, but these are so uncommon that it is probably sufficient merely to mention that they exist. Lead, copper and zinc, in small amounts, may also be picked up from pipe by corrosive waters. Spectroscopic traces of other metals have been found in natural water supplies but, since they are present in only spectroscopic traces, they need not be considered. Trade-waste contamination of waters may also furnish unusual constituents, one of which is chromium.

For ordinary industrial uses and for the usual run of natural and treated water supplies, the mineral constituents, in Table 15A are the only ones that need to be considered:

Alkalinity: Bicarbonate, Carbonate, and Caustic

Alkalinity is determined by titration with a standard acid solution, using phenolphthalein and methyl orange as indicators. The results of titration with the methyl orange indicator are expressed as "methyl orange alkalinity" or "total alkalinity." The results of titration with phenolphthalein indicator are expressed as "phenolphthalein alkalinity" (most natural water supplies contain some free carbon dioxide and show no phenolphthalein alkalinity).

(1) If no phenolphthalein alkalinity is present, all of the alkalinity is assumed to be bicarbonate alkalinity.

(2) If phenolphthalein alkalinity is present, twice the phenolphthalein alkalinity, if less than or equal to the methyl orange alkalinity, is assumed to be carbonate alkalinity.

(3) If twice the phenolphthalein figure exceeds the methyl orange alkalinity, the excess is presumed to be "caustic" or hydroxide alkalinity.

NOTE: There are certain errors inherent in these determinations and these assumptions are not strictly in accordance with physical chemistry concepts, but these methods are simple and very satisfactory for most of the calculations involved in water treatment.

Obviously, in solutions as dilute as fresh water supplies are, the salts are not present as such but instead are practically completely dissociated into the corresponding anions and cations. However, it is often convenient and simpler to visualize some of the salts as if they were undissociated. Thus, it is common practice to refer to the calcium bicarbonate or calcium sulfate content of a water as if these substances were present as undissociated salts instead of as ions. In other cases, it may be simpler to consider the ions that are present.

Hardness: Calcium and Magnesium

The hardness of a water is due to its calcium and magnesium content. Hardness in English-speaking countries is expressed in terms of calcium

carbonate. Calcium hardness is that hardness due to soluble calcium salts; magnesium hardness, to soluble magnesium salts. Total hardness is the sum of the calcium hardness plus the magnesium hardness.

NOTE: The term, hardness, was originally applied to waters that were hard to wash in; it referred to the soap-wasting properties of water. With most normally alkaline waters, these soap-wasting properties are directly and proportionately due to the calcium and magnesium content. It is obvious that in an acid water, the mineral acids present would also act as hardness. Similarly, if appreciable amounts of soluble iron, aluminum, or certain other heavy metals were present, these also would waste soap. However, these are exceptional cases and there is no need of complicating a simple definition with them.

Carbonate hardness, bicarbonate hardness, and temporary hardness are synonymous terms for that hardness attributed to the bicarbonates of calcium and/or magnesium. The first of these, carbonate hardness, is now the preferred term. Noncarbonate hardness, sulfate hardness, and permanent hardness are synonymous terms for that hardness due to the sulfates, chlorides and/or nitrates of calcium and/or magnesium. The first of these, noncarbonate hardness, is now the preferred term.

The amounts of carbonate and noncarbonate hardness present in a given water are determined by inspection of the analysis as follows:

(1) If the methyl orange alkalinity of the water equals or exceeds the total hardness, all of the hardness is present as carbonate hardness.

(2) If the methyl orange alkalinity of the water is less than the total hardness, the carbonate hardness equals the alkalinity.

(3) The noncarbonate hardness, under the conditions in (2), is equal to the total hardness minus the methyl orange alkalinity.

While the terms "carbonate hardness" and "noncarbonate hardness" are often used in the text, there are some deviations for the sake of clarity. For instance, it is not at all obvious what is meant if it is stated that the calcium carbonate hardness breaks down, on heating, to form calcium carbonate. On the other hand, if it is stated that the calcium bicarbonate hardness breaks down, on heating, to form calcium carbonate, it is immediately obvious that a definite change has taken place. In other cases also, especially when sodium alkalinity is also present, it is clearer in showing the relationships to use the terms, "calcium alkalinity" and "magnesium alkalinity" than the terms "calcium carbonate hardness" and "magnesium carbonate hardness."

NOTE: If the methyl orange alkalinity exceeds the total hardness, the excess is the sodium alkalinity.

Calcium Carbonate Scale. Since calcium carbonate is much less soluble than magnesium carbonate and both of them are very much less soluble than sodium carbonate, it is convenient to visualize the alkalinity as bound first to the calcium, second to the magnesium, and third to the sodium. Such a visualization is helpful for practical purposes, for, when a water containing the bicarbonates of calcium, magnesium, and sodium is heated, the calcium carbonate is the first to be deposited, magnesium carbonate next, while sodium carbonate is so extremely soluble that no separation in the solid form would occur until the solution was greatly concentrated by evaporation. The solubilities of these three carbonates at 212°F are shown in Table 16.

TABLE 16. CARBONATES: SOLUBILITIES OF THE CARBONATES OF CALCIUM, MAGNESIUM, AND SODIUM AT 212°F

Name	Formula	Solubility as $CaCO_3$	
		(ppm)	(gpg)
Calcium carbonate	$CaCO_3$	13	0.8
Magnesium carbonate	$MgCO_3$	75	4.4
Sodium carbonate	Na_2CO_3	289000	16900.0

An inspection of 233 river, lake, spring and well-water analyses in Chapter 1 will indicate that only 10.3 per cent have magnesium alkalinities exceeding 75 ppm, expressed as $CaCO_3$, and these are divided as follows: 76 to 85 ppm, 3.9 per cent; 86 to 100 ppm, 3.0 per cent; 100 to 125 ppm, 2.1 per cent; and 126 to 147 ppm, 1.3 per cent. This goes far to explain why it is that calcium carbonate is the principal scale-former in condensers and other water-jacketed equipment, water heaters, hot-water piping and fixtures, for, even if the bicarbonates were entirely broken down to the carbonates, there are but relatively few waters which contain enough magnesium alkalinity to exceed the solubility of magnesium carbonate. Also, in practically all cases where the raw water is merely heated but not actually boiled or concentrated, as in the steam boiler, the decomposition of bicarbonates is far from complete; it can be expected that, under such conditions, calcium carbonate will usually be the principal scale-former.

There is a widespread opinion that calcium carbonate scale cannot form unless water is heated beyond 130°F. This is incorrect, for with some waters even a very slight rise in temperature is sufficient to form calcium carbonate scale. For instance, in tropical or semitropical locations, heavy calcium carbonate scale formation in cold-water mains is not unknown. As this is treated very fully in Chapter 7, it need only be mentioned very briefly here that there is an equilibrium, at each temperature, between the free carbon dioxide content of the water and the amount of calcium bicarbonate that can be held in solution and that with some waters even a slight elevation of temperature is sufficient to upset this equilibrium and cause calcium carbonate to deposit.

An interesting phenomenon is the occasional deposition of some calcium carbonate in pond waters, caused by microorganisms. Some of these, under favorable conditions, use up all the free carbon dioxide content of the water and some of the carbon dioxide content of the bicarbonates, forming thereby some normal carbonate. If the amount of carbonate so formed is much over 1 gpg (17 ppm), precipitation of part of the calcium hardness can occur.

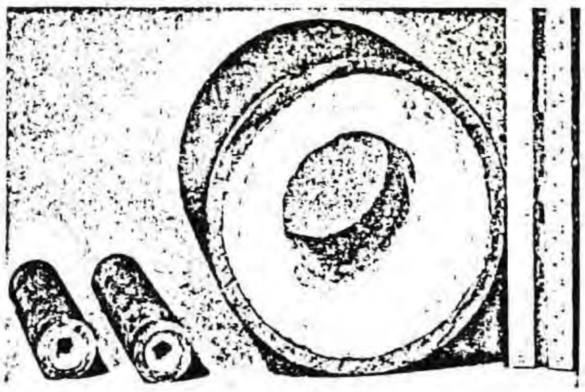


Figure 5. Scaled hot-water pipes.

Calcium Carbonate and Magnesium Hydroxide Scale. At the temperatures prevailing in the steam boiler, both calcium bicarbonate and magnesium bicarbonate break down to form scale, but whereas the calcium scale consists of calcium carbonate, the magnesium deposits as magnesium hydroxide. This is because the magnesium bicarbonate decomposes first to magnesium carbonate and this reacts with the water to form magnesium hydroxide and free carbon dioxide. Sodium bicarbonate undergoes a similar decomposition in the boiler but, since caustic soda is extremely soluble, it remains in solution. These reactions are as follows:

$$(1)\qquad Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2$$

$$(2)\qquad Mg(HCO_3)_2 \rightarrow MgCO_3 + H_2O + CO_2$$
$$MgCO_3 + H_2O \rightarrow Mg(OH)_2 + CO_2$$

$$(3)\qquad 2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$
$$Na_2CO_3 + H_2O \rightarrow 2NaOH + CO_2$$

The carbon dioxide formed leaves the boiler with the steam. In the case of the sodium carbonate, the conversion to sodium hydroxide often exceeds 80 per cent. The magnesium hydroxide in the scale may lose part of its water content by baking on the tubes and appear partly as magnesium oxide. The solubilities of the hydroxides of calcium, magnesium, and sodium, expressed as ppm of $CaCO_3$, at 212°F are given in Table 17.

Under higher temperatures and pressures, the solubilities of both calcium carbonate and magnesium hydroxide decrease. At about 210 psi (392°F), the solubility of calcium carbonate is a little less than 5 ppm and that of magnesium hydroxide is only slightly over 1 ppm, expressed as $CaCO_3$. Calcium hydroxide also has a solubility that decreases with rise in temperature. At 32°F its solubility is 2390 ppm, at 212°, 888 ppm, and at 210 psi (392°F), 134 ppm, expressed as $CaCO_3$. It is not likely to be found in a boiler scale, however, unless the boiler feed water was grossly overtreated with lime.

TABLE 17. HYDROXIDES: SOLUBILITIES OF THE HYDROXIDES OF CALCIUM, MAGNESIUM, AND SODIUM AT 212°F

Name	Formula	Solubility as $CaCO_3$	
		(ppm)	(gpg)
Calcium hydroxide	$Ca(OH)_2$	888	51.8
Magnesium hydroxide	$Mg(OH)_2$	8	0.5
Sodium hydroxide	NaOH	975000	56900.

Calcium Sulfate Scale. Calcium sulfate is the only scale-forming salt in the noncarbonate hardness for magnesium sulfate, and the chlorides and nitrates of both calcium and magnesium have solubilities exceeding 150,000 ppm by weight expressed as $CaCO_3$, even at 32°F and over 356,000 ppm at 212°F. Calcium sulfate, in the form of gypsum, has a solubility curve which, on elevations of temperature, shows a rise up to about 104°F, after which it falls until, at 212°F, it is slightly below the solubility at 32°F. At boiler temperatures the curve falls rapidly, until at 322 psi it is only some 40 ppm, expressed as calcium carbonate. This is shown in Table 18.

It is therefore evident that the tolerance for calcium sulfate in a cooling water would be large—over 1200 ppm (70 gpg) expressed as $CaCO_3$. This is taken into account in the acid treatment of cooling waters as described in Chapter 7. It is also necessary to see that the blowdown on a cooling pond is regulated so as to maintain the calcium sulfate content below some 1200 ppm, expressed as $CaCO_3$. Owing to its low solubility at the temperatures prevailing in steam boilers and because it forms a very hard and adherent scale, no amount of calcium sulfate can be tolerated in steam boilers.

Thermal Conductivities of Scales. From measurements made by Ernst, Eberle and Holzhauer, Reutlinger, Croft, and Partridge and White, the thermal conductivities (K) of adherent boiler scales, expressed in Btu per square foot of area, per foot of thickness, per hour, per 1°F temperature difference, have been found to lie between 0.66 and 2.06 with a mean value of approximately 1.5. The degree of porosity of the scale affects the thermal conductivity, as apparently these pores may be filled with steam instead of water under boiler operating conditions, thus reducing the thermal conductivity in much the same manner as the air cells in the commonly used heat-insulating materials. There is some evidence that such porous scales may have thermal conductivities of only 0.2 Btu per sq ft per ft per hr per 1°F.

TABLE 18. CALCIUM SULFATE: SOLUBILITIES AT 32 TO 428°F

°F	Solubility as $CaCO_3$	
	(ppm)	(gpg)
32	1293	75.5
104	1551	90.5
212	1246	72.7
338 (100 psi)	103	6.0
392 (210 psi)	56	3.3
428 (322 psi)	40	2.3

For comparison, the thermal conductivity of firebrick is about 0.75 and steel about 26. Hardwater scales therefore have thermal conductivities of only some 3 per cent to 8 per cent (average about 5 per cent) of that of steel or about the same as that of firebrick. In other words, hardwater scales are practically as good heat-insulating materials as firebrick. Unfortunately, scale forms in the wrong places which accounts for its being called "misplaced insulation."

In order to pass a given number of heat units through a certain area of a vessel in a given period of time, it is necessary to maintain a definite differential of temperature between the inside and the outside of the vessel. If the walls of the vessel consist of clean, unscaled metal, the temperature differential that must be maintained is very much less than if the metal is scaled. How much this temperature differential must be raised, for various rates of heat transfer, if one-tenth of an inch of scale is present, is shown in Table 19, which has been calculated for two scales having thermal conductivities (K) of 1.5 and 0.75.

The heat-insulating properties of hard-water scales are objectionable not only in steam boilers and water heaters but also in water-cooled equipment such as condensers, internal combustion engines and other water-jacketed equipment. Furthermore, these scale deposits do not form

TABLE 19. SCALE: TEMPERATURE ELEVATIONS, AT VARIOUS RATES OF HEAT TRANSFER, CAUSED BY ONE-TENTH INCH THICKNESSES OF TWO SCALES

Rate of Heat Transfer (Btu/sq ft/hr)	Increase in Temperature Differential Caused by One-Tenth Inch of Scale (°F)	
	$K = 0.75$	$K = 1.5$
2000	22	11
5000	56	28
10000	111	56
20000	222	111
40000	444	222
60000	667	333
80000	889	444
100000	1110	556
120000	1330	667
140000	1560	778

a layer which is of even thickness and uniformly distributed over the entire heat transfer area. Instead, scale forms most rapidly and consequently is thickest at points where the rate of heat transfer is greatest.

The maximum safe operating temperature for mild boiler steel is considered to be about 900°F. Temperatures much above this point will result in bagging (Figure 6) or failure (Figure 7). Failures of tubes in the highly irradiated sections of modern boilers have been caused by scale thicknesses of less than 0.04 inch. This agrees quite well with the calculated figures, for, if $K = 0.75$ is assumed as the thermal conductivity of the scale, a simple calculation will show 0.04-inch thickness of scale is sufficient to cause boiler metal temperatures exceeding 900°F at heat transfer rates of 100,000 or more Btu per sq ft per hr in boilers operating at pressures of 400 psia or over. At higher pressures, even smaller thicknesses of scale may cause boiler metal temperatures above 900°F and, if a porous scale with a value for K of 0.2 or less is encountered, calculations indicate that even less than 0.01-inch thickness of scale may be sufficient to cause failure of the boiler metal.

Figure 6. Bagged boiler tube caused by scale.

Figure 7. Boiler tube failure caused by scale.

In water jackets, scale is equally objectionable. In Diesel or other internal combustion engines, scaled surfaces in the water jackets cause increases in temperature differentials between the fire side and water side in much the same manner as in the steam boiler. As the scale increases in thickness, this temperature differential likewise increases, until finally it becomes so great that the metal is highly overheated and fails. Cylinder heads on Diesel engines are especially prone to cracking from scale deposits. Figure 9 illustrates such a failure. In surface condensers and other nonfired vessels, failure of the metal from overheating could not occur because the temperature differential is too small. In a surface condenser, operating on exhaust steam and under a partial vacuum, of course, there may be less than 50°F temperature differential between the vapor side and the water side of the metal. It is on account of this small temperature differential that scales are so troublesome in condensers, for even a very thin scale will increase the temperature differential, thus lowering the vacuum in the exhaust and decreasing the efficiency of the prime mover.

Figure 8. Scaled flue from locomotive boiler.

Figure 9. Cracked Diesel-engine cylinder head caused by scale.

Hard-water scales are also highly objectionable because they decrease the effective diameter of pipe lines and thus greatly reduce their carrying capacity. It is not uncommon to see 6-inch pipe with one-inch layer of scale in it, thus reducing its effective diameter to 4 inches and its carrying capacity to less than one-half of what it was originally. Nor is it necessary to have very thick scales in order to reduce the flow rates, especially in the case of smaller pipe. Only one-fourth inch of scale in a one-inch pipe, for instance, will reduce its effective diameter to one-half inch and the maximum flow rate obtainable would be only one-fourth of what it was originally.

Soap Wastage by Hardness. When a hard water comes in contact with soap, the calcium and magnesium ions react with the ions of the fatty acids to precipitate the practically insoluble calcium and magnesium soaps. With pure soap, this destruction by hardness amounts to 1½ pounds of soap per 1000 gallons of water for each grain per gallon (17 ppm) of hardness present, as shown in Table 20.

TABLE 20. HARDNESS: SOAP DESTRUCTION OF WATER OF VARIOUS HARDNESSES

Hardness as CaCO$_3$		Soap Wastage	Hardness as CaCO$_3$		Soap Wastage
(gpg)	(ppm)	(lb/1000 gal)	(gpg)	(ppm)	(lb/1000 gal)
1	17	1.5	16	274	24.0
2	34	3.0	17	291	25.5
3	51	4.5	18	309	27.0
4	69	6.0	19	326	28.5
5	86	7.5	20	343	30.0
6	103	9.0	22	377	33.0
7	120	10.5	24	411	36.0
8	137	12.0	26	446	39.0
9	154	13.5	28	480	42.0
10	171	15.0	30	514	45.0
11	189	16.5	35	549	52.5
12	206	18.0	40	583	60.0
13	223	19.5	45	771	67.5
14	240	21.0	50	857	75.0
15	257	22.5	60	1028	90.0

As the soap destruction is directly proportional to the amount of hardness, a standard solution of soap may be employed to measure the hardnesses of various waters and this figure is often called the "soap hardness." This should agree with the hardness of the water when determined by gravimetric methods, but certain inaccuracies in making the determinations may lead to appreciable discrepancies in the results. This is especially the case with the older Clark method. The potassium palmitate or Blacher method yields much more satisfactory results.

As can be deduced from Table 20, the soap destruction in textile plants, laundries, and other industries where cleansing operations with soap are conducted are large when hard waters are used. Therefore, softening of the water used in such industries effects huge savings. Softening the water supply not only saves soap and other detergents, but it also effects an incomparably better cleansing and furnishes a superior product. In textile plants and laundries, the washed materials have a better appearance, softer feel, and an increased life. In dyeing, softened water is of importance in securing even dyeing, free from spots and streaks. In the manufacture of rayon, it has been found extremely important to eliminate even a few ppm of hardness, and water with a practically zero content of hardness is a prime requisite.

Figure 10. Left: hard water and soap. Right: zero hardness water and soap.

Figure 11. Photomicrograph of linen washed in hard water.

Hard water is also a drawback in many other industries, even when soap is not used in processing operations. In alkaline baths, for instance, scale formation is common and causes many processing difficulties. These processes and the difficulties caused by hard waters in various industries are further discussed in Chapter 5.

Hardness of Industrial Water Supplies. The tabulated analyses of various water supplies in Chapter 1 are from a sufficient number of locations to give a fair idea of the ranges in hardness that may be encountered with various industrial water supplies. The attempted classification of natural water supplies as soft, moderately hard, hard, very hard, and extremely hard is unsatisfactory and misleading because (1) the tolerances for hardness for different industrial uses vary so greatly often even in the same plant, and (2) these terms are subject to almost as many interpretations as there are listeners.

Figure 12. Milk bottles washed with caustic soda in hard water vs. zero hardness water.

Figure 13. Deposits on bottle pasteurized in hard water.

Concerning the first, an 85-ppm (5-gpg) hardness water may be "soft" enough for the process water in a paper mill but too "hard" to use in the mill's boilers. Or a 50-ppm (3-gpg) hardness water may be considered "very soft" and satisfactory by a carbonated beverage bottler, while a rayon manufacturer may consider the same water as "hard" and very unsatisfactory. This matter of water requirements for various end uses in a number of different industries is discussed very fully in Chapter 5.

Concerning the second, an item in a Midwestern newspaper some years ago had a headline which blazoned forth that "—— Gets Soft Water Supply" and then the subhead under it stated, "New Well Has a Hardness of Only 20 Grains." Obviously, a water that contains hardness cannot be considered a soft water and a water that contains 20 gpg (343 ppm) is a water that would usually be considered as "very hard" or even "extremely hard." For instance, it is about twenty times as hard as the water supply in Boston or the Catskill supply used in New York; about six times as hard as the water supply of Baltimore and about three times as hard as the water supplies in Cleveland, Chicago, and Milwaukee.

Yet, on reading the item under the headlines, it developed that the well water supply previously used had a hardness of 60 to 70 gpg (1028 to 1200 ppm). Quite naturally then, the reporter considered that any water having only one-third as much hardness as the hard water he was accustomed to must be a soft water. This illustration is a rather extreme one and sounds absurd, but that is only because the hardnesses of the well waters in that town are so much higher than the hardnesses of the waters that most of us are accustomed to in daily use. For instance, there are over 650 municipal water-softening plants in North America, and the waters furnished by these plants are considered to be "soft" waters by millions of users. Yet, with the exception of a scant dozen or so, these plants invariably merely reduce the hardness of the raw water to 85 ppm (5 gpg).

Such "soft" waters, when used in laundries or similar washing processes, are so "hard" that they will waste from 35 to 45 per cent of the total soap used or, expressed in another way, as shown in Table 20, each 1000 gallons will waste about 7½ pounds of pure soap. Therefore, while these waters are "soft" enough for most household uses and these municipalities are to be highly commended for reducing the hardness of the raw waters to this extent, these waters are too "hard" for the great majority of industrial uses.

NOTE: While the average consumption of water in municipalities is about 100 gallons per capita per day, only some 1.2 gallons per capita per day reacts completely with soap. At first glance, this looks absurdly low but it must be considered that, when a person takes a bath, he does not use enough soap to raise a lather with all the water in the tub. Instead, he soaps portions of his anatomy only when out of the water and then rinses in the tub. Consequently, only a thin film of water reacts completely with the soap. The same obviously applies as well to shower baths or in washing in the wash bowl. On the other hand, in dish washing or in the washing machine, all of the water used in the sudsing operations completely reacts with the soap. Yet the cost of the soap

Table 21. Hardness: Variations in Hardness of a Group of Ninety-eight River Waters Over a One-Year Period

Name of River	Sampled at or near	Hardness as ppm $CaCO_3$		
		(max.)	(min.)	(aver.)
Alabama	Selma, Ala.	67	28	45
Allegheny	Kittanning, Pa.	90	26	47
Arkansas	Arkansas City, Kans.	473	238	336
Big Blue	Manhattan, Kans.	296	129	225
Brazos	Waco, Texas	652	176	381
Cache	Mounds, Ill.	141	44	73
Cahaba	Birmingham, Ala.	74	21	43
Cedar	Cedar Rapids, Ia.	267	87	186
Chattahoochee	West Point, Ga.	27	5	15
Chikaskia	Argonia, Kans.	251	165	209
Chippewa	Eau Claire, Wis.	78	82	52
Cimarron	Englewood, Kans.	453	283	352
Clackamas	Cazadero, Ore.	29	12	19
Columbia	Cascade Locks, Wash.	67	41	57
Columbia	Northport, Wash.	76	56	64
Cottonwood	Emporia, Kans.	475	200	353
Crooked	Prineville, Ore	149	46	110
Cumberland	Nashville, Tenn.	102	65	80
Delaware	Lambertville, N.J.	61	24	44
Deschutes	Moody, Ore.	50	23	32
Des Moines	Keosauqua, Ia.	406	116	231
Embarrass	Charleston, Ill.	308	161	226
Fall	Neodesha, Kans.	279	156	222
Flint	Albany, Ga.	48	17	28
Fox	Ottawa, Ill.	369	209	281
Grand	Grand Rapids, Mich.	263	164	218
Grande Ronde	Elgin, Ore.	67	20	31
Hudson	Hudson, N.Y.	89	45	69
Illinois	La Salle, Ill.	277	157	215
Iowa	Iowa City, Ia.	267	84	193
James	Richmond, Va.	71	26	47
Kalamazoo	Kalamazoo, Mich.	260	125	212
Kankakee	Kankakee, Ill.	284	171	231
Kansas	Holliday, Kans.	430	135	249
Kaskaskia	Carlyle, Ill.	255	105	200
Kentucky	Frankfort, Ky.	94	38	68
Klickitat	Klickitat, Wash.	42	23	31
Lehigh	South Bethlehem, Pa.	105	26	59
Marmaton	Fort Scott, Kans.	272	180	239
Maumee	Toledo, O.	290	150	210
Medicine Lodge	Kiowa, Kans.	995	323	589
Miami	Dayton, O.	303	139	246
Mississippi	Memphis, Tenn.	184	108	139
Mississippi	Minneapolis, Minn.	188	104	157
Missouri	Kansas City, Kans.	348	159	229
Monongahela	Elizabeth, Pa.	57	26	39
Muddy	Murphysboro, Ill.	222	41	112
Muskingum	Zanesville, O.	209	70	147
Okanogan	Okanogan, Wash.	103	40	72
Oostanula	Rome, Ga.	118	27	41

Table 21. Hardness: Variations in Hardness of a Group of Ninety-eight River Waters over a One-Year Period *(Continued)*

Name of River	Sampled at or near	Hardness as ppm $CaCO_3$		
		(max.)	(min.)	(aver.)
Osage	Boicourt, Kans.	323	111	217
Oswegatchie	Ogdensburg, N.Y.	58	32	47
Pearl	Jackson, Miss.	35	14	23
Peedee	Peedee, S.C.	33	17	21
Platte	Columbus, Nebr.	301	176	232
Platte, North	North Platte, Nebr.	201	134	164
Potomac	Cumberland, Md.	148	41	79
Powder	North Powder, Ore.	116	59	85
Raritan	Bound Brook, N.J.	55	29	46
Red	Shreveport, La.	779	96	255
Republican	Junction, Kans.	282	163	230
Rock	Rockford, Ill.	282	127	215
Rogue	Tolo, Ore.	37	18	25
Sacramento	Sacramento, Calif.	81	40	61
Salinas	Paso Robles, Calif.	332	191	265
Saluda	Columbia, S.C.	40	20	26
San Antonio	Bradley, Calif.	460	154	244
San Gabriel	Azusa, Calif.	199	136	162
Sangamon	Decatur, Ill.	349	179	245
San Joaquin	Lathrop, Calif.	186	22	91
Santa Ana	Corona, Calif.	248	165	206
Shenandoah	Millville, W. Va.	137	57	114
Siletz	Siletz, Ore.	33	8	15
Skagit	Sedro Woolley, Wash.	42	18	27
Smoky Hill	Lindsborg, Kans.	510	209	348
Snake	Weiser, Idaho	156	66	123
Solomon	Beloit, Kans.	372	211	296
Spokane	Spokane, Wash.	59	22	43
Spring	Baxter Springs, Kans.	275	114	199
Susquehanna	West Pittston, Pa.	94	33	59
Tennessee	Knoxville, Tenn.	94	55	73
Tombigbee	Epes, Ala.	66	35	52
Umatilla	Umatilla, Ore.	145	25	85
Umpqua	Elkton, Ore.	40	21	29
Ventura	Ventura, Calif.	449	344	388
Verdigris	Coffeyville, Kans.	331	120	223
Vermilion	Streator, Ill.	337	202	257
Wabash	Logansport, Ind.	637	169	348
Wabash, Little	Carmi, Ill.	160	46	87
Wallowa	Joseph, Ore.	46	33	41
Walnut	Winfield, Kans.	389	178	299
Wateree	Camden, S.C.	38	14	23
Wenatchee	Cashmere, Wash.	43	13	23
White, E. Fork	Azalia, Ind.	305	174	247
White, W. Fork	Indianapolis, Ind.	394	190	304
Willamette	Salem, Ore.	28	12	19
Wisconsin	Portage, Wisc.	80	35	63
Youghiogeny	McKeesport, Pa.	200	47	86
Yakima	Prosser, Wash.	150	39	65
Yukon	Anvik, Alaska	151	68	120

wasted by this approximately 1 per cent of hard raw water is so large that it is some two to three times as great as the cost of the chemicals used in softening all of the water. Therefore, when a municipality "softens" a raw water having a hardness of 200, 300, 400, 500 or more ppm down to 85 ppm, it not only furnishes a water that is quite suitable for most household uses, but it also cuts every citizen's soap bill down to a fraction of what it was with the raw water. In the aggregate, these soap savings are so large that in many cities they may be measured in hundreds of thousands of dollars per year.

Therefore, it is obvious that instead of trying to classify water supplies by these exceedingly loose and indefinite terms, it is necessary to study the composition of each water in conjunction with the requirements for its various end uses. It is also necessary to know what variations in composition are to be expected.

In Chapter 1, it was stated that the composition of a river water is subject to fluctuations over a rather wide range. The ranges of hardness, over a one-year period, of the ninety-eight river waters in Table 4 of Chapter 1, are given in Table 21. An inspection of these analyses will show that in some of these rivers, the maximum hardness is a scant third higher than the minimum hardness, while in others the maximum hardness may be as much as 8½ times the minimum hardness. Expressed in another way, the smallest difference between minimum and maximum hardness is 13 ppm (0.8 gpg); the greatest is 683 ppm (40 gpg).

As these analyses were not made daily but were instead made every 10 days on composite samples, there may have been even greater variations than shown. In any event, this table clearly indicates the advisability of collecting as complete analytical data as possible regarding the changes in composition of any river water intended to furnish the water supply for an industrial plant. Temperature measurements are also important, especially if the river water is also to be used for cooling purposes. This last feature is more fully discussed in Chapter 7.

Surface waters from very large lakes, however, are usually quite constant in composition, as shown by the curves in Figure 14, although temperature variations will be encountered. Some small lakes, ponds, and reservoirs may show considerable seasonal variations in composition, but these, owing to the ironing out effect of their volume, are usually much less abrupt in their changes than is the case with river waters. Others show but small ranges in composition.

A ground water supply, especially if drawn from a deep well, usually shows but slight fluctuations in composition. Such well waters, also, are remarkably constant in temperature throughout the year. Many shallow wells likewise show but small ranges in composition, while others vary over a wider range. Well waters, especially shallow ones, may be contaminated by industrial wastes. In one case, two large shallow wells showed slight acidities at times, due to trade wastes dumped in a disposal pit some 600 feet away. In another case, wells near a small stream carrying acid wastes showed an appreciable content of ferrous sulfate, aluminum sulfate, and sulfuric acid, as well as variations in hardness.

Water Softening. The processes whereby the hardness of a water is reduced or removed are known as water softening. The various water-softening processes and the chapters in which they are described are: (1) zeolite (sodium cation-exchange) water-softening process—Chapter 13; (2) hydrogen cation-exchange process—Chapter 14; (3) ion-exchange demineralizing process—Chapter 15; (4) distillation—Chapter 15; (5) cold lime-soda water-softening processes—Chapter 16; and (6) hot lime-soda water-softening process—Chapter 17.

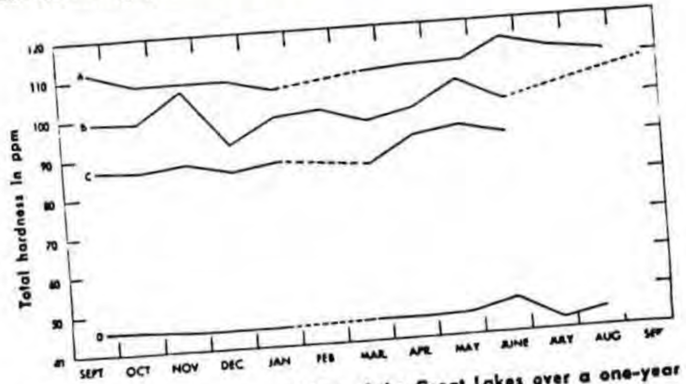


Figure 14. Hardness curves of four of the Great Lakes over a one-year period, showing relatively constant composition.
A—Lake Erie at Buffalo, N. Y.
B—Lake Michigan at St. Ignace, Mich.
C—Lake Huron at Port Huron, Mich.
D—Lake Superior at Sault Ste. Marie, Mich.

Sodium Salts

The sodium salts that may occur in various natural water supplies are the sulfate, chloride, nitrate, bicarbonate, and, rarely, carbonate. As to the quantities present in different fresh water supplies, these vary over a wide range. For instance, in the analyses of the various river, lake, spring, and well waters listed in Chapter 1, the sodium salts range from as little as 2 per cent to as much as 98 per cent of the total salts present, the average figure being 25 per cent.

These sodium salts are extremely soluble in either cold or hot water, as is shown in Table 22 (which also includes the hydroxide). Owing to these high solubilities, the sodium salts do not form scales, either on heating or on evaporating in the steam boiler, unless the evaporation is carried out to undue lengths. Also they do not waste soaps since the soaps that are most widely employed are sodium salts of certain of the

Table 22. Sodium Salts: Solubilities of Sodium Bicarbonate, Carbonate, Chloride, Hydroxide, Nitrate and Sulfate

Name	Formula	Solubility as ppm of $CaCO_3$	
		(at 32°F)	(at 212°F)
Sodium bicarbonate	$NaHCO_3$	38400	decomposes
Sodium carbonate	Na_2CO_3	62600	289000
Sodium chloride	NaCl	225000	241000
Sodium hydroxide	NaOH	370000	975000
Sodium nitrate	$NaNO_3$	248000	378000
Sodium sulfate	Na_2SO_4	33200	298000

higher fatty acids; there is no reaction between the sodium salts in water and soap.

NOTE: Strong solutions of sodium salts will throw soap out of solution, this effect being known as "salting out." The composition of the soap is unaltered by "salting out" and it can be redissolved either in fresh water or by diluting the saline solution.

Therefore, for many industrial uses moderate amounts of sodium salts in the water supply are of little or no importance. They do increase the amount of blowdown on the steam boiler, and if much sodium bicarbonate is present, it may be advisable to remove it or to neutralize most of it with sulfuric acid and then to aerate or degasify the acid-treated water before feeding it to the boiler, in order to reduce the free carbon dioxide content of the steam.

Sodium bicarbonate also has a yellowing effect on clothes laundered in water containing it, owing to the formation of an oxycellulose when the bicarbonate concentrates under the heat of the iron. The effect is very marked when the sodium bicarbonate alkalinity exceeds 200 ppm; is noticeable above 100 ppm but is unobjectionable below 60 ppm, all expressed as $CaCO_3$.

In Table 23 are given the analyses of a number of natural water supplies that are high in sodium alkalinity. Most of these are well waters and many of them have a remarkably low hardness. Similar waters have been obtained under known deposits of glauconite (greensand) and it is quite possible that many of these low hardnesses are due to the softening action of zeolite deposits on pocketed or extremely slowly moving ground water.

Sodium salts are objectionable in the processing or manufacture of certain cellulose products, dielectrics, fine drugs and chemicals, synthetic rubber, plastics, photographic materials, silver-plated ware and many other materials. High sodium alkalinity waters are often objectionable in high-pressure steam boilers, laundries and textile plants. Formerly, distillation was the only process known for removing sodium salts from water. Now sodium bicarbonate may be removed by hydrogen zeolite and the sulfate, chloride, or nitrate by a combination treatment with hydrogen zeolite followed by treatment with an anion exchanger or acid absorbent. The processes for removing sodium salts are described in the following chapters: hydrogen cation-exchange process in Chapter 14, ion-exchange demineralizing process in Chapter 15, and distillation in Chapter 15.

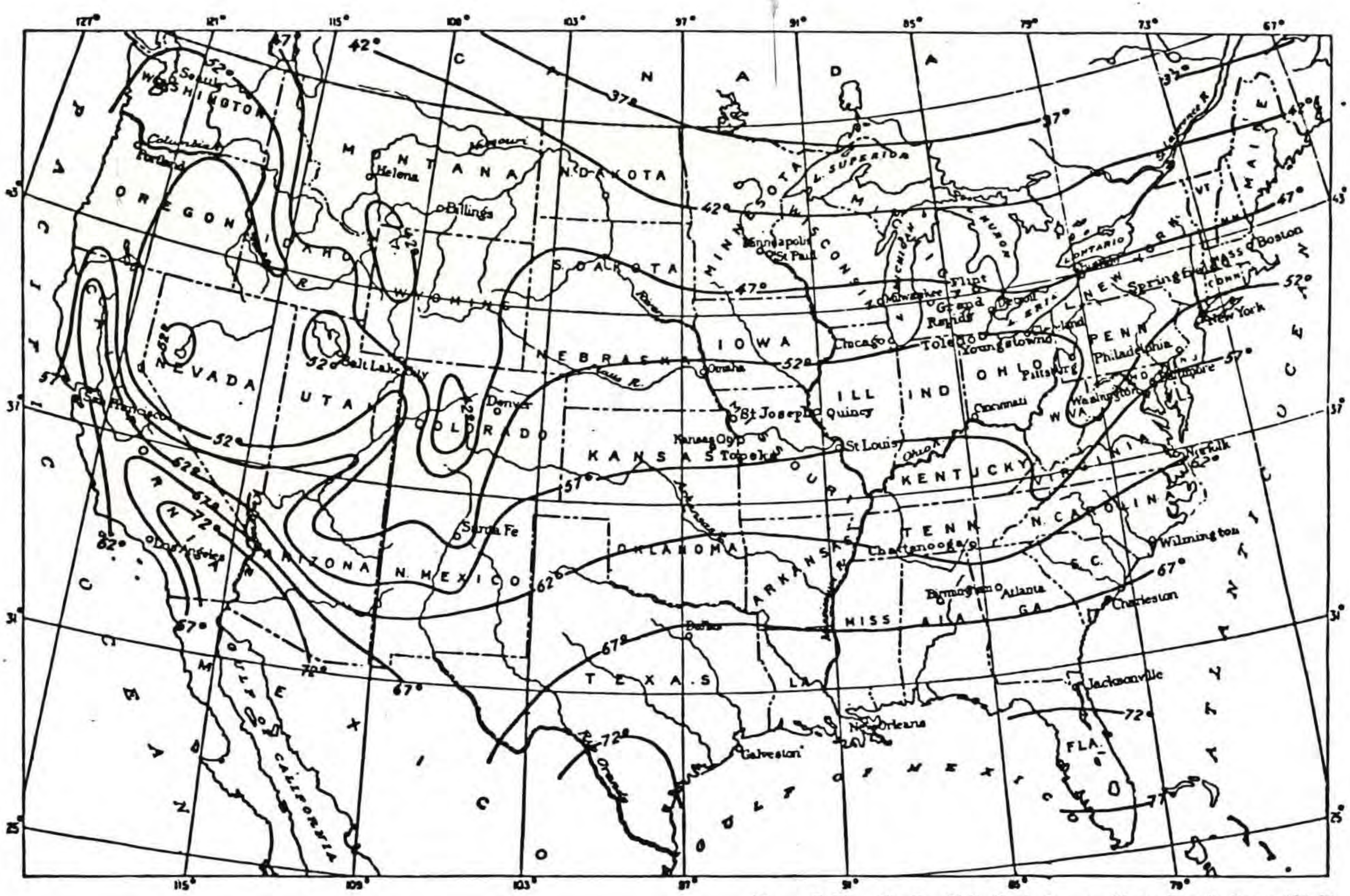
Silica

Silica, in amounts ranging from a fraction of 1 ppm to over 100 ppm, is found in all natural water supplies. In the analyses of rain, hail, and snow, listed in Chapter 1, the silica contents range from 0.1 ppm to 2.8 ppm. In the analyses of various surface and ground waters, listed in the same chapter, the silica contents range from 1 ppm to 107 ppm. Table 24 shows the maximum, minimum, and average silica contents of a group of ninety-eight rivers over a one-year period. It will be noted that these vary over a wide range, the maximum figure ranging from two to forty times the minimum figure.

The above refers to the soluble silica content and not to the silica which may be present in the suspended matter. Suspended matter may be removed from a water supply by coagulation and filtration, but these processes have little effect in reducing the soluble silica content.

Silica is particularly objectionable in modern high-pressure boilers, where it has pronounced scale-forming tendencies. If calcium hardness is present in the boiler salines, the scale formed may be a calcium silicate; if soluble alumina is present, an aluminosilicate scale, such as analcite, may be formed; and under other conditions, the scale may consist almost entirely of silica. These silica scales are usually very hard, glassy, adherent, and difficult to remove. Their thermal conductivities are usually very low and tube failures often occur with even very thin silica scales. Silica is frequently carried over with the steam, forming scale in superheater tubes and on turbine blades. While this action is usually ascribed to mechanical carryover, there is another explanation that has been advanced, namely, that the silica is soluble to a certain extent in high-pressure steam.

In low and moderate pressure steam boilers, silica scale can usually be avoided by maintaining a small excess of phosphate and a ratio of alkalinity to silica of at least 1:1 in the boiler salines. In boilers operated at 600 psi or over, treatment of the make-up water to reduce its silica content is frequently necessary. In fact, many engineers recommend that the silica content of the boiler salines should be below 60 ppm and, in certain cases, even as low as 15 ppm. This is not only to prevent scale in



(From Collins, W. D., U.S. Geol. Survey, Water-Supply Paper 520-F)

Figure 38. Approximate temperature of water from nonthermal wells at depths of 30 to 60 feet.

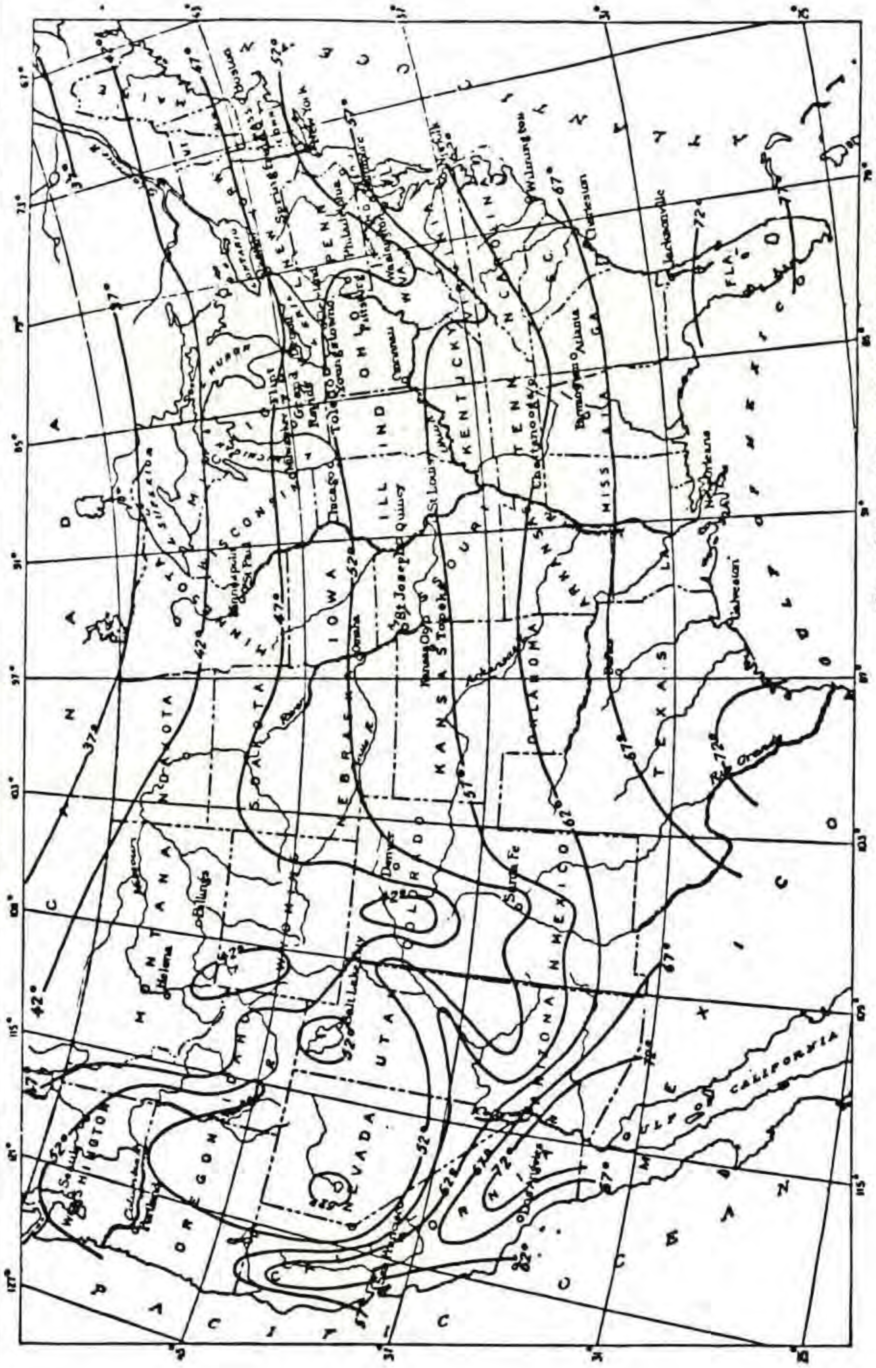


Figure 38. Approximate temperature of water from nonthermal wells at depths of 30 to 60 feet. *(From Collins, W. D., U.S. Geol. Survey, Water-Supply Paper 520-F)*

similar decrease of range with depth in North Dakota. . . . From a study of over 3,000 records of temperature of ground water, C. E. Van Ostrand has computed that under normal conditions the temperature of ground water obtained at a depth of 30 to 60 feet will generally exceed by 2° or 3° the mean annual air temperature. In exceptional localities the excess may amount to 5° or 6°. In southern California it may reach 10°.

"After careful examination of the available data relating to increase of earth temperature with depth, a committee of the British Association for the Advancement of Science adopted as the most probable average rate an increase of 1°F for each 64 feet of depth.[1] On this basis, water from a depth of 640 feet would have a uniform temperature of 10°F above the temperature at 30 or 60 feet. At 200 feet the increase would only be 3°."

Surface Waters. Surface waters are usually subject to large seasonal variations in temperature. In general, with rivers of the United States the difference between winter minimum and summer maximum water temperatures will range from 30 to even as much as 60°F. Winter temperatures of 33 to 36°F are common with river waters over much of the country, and summer temperatures of 75 to 80°F are common and may exceed 85°F. Lakes, ponds, and reservoirs are also subject to seasonal variations in temperature which are particularly wide in range in the shallower waters.

Seawater. At locations where seawater is available, the amounts obtainable are obviously dependent only on the size of intakes, pipe lines, and pumps. Therefore, it is used only once through and then discharged to waste. The annual temperature variations encountered in various locations may cover a range as low as 11° to slightly over 50°F. Location and depth of intake, whether in a bay or fronting the open ocean, currents, etc., will affect the temperature. Minimum winter temperatures may be as low as a couple of degrees Fahrenheit below the freezing point of fresh water and maximum summer temperatures may exceed 80°F.

Scale and Deposits in Cooling Systems

Cooling systems may become clogged with (1) scale, (2) corrosion deposits, (3) sediment, and (4) organic growths.

Scale. The principal scale-forming material in cooling systems is calcium carbonate formed by the decomposition of calcium bicarbonate into calcium carbonate, carbon dioxide, and water, as shown in the following reaction:

$$Ca(HCO_3)_2 \rightleftharpoons CaCO_3 + CO_2 + H_2O$$

In water free from carbon dioxide, calcium carbonate has a very low solubility—about 15 ppm at 32°F and about 13 ppm at 212° or less than

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[1] British Assoc. Adv. Sci. Rept., Fifty-second Meeting, p. 88, 1882.

1 gpg. In water saturated at atmospheric pressure with carbon dioxide at 32°F, 1620 ppm of $CaCO_3$ (94½ gpg) will dissolve, forming calcium bicarbonate. If this water were boiled for a sufficient length of time, the calcium bicarbonate would decompose to calcium carbonate; the carbon dioxide would all be driven off, and since the solubility of calcium carbonate is only 13 ppm at 212°F, the amount of calcium carbonate deposited would be $1620 - 13 = 1607$ ppm (93.7 gpg), which is equivalent to 6.7 tons of scale and sludge per million gallons. Cooling waters, however, are not saturated with carbon dioxide, do not contain 1620 ppm of calcium alkalinity, and are not heated to the boiling point. Very few cooling waters will have calcium alkalinities of more than one-fourth of this maximum figure of 1620 ppm and most cooling waters would have calcium alkalinities under 300 ppm. The amounts of scale that such waters can form in cooling systems are, however, very large and very troublesome even though they never reach, fortunately, more than a fraction of this 6.7 tons per million gallons.

With any specific content of free carbon dioxide there is an equilibrium at each temperature, which establishes the maximum amount of calcium bicarbonate that can be held in solution. Raising this temperature decreases this maximum solubility, the above reaction proceeding toward the right until the equilibrium for the new temperature is reached. From this, it is apparent that with certain waters high in calcium bicarbonate content and low in free carbon dioxide, even a very slight elevation in temperature may be sufficient to form scale.

NOTE: In tropical or semi-tropical climates, scale formation may occur in the cold-water mains. A section of a 4-inch cold-water main, sent to the author from Haiti, was clogged to approximately a 2-inch effective diameter by calcium carbonate scale. In this case, the source of the water was limestone springs in the mountains and the elevation in temperature on flowing through the mains was sufficient to cause this heavy scale formation.

The Langelier index (or calcium carbonate saturation index) is of value in predicting the scale-forming tendencies of a cooling water. In order to calculate the index it is necessary to have (1) the methyl orange alkalinity, (2) the calcium hardness, (3) the total solids (approximately), (4) the pH value and (5) the temperature to which the water will be raised. From these, by using the formulae in Table 70, it is possible to calculate the index and predict the tendencies of a cooling water. These tables were calculated and arranged by the author for field use by nontechnical men and will be found simple, rapid, and accurate enough for all practical purposes. In calculating these, the residue-temperature adjustments of Larson and Buswell were taken into consideration. Figures have been rounded off to tenths, which are more accurate than required for cooling purposes.

TABLE 70. DATA FOR RAPID CALCULATIONS OF THE LANGELIER INDEX (CALCIUM CARBONATE SATURATION INDEX)

[Based on the Langelier formula, Larson-Buswell residue, temperature adjustments; arranged by Nordell]

A

Total Solids (ppm)	*A*
50– 300	0.1
400–1000	0.2

B

Temperature (°F)	*B*
32– 34	2.6
36– 42	2.5
44– 48	2.4
50– 56	2.3
58– 62	2.2
64– 70	2.1
72– 80	2.0
82– 88	1.9
90– 98	1.8
100–110	1.7
112–122	1.6
124–132	1.5
134–146	1.4
148–160	1.3
162–178	1.2

C

Calcium Hardness (ppm of $CaCO_3$)	*C*
10– 11	0.6
12– 13	0.7
14– 17	0.8
18– 22	0.9
23– 27	1.0
28– 34	1.1
35– 43	1.2
44– 55	1.3
56– 69	1.4
70– 87	1.5
88– 110	1.6
111– 138	1.7
139– 174	1.8
175– 220	1.9
230– 270	2.0
280– 340	2.1
350– 430	2.2
440– 550	2.3
560– 690	2.4
700– 870	2.5
880–1000	2.6

D

M. O. Alkalinity (ppm of $CaCO_3$)	*D*
10– 11	1.0
12– 13	1.1
14– 17	1.2
18– 22	1.3
23– 27	1.4
28– 35	1.5
36– 44	1.6
45– 55	1.7
56– 69	1.8
70– 88	1.9
89– 110	2.0
111– 139	2.1
140– 176	2.2
177– 220	2.3
230– 270	2.4
280– 350	2.5
360– 440	2.6
450– 550	2.7
560– 690	2.8
700– 880	2.9
890–1000	3.0

(1) Obtain values of *A*, *B*, *C* and *D* from above table.

(2) $pH_s = (9.3 + A + B) - (C + D)$.

(3) Saturation index = $pH - pH_s$.

If index is 0, water is in chemical balance.

If index is a plus quantity, scale-forming tendencies are indicated.

If index is a minus quantity, corrosive tendencies are indicated.

In using the index, a modicum of common sense and practicality are necessary, for the calculated indices are not quantitative, and since the cooling water runs rather rapidly through a cooling system, there is no assurance that calculated equilibria, even if they could be calculated with hair-splitting accuracy, would be reached. In practice, what is done is to use the index as a basis in calculating the treatment required. Then removable lengths of pipe or metal inserts are placed at strategic points and the results are watched. If scale formation is still too heavy, the treatment is adjusted to give a somewhat lower index. If undue corrosion occurs, the treatment is adjusted to give a somewhat higher index.

NOTE: A further extension of Langelier's work may be found in the *Journal of the American Water Works Association*, 38 (1946) pp. 169–178, "Chemical Equilibria in Water Treatment" and pp. 179–185, "Effect of Temperature on the pH of Natural Waters."

16. COLD LIME-SODA WATER-SOFTENING PROCESSES

THE ART of water softening is only a little over a century old, dating back to 1841 when a Scottish Professor of Chemistry in Aberdeen University, Thomas Clark, was granted a patent on "A New Mode of Rendering Certain Waters (including the Thames) Less Impure and Less Hard, for the Supply and Use of Manufactories, Villages, Towns and Cities." Clark's method was to add lime to the water, thus reducing the bicarbonate hardness by precipitation of the calcium alkalinity as calcium carbonate and the magnesium alkalinity as magnesium hydroxide, the added lime being also precipitated as calcium carbonate.

The precipitates were then settled out by plain subsidence and the settled water was either used without further treatment or filtered before use. Clark's process reduced only the bicarbonate hardness, but later John Henderson Porter used soda ash in addition to lime, thus reducing the noncarbonate as well as the bicarbonate hardness. This method of softening water was formerly known as the Porter-Clark process but is now more commonly known as the cold lime-soda process. Clark also established calcium carbonate (in grains per imperial gallon) as the unit of hardness, defining this as follows: "Each degree of hardness is as much as a grain of chalk, or the lime or the calcium in a grain of chalk, would produce in a gallon of water, by whatever means dissolved."

NOTE: As noted by M. N. Baker in "The Quest for Pure Water" (The American Water Works Association, 1948), a book which the author heartily recommends for its wealth of historical data, it had been known for at least a century before Clark's invention, that alkaline salts would soften water. Baker cites Dr. Peter Shaw (1730), Dr. Francis Home (1756), Dr. John Rutty (1758), Henry Cavendish (1765), Thomas Henry (1781), Edmund Davy (1818), and Abraham Booth (1830) as earlier investigators.

Principles of Operation

In Table 105, the solubilities of the bicarbonates, carbonates, chlorides, hydroxides, and sulfates of calcium, magnesium, and sodium, in terms of their calcium carbonate equivalents and in ppm and gpg at 32 and 212°F, are given. It will be noted that all the sodium compounds are extremely soluble and that the compounds of calcium and magnesium having the lowest solubilities are calcium carbonate and magnesium hydroxide, which explains why, in the lime-soda processes, the calcium is precipitated as the carbonate and the magnesium as the hydroxide.

TABLE 105. SOLUBILITIES OF CALCIUM, MAGNESIUM AND SODIUM BICARBONATES, CARBONATES, CHLORIDES, HYDROXIDES AND SULFATES

Name	Formula	(ppm of $CaCO_3$)		(gpg of $CaCO_3$)	
		at 32°F	at 212° F	at 32° F	at 212° F
Calcium bicarbonate	$Ca(HCO_3)_2$	1620	decomp.	94.5	decomp.
Calcium carbonate	$CaCO_3$	15	13	0.9	0.8
Calcium chloride	$CaCl_2$	336000	554000	19600	32300
Calcium hydroxide	$Ca(OH)_2$	2390	888	139	51.8
Calcium sulfate	$CaSO_4$	1290	1250	75.3	72.9
Magnesium bicarbonate	$Mg(HCO_3)_2$	37100	decomp.	2170	decomp.
Magnesium carbonate	$MgCO_3$	101	75	5.9	4.4
Magnesium chloride	$MgCl_2$	362000	443000	21100	25900
Magnesium hydroxide	$Mg(OH)_2$	17	8	1.0	0.5
Magnesium sulfate	$MgSO_4$	170000	356000	9920	20800
Sodium bicarbonate	$NaHCO_3$	38700	decomp.	2260	decomp.
Sodium carbonate	Na_2CO_3	61400	290000	3580	16900
Sodium chloride	$NaCl$	225000	243000	13100	14200
Sodium hydroxide	$NaOH$	370000	970000	14200	56900
Sodium sulfate	Na_2SO_4	33600	210000	1970	12300

Calcium, Magnesium, and Sodium Alkalinities. Although the salts in such a dilute solution as water do not exist as such but as ions, it is convenient to picture the bicarbonate radical as bound first to the calcium and second to the magnesium, for this is the order in which precipitation occurs when lime is added to water containing these bicarbonates. That is, calcium carbonate, owing to its low solubility, would first be precipitated. Magnesium carbonate, being roughly about six times as soluble, would not precipitate as the carbonate except for the amount exceeding its solubility. But on continued addition of lime, magnesium hydroxide, which has a very low solubility, would be precipitated next. The sodium salts are all extremely soluble.

Therefore, on inspection of a water analysis, the alkalinity is first calculated as being bound to the calcium and is called "calcium alkalinity." If there is any alkalinity left over, it is calculated as being bound to magnesium and is termed "magnesium alkalinity." With a relatively small number of natural waters, an excess of alkalinity may be present above the or "negative Alk. C." is below −10 ppm, the dosage of lime should be increased, and if above zero, it should be decreased.

NOTE: The term "negative Alk. C." or "negative caustic alkalinity" is probably peculiar to the water-softening industry. It is based on the following equation yielding a negative result:

$$(2 \times \text{Pht. Alk.}) - \text{M.O. Alk.} = \text{Alk. C.}$$

For instance, if the effluent has a M.O. Alk. of 30 and a Pht. Alk. of 18, it has 6 ppm of Alk. C. or a positive quantity as:

$$(2 \times 18 \text{ ppm}) - 30 \text{ ppm} = 6 \text{ ppm Alk. C.}$$

However, if the effluent has a M.O. Alk. of 30 and a Pht. Alk. of say 13, it would be said to have 4 ppm of negative Alk. C., according to the following:

$$(2 \times 13 \text{ ppm}) - 30 \text{ ppm} = -4 \text{ ppm Alk. C.}$$

Lime and Gypsum Treatment. If the raw water contains sodium bicarbonate, as is the case with a relatively small proportion of natural waters, the calculation for the lime dosage is carried out in the same way, but it is obvious that $H - A$ would be a negative figure, thus indicating that no soda ash were needed except for the 0.25 lb per 1000 gallons excess. In such cases, $A - H$ will indicate the number of ppm of sodium bicarbonate (expressed at $CaCO_3$) present. In order to obtain this as pounds of Na_2CO_3 present after the lime treatment, the following equation may be used:

$$\frac{A - H}{113} = \text{lb } Na_2CO_3 \text{ per 1000 gallons}$$

If this Na_2CO_3 figure is less than 0.25 lb per 1000 gallons, the deficiency may be made up by adding whatever fraction of a pound per 1000 gallons of soda ash would be required to make the proper excess. If the result obtained is much above this excess of about 0.25 lb per 1000 gallons, this excess may be reduced to the correct amount by adding the requisite amount of gypsum ($CaSO_4 \cdot 2H_2O$), the reaction being as follows:

$$Na_2CO_3 + CaSO_4 \cdot 2H_2O \rightarrow CaCO_3 + Na_2SO_4 + 2H_2O$$

As 1 lb of Na_2CO_3 would require 1.62 lb of gypsum, the correction required, for instance, by a water which on lime treatment would yield 0.45 lb of Na_2CO_3, would be:

$$(0.45 - 0.25) \times 1.62 = 0.32 \text{ lb } CaSO_4 \cdot 2H_2O \text{ per 1000 gallons}$$

Phosphate Treatment. If the hot lime-soda softened water is to have a supplementary treatment with phosphate, as is common practice in treating feed waters for high-pressure boilers, the excess M.O. alkalinity is usually lower than that given above and the caustic alkalinity is usually carried in the range of 0 to +10 ppm. Adjustment of the lime dosage is then made as follows: if the Alk.C. of the filtered effluent is less than 0 ppm, the dosage of lime is increased; whereas if the Alk.C. is more than 10 ppm, the dosage of lime is decreased. The dosage of soda ash is considered to be right if the total hardness (H) is in the range of 10 to 20 ppm. If H is greater than 20 ppm, the dosage of soda ash is increased; if H is less than 10 ppm, the dosage of soda ash is decreased.

As for the phosphate dosage, if the hardness (H) of the filtered phosphate-treated water is zero and the phosphate content is approximately 5 ppm as PO_4, the dosage of phosphate is considered to be within the correct range. If H is not zero or if the PO_4 is less than 5 ppm, the phosphate dosage should be increased; if H is zero and the PO_4 is over 5 ppm, the dosage of phosphate should be decreased. As here used, zero means that the total hardness is 2 ppm or less.

The reactions occurring with hydrated lime and soda ash in the hot lime-soda process and also typical reactions for the phosphates and phosphoric acid with the carbonates are given in Table 120. The phosphate reactions are written without including the water of crystallization. For the composition of the various phosphates, see the note under Table 66 in Chapter 6.

Dolomitic Lime or Magnesia. For the calculations of dolomitic lime or magnesia dosages for silica removal by the hot process, see Chapter 18.

Hot Lime-Soda Water Softeners: Types and Designs

Basically, hot lime-soda water softeners may be divided into two main types: (1) the sludge-blanket type and (2) the conventional type. Both these types are available in a number of designs, depending on the degree of deaeration required, whether condensate as well as make-up should be handled (and if so, what percentage of condensate), whether phosphate treatment is required, and whether silica removal is of importance. The sludge-blanket type is the newest type. It was designed primarily for silica removal, as the upward filtration through the sludge blanket uses the silica-removal properties of magnesia much more efficiently than the conventional type. Also, like the sludge-blanket type of cold lime-soda water softener, it utilizes the lime more efficiently and furnishes a clearer effluent. The sludge-blanket type of hot lime-soda water softener is illustrated and described in Chapter 18.

The various forms or designs in which each of these types are available may be grouped as: (1) for 100 per cent make-up and reduction of dissolved oxygen to less than 0.3 ml/liter; (2) for 100 per cent make-up carbonate have increased the size of the catalyst. Magnesium hydroxide, however, does not form adherent deposits, nor are coagulants of any value in making magnesium deposits adhere. The Spiractor process is therefore largely limited to the removal of calcium.

The detention period in the Spiractor is very much less than in any other type of equipment, as it is only eight to twelve minutes as compared with two to four hours for the conventional type and one hour for the sludge-blanket type. Also, since the by-product is a granular material which drains rapidly to less than 5 per cent of moisture, its disposal is a much simpler matter than that of the usual lime soda sludge, which is a pasty material containing about 90 per cent of water.

In operating the Spiractor, the catalyst bed expands as the granules grow. Since, by the hydraulic grading effected in the equipment, the largest granules are in the bottom, removal of these is effected at periodic intervals by means of a quick-opening type of valve. It is also necessary to add fresh catalyst to the bed from time to time. Roughly, the amount of new catalyst to be added is about 0.043 lb per 1000 gallons per 100 ppm of calcium hardness removed. This figure varies slightly, depending on the amount of free CO_2 present and the amount of lime reacting with magnesium.

Figure 101. Spent spiractor catalyst granule, cut in half to show original particle (center) and surrounding shells of calcium carbonate deposits. Highly magnified.

In European practice, lime dissolvers are frequently used with the Spiractor, whereas in American practice, a lime slurry is fed. The chemical feeders may be either of the wet or the dry type. Filters are usually required with the catalyst type of softening equipment; they may be either of the gravity or pressure type and the filter medium may be sand, anthrafilt, or calcite. In general, the catalyst type of lime-soda water softener is best adapted to the softening of water having a hardness composed mostly of calcium salts and a temperature above 50°F. Or, it is of value as a preliminary step preceding a sludge blanket or a conventional type of softener.

Intermittent or Batch-Process Type. Since this type of cold lime-soda water softener is now so seldom used, a very brief description will suffice.

A plant of this type generally consists of three units, and the operations are so staggered that, while the water and chemicals are being mixed in one unit, the next unit is settling and the effluent from the third unit is being drawn off to service.

The usual procedure in operating each unit was to (1) fill the tank with water, (2) add weighed amounts of chemicals and stir thoroughly with a mechanical type of agitator, (3) allow sludge to settle, (4) draw off effluent, and (5) draw off sludge. Excellent results were obtainable when careful dosage and sufficient agitation time were allowed. This type of equipment has practically gone out of existence because of (1) higher cost of equipment, (2) greater space requirements, and (3) greater labor costs.

Results with the Various Cold Lime-Soda (or Chemical-Precipitation) Processes

In Table 105, the solubilities of calcium carbonate and magnesium hydroxide (in terms of $CaCO_3$ equivalents) in distilled water, free from carbon dioxide, are given. In Figures 102 and 103 the guaranteed removal results for these substances in the cold lime-soda processes are in the form of curves at various alkalinities. It will be noted that the guaran-

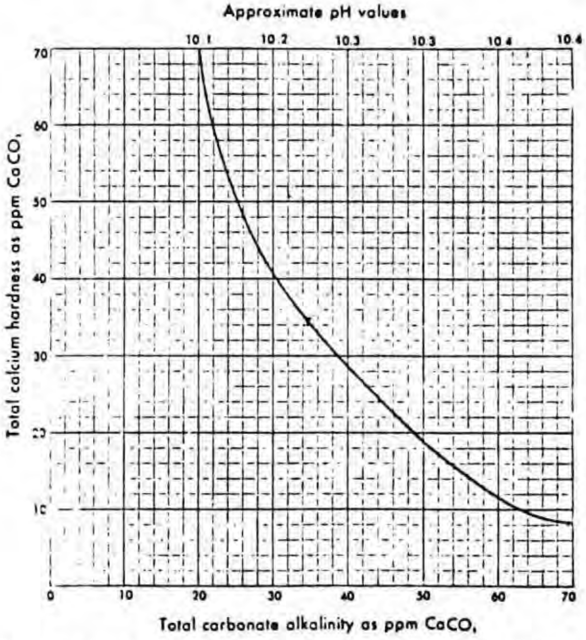

Figure 102. Calcium carbonate residuals. Guaranteed maxima.

usually mounted at floor level to afford the required positive head and prevent flashing on the suction sides of the pumps. The required height of the water level in the settling tank is determined beforehand from the number of feet of head on the suction side of the service pump, specified by the manufacturer, plus some 13 to 15 feet of head to take care of friction losses through the filter bed and piping.

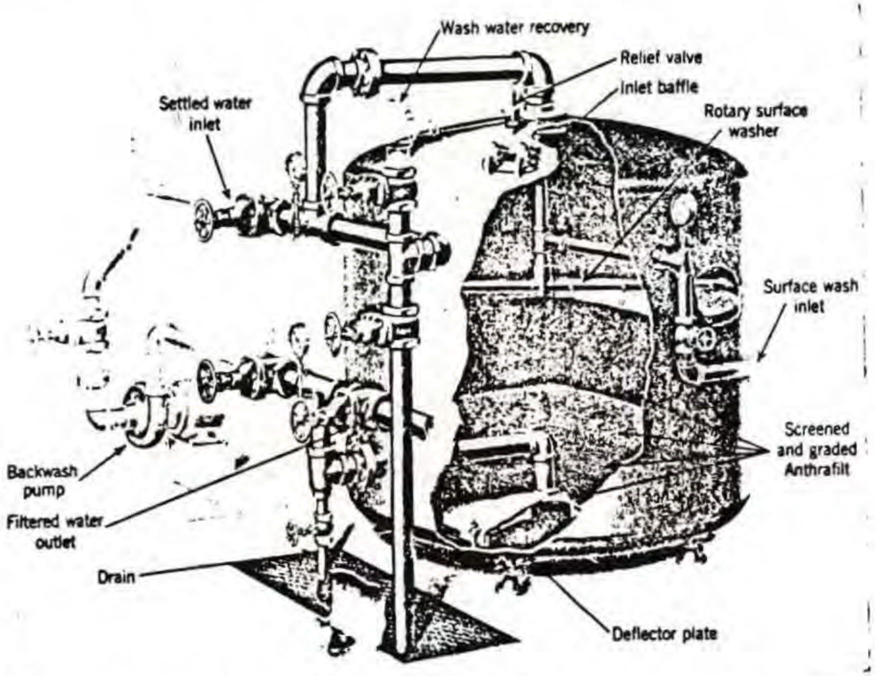

Figure 108. Filter. One unit of a battery, cut away to show interior construction and rotary surface washer.

Chemicals: Reactions and Dosages

Lime and Soda Ash. The principal chemicals used in the hot process are (1) hydrated or chemical lime and (2) soda ash. Hydrated lime of good, average commercial quality will contain approximately 93 per cent of $Ca(OH)_2$. Chemical lime of good, average commercial quality will contain approximately 90 per cent of CaO; it should be slaked before use. Soda ash of good, average commercial quality will contain about 99 per cent of Na_2CO_3 and 98 per cent is usually assumed as its purity in making calculations. In practice, the dosages of chemicals required are usually calculated roughly from the above assumptions of

purity and final adjustments in dosages are made according to measurements of the methyl orange alkalinity (M.O. Alk.) and phenolphthalein alkalinity (Pht. Alk.) of the filtered effluent from the hot-process softener.

The approximate dosages of commercial chemicals are calculated as follows:

When A = alkalinity as ppm $CaCO_3$
Mg = magnesium hardness as ppm $CaCO_3$
H = total hardness as ppm $CaCO_3$

Hydrated Lime (93% $Ca(OH)_2$). The number of pounds per 1000 gallons of water treated $= \dfrac{A + \text{Mg}}{151}$.

(Or, if chemical lime (90% CaO) is used, the number of pounds per 1000 gallons of water treated $= \dfrac{A + \text{Mg}}{193}$.)

Soda Ash (98% Na_2CO_3). The number of pounds per 1000 gallons of water treated $= \dfrac{H - A}{111}$ + required excess (usually 0.25 lb). See Figure 109 for effect of excess soda ash in depressing the hardness.

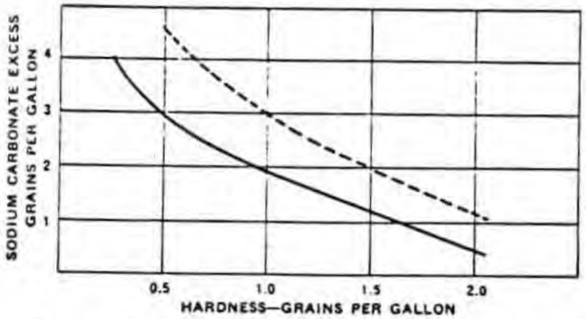

Figure 109. Hot lime-soda effluent hardness curves. Broken line shows guaranteed results. Solid line shows actual operating results.

If the water is not to be treated further with phosphate, the final adjustments of the chemical dosages are made so that the range of methyl orange alkalinity (M.O. Alk.) in the filtered effluent should be from 20 to 30 ppm, expressed as $CaCO_3$, and the caustic alkalinity should range from 0 to −10 ppm, expressed as $CaCO_3$. If the M.O. Alk. is below 20 ppm, the dosage of soda ash should be increased; and if above 30 ppm, it should be decreased. If the so-called "negative caustic alkalinity"

Table 126. Bicarbonates: Anion and Cations Conversion Factors

To Convert	To	Multiply by		To Convert	To	Multiply by
HCO_3	$Ca(HCO_3)_2$	1.33	Bicarbonates	$Ca(HCO_3)_2$	HCO_3	0.753
HCO_3	$Mg(HCO_3)_2$	1.20	*anion*	$Mg(HCO_3)_2$	HCO_3	0.834
HCO_3	$NaHCO_3$	1.38	*and*	$NaHCO_3$	HCO_3	0.726
Ca	$Ca(HCO_3)_2$	4.05	*cations*	$Ca(HCO_3)_2$	Ca	0.247
Mg	$Mg(HCO_3)_2$	6.02		$Mg(HCO_3)_2$	Mg	0.166
Na	$NaHCO_3$	3.65		$NaHCO_3$	Na	0.274

Table 127. Carbonates: Anion and Cations Conversion Factors

To Convert	To	Multiply by		To Convert	To	Multiply by
CO_3	$CaCO_3$	1.67	Carbonates	$CaCO_3$	CO_3	0.600
CO_3	$MgCO_3$	1.41	*anion*	$MgCO_3$	CO_3	0.712
CO_3	Na_2CO_3	1.77	*and*	Na_2CO_3	CO_3	0.566
Ca	$CaCO_3$	2.50	*cations*	$CaCO_3$	Ca	0.400
Mg	$MgCO_3$	3.47		$MgCO_3$	Mg	0.288
Na	Na_2CO_3	2.30		Na_2CO_3	Na	0.434

Table 128. Chlorides: Anion and Cations Conversion Factors

To Convert	To	Multiply by		To Convert	To	Multiply by
Cl	$CaCl_2$	1.57	Chlorides	$CaCl_2$	Cl	0.639
Cl	$MgCl_2$	1.34	*anion*	$MgCl_2$	Cl	0.745
Cl	NaCl	1.65	*and*	NaCl	Cl	0.607
Ca	$CaCl_2$	2.77	*cations*	$CaCl_2$	Ca	0.361
Mg	$MgCl_2$	3.92		$MgCl_2$	Mg	0.255
Na	NaCl	2.54		NaCl	Na	0.393

Table 129. Hydroxides: Anion and Cations Conversion Factors

To Convert	To	Multiply by		To Convert	To	Multiply by
OH	$Ca(OH)_2$	2.18	Hydroxides	$Ca(OH)_2$	OH	0.459
OH	$Mg(OH)_2$	1.72	*anion*	$Mg(OH)_2$	OH	0.583
OH	NaOH	2.35	*and*	NaOH	OH	0.425
Ca	$Ca(OH)_2$	1.85	*cations*	$Ca(OH)_2$	Ca	0.541
Mg	$Mg(OH)_2$	2.40		$Mg(OH)_2$	Mg	0.417
Na	NaOH	1.74		NaOH	Na	0.575

Table 130. Nitrates: Anion and Cations Conversion Factors

To Convert	To	Multiply by		To Convert	To	Multiply by
NO_3	$Ca(NO_3)_2$	1.32	Nitrates	$Ca(NO_3)_2$	NO_3	0.756
NO_3	$Mg(NO_3)_2$	1.19	*anion*	$Mg(NO_3)_2$	NO_3	0.838
NO_3	$NaNO_3$	1.37	*and*	$NaNO_3$	NO_3	0.730
Ca	$Ca(NO_3)_2$	4.10	*cations*	$Ca(NO_3)_2$	Ca	0.244
Mg	$Mg(NO_3)_2$	6.10		$Mg(NO_3)_2$	Mg	0.164
Na	$NaNO_3$	3.70		$NaNO_3$	Na	0.271

Table 131. Sulfates: Anion and Cations Conversion Factors

To Convert	To	Multiply by		To Convert	To	Multiply by
SO_4	$CaSO_4$	1.42	Sulfates	$CaSO_4$	SO_4	0.706
SO_4	$MgSO_4$	1.25	*anion*	$MgSO_4$	SO_4	0.798
SO_4	Na_2SO_4	1.48	*and*	Na_2SO_4	SO_4	0.676
Ca	$CaSO_4$	3.40	*cations*	$CaSO_4$	Ca	0.294
Mg	$MgSO_4$	4.95		$MgSO_4$	Mg	0.202
Na	Na_2SO_4	3.09		Na_2SO_4	Na	0.324

Table 132. Carbon Dioxide-Carbonates Conversion Factors

To Convert CO_2 to	Multiply by	Reactions (to form carbonates)	To Convert to CO_2	Multiply by
$Ca(OH)_2$	1.68	$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$	$Ca(OH)_2$	0.594
CaO	1.28	$CaO + CO_2 \rightarrow CaCO_3$	CaO	0.785
$Mg(OH)_2$	1.33	$Mg(OH)_2 + CO_2 \rightarrow MgCO_3 + H_2O$	$Mg(OH)_2$	0.754
MgO	0.916	$MgO + CO_2 \rightarrow MgCO_3$	MgO	1.09
NaOH	1.82	$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$	NaOH	0.550
Na_2O	1.41	$Na_2O + CO_2 \rightarrow Na_2CO_3$	Na_2O	0.710

Table 133. Carbon Dioxide-Bicarbonates Conversion Factors

To Convert CO_2 to	Multiply by	Reactions (to form Bicarbonates)	To Convert to CO_2	Multiply by
$CaCO_3$	2.27	$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$	$CaCO_3$	0.440
$Ca(OH)_2$	0.842	$Ca(OH)_2 + 2CO_2 \rightarrow Ca(HCO_3)_2$	$Ca(OH)_2$	1.19
CaO	0.637	$CaO + 2CO_2 + H_2O \rightarrow Ca(HCO_3)_2$	CaO	1.57
$MgCO_3$	1.92	$MgCO_3 + CO_2 + H_2O \rightarrow Mg(HCO_3)_2$	$MgCO_3$	0.522
$Mg(OH)_2$	0.663	$Mg(OH)_2 + 2CO_2 \rightarrow Mg(HCO_3)_2$	$Mg(OH)_2$	1.51
MgO	0.458	$MgO + 2CO_2 + H_2O \rightarrow Mg(HCO_3)_2$	MgO	2.18
Na_2CO_3	2.41	$Na_2CO_3 + CO_2 + H_2O \rightarrow 2NaHCO_3$	Na_2CO_3	0.415
NaOH	0.909	$NaOH + CO_2 \rightarrow NaHCO_3$	NaOH	1.10
Na_2O	0.704	$Na_2O + 2CO_2 + H_2O \rightarrow 2NaHCO_3$	Na_2O	1.42

Table 134. Hydrochloric Acid Conversion Factors

To Convert HCl to	Multiply by	Reactions (to form Chlorides)	To Convert to HCl	Multiply by
$CaCO_3$	1.37	$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$	$CaCO_3$	0.729
$Ca(OH)_2$	1.02	$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$	$Ca(OH)_2$	0.985
CaO	0.769	$CaO + 2HCl \rightarrow CaCl_2 + H_2O$	CaO	1.30
$CaCl_2$	1.52		$CaCl_2$	0.657
$MgCO_3$	1.16	$MgCO_3 + 2HCl \rightarrow MgCl_2 + H_2O + CO_2$	$MgCO_3$	0.865
$Mg(OH)_2$	0.799	$Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O$	$Mg(OH)_2$	1.25
MgO	0.552	$MgO + 2HCl \rightarrow MgCl_2 + H_2O$	MgO	1.81
$MgCl_2$	1.31		$MgCl_2$	0.766
Na_2CO_3	1.45	$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$	Na_2CO_3	0.688
NaOH	1.10	$NaOH + HCl \rightarrow NaCl + H_2O$	NaOH	0.912
Na_2O	0.849	$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$	Na_2O	1.18
NaCl	1.60		NaCl	0.624
Cl	0.973		Cl	1.03

BETZ HANDBOOK

OF INDUSTRIAL

WATER CONDITIONING

SIXTH EDITION

1962

Published by

BETZ®

TREVOSE, PENNSYLVANIA 19047

SIXTH EDITION—1962
Seventh Printing—May, 1974
Library of Congress Catalog Card Number: 62-21097

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BETZ LABORATORIES, INC.
TREVOSE, PENNSYLVANIA 19047

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Printed in U. S. A.

Acknowledgment

This book was prepared by the engineering and technical staff of Betz Laboratories, Inc. Many individuals contributed to this edition and previous editions. We particularly wish to thank the following for their editorial contributions to this Sixth Edition.

H. L. Boyer
A. B. Cherry
R. B. Conlan
J. M. Donohue
C. M. Frova
P. J. Gaughan
H. B. Haldeman
R. H. Hayman
J. B. Lord
J. J. Maguire
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C. A. Noll
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L. F. Probst
R. L. Reed
J. H. Richards
C. J. Schafer
J. R. Schieber
B. F. Shema
W. A. Tanzola
J. G. Weidman
G. A. Wilhelm

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when the water is heated to the saturation temperature for the pressure imposed on the system. The remaining 5 to 10% of the initial oxygen content must be removed through molecular diffusion. In ridding the system of this last 5 to 10% of the initial oxygen content, it is obvious that the rapidity of oxygen removal will be a function of the heater design and also of the rapidity with which the surrounding atmosphere is changed and gases vented from the system.

The practical considerations involved in the removal of dissolved oxygen from boiler feed water may be briefly summarized as:

Heating the water to the boiling temperature for the pressure under which the process is conducted (saturation conditions).

Providing a heater design that secures intimate mixing of steam and water.

Continuously venting from the system the mixture of gases and steam.

REMOVAL OF CARBON DIOXIDE AND AMMONIA. Unlike oxygen, carbon dioxide and ammonia do not obey Henry's Law because they unite chemically with water. At elevated temperatures their deviation from Henry's Law decreases due to decreased chemical combination with the solvent. The mechanism of removal of these gases is primarily molecular diffusion rather than mechanical separation.

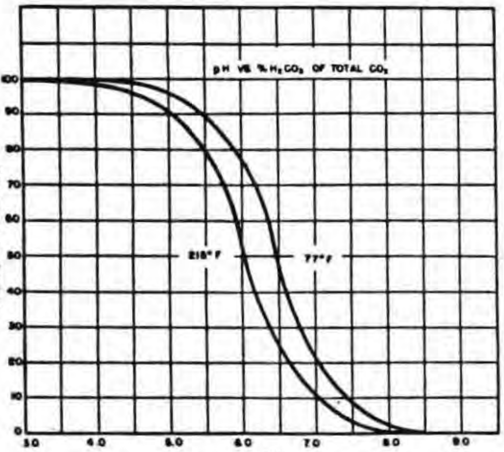

Figure 20-1 • Per Cent CO_2 Available for Removal

When carbon dioxide is dissolved in water it forms a relatively unstable compound, carbonic acid (H_2CO_3). This acid ionizes into the bicarbonate radical (HCO_3^-) and the hydrogen ion (H^+). Further ionization of the bicarbonate radical takes place to form the carbonate radical ($CO_3^=$) and the hydrogen ion (H^+) as illustrated.

$$CO_2 + H_2O \rightleftarrows H_2CO_3$$
carbon dioxide + water ⇄ carbonic acid

$$H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$
carbonic acid ⇄ hydrogen ion + bicarbonate ion

$$HCO_3^- \rightleftarrows CO_3^= + H^+$$
bicarbonate ion ⇄ carbonate ion + hydrogen ion

The hydrogen ion concentration or pH controls the distribution of carbon dioxide among these three forms. It is only in the form of carbonic acid (H_2CO_3) that a gas solution pressure is exerted and that carbon dioxide can be removed by deaeration. Figure 20-1 illustrates the availability of carbon dioxide for removal by deaeration and indicates it is at the more acid pH values that the most efficient removal of carbon dioxide can be obtained.

When ammonia gas is dissolved in water, it forms an unstable compound, ammonium hydroxide (NH_4OH). Ammonium hydroxide ionizes to form the ammonium ion (NH_4^+) and the hydroxyl ion (OH^-) as illustrated.

$$NH_3 + H_2O \rightleftarrows NH_4OH$$
ammonia + water ⇄ ammonium hydroxide

$$NH_4OH \rightleftarrows NH_4^+ + OH^-$$
ammonium hydroxide ⇄ ammonium ion + hydroxyl ion

The hydroxyl ion concentration controls the distribution of ammonia between these two forms. It is only in the form of ammonium hydroxide (NH_4OH) that a gas solution pressure is exerted and that ammonia can be removed by deaeration. Figure 20-2

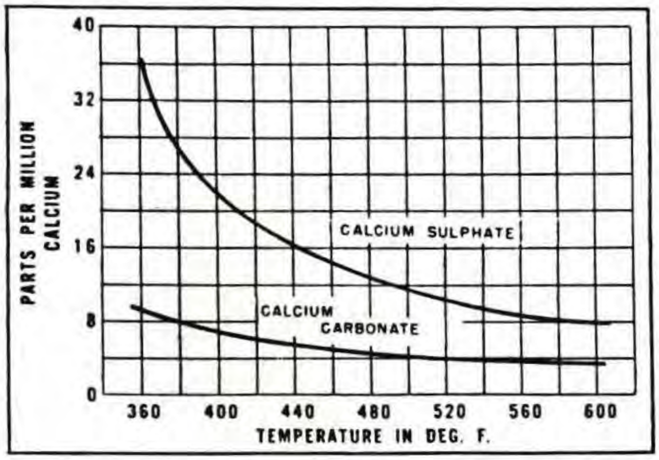

Figure 22-3 • Calcium Solubility for Calcium Sulfate and Calcium Carbonate

necessary to employ certain factors of safety in interpreting these data. For example, the usual boiler water will contain a variety of salts in solution, tending to alter the theoretical solubilities illustrated. Specifically, in the case of calcium sulfate, an increase in the quantity of sodium sulfate present will lower the calcium sulfate solubility.

Because of the high solubility of calcium sulfate as shown in Figure 22-3 it is relatively simple to introduce chemical treatment to the boiler water and, with proper control, to avoid deposition of calcium sulfate scale.

The use of sodium carbonate (soda ash) was one of the first materials employed to prevent calcium sulfate scale formation. As can be seen from Figure 22-3 calcium carbonate is considerably more insoluble than calcium sulfate and accordingly will be preferentially precipitated. However, calcium carbonate in itself can form a hard adherent deposit and is frequently found as a constituent of boiler scale.

Calcium phosphate and calcium silicate are frequently deposited as boiler scale. Calcium silicate may be formed either from the combination of the calcium and silicate ions naturally present in the boiler feedwater or as a result of the misguided use of sodium silicate as internal chemical treatment. Calcium phosphate, on the other hand, is invariably the result of treatment of the boiler water by the use of the various phosphate salts commonly employed for this purpose.

Magnesium salts present in the boiler feedwater are usually more easily prevented from forming scale than are the calcium salts. Normally, the magnesium salts found incorporated in boiler scale are magnesium hydroxide, magnesium silicate or magnesium phosphate. The latter salt, magnesium phosphate, tends to form a very sticky deposit, not very hard in nature, but requiring turbining for its removal.

SILICA

As mentioned previously, calcium silicate deposits may prove quite troublesome in boiler operation. However, another source of concern is the tendency for silica to form scales of a complex nature, which may or may not include calcium and magnesium in their structure. Particularly in combination with aluminum, silica tends to form complex scales which have been identified by X-ray diffraction methods. Formation of such complex deposits usually occurs in boilers operating at the higher pressures and proper treatment of the boiler water requires the maintenance of both silica and aluminum concentrations at a minimum. Under such operating conditions, the prevention of complex silica scales is primarily a problem for external treatment. The maintenance of high phosphate and alkalinity concentrations in the boiler water is an aid in control of the problem, but only limited silica concentrations can be controlled. Blowdown can be used to reduce silica concentrations to tolerable levels.

The concern for silica is not always because silica concentrations are too high. In some cases, silica can be too low. This situation occurs primarily with waters that contain high magnesium concentrations and low silica values. In these special cases, magnesium will tend to precipitate as magnesium phosphate which produces a sticky sludge. Precipitation in this form is aggravated when the feedwater enters the boiler in a region of low alkalinity and poor circulation. Under these conditions, increasing the silica content presented by oil contamination of the boiler water. While certain methods of internal treatment may slightly aggravate or slightly minimize the problem caused by oil, there is no method of internal treatment which can be relied upon to cope with any appreciable oil contamination. Since the extent of the difficulties caused by oil are more or less unpredictable, external removal of oil from the boiler feedwater is the only safe policy.

IDENTIFICATION OF SCALE DEPOSITS

In addition to the microscope and gravimetric chemical analyses, a useful tool in identifying boiler scale deposits is the X-ray diffraction method. Any material possessing a crystalline structure will yield a distinctive X-ray pattern which will always be the same and which can be compared with the pattern of standard materials on file. It is thus possible to identify complex chemical compounds and their individual crystalline structure whereas only the hypothetical structure could be obtained from the usual chemical analysis.

Fig. 22-4
Crystalline Scale Constituents, Identified by X-ray Diffraction

NAME	FORMULA
Acmite	$Na_2O.Fe_2O_3.4SiO_2$
Analcite	$Na_2O.Al_2O_3.4SiO_2.2H_2O$
Anhydrite	$CaSO_4$
Aragonite	$CaCO_3$
Brucite	$Mg(OH)_2$
Calcite	$CaCO_3$
Cancrinite	$4Na_2O.CaO.4Al_2O_3.2CO_2.9SiO_2.3H_2O$
Hematite	Fe_2O_3
Hydroxyapatite	$Ca_{10}(OH)_2(PO_4)_6$
Magnetite	Fe_3O_4
Noselite	$4Na_2O.3Al_2O_3.6SiO_2.SO_4$
Pectolite	$Na_2O.4CaO.6SiO_2.H_2O$
Quartz	SiO_2
Serpentine	$3MgO.2SiO_2.2H_2O$
Thenardite	Na_2SO_4
Wollastonite	$CaSiO_3$
Xonotlite	$5CaO.5SiO_2.H_2O$

Figure 22-5 • Analysis of Boiler Deposits by X-ray Fluorescence

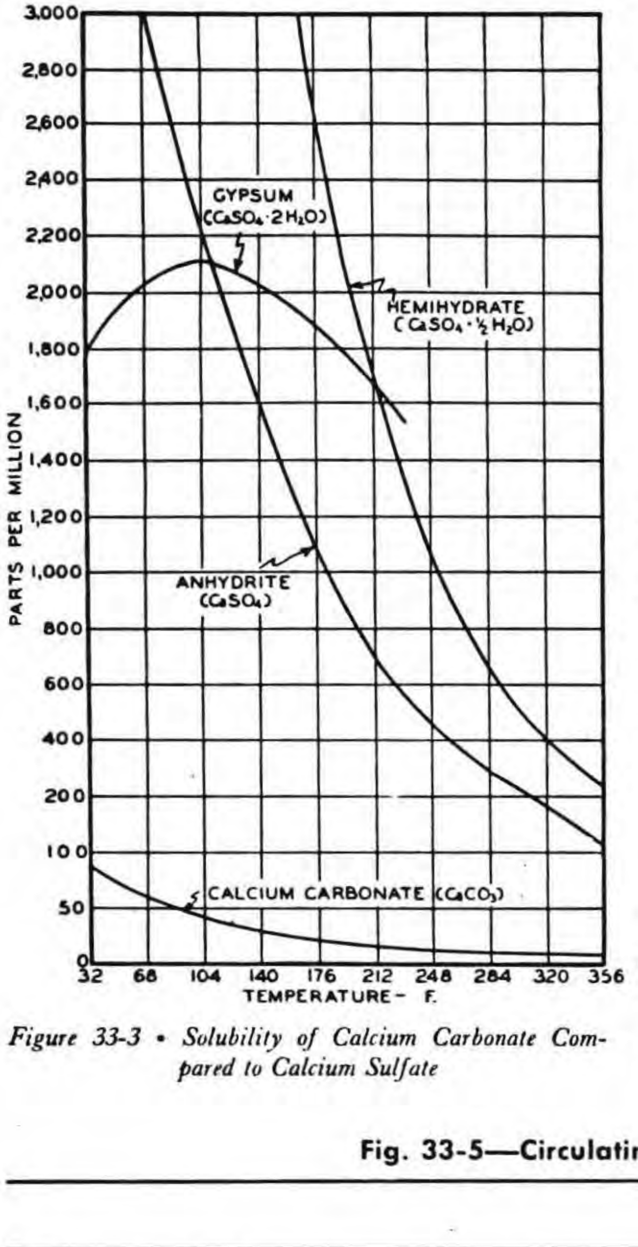

Figure 33-3 • Solubility of Calcium Carbonate Compared to Calcium Sulfate

Figure 33-4—Typical Analysis of Scales From Open Recirculating Systems

Source	Condenser, %	Pipe Cooler, %
Calcium as CaO	49.79	39.85
Magnesium as MgO	2.42	2.20
Iron as Fe_2O_3	0.61	6.98
Aluminum as Al_2O_3	0.21	0.52
Carbonate as CO_2	39.00	30.20
Sulfate as SO_3	1.29	0.50
Silica as SiO_2	0.15	3.85
Loss on Ignition	6.05	15.00

At 2.0 cycles of concentration, the pHs is 7.3, equivalent to the circulating water pH. Stability Index of 7.3 also indicates a non scaling condition. At two cycles of concentration, calcium carbonate scale would not be expected.

At 3.0 cycles of concentration, a positive Saturation Index of 1.5 is obtained and a Stability Index of 5.3. These values indicate an appreciable tendency toward calcium carbonate scale formation. It would not be safe to exceed 2.0 cycles of concentration with this water, without employing some form of treatment. With organic and inorganic surface active agents, it would be possible to maintain 3.0 cycles of concentration without calcium carbonate scale formation, but this concentration could not be tolerated without such treatment.

Fig. 33-5—Circulating Water Analyses

	Makeup	Circulating Water at 2.0 Cycles	Circulating Water at 3.0 Cycles
Total Hardness as $CaCO_3$	60	120	180
Calcium as $CaCO_3$	50	100	150
Magnesium as $CaCO_3$	10	20	30
P Alkalinity as $CaCO_3$	0	0	10
M Alkalinity as $CaCO_3$	50	100	150
Sulfate as SO_4	40	80	120
Chloride as Cl	10	20	30
Silica as SiO_2	5	10	15
		Above values expressed in ppm	
pH	7.0	7.3	8.3
pHs (140F)	7.8	7.3	6.8
Saturation Index	—0.8	0.0	+1.5
Stability Index	8.6	7.3	5.3
Interpretation	Non scale forming	Non scale forming	Scale forming

CRC Handbook of Chemistry and Physics

69TH Edition

1988—1989

* ANNIVERSARY EDITION *
75
YEARS
1913 • 1988

Editor-in-Chief

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CRC
CRC Press, Inc.
Boca Raton, Florida

PHYSICAL CONSTANTS OF INORGANIC COMPOUNDS (continued)

	Name	Synonyms and Formulae	Mol. wt.	Crystalline form, properties and index of refraction	Density or spec. gravity	Melting point, °C	Boiling point, °C	Solubility, in grams per 100 cc		
								Cold water	Hot water	Other solvents
c55	sulfate	$CdSO_4$	208.47	wh, rhomb	4.691_4^{20}	1000		75.5^0	60.8^{100}	i al, acet, NH_3
c56	sulfate, hydrate	$CdSO_4{\cdot}H_2O$	226.48	monocl	3.79^{20}	tr 108		s	s	i al
c57	sulfate, hydrate	$CdSO_4{\cdot}7H_2O$	334.57	col, monocl	2.48	tr 4		s		i al
c58	sulfate hydrate	$3CdSO_4{\cdot}8H_2O$	769.53	col, monocl, 1.565	3.09	tr 41.5		113^0	s	
c59	sulfide	Nat. greenockite, CdS	144.47	yel-or hex, 2.506, 2.529	4.82	1750^{100atm}	subl in N_2, 980	0.00013^{18}	colloid	s a; v sl s NH_4OH
c60	sulfite	$CdSO_3$	192.47	cr		d		sl s		i al; s a, NH_4OH
c61	tartrate	$CdC_4H_4O_4$	260.48	wh cr powd				sl s		s a, NH_4OH
c62	telluride	CdTe	240.01	blk, cub	5.850^{15}	1121	1091	i		i a; d HNO_3
c63	tungstate	$CdWO_4$	360.26	yel cr				0.05		s NH_4OH
	Cadmium complexes									
c64	tetramminecadmium *per*rhenate	$[Cd)NH_3)_4](ReO_4)_2$	680.94		3.714_4^{25}					0.037 conc NH_4OH
c65	tetrapyridine cadmiumfluosilicate	$[Cd(C_5H_5N)_4]SiF_6$	570.89	wh, tricl	2.282					
c66	**Calcium**	Ca	40.08	silv wh soft met, cub	1.54	839 ± 2	1484	d to H_2 + $Ca(OH)_2$	d	s a, liq NH_3; sl s al; i bz
c67	acetate	$Ca(C_2H_3O_2)_2$	158.17	col cr; 1.55, 1.56, 1.57		d		37.4^0	29.7^{100}	sl s al
c68	acetate, dihydrate	$Ca(C_2H_3O_2)_2{\cdot}2H_2O$	194.20	col need		$-1H_2O$, 84		34.7^{20}	33.5^{50}	
c69	acetate, monohydrate	$Ca(C_2H_3O_2)_2{\cdot}H_2O$	176.18	col need		d		43.6^0	34.3^{100}	sl s al
c70	aluminate	$CaAl_2O_4$ (or $CaO{\cdot}Al_2O_2$)	158.04	wh monocl, tricl or rhomb; 1.643, 1.665, 1.663	2.981^{25}	1600		d		s HCl; i HNO_3, H_2SO_4
c71	(tri-)aluminate	$Ca_3Al_2O_6$ (or $3CaO{\cdot}Al_2O_2$)	270.20	wh, cub, 1.710	3.038^{25}	d 1535		i		
c72	(tri-)aluminate hexahydrate	$3CaO{\cdot}Al_2O_3{\cdot}6H_2O$	378.29	col, oct, 1.603	2.52^{20}	d 700—800		d		
c73	aluminosilicate	$2CaO{\cdot}Al_2O_3{\cdot}SiO_3$	274.20	col, tetr, 1.669, 1.658	3.048	1590 ± 2				d a
c74	aluminosilicate	Nat. anorthite, $CaAl_3{\cdot}Si_2O_6$ (or $CaO{\cdot}Al_2O_3{\cdot}2SiO_2$)	278.21	wh, tricl, 1.5832	2.765	1551				
c75	*ortho*arsenate	$Ca_3(AsO_4)_2$	398.08	col amorph powd	3.620	1.455		0.013^{25}		
c76	arsenate, trihydrate	Nat. haidingerite, $2CaO{\cdot}As_2O_5{\cdot}3H_2O$	396.04	col, rhomb, 1.590, 1.602, 1.638	2.967					
c77	arsenide	Ca_3As_2	270.08	red cr	3.031^{25}	d		d	d	d a; s h HNO_3
c78	azide	$Ca(N_3)^2$	124.12	col, rhomb, hyg		$-3H_2O$, 110; exp 144-156		38.1^0	45^{15}	d a; s h HNO_3 0.211^{16} al; i eth
c79	benzoate	$Ca(C_7H_5O_2)_2{\cdot}3H_2O$	336.36	col, rhomb	1.436	$-3H_2O$, 110		2.7^0	8.3^{80}	
c80	*meta*borate	$Ca(BO_2)_2$	125.70	cil, flat rhomb pr, 1.550, 1.660, 1.680		1154		sl s		s a, NH_4 salts; sl s ac a
c81	*meta*borate, hexahydrate	$Ca(BO_2)_3{\cdot}6H_2O$	233.79	col, tetr, 1.520, 1.502	1.88			0.25^{20}		
c82	*tetra*borate	CaB_4O_7	195.32	readily vitrified		986				
c83	boride	CaB_6	104.94	blk, cub	2.3^{30}	2235		i	i	s HNO_3; sl s conc H_2SO_4
c84	bromide	$CaBr_2$	199.89	col, rhomb need, deliq	3.353^{25}	sl d 730	806—812	142^{30}	312^{106}	s al, acet, a; sl a NH_3, MeOH
c85	bromate	$Ca(BrO_3)_2{\cdot}H_2O$	313.90	monocl cr	3.329	$-H_2O$, 180		v s	v s	
c86	bromide, hexahydrate	$CaBr_2{\cdot}6H_2O$	307.98	col, hex cr	2.295	38.2	149	594^0	1360^{25}	s al, acet a
c87	butyrate	$Ca(C_4H_7O_2)_2{\cdot}3H_2O$	268.32	col cr				s	sl s	
c88	carbide	CaC_2	64.10	col, tetr, 1.75	2.22	stab 25—447	2300	d	d	
c89	carbonate	Nat. aragonite, $CaCO_3$	100.09	col, rhomb, 1.530, 1.681, 1.685	2.930	tr to calcite 520	d 825	0.00153^{25}	0.00190^{75}	s a, NH_4Cl
c90	carbonate	Nat. calcite, $CaCO_3$	100.09	col, rhomb or hex, 1.6583, 1.4864	2.710^{18}	1339^{1025}	d 898.6	0.0014^{25}	0.0018^{75}	s a, NH_4Cl
c91	carbonate, hexahydrate	$CaCO_3{\cdot}6H_2O$	208.16	col, monocl, 1.460, 1.535, 1.545	1.771^0					
c92	chlorate	$Ca(ClO_3)_2$	206.98	wh cr, hyg		340 ± 10 (− some O)		s	s	s al, acet
c93	chlorate, dihydrate	$Ca(ClO_3)_2{\cdot}2H_2O$	243.01	wh-yelsh, rhomb, or monoc, deliq	2.711	$-H_2O$, 100		177.8^8	v s	s al, acet
c94	*per*chlorate	$(CaClO_4)_2$	238.98	col cr	2.651	d 270		188.6^{25}	v s	166.2^{25}_{26} al; 237.4 MeOH
c95	chloride	$CaCl_2$	110.99	col, cub, deliq 1.52	2.15_4^{25}	782	>1600	74.5^{20}	159^{100}	s al, acet, ace a
c96	chloride aluminate	$3CaO{\cdot}Al_2O_3{\cdot}CaCl_2{\cdot}10H_2O$	561.34	col, monocl or hex, hex, 1.550, 1.535	1.892^{14}	$-H_2O$, 105	$-8H_2O$, 350	sl s	d	s a
c97	chloride, dihydrate	$CaCl_2{\cdot}2H_2O$	147.02	col cr	0.835			97.7^0	326^{60}	50^{80} al
c98	chloride, hexahydrate	$CaCl_2{\cdot}6H_2O$	219.08	col, trig, deliq, 1.417, 1.393	1.71^{25}	26.92	$-4H_2O$, 30, $-6H_2O$, 200	279^0	536^{20}	s al
c99	chloride, monohydrate	$CaCl_2{\cdot}H_2O$	129.00	col cr, deliq		260		76.8^0	249^{100}	s al; i acet
c100	chloride fluoride *ortho*phosphate	$3Ca_3(PO_4)_2{\cdot}CaClF$	1025.08	col cr, 1.634, 1.631	3.14	1270		v sl s		
c101	chlorite	$Ca(ClO_2)_2$	174.98	wh, cub	2.71			d	d	i al
c102	*hypo*chlorite	$Ca(ClO)_2$	142.98	wh powd or flat pl, 1.545, 1.69	2.35	d 100		s		i al

CORROSION BASICS

An Introduction

National Association of Corrosion Engineers

Published by

National Association of Corrosion Engineers
1440 South Creek Drive
Houston, Texas 77084

Library of Congress Catalog Card Number: 84-061042
ISBN 0-915567-02-4

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This chapter offers a general overview of corrosion and the reasons for studying it. A glossary of corrosion-related terms is included.

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Chapter 3 — Metallurgy 49

This chapter discusses the effects of metal structure, alloying elements, mechanical working, and heat treatment on corrosion behavior.

Chapter 4 — Materials 69

The properties of a wide variety of materials (alloys and nonmetals) are compared with regard to corrosion resistance and mechanical properties.

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Chapter 6 — Environmental Cracking 111

The factors involved is stress corrosion, hydrogen embrittlement, and liquid metal embrittlement are defined, and the metals susceptible to attack in specific environments are enumerated.

Chapter 7 — Inhibitors 127

Anodic, cathodic, and filming inhibitors are discussed along with oxygen scavengers as means of reducing corrosion in aqueous and nonaqueous systems. Mechanisms of inhibition and examples of many practical applications are cited.

Chapter 8 — Corrosion by Water and Steam 149

Factors affecting corrosion of various materials in fresh water, soft water, boiling H_2O reactors, and superheated steam are discussed in this chapter. Several kinds of corrosion are discussed, as well as action of inhibitors and bacteria.

Chapter 9 — Cathodic Protection 179

An easy-to-understand chapter on the present-day factors in practical cathodic protection practices and important design features.

Chapter 10 — Underground Corrosion 203

Certain electrochemical aspects of corrosion are described here, together with an excellent description of how underground corrosion is controlled in various types of soil environments using various techniques.

Chapter 11 — Atmospheric Corrosion 221

This chapter summarizes metal behavior in air atmospheres throughout the world and especially in the more corrosive areas where heavy industry and salt spray may be present. Preventive measures are discussed briefly.

Chapter 12 — Coatings 245

The testing, selection, application, and use of organic and inorganic coatings for use in the atmosphere or as linings are described with emphasis on surface preparation and the function of the coating material.

Chapter 13 — High-Temperature Corrosion 275

This chapter covers the broad field of high-temperature corrosion, including air, flue gases, molten salts and metals, vacuum, etc. It also gives some attention to mechanical properties at high temperatures.

Chapter 14 — Testing and Inspection 309

The many methods of testing for corrosion and measuring corrosion rates are described and evaluated. Necessary precautions and parameters to watch for in evaluating test results are given.

Chapter 15 — Design and Failure Analysis 337

Some common sense design features for industrial process equipment are presented with a discussion of problems that occur when these precautions are ignored. A brief description of practical ways of combatting various types of corrosion is also presented. Economic considerations are emphasized.

INTRODUCTION

This book was originally issued as the *Basic Corrosion Course* in 1970. The utility of that publication can be appreciated when it is realized that 13 printings were necessary to supply the great number of persons interested in the subject.

As envisioned by the Editor in the Introduction of the original book, some revision is necessary with the passage of time. This has been accomplished with a minimum of change from the initial format and material content of the original. The authors of the first edition provided such an excellent coverage of the subject matter that only some rearrangement of the text and updating has been necessary.

Those responsible for the topical matter of the first edition were as follows:

Editor	A. deS. Brasunas
Scope of the Subject	A. deS. Brasunas and N. E. Hamner
Basics	F. L. LaQue and N. D. Greene
Metallurgy	R. F. Hochman
Materials	M. G. Fontana and J. H. Peacock
Localized Corrosion	H. P. Godard
Stress Corrosion Cracking	H. L. Logan
Cathodic Protection and Soils	A. W. Peabody and M. E. Parker
Inhibitors	N. Hackerman and E. S. Snavely
Atmospheric Corrosion	K. G. Compton
Coatings	N. E. Hamner
High Temperature Corrosion	A. deS. Brasunas and J. J. Moran, Jr.
Water Corrosion	W. E. Berry
Testing	B. W. Lifka and F. L. McGeary
Failure Analysis	E. D. Verink

A great amount of the material written by these authors has been retained. Changes have been made where it was believed a better continuity, less repetition, and more recent data would improve the development of the subject. Those responsible for the revisions are C. P. Dillon, J. S. Snodgrass, L. S. Van Delinder, and H. A. Webster.

This book provides a general coverage of the wide field of corrosion control. It is designed to be helpful to those being initiated into the work, and consequently attempts to present each corrosion process or control procedure in the most basic terms. A comprehensive discussion of the topics has not been attempted. Certainly the book is not represented as providing the latest or most erudite discussion of the subject. Yet for those knowledgeable in the field of corrosion control, we hope that each chapter presents some aspect of the work in terms that are stimulating and helpful. We solicit suggestions for improvement of the work.

To assist the reader, a bibliography is provided at the end of each chapter for those who may want to pursue a topic further. Many of the books which are listed in more than one chapter are obviously regarded as prime sources for corrosion information. The appendix to Chapter 1 contains a list of definitions of corrosion-related terms. A comprehensive and thoroughly cross referenced subject index is located in the back of the book and should provide a ready guide for all persons wishing to find specific items.

Education in corrosion control is our primary concern. We sincerely hope this new edition will contribute even more capably in attaining that goal. As with the preponderance of the first edition, a portion of the Introduction must be repeated: "We trust that ... this book will be of considerable benefit to the nation, to numerous industries, and to individuals all over the world who will take advantage of the opportunity afforded them by this educational effort."

L. S. Van Delinder
Editor and Chairman of Subcommittee ETC-1
NACE Education and Training Committee
May, 1984

centuate pitting at pores, cracks, or other voids in the film. If the film attains any significant thickness, the loss of heat transfer through the metal and deposited scale can be a problem in certain applications. Thus, the development of scales on metal surfaces is an important consideration when using metals in waters.

The factors that affect scaling (*i.e.*, the deposition of primarily calcareous deposits) are the total dissolved solids, calcium ion concentration, methyl orange alkalinity (bicarbonates and carbonates), and temperature. Calcium and magnesium carbonates have an inverse solubility with temperature, therefore they tend to deposit scale with rising temperature. In extreme cases, scaling by insoluble calcium sulfate also can be a problem, although it is not a prevalent one under most conditions.

The tendency of a water to deposit such scale, or of the temperature required to initiate such deposition to exist, can be estimated from the Langelier-Ryznar Index, as shown in Table 8.2. From the relationship between the controlling factors, one can estimate the pH_S (*i.e.*, the pH which the water in question would acquire if saturated with calcium carbonate). This can then be used to calculate either the Corrosion Index (which indicates the corrosivity to ordinary cement or concrete), the Saturation Index, *or* (by substituting the measured pH for the pH_S) the temperature at which deposition will be initiated (Table 8.3).

TABLE 8.3 — Calculation of Scaling Temperature

Conditions:

pH = 7.5
TDS = 300 ppm
Ca = 45 ppm
M.O.Alk. = 120 ppm

A = 0.1
C = 1.3
D = 2.1

$$\begin{aligned} B &= pH - 9.3 - A + C + D \\ &= 7.5 - 9.3 - 0.1 + 1.3 + 2.1 \\ &= 10.9 - 9.4 \\ &= 1.5 \\ &= 1.5 \quad 132\ F \text{ or } 55\ C \end{aligned}$$

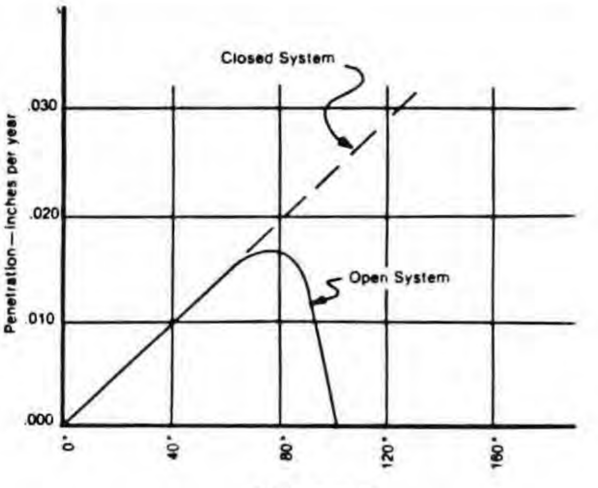

FIGURE 8.2 — Effect of oxygen on corrosion of steel.

The effect of oxygen on corrosion with increasing temperature is also shown in Figure 8.2, indicating the results in a closed versus an open container (the latter permitting natural deaeration by ebullition). In a closed vessel, corrosion continues to increase with temperature, whence the requirement for removing dissolved oxygen from ~~hot water~~ systems and boilers.

TABLE 8.2 — Scaling by Water

Corrosion Index = $pH - pH_s$ Where 0 indicates balanced conditions,
+ indicates scale formation
− indicates scale dissolution or corrosion

Stability Index = $2\,pH_s - pH$ Where values greater than 7.5 indicate increasing corrosivity

$pH_s = (9.3 + A + B) - (C + D)$

Total Solids	A	Ca as $CaCO_3$	C	M.O.Alk.	D
50-330	0.1	10-11	0.6	10-11	1.0
400-1000	0.2	12-13	0.7	12-13	1.1
		14-17	0.8	14-17	1.2
Temp. °F	**B**	18-22	0.9	18-22	1.3
		23-27	1.0	23-27	1.4
32-34	2.6	28-34	1.1	28-35	1.5
36-42	2.5	35-43	1.2	36-44	1.6
44-48	2.4	44-45	1.3	45-55	1.7
50-56	2.3	56-69	1.4	56-69	1.8
58-62	2.2	70-87	1.5	70-88	1.9
64-70	2.1	88-110	1.6	89-110	2.0
72-80	2.0	111-138	1.7	111-139	2.1
82-88	1.9	139-174	1.8	140-176	2.2
90-98	1.8	175-220	1.9	177-220	2.3
100-110	1.7	230-270	2.0	230-270	2.4
112-122	1.6	280-340	2.1	280-340	2.5
124-132	1.5	350-430	2.2	360-440	2.6
134-146	1.4	440-450	2.3	450-550	2.7
148-160	1.3	560-690	2.4	560-590	2.8
162-178	1.2	700-870	2.5	700-880	2.9
178-194	1.1	880-1000	2.6	890-1000	3.0
194-210					

NOTE: Use actual pH of water when calculating "B," the temperature at which the water will cause scale

The effect of oxygen and pH is shown in Figure 8.3. In a broad range of about pH 5 to 9, the corrosion rate can be expressed simply in terms of the amount of dissolved oxygen present (*e.g.*, μm/y

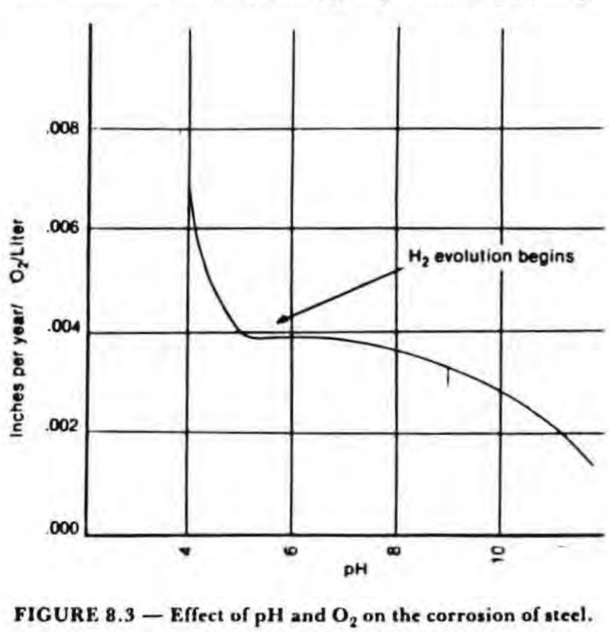

FIGURE 8.3 — Effect of pH and O_2 on the corrosion of steel.

DATA BOOK

for practicing engineers
and those who work with
Water, Wastewater Treatment,
Pollution Control and Water Reclamation.

Sixteenth Printing

Compiled by

THE PERMUTIT COMPANY, INC.
a subsidiary of Zurn Industries, Inc.
30 Technology Drive, Warren, NJ 07059
Telephone: 908/668-1700, FAX: 908/668-1393

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Printed in U.S.A.
24781-7.5M-10/91

INTRODUCTION

The basic inventions, processes and patents introduced by The Permutit Company are the foundations of a great part of all modern water and wastewater treatment technology. These include:

- The Cation Exchange Water Softening Process
- Sea Water Regeneration of Ion Exchangers
- Continuous Automatic Water Softening
- Fluoride Removal
- Ion Exchange for Isotope Separation (Uranium Refining)
- Water Clarification by Solids Contact Separation
- Anion Exchange Resins
- Silica Removal Process
- Three Step Demineralizing
- Water Softening by Catalytic Precipitation
- The Automatic Valveless Gravity Filter
- Double Dish Underdrain Systems
- Triad Bed Ion Exchange
- Chevron Shaped High Rate Tube Settlers
- Progressive Mode Continuous Ion Exchange
- Calex Condensate Treatment Process
- Sulfex Heavy Metals Removal Process

This innovative posture is an integral part of Permutit's philosophy today.

The Permutit Company was incorporated in 1913. In the eight decades since 1913, Permutit, consistent with its origins in research and innovative growth, has pioneered in virtually every aspect of water and wastewater treatment. The Company is expert in clarification, filtration, aeration, deaeration, degasification, dewatering, separation and reverse osmosis as well as all phases of ion exchange. Permutit also offers unique experience in providing integrated controls for all of the process equipment it builds. Its current integrated facilities/headquarters are in Warren, New Jersey.

Advice from Permutit experts on water treatment and waste treatment problems is available to you and your consultants. Analyses of water samples will be made by arrangement with the Permutit Technical Department. Subsequently, equipment, standard or custom design, may be specified to meet your specific requirements.

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SECTION 15. SOLUBILITY OF GASES IN WATER AT 760 MM

a, the absorption coefficient, is the volume of gas when reduced to 0° and 760 mm., absorbed by one volume of water when the pressure of the gas itself, without the aqueous tension, amounts to 760 mm.

q is the weight of gas in grams dissolved in 100 grams of water when the total pressure (i.e., the sum of the partial pressure of the gas plus the aqueous tension at the given temperature) is 760 mm.

Temp.° C	*Nitrogen**		*Oxygen*		*Hydrogen*		*Carbon Dioxide*	
	a	*q*	*a*	*q*	*a*	*q*	*a*	*q*
0	0.02354	0.002942	0.04889	0.006945	0.02148	0.0001922	1.713	0.3346
1	0.02297	0.002869	0.04758	0.006756	0.02126	0.0001901	1.646	0.3213
2	0.02241	0.002798	0.04633	0.006574	0.02105	0.0001881	1.584	0.3091
3	0.02187	0.002730	0.04512	0.006400	0.02084	0.0001862	1.527	0.2978
4	0.02135	0.002663	0.04397	0.006232	0.02064	0.0001843	1.473	0.2871
5	0.02086	0.002600	0.04287	0.006072	0.02044	0.0001824	1.424	0.2774
6	0.02037	0.002537	0.04180	0.005918	0.02025	0.0001806	1.377	0.2681
7	0.01990	0.002477	0.04080	0.005773	0.02007	0.0001789	1.331	0.2589
8	0.01945	0.002419	0.03983	0.005632	0.01989	0.0001772	1.282	0.2492
9	0.01902	0.002365	0.03891	0.005498	0.01972	0.0001756	1.237	0.2403
10	0.01861	0.002312	0.03802	0.005368	0.01955	0.0001740	1.194	0.2318
11	0.01823	0.002263	0.03718	0.005246	0.01940	0.0001725	1.154	0.2239
12	0.01786	0.002216	0.03637	0.005128	0.01925	0.0001710	1.117	0.2165
13	0.01750	0.002170	0.03559	0.005014	0.01911	0.0001696	1.083	0.2098
14	0.01717	0.002126	0.03486	0.004906	0.01897	0.0001682	1.050	0.2032
15	0.01685	0.002085	0.03415	0.004802	0.01883	0.0001668	1.019	0.1970
16	0.01654	0.002045	0.03348	0.004703	0.01869	0.0001654	0.985	0.1903
17	0.01625	0.002006	0.03283	0.004606	0.01856	0.0001641	0.956	0.1845
18	0.01597	0.001970	0.03220	0.004514	0.01844	0.0001628	0.928	0.1789
19	0.01570	0.001935	0.03161	0.004426	0.01831	0.0001616	0.902	0.1737
20	0.01545	0.001901	0.03102	0.004339	0.01819	0.0001603	0.878	0.1688
21	0.01522	0.001869	0.03044	0.004252	0.01805	0.0001588	0.854	0.1640
22	0.01498	0.001838	0.02988	0.004169	0.01792	0.0001575	0.829	0.1590
23	0.01475	0.001809	0.02934	0.004087	0.01779	0.0001561	0.804	0.1540
24	0.01454	0.001780	0.02881	0.004007	0.01766	0.0001548	0.781	0.1493
25	0.01434	0.001751	0.02831	0.003931	0.01754	0.0001535	0.759	0.1449
26	0.01413	0.001724	0.02783	0.003857	0.01742	0.0001522	0.738	0.1406
27	0.01394	0.001698	0.02736	0.003787	0.01731	0.0001509	0.718	0.1366
28	0.01376	0.001672	0.02691	0.003718	0.01720	0.0001496	0.699	0.1327
29	0.01358	0.011647	0.02649	0.003651	0.01709	0.0001484	0.682	0.1292
30	0.01342	0.001624	0.02608	0.003588	0.01699	0.0001474	0.665	0.1257
35	0.01256	0.001501	0.02440	0.003315	0.01666	0.0001425	0.592	0.1105
40	0.01184	0.001391	0.02306	0.003082	0.01644	0.0001384	0.530	0.0973
45	0.01130	0.001300	0.02187	0.002858	0.01624	0.0001341	0.479	0.0860
50	0.01088	0.001216	0.02090	0.002657	0.01608	0.0001287	0.436	0.0761
60	0.01023	0.001052	0.01946	0.002274	0.01600	0.0001178	0.359	0.0576
70	0.00977	0.000851	0.01833	0.001856	0.0160	0.000102		
80	0.00958	0.000660	0.01761	0.001381	0.0160	0.000079		
90	0.0095	0.00038	0.0172	0.00079	0.0160	0.000046		
100	0.0095	0.00000	0.0170	0.00000	0.0160	0.000000		

* Atmospheric Nitrogen 98.815% Vol. N_2 + 1.185% Vol. A

SECTION 75. STABILITY INDEXES

CaCO, SATURATION INDEX (LANGELIER INDEX)

(Based on the Langelier Formula: Larson—Buswell: Residue—Temperature Adjustments: Arranged by Nordell)

1. pH. − (9.30 + A + B) — (C + D)
(NOTE. Values of A, B, C & D are obtained from tables A, B, C & D)
2. Saturation Index = pH — pH.

If index is O, water is in chemical balance.

If index is a plus quantity, scale forming tendencies are indicated.

If index is a minus quantity, corrosive tendencies are indicated.

Example: To find the saturation index at 124° F. of water which has the following characteristics: Total solids—400 ppm; calcium hardness as $CaCO_3$—240 ppm; alkalinity as $CaCO_3$—196 ppm; and pH of 7.2. Then:

Total solids .... 400 ppm = 0.16 (from table A)
Temperature ...... 124° F. = 1.53 (from table B)
Calcium hardness
as $CaCO_3$ .... 240 ppm = 1.98 (from lower table C)
Alkalinity
as $CaCO_3$ .... 196 ppm = 2.29 (from upper table D)

Substituting: pH. = (9.30 + 0.16 + 1.53) — (1.98 + 2.29) = 6.72 (or 6.7)
Saturation Index = 7.2 — 6.7 = +0.5

A

Total Solids in ppm

Ppm Total Solids	
50	.07
75	.08
100	.10
150	.11
200	.13
300	.14
400	.16
600	.18
800	.19
1000	.20
2000	.23
3000	.25
4000	.26
5000	.27
6000	.28

B

Temperatures in degrees Fahrenheit

	UNITS				
TENS	0	2	4	6	8
30		2.60	2.57	2.54	2.51
40	2.48	2.45	2.43	2.40	2.37
50	2.34	2.31	2.28	2.25	2.22
60	2.20	2.17	2.14	2.11	2.09
70	2.06	2.04	2.03	2.00	1.97
80	1.95	1.92	1.90	1.88	1.86
90	1.84	1.82	1.80	1.78	1.76
100	1.74	1.72	1.71	1.69	1.67
110	1.65	1.64	1.62	1.60	1.58
120	1.57	1.55	1.53	1.51	1.50
130	1.48	1.46	1.44	1.43	1.41
140	1.40	1.38	1.37	1.35	1.34
150	1.32	1.31	1.29	1.28	1.27
160	1.26	1.24	1.23	1.22	1.21
170	1.19	1.18	1.17	1.16	

C

Calcium hardness expressed as ppm $CaCO_3$
(For 3 to 209 ppm $CaCO_3$, use upper table)
(For 210 to 990 ppm $CaCO_3$, use lower table)

	UNITS									
TENS	0	1	2	3	4	5	6	7	8	9
0				0.08	0.20	0.30	0.38	0.45	0.51	0.56
10	0.60	0.64	0.68	0.72	0.75	0.78	0.81	0.83	0.86	0.88
20	0.90	0.92	0.94	0.96	0.98	1.00	1.02	1.03	1.05	1.06
30	1.08	1.09	1.11	1.12	1.13	1.15	1.16	1.17	1.18	1.19
40	1.20	1.21	1.23	1.24	1.25	1.26	1.26	1.27	1.28	1.29
50	1.30	1.31	1.32	1.33	1.34	1.34	1.35	1.36	1.37	1.37
60	1.38	1.39	1.39	1.40	1.41	1.42	1.42	1.43	1.43	1.44
70	1.45	1.45	1.46	1.47	1.47	1.48	1.48	1.49	1.49	1.50
80	1.51	1.51	1.52	1.52	1.53	1.53	1.54	1.54	1.55	1.55
90	1.56	1.56	1.57	1.57	1.58	1.58	1.58	1.59	1.59	1.60
100	1.60	1.61	1.61	1.61	1.62	1.62	1.63	1.63	1.64	1.64
110	1.64	1.65	1.65	1.66	1.66	1.66	1.67	1.67	1.67	1.68
120	1.68	1.68	1.69	1.69	1.70	1.70	1.70	1.71	1.71	1.71
130	1.72	1.72	1.72	1.72	1.73	1.73	1.74	1.74	1.74	1.75
140	1.75	1.75	1.75	1.76	1.76	1.76	1.77	1.77	1.77	1.78
150	1.78	1.78	1.78	1.79	1.79	1.79	1.80	1.80	1.80	1.80
160	1.81	1.81	1.81	1.81	1.82	1.82	1.82	1.82	1.83	1.83
170	1.83	1.84	1.84	1.84	1.84	1.85	1.85	1.85	1.85	1.85
180	1.86	1.86	1.86	1.86	1.87	1.87	1.87	1.87	1.88	1.88
190	1.88	1.88	1.89	1.89	1.89	1.89	1.89	1.90	1.90	1.90
200	1.90	1.91	1.91	1.91	1.91	1.91	1.92	1.92	1.92	1.92

	TENS									
HUNDREDS	0	10	20	30	40	50	60	70	80	90
200		1.92	1.94	1.96	1.98	2.00	2.02	2.03	2.05	2.06
300	2.08	2.09	2.11	2.12	2.13	2.15	2.16	2.17	2.18	2.19
400	2.20	2.21	2.23	2.24	2.25	2.26	2.26	2.27	2.28	2.29
500	2.30	2.31	2.32	2.33	2.34	2.34	2.35	2.36	2.37	2.37
600	2.38	2.39	2.39	2.40	2.41	2.42	2.42	2.43	2.43	2.44
700	2.45	2.45	2.46	2.47	2.47	2.48	2.48	2.49	2.49	2.50
800	2.51	2.51	2.52	2.52	2.53	2.53	2.54	2.54	2.55	2.55
900	2.55	2.56	2.57	2.57	2.58	2.58	2.58	2.59	2.59	2.60

D

Alkalinity expressed as ppm $CaCO_3$
(For 1 to 209 ppm $CaCO_3$, use upper table)
(For 210 to 990 ppm $CaCO_3$, use lower table)

	UNITS									
TENS	0	1	2	3	4	5	6	7	8	9
0		0.00	0.30	0.48	0.60	0.70	0.78	0.85	0.90	0.95
10	1.00	1.04	1.08	1.11	1.15	1.18	1.20	1.23	1.26	1.29
20	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.43	1.45	1.46
30	1.48	1.49	1.51	1.52	1.53	1.54	1.56	1.57	1.58	1.59
40	1.60	1.61	1.62	1.63	1.64	1.65	1.66	1.67	1.68	1.69
50	1.70	1.71	1.72	1.72	1.73	1.74	1.75	1.76	1.76	1.77
60	1.78	1.79	1.79	1.80	1.81	1.81	1.82	1.83	1.83	1.84
70	1.85	1.85	1.86	1.86	1.87	1.88	1.88	1.89	1.89	1.90
80	1.90	1.91	1.91	1.92	1.92	1.93	1.93	1.94	1.94	1.95
90	1.95	1.96	1.96	1.97	1.97	1.98	1.98	1.99	1.99	2.00
100	2.00	2.00	2.01	2.01	2.02	2.02	2.03	2.03	2.03	2.04
110	2.04	2.05	2.05	2.05	2.06	2.06	2.06	2.07	2.07	2.08
120	2.08	2.08	2.09	2.09	2.09	2.10	2.10	2.10	2.11	2.11
130	2.11	2.12	2.12	2.12	2.13	2.13	2.13	2.14	2.14	2.14
140	2.15	2.15	2.15	2.16	2.16	2.16	2.16	2.17	2.17	2.17
150	2.18	2.18	2.18	2.18	2.19	2.19	2.19	2.20	2.20	2.20
160	2.20	2.21	2.21	2.21	2.21	2.22	2.22	2.23	2.23	2.23
170	2.23	2.23	2.23	2.24	2.24	2.24	2.24	2.25	2.25	2.25
180	2.26	2.26	2.26	2.26	2.26	2.27	2.27	2.27	2.27	2.28
190	2.28	2.28	2.28	2.29	2.29	2.29	2.29	2.29	2.30	2.30
200	2.30	2.30	2.30	2.31	2.31	2.31	2.31	2.32	2.32	2.32

	TENS									
HUNDREDS	0	10	20	30	40	50	60	70	80	90
200		2.32	2.34	2.36	2.38	2.40	2.42	2.43	2.45	2.46
300	2.48	2.49	2.51	2.52	2.53	2.54	2.56	2.57	2.58	2.59
400	2.60	2.61	2.62	2.63	2.64	2.65	2.66	2.67	2.68	2.69
500	2.70	2.71	2.72	2.72	2.73	2.74	2.75	2.76	2.76	2.77
600	2.78	2.79	2.79	2.80	2.81	2.81	2.82	2.83	2.83	2.84
700	2.85	2.85	2.86	2.86	2.87	2.88	2.88	2.89	2.89	2.90
800	2.90	2.91	2.91	2.92	2.92	2.93	2.93	2.94	2.94	2.95
900	2.95	2.96	2.96	2.97	2.97	2.98	2.98	2.99	2.99	3.00

RYZNAR STABILITY INDEX

The Ryznar Index is a method of quantifying the scale forming or corrosive effect of water. It is based upon the pH of the water and the water's pH of saturation. The pH of saturation, "pHs", is that pH at which a water cannot hold additional calcium in solution. The Ryznar Index equation is: RI = 2 pHs − pH. Ryznar Index values above 6 are progressively corrosive; values below 6 are progressively scale forming.

APPENDIX B

12.2 ANALYTIKEM LABORATORY REPORT

Supplemental, December 29, 1992

Original, December 4, 1992

AnalytiKEM *An American NuKEM Company*

AnalytiKEM Inc.
28 Springdale Road
Cherry Hill, NJ 08003
609/751-1122
1-800-TRY-LAB1
Fax: 609/751-0824

TEST REPORT NO. A28958, Supplemental

December 29, 1992

Prepared for:

Norlite Corporation
628 South Saratoga Street
Cohoes, NY 12047

Attention: Richard Slaugh

Project: Salt Kill Creek

Reviewed & Approved by: for

Name: Carmine M. Fioriglio

Title: QA/QC Manager

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I. Certification

AnalytiKEM, Inc.
Current Certifications/Regulatory Approvals

Tabulated below are the current laboratory certifications that are held by each AnalytiKEM Laboratory. Analyses performed at multiple AnalytiKEM locations will be noted in the test report.

Cherry Hill, NJ		Rock Hill, SC		Houston Analytical, TX	
State	Cert #	State	Cert #	State	Cert #
Arkansas	*	S. Carolina	46067	N. Dakota	R-006
Connecticut	PH-0715	N. Carolina	316	Oklahoma	8403
Florida	880985G	New Jersey	79795	Texas Water Commission	*
Massachusetts	NJ117			Louisiana	92-07
New Jersey	04012			S. Carolina	82011
New York	10815			N. Carolina	367
N. Carolina	258			Wisconsin	998010530
N. Dakota	R-038			New Jersey	82869
Pennsylvania	68366				
S. Carolina	94004				
Tennessee	02908				
Vermont	*				
Oklahoma	9107				

* No certification numbers are issued for these states.

II. Definition of Terms

Term	Definition
D	Detected; result must be greater than zero.
DI	Deionized Water
J	Compound was detected at levels below the practical quantitation limit. The level reported is approximate.
MS/MSD	Matrix Spike/Matrix Spike Duplicate.
NA	Analysis not applicable to the sample matrix.
ND	Not Detected
NR	Not Requested
NTU	Nephelometric Turbidity Units
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
U	Compound was analyzed for but not detected. The preceding number is the practical quantitation limit for the compound.
ppb	Parts-per-billion; may be converted to ppm by dividing by 1,000.
ppm	Parts-per-million; may be converted to ppb by multiplying by 1,000.
ug/l	Micrograms of constituent per liter of sample; equivalent to parts-per-billion.
ug/kg	Micrograms of constituent per kilogram of sample; equivalent to parts-per-billion.
ug/kg dw	Micrograms of constituent per kilogram of sample reported on a dry weight basis.
CCC	Calibration Check Compound; used to verify the precision of a GC/MS calibration curve.
SPCC	System Performance Check Compound; used to verify the correct operation of a GC/MS instrument.
PQL	Practical Quantitation Limit; the minimum level at which compounds can be dependably quantitated.
B	Analyte detected in associated blank as well as the sample. It indicates possible/probable blank contamination.

III. Sample Designations

AnalytiKEM Designation	Client Designation	Matrix	Date Sampled
A28958-1	A1	Aqueous	11/13/92
A28958-2	A2	Aqueous	11/13/92

Note: Samples will be held for 30 days beyond the test report date unless otherwise requested.

IV. Methodology

General Chemistry

Method 160.1, Total Dissolved Solids (Dried at 180 degrees C), Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, USEPA, 1979.

V. Analytical Results

General Chemistry

	Sample Designation		
Parameter	Method Blank	A28958-1 A1	A28958-2 A2
Total Dissolved Solids	10,000 U	11,000,000	16,000,000
Units	(ug/l)	(ug/l)	(ug/l)

AnalytiKEM *An American NuKEM Company*

AnalytiKEM Inc.
28 Springdale Road
Cherry Hill, NJ 08003
609/751-1122
1-800-TRY-LAB1
Fax: 609/751-0824

TEST REPORT NO. A28958

December 4, 1992

Prepared for:

Norlite Corporation
628 South Saratoga Street
Cohoes, NY 12047

Attention: **Richard Schlauch**

Project: **Salt Kill Creek**

Reviewed &
Approved by: Michael Shmookler, Ph.D. for

Name: **Carmine M. Fioriglio**

Title: **QA/QC Manager**

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I. Certification

AnalytiKEM, Inc.
Current Certifications/Regulatory Approvals

Tabulated below are the current laboratory certifications that are held by each AnalytiKEM Laboratory. Analyses performed at multiple AnalytiKEM locations will be noted in the test report.

Cherry Hill, NJ		Rock Hill, SC		Houston Analytical, TX	
State	Cert #	State	Cert #	State	Cert #
Arkansas	*	S. Carolina	46067	N. Dakota	R-006
Connecticut	PH-0715	N. Carolina	316	Oklahoma	8403
Florida	880985G	New Jersey	79795	Texas Water Commission	*
Massachusetts	NJ117			Louisiana	92-07
New Jersey	04012			S. Carolina	82011
New York	10815			N. Carolina	367
N. Carolina	258			Wisconsin	998010530
N. Dakota	R-038			New Jersey	82869
Pennsylvania	68366				
S. Carolina	94004				
Tennessee	02908				
Vermont	*				
Oklahoma	9107				

* No certification numbers are issued for these states.

II. Definition of Terms

Term	Definition
D	Detected; result must be greater than zero.
DI	Deionized Water
J	Compound was detected at levels below the practical quantitation limit. The level reported is approximate.
MS/MSD	Matrix Spike/Matrix Spike Duplicate.
NA	Analysis not applicable to the sample matrix.
ND	Not Detected
NR	Not Requested
NTU	Nephelometric Turbidity Units
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
U	Compound was analyzed for but not detected. The preceding number is the practical quantitation limit for the compound.
ppb	Parts-per-billion; may be converted to ppm by dividing by 1,000.
ppm	Parts-per-million; may be converted to ppb by multiplying by 1,000.
ug/l	Micrograms of constituent per liter of sample; equivalent to parts-per-billion.
ug/kg	Micrograms of constituent per kilogram of sample; equivalent to parts-per-billion.
ug/kg dw	Micrograms of constituent per kilogram of sample reported on a dry weight basis.
CCC	Calibration Check Compound; used to verify the precision of a GC/MS calibration curve.
SPCC	System Performance Check Compound; used to verify the correct operation of a GC/MS instrument.
PQL	Practical Quantitation Limit; the minimum level at which compounds can be dependably quantitated.
B	Analyte detected in associated blank as well as the sample. It indicates possible/probable blank contamination.

III. Sample Designations

AnalytiKEM Designation	**Client Designation**	**Matrix**	**Date Sampled**
A28958-1	A1	Aqueous	11/13/92
A28958-2	A2	Aqueous	11/13/92
A28958-3	B2	Aqueous	11/13/92
A28958-4	D1	Aqueous	11/13/92
A28958-5	D2	Aqueous	11/13/92
A28958-6	B1	Aqueous	11/13/92

Note: Samples will be held for 30 days beyond the test report date unless otherwise requested.

IV. Methodology

Metals

Method 3010, Acid Digestion of Aqueous Samples and Extracts for Total Metals for Analysis by Flame Atomic Absorption Spectroscopy or Inductively Coupled Plasma Spectroscopy, Test Methods for Evaluating Solid Waste. Physical/Chemical Methods, SW846, Third Edition, USEPA, 1986, with all promulgated revisions.

Method 6010, Inductively Coupled Plasma Atomic Emission Spectroscopy, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW846, Third Edition, USEPA, 1986, with all promulgated revisions.

General Chemistry

Method 130.2, Hardness, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, USEPA, January 1982.

Method 9040, pH Electrometric Measurement, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW846, Third Edition, USEPA, 1986, with all promulgated revisions.

Method 160.1, Total Dissolved Solids (Dried at 180 degrees C), Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, USEPA, 1979.

Method 160.2, Total Suspended Solids (Dried at 103-105 degrees C), Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, USEPA, 1979.

Method 310.1, Alkalinity (Titrimetric, pH4.5), Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, USEPA, 1979.

Method 9038, Sulfate (Turbidimetric), Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW846, Third Edition, USEPA, 1986, with all promulgated revisions.

V. Analytical Results

Metals

Sample Designation

Parameter	Method Blank	A28958-1 A1	A28958-1 (Duplicate) A1	A28958-2 A2	A28958-3 B2
Aluminum, total	200 U	6,600	6,600	2,600	730
Calcium, total	5,000 U	90,000	90,000	44,000	67,000
Iron, total	100 U	14,000	14,000	4,800	1,100
Magnesium, total	5,000 U	10,000	10,000	6,600	16,000
Manganese, total	15 U	370	360	110	46
Units	(ug/l)	(ug/l)	(ug/l)	(ug/l)	(ug/l)

Sample Designation

Parameter	Method Blank	A28958-4 D1	A28958-5 D2	A28958-6 B1
Aluminum, total	200 U	880	1,100	720
Calcium, total	5,000 U	40,000	47,000	77,000
Iron, total	100 U	1,500	1,600	1,300
Magnesium, total	5,000 U	14,000	15,000	20,000
Manganese, total	15 U	52	61	44
Units	(ug/l)	(ug/l)	(ug/l)	(ug/l)

V. Analytical Results (Cont'd)

General Chemistry

Sample Designation

Parameter	Method Blank	A28958-1 A1	A28958-2 A2	A28958-3 B2
pH, units	--	9.4	9.4	7.7
Total Suspended Solids	10,000 U	630,000; 630,000 *	730,000	10,000 U
Total Dissolved Solids	10,000 U	1,500,000; 1,500,000 *	17,000,000	450,000
Hardness, as $CaCO_3$	--	200,000	160,000	250,000
Sulfate	--	3,300,000	4,700,000	63,000
Alkalinity, Bicarbonate	--	3,300,000; 3,400,000 *	4,000,000	170,000
Alkalinity, Carbonate	--	410,000; 460,000 *	560,000	1,200
Alkalinity, Hydroxide	--	1,000 U; 1,000 U*	1,000 U	1,000 U
Units	(ug/1)	(ug/1)	(ug/1)	(ug/1)

Sample Designation

Parameter	Method Blank	A28958-4 D1	A28958-5 D2	A28958-6 B1
pH, units	--	8.5	8.8	8.5
Total Suspended Solids	10,000 U	10,000 U	77,000	19,000
Total Dissolved Solids	10,000 U	2,500,000	2,500,000	470,000
Hardness, as $CaCO_3$	--	180,000	190,000	240,000
Sulfate	--	700,000	740,000	71,000
Alkalinity, Bicarbonate	--	480,000	1,100,000	170,000
Alkalinity, Carbonate	--	13,000	25,000	2,000
Alkalinity, Hydroxide	--	1,000 U	1,000 U	1,000 U
Units	(ug/l)	(ug/l)	(ug/l)	(ug/l)

* Duplicate analysis.

VI. Quality Control Data

Metals

Aqueous Matrix Spike/Matrix Spike Duplicate Recovery Data

Sample Spiked A28958-1

Parameter	Amount of Spike	Recovery MS	Recovery MSD	RPD	Control Limits Recovery	Control Limits Max. RPD
Aluminum	500	88	98	11	56-115	23
Calcium	300	*	*	--	11-148	37
Calcium ϕ	300	100	--	--	11-148	37
Iron	300	80	94	16	69-112	10
Iron ϕ	300	96	--	--	69-112	10
Magnesium	300	85	92	8	68-112	10
Manganese	20	85	89	5	82-105	10
Units	(ug)	(%)	(%)	(%)	(%)	(%)

* Not recovered due to high amount of analyte detected in the sample.

Recovery: 0 out of 10 outside control limits

RPD: 1 out of 4 outside control limits

VI. Quality Control Data (Cont'd)

General Chemistry

Aqueous Matrix Spike/Matrix Spike Duplicate Recovery Data

Sample Spiked A28958-1

Parameter	Amount of Spike	Recovery MS	Recovery MSD	RPD	Control Limits Recovery	Control Limits Max. RPD
Sulfate	1,600	103	102	1	66-141	8
Units	(ug)	(%)	(%)	(%)	(%)	(%)

Recovery: 0 out of 2 outside control limits

RPD: 0 out of 1 outside control limits

AnalytiKEM An American NUKEM Company

28 Springdale Road
Cherry Hill, New Jersey 08003
(609) 751-1122 • (215) 923-2068
Fax: (609) 751-0824

Chain-of-Custody

454 South Anderson Road BTC 532
Rock Hill, South Carolina 29730
(803) 329-9690
Fax: (803) 329-9689

Client NORLITE CORP

Project: SALT KILL

AnalytiKEM Contact ELISHA TEAWINKLE

SAMPLE DESIGNATION	DATE	MATRIX	40 ml vials	950 ml Org. Pres.	ml Unpres.	ml Unpres.	1000 ml HNO_3	ml H_2SO_4	ml H_2SO_4	ml NaOH	1Gal.		PARAMETERS
A1	11/13/92	WATER									X		
A1. HNO_3 PRESERVED							X						
A2											X		
A2. HNO_3 PRESERVED							X						
B1											X		
B1. HNO_3 PRESERVED							X						
B2											X		
B2. HNO_3 PRESERVED	↓	↓					X						

1. **Field Measurements:**

Data Sheets: Y N

Filtered: Y Not Required

II. **Field Conditions/Comments:** ANALYSE PER RICH SCHWAICH'S INSTRUCTIONS.

III. **Special Instructions:**
(Detection Limits, Data Package, etc.)

Relinquished By:	Time/Date:	Received By:	Time/Date:
Richard J Brandle	5:30pm 11/13/92		11/17/92 1120

AnalytiKEM An American NUKEM Company

28 Springdale Road
Cherry Hill, New Jersey 08003
(609) 751-1122 • (215) 923-2068
Fax: (609) 751-0824

Chain-of-Custody

454 South Anderson Road BTC 532
Rock Hill, South Carolina 29730
(803) 329-9690
Fax: (803) 329-9689

Client NORLITE Corp

Project: SALT Kill

AnalytiKEM Contact ELISHA TEAWINKLE

SAMPLE DESIGNATION	DATE	MATRIX	40 ml vials	950 ml Org. Pres.	___ ml Unpres.	___ ml Unpres.	1000 ml HNO_3	___ ml H_2SO_4	___ ml H_2SO_4	___ ml NaOH	1Gal/ UNPRES		PARAMETERS
D1	11/13/92	WATER									X		
D1. HNO_3 PRESERVED	↓	↓					X						
D2											X		
D2. HNO_3 PRESERVED							X						

1. **Field Measurements:**

Data Sheets: Y N

Filtered: Y Not Required

II. **Field Conditions/Comments:** ANALYSE PER RICH SCHLAICH'S INSTRUCTIONS

III. **Special Instructions:**
(Detection Limits, Data Package, etc.)

Relinquished By:	Time/Date:	Received By:	Time/Date:
Richard	5:30pm 11/13/92	Kim Jones	1000 11/17/92

ANALYTIKEM
SAMPLE RECEIPT CHECKLIST

AnalytiKEM

ME Minlite

ANALYTIKEM NO. 29958

NAME

COMMENTS

SHIPPED 525 372 4114
✓ AIR BILL #
HAND-DELIVERED

✓ COC PRESENT ON RECEIPT
NO COC ON RECEIPT
COC TAPE ON CONTAINERS/COOLERS

✓ NO COC TAPE ON CONTAINERS/COOLERS

SAMPLE(S) INTACT ON RECEIPT
✓ SAMPLE(S) BROKEN/LEAKING — 1-950ml B1- HNO3 preserved Rec'd Broken
OTHER (SEE COMMENTS) — B1 gal. jug not Rec'd

✓ PROPER TEMPERATURE
IMPROPER TEMPERATURE

✓ PROPERLY PRESERVED
IMPROPERLY PRESERVED
NA

✓ RECEIVED WITHIN HOLDING TIME
✓ NOT RECEIVED WITHIN HOLDING TIME
NA

✓ DISCREPANCIES BETWEEN COC AND SAMPLE LABELS — Rec'd #1 A1- 1gal unp
A1 950 HNO3
#2 A2 1gal unp
A2 950 HNO3

NO DISCREPANCIES NOTED — #3 B2 1-950 HNO3
B2 1-950 unp
#4 D1- 1-gal unp
D1 - 1-950 HNO3

LES INSPECTED AND LOGGED BY:

/TIME: 11/17/92 110 — #5 D2 - 1gal unp
D2 - 1-950 HNO3

TITLE

PROJECT NO. (1924) m1

BOOK NO.

Work continued from Page ______

DATE	SAMPLE#	INIT WT/VOL	FINAL VOL.	SPIKE AMT.	COMMENTS
(F03)	28998-21	1.85	100		
11/30/92	-22	1.36			
	-23	1.70			
	-24	1.04	↓		
	-25	100	50		FIELD BLANK
	-26	↓	↓		↓
	-24Dup	1.04	100		
	-24MS	1.22		520PP/SB	
	-24MSD	1.07			
	DFSPK	1.0		↓	
	Blank	1.0	↓		
1-30-92	28958-1	100mL	100mL		HOMOGENIZE WE.
TU1	-2				
	-3				
	-4				
	-5				
	-6				
	-1DUP				
	-1MS			300ug EACH	
	-1MSD				
	D.SPK			↓	↓
	Blank	↓	↓		

SCIENTIFIC BINDERY PRODUCTIONS CHICAGO 60605

Work continued to Page ______

SIGNATURE	Alex M. Nal	DATE 11-30-92
DISCLOSED TO AND UNDERSTOOD BY Mirko Vo R	DATE 12/7/92	WITNESS	DATE

ma

ICP RUN SUMMARY

Sample Spiked: 28958-1

Spike Amount 100· **ug**

Final Volume 500 **mls**

Metal	Sample Spiked (wt:_____g) ug/ml	Spike Recovery (wt:_____g) ug/ml	%	Spike Duplicate (wt:_____g) ug/ml	%	RPD	OI
Ca	89.820	95.530	191	96.510	223	15	100

Date: 12/4/92
Task File: Calcium
Analyst: J. Napolitan
Reference: 1869-ICP
Samples Run:
28958-(1-5) dilutions

Start Time:
End Time:
Sample Time: **min/sample**

m3

```
port 2                                          12-04-1992 @ 04:09:31 -- 1

sk:  CALCIUM  Result File:  28958 - Analysis Results

   Sample Name      CA 317.933
-04-1992
  1 HIGH STD            24.908
  2 ICV                 10.130
  3 ICB                  0.000
  4 ICS A               19.866
  5 ICS AB              19.885
  6 CCV                 10.074
  7 CCB                  0.000
  8 28958-1             17.964
  9 28958-1 DUP         18.078
 10 28958-1 MS          19.110
 11 28958-1 MSD         19.302
 12 28958-2             22.043
 13 28958-3             13.327
 14 28958-4             19.845
 15 28958-5             23.623
 16 CCV                  9.985
 17 CCB             <    0.000
 18 ICS A               19.693
 19 ICS AB              19.808
 20 CCV                 10.047
 21 CCB             <    0.000
```

m4

```
2-04-1992 @ 03:45:22 -- 1



or Wavelength Calibration, Use (S)pecial or (C)al. Standards ?  C

nter STANDARD NUMBER (1 - 4) or -1 to EXIT:   1

tandard #1 solution aspirating - CONTINUE ?  Y

Scanning Around CA 317.933
         Peak     Replication   Peak Pos.       Off Peak       Off Peak
lement   Position    Number     Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 CA      No Peak!      1            N/A
LANK RE-CALCULATED AT END OF CALIBRATION
nter STANDARD NUMBER (1 - 4) or -1 to EXIT:   2

tandard #2 solution aspirating - CONTINUE ?  Y

Scanning Around CA 317.933
         Peak     Replication   Peak Pos.       Off Peak       Off Peak
lement   Position    Number     Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 CA      -0.0001       1           9727
                                STANDARD #2
lement  Wavelength   Ave Int   % R.S.D.  Ref Blank Int  Off Peak Int  Net Int
 CA      317.933      9727      N/A                          0          9727
nter STANDARD NUMBER (1 - 4) or -1 to EXIT:   3

tandard #3 solution aspirating - CONTINUE ?  Y

Scanning Around CA 317.933
         Peak     Replication   Peak Pos.       Off Peak       Off Peak
lement   Position    Number     Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 CA       0.0002       1           18215
                                STANDARD #3
lement  Wavelength   Ave Int   % R.S.D.  Ref Blank Int  Off Peak Int  Net Int
 CA      317.933      18215     N/A                          0         18215
nter STANDARD NUMBER (1 - 4) or -1 to EXIT:   4

tandard #4 solution aspirating - CONTINUE ?  Y

Scanning Around CA 317.933
         Peak     Replication   Peak Pos.       Off Peak       Off Peak
lement   Position    Number     Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 CA       0.0005       1           43284
                                STANDARD #4
lement  Wavelength   Ave Int   % R.S.D.  Ref Blank Int  Off Peak Int  Net Int
 CA      317.933      43284     N/A                          0         43284
nter STANDARD NUMBER (1 - 4) or -1 to EXIT:  -1

                                STANDARD #1
lement  Wavelength   Ave Int   % R.S.D.  Ref Blank Int  Off Peak Int  Net Int
 CA      317.933      1533      N/A                          0          1533
```

m5

```
-04-1992 @ 03:49:50 -- 1


atistics For Fitted Curve


                          Results For CA 317.933

       Low Intensity  High Intensity Intercept     Slope    Curvature
       ---------------------------------------------------------------
rve 1       1533          43284        -0.92210   0.00060       0.00000

andard   Intensity      Concen.    Calc. Con.   Con. Error  % Error   Order
------------------------------------------------------------------------------
 1          1533         0.000       0.001        0.001                 1
 2          9727         5.000       4.936       -0.064     -1.29       1
 3         18215        10.000      10.047        0.047      0.47       1
 4         43284        25.000      25.144        0.144      0.58       1

e RMS Error is    0.859%
```

m6

```
nalyze Samples                                    12-04-1992 @ 03:50:13 -- 1



lculate Dilution Correction ?  Y
 HIGH STD



IGH STD

gin Analysis - Sample Number 1

   Ele.  Wave-   Mean Peak  Mean Peak                      Net Peak
   Sym.  length  Position   Intensity                      Intensity

    CA  317.933     0.0005      42892                         42892

lculating Concentrations for Sample Number 1

em. Wave-    Net Peak   Calculated    Interference      Net             Dilution
m. length   Intensity  Concentration  Correction   Concentration      Correction

 317.933       42892        24.908                         24.908          24.908
 ICV



CV


gin Analysis - Sample Number 2

   Ele.  Wave-   Mean Peak  Mean Peak                      Net Peak
   Sym.  length  Position   Intensity                      Intensity

    CA  317.933     0.0002      18353                         18353

lculating Concentrations for Sample Number 2

em. Wave-    Net Peak   Calculated    Interference      Net             Dilution
. length    Intensity  Concentration  Correction   Concentration      Correction

 317.933       18353        10.130                         10.130          10.130
 ICB
```

m 7

```
alyze Samples                                        12-04-1992 @ 03:53:04 -- 2



CB

gin Analysis - Sample Number 3

  Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
  Sym.  length  Position   Intensity                   Intensity

   CA  317.933   No Peak!       1532                        1532

lculating Concentrations for Sample Number 3

em. Wave-    Net Peak   Calculated    Interference     Net            Dilution
m. length   Intensity  Concentration  Correction  Concentration      Correction

 317.933        1532        0.000                          0.000          0.000
ICS A

ter Sample Weight    2

ter Sample Volume    2

ter Sample Volume    50



S A

gin Analysis - Sample Number 4

  Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
  Sym.  length  Position   Intensity                   Intensity

   CA  317.933    0.0005       34520                       34520

lculating Concentrations for Sample Number 4

em. Wave-    Net Peak   Calculated    Interference     Net            Dilution
m. length   Intensity  Concentration  Correction  Concentration      Correction

 317.933       34520       19.866                         19.866        496.650
ICS AB
```

m8

```
alyze Samples                                   12-04-1992 @ 03:54:48 -- 3



S AB

gin Analysis - Sample Number 5

   Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
   Sym.  length  Position   Intensity                   Intensity

    CA  317.933     0.0003      34552                      34552

lculating Concentrations for Sample Number 5

em. Wave-    Net Peak   Calculated    Interference      Net            Dilution
m. length   Intensity  Concentration   Correction  Concentration     Correction

 317.933        34552         19.885                       19.885        497.125
 CCV

ter Sample Weight    1

ter Sample Volume    1



CV


gin Analysis - Sample Number 6

   Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
   Sym.  length  Position   Intensity                   Intensity

    CA  317.933     0.0005      18260                      18260

lculating Concentrations for Sample Number 6

em. Wave-    Net Peak   Calculated    Interference      Net            Dilution
m. length   Intensity  Concentration   Correction  Concentration     Correction

 317.933        18260         10.074                       10.074         10.074
 CCB
```

m9

```
nalyze Samples                                       12-04-1992 @ 03:56:28 -- 4


CB

gin Analysis - Sample Number 7

   Ele.  Wave-   Mean Peak  Mean Peak                Net Peak
   Sym.  length  Position   Intensity                Intensity

    CA  317.933    No Peak!       1532                    1532

alculating Concentrations for Sample Number 7

lem. Wave-    Net Peak   Calculated    Interference      Net            Dilution
ym. length   Intensity  Concentration  Correction  Concentration       Correction

A 317.933        1532         0.000                         0.000            0.000
 28958-1

nter Sample Volume    5



8958-1

gin Analysis - Sample Number 8

   Ele.  Wave-   Mean Peak  Mean Peak                Net Peak
   Sym.  length  Position   Intensity                Intensity

    CA  317.933     0.0003      31361                   31361

alculating Concentrations for Sample Number 8

lem. Wave-    Net Peak   Calculated    Interference      Net            Dilution
ym. length   Intensity  Concentration  Correction  Concentration       Correction

A 317.933       31361        17.964                        17.964           89.820
 28958-1 DUP


8958-1 DUP
```

m10

```
nalyze Samples                                       12-04-1992 @ 03:58:04 -- 5


gin Analysis - Sample Number 9

    Ele.  Wave-   Mean Peak  Mean Peak              Net Peak
    Sym.  length  Position   Intensity              Intensity

     CA  317.933    0.0004      31550                  31550

lculating Concentrations for Sample Number 9

lem. Wave-   Net Peak   Calculated    Interference      Net           Dilution
ym. length  Intensity  Concentration   Correction  Concentration     Correction

A 317.933     31550       18.078                        18.078          90.390
 28958-1 MS



8958-1 MS

gin Analysis - Sample Number 10

    Ele.  Wave-   Mean Peak  Mean Peak              Net Peak
    Sym.  length  Position   Intensity              Intensity

     CA  317.933    0.0009      33265                  33265

lculating Concentrations for Sample Number 10

lem. Wave-   Net Peak   Calculated    Interference      Net           Dilution
ym. length  Intensity  Concentration   Correction  Concentration     Correction

 317.933     33265       19.110                        19.110          .95.550
 28958-1 MSD



958-1 MSD

gin Analysis - Sample Number 11

    Ele.  Wave-   Mean Peak  Mean Peak              Net Peak
    Sym.  length  Position   Intensity              Intensity
```

m11

```
      CA  317.933     0.0005      33583                      33583

alculating Concentrations for Sample Number 11

lem. Wave-    Net Peak   Calculated    Interference      Net           Dilution
ym. length   Intensity  Concentration  Correction  Concentration     Correction

A 317.933       33583        19.302                      19.302          96.510
 28958-2

nter Sample Volume    2



8958-2

egin Analysis - Sample Number 12

    Ele.  Wave-   Mean Peak  Mean Peak                  Net Peak
    Sym.  length  Position   Intensity                  Intensity

     CA  317.933     0.0005      38135                    38135

lculating Concentrations for Sample Number 12

lem. Wave-    Net Peak   Calculated    Interference      Net           Dilution
ym. length   Intensity  Concentration  Correction  Concentration     Correction

A 317.933       38135        22.043                      22.043          44.086
 28958-3

nter Sample Weight    5

nter Sample Weight    1

nter Sample Volume    5



8958-3

gin Analysis - Sample Number 13
```

m12

```
nalyze Samples                                  12-04-1992 @ 04:01:45 -- 7


   Ele.  Wave-   Mean Peak  Mean Peak                    Net Peak
   Sym.  length  Position   Intensity                    Intensity

    CA  317.933     0.0008       23661                       23661

lculating Concentrations for Sample Number 13

em. Wave-    Net Peak   Calculated   Interference     Net             Dilution
m. length   Intensity  Concentration  Correction  Concentration      Correction

 317.933        23661        13.327                       13.327          66.635
28958-4

nter Sample Weight  User Abort

nter Sample Volume    2



958-4

gin Analysis - Sample Number 14

   Ele.  Wave-   Mean Peak  Mean Peak                    Net Peak
   Sym.  length  Position   Intensity                    Intensity

    CA  317.933     0.0005       34485                       34485

lculating Concentrations for Sample Number 14

em. Wave-    Net Peak   Calculated   Interference     Net             Dilution
m. length   Intensity  Concentration  Correction  Concentration      Correction

 317.933        34485        19.845                       19.845          39.690
28958-5


958-5

gin Analysis - Sample Number 15
```

m13

```
lyze Samples                                          12-04-1992 @ 04:03:43 -- 8


   Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
   Sym.  length  Position    Intensity                  Intensity

    CA  317.933    0.0006      40759                      40759

lculating Concentrations for Sample Number 15

lem. Wave-    Net Peak   Calculated    Interference     Net            Dilution
ym. length   Intensity  Concentration  Correction  Concentration     Correction

 317.933        40759        23.623                      23.623          47.246
CCV



CV

gin Analysis - Sample Number 16

   Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
   Sym.  length  Position    Intensity                  Intensity

    CA  317.933    0.0008      18111                      18111

lculating Concentrations for Sample Number 16

lem. Wave-    Net Peak   Calculated    Interference     Net            Dilution
ym. length   Intensity  Concentration  Correction  Concentration     Correction

 317.933        18111         9.985                       9.985          19.970
CCV

CCB



CB

gin Analysis - Sample Number 17

   Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
   Sym.  length  Position    Intensity                  Intensity
```

m14

```
lyze Samples                                      12-04-1992 @ 04:05:38 -- 9


    CA  317.933   No Peak!       1505                     1505

lculating Concentrations for Sample Number 17

em. Wave-   Net Peak   Calculated    Interference      Net            Dilution
ym. length  Intensity  Concentration  Correction  Concentration      Correction

 317.933        1505       -0.016                    <      0.000 <         0.000
 ICS A



CS A

gin Analysis - Sample Number 18

nter Sample Weight    2

nter Sample Volume    50



CS A

gin Analysis - Sample Number 18

   Ele.  Wave-   Mean Peak  Mean Peak                      Net Peak
   Sym.  length  Position   Intensity                      Intensity

    CA  317.933    0.0006      34233                         34233

lculating Concentrations for Sample Number 18

lem. Wave-   Net Peak   Calculated    Interference      Net            Dilution
ym. length  Intensity  Concentration  Correction  Concentration      Correction

 317.933       34233       19.693                          19.693         492.325
 ICS AB



CS AB
```

mi5

```
alyze Samples                                            12-04-1992 @ 04:06:51 -- 10


gin Analysis - Sample Number 19

    Ele.  Wave-   Mean Peak  Mean Peak                     Net Peak
    Sym.  length  Position   Intensity                     Intensity

     CA  317.933     0.0009      34423                       34423

lculating Concentrations for Sample Number 19

lem. Wave-    Net Peak   Calculated    Interference      Net            Dilution
ym. length   Intensity  Concentration   Correction   Concentration     Correction

A 317.933       34423        19.808                        19.808          495.200
 CCV

nter Sample Weight    1

nter Sample Volume    1



CV


gin Analysis - Sample Number 20

    Ele.  Wave-   Mean Peak  Mean Peak                     Net Peak
    Sym.  length  Position   Intensity                     Intensity

     CA  317.933     0.0006      18215                       18215

alculating Concentrations for Sample Number 20

lem. Wave-    Net Peak   Calculated    Interference      Net            Dilution
ym. length   Intensity  Concentration   Correction   Concentration     Correction

A 317.933       18215        10.047                        10.047           10.047
 CCB



CB
```

M16

ICP RUN SUMMARY

Sample Spiked: 28958-1

Spike Amount ~~300~~gn 306 **ug**

Final Volume 100 **mls**

Metal	**Sample Spiked** (wt:______g) ug/ml	**Spike Recovery** (wt:______g) ug/ml	%	**Spike Duplicate** (wt:______g) ug/ml	%	**RPD**
Al	6.638	9.273	88	9.588	98	11
Ca	←	Over	Calibration			→
Fe	13.704	16.099	80	16.521	94	16
Mg	10.340	12.896	85	13.092	92	8
Mn	0.369	2.815	85	3.046	89	5
~~K Na~~	~~15.962~~					→
Na	←	Over Flow			→	

Date: 12/4/92

Task File: Dirt

Analyst: J. Napolitan

Reference: 1868-ICP

Samples Run:

28958-(1-6)

Start Time:

End Time:

Sample Time: ______ **min/sample**

m17

```
port 2                                                 12-04-1992 @ 03:31:19 -- 2



    Sample Name     K  766.491  NA 588.995
2-04-1992
   1 HIGH STD          25.071       24.538
   2 ICV                9.501       10.137
   3 ICB           <    0.050        0.206
   4 ICB           <    0.050        0.489
   5 ICS A         <    0.050        0.340
   6 ICS AB        <    0.050        0.255
   7 CCV                9.799        9.735
   8 CCB           <    0.050        0.220
   9 PBW           <    0.050        0.212
  10 28958-1           15.962     Overflow
  11 28958-1 DUP       23.742     Overflow
  12 28958-1 MS        35.044     Overflow
  13 28958-1 MSD        7.388       36.485
  14 LCS I              9.869       16.463
  15 28958-2            8.390     Overflow
  16 28958-3            9.144       55.278
  17 28958-4            2.823       12.224
  18 28958-5            2.803       35.842
  19 CCV               11.337       16.445
  20 CCB                0.977        4.137
  21 28958-6            8.727       75.612
  22 28958-6 SER D      1.364       22.262
  23 ICS A              0.163        3.858
  24 ICS AB             0.580        3.810
  25 CCV               11.119       14.505
  26 CCV               11.476       14.128
  27 CCV               11.228       13.359
  28 CCB                0.411        3.322
  29 CCB                0.372        3.071
```

m18

```
2-04-1992 @ 01:10:33 -- 1



ave previously acquired Calibration data for this task ?  N

or Wavelength Calibration, Use (S)pecial or (C)al. Standards ?  C

nter STANDARD NUMBER (1 - 4) or -1 to EXIT:    1

tandard #1 solution aspirating - CONTINUE ?  Y

Scanning Around MN 257.610
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 MN      No Peak!       1            N/A              853            832
Scanning Around FE 259.940
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 FE      No Peak!       1            N/A
Scanning Around MG 279.553
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 MG       0.0014        1            N/A
Scanning Around CA 317.933
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 CA      No Peak!       1            N/A
Scanning Around AL 396.152
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 AL      No Peak!       1            N/A
Scanning Around NA 588.995
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 NA       0.0005        1            N/A
Scanning Around K 766.491
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
  K      No Peak!       1            N/A
LANK RE-CALCULATED AT END OF CALIBRATION
ter STANDARD NUMBER (1 - 4) or -1 to EXIT:    2

andard #2 solution aspirating - CONTINUE ?  Y

Scanning Around MN 257.610
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 MN       0.0011        1           95194            1526           1413
canning Around FE 259.940
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 FE       0.0005        1           31650
canning Around MG 279.553
          Peak     Replication    Peak Pos.       Off Peak       Off Peak
ement    Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
```

```
Scanning Around CA 317.933
            Peak      Replication    Peak Pos.       Off Peak       Off Peak m19
lement    Position       Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 CA        0.0005          1              9051
Scanning Around AL 396.152
            Peak      Replication    Peak Pos.       Off Peak       Off Peak
lement    Position       Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 AL        0.0003          1             22155
Scanning Around NA 588.995
            Peak      Replication    Peak Pos.       Off Peak       Off Peak
lement    Position       Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
 NA        0.0009          1             79520
Scanning Around K 766.491
            Peak      Replication    Peak Pos.       Off Peak       Off Peak
lement    Position       Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
  K        0.0003          1              1806
                                     STANDARD #2
lement   Wavelength     Ave Int    % R.S.D.   Ref Blank Int  Off Peak Int   Net Int
 AL       396.152        22155       N/A                           0          22155
 CA       317.933         9051       N/A                           0           9051
 FE       259.940        31650       N/A                           0          31650
 MG       279.553       183199       N/A                           0         183199
```

m20

```
2-04-1992 @ 01:20:20 -- 2


MN      257.610        95194       N/A                                    1470        93725
 K      766.491         1806       N/A                                       0         1806
NA      588.995        79520       N/A                                       0        79520
nter STANDARD NUMBER (1 - 4) or -1 to EXIT:    3

tandard #3 solution aspirating - CONTINUE ?  Y

Scanning Around MN 257.610
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
MN        0.0013        1           189641           2464          1955
Scanning Around FE 259.940
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
FE        0.0006        1            60949
Scanning Around MG 279.553
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
MG        0.0008        1           365783
Scanning Around CA 317.933
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
CA        0.0009        1            16639
Scanning Around AL 396.152
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
AL        0.0002        1            40613
Scanning Around NA 588.995
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
NA        0.0012        1           133075
Scanning Around K 766.491
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
K        -0.0004        1             2231
                                 STANDARD #3
lement  Wavelength    Ave Int   % R.S.D.  Ref Blank Int  Off Peak Int   Net Int
AL      396.152        40613     N/A                              0        40613
CA      317.933        16639     N/A                              0        16639
FE      259.940        60949     N/A                              0        60949
MG      279.553       365783     N/A                              0       365783
MN      257.610       189641     N/A                           2210       187432
 K      766.491         2231     N/A                              0         2231
NA      588.995       133075     N/A                              0       133075
ter STANDARD NUMBER (1 - 4) or -1 to EXIT:    4

andard #4 solution aspirating - CONTINUE ?  Y

canning Around MN 257.610
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
ement    Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
MN        0.0012        1           461408           4823          3579
canning Around FE 259.940
          Peak      Replication   Peak Pos.       Off Peak       Off Peak
```

m21

```
FE       0.0003         1            149772
Scanning Around MG 279.553
          Peak     Replication   Peak Pos.       Off Peak        Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
MG       0.0010         1            902812
Scanning Around CA 317.933
          Peak     Replication   Peak Pos.       Off Peak        Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
CA       0.0007         1             39880
Scanning Around AL 396.152
          Peak     Replication   Peak Pos.       Off Peak        Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
AL       0.0002         1             94808
Scanning Around NA 588.995
          Peak     Replication   Peak Pos.       Off Peak        Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
NA       0.0010         1            292505
Scanning Around K 766.491
          Peak     Replication   Peak Pos.       Off Peak        Off Peak
lement   Position     Number      Intensity    Pnt. 1 Intens  Pnt. 2 Intens
K        0.0001         1              3803
                                STANDARD #4
```

ma2

```
2-04-1992 @ 01:26:00 -- 3


lement  Wavelength    Ave Int    % R.S.D.  Ref Blank Int  Off Peak Int  Net Int
 AL      396.152        94808      N/A                               0    94808
 CA      317.933        39880      N/A                               0    39880
 FE      259.940       149772      N/A                               0   149772
 MG      279.553       902812      N/A                               0   902812
 MN      257.610       461408      N/A                            4201   457207
  K      766.491         3803      N/A                               0     3803
 NA      588.995       292505      N/A                               0   292505
nter STANDARD NUMBER (1 - 4) or -1 to EXIT:  -1

                                 STANDARD #1
lement  Wavelength    Ave Int    % R.S.D.  Ref Blank Int  Off Peak Int  Net Int
 AL      396.152         3592      N/A                               0     3592
 CA      317.933         1389      N/A                               0     1389
 FE      259.940         1417      N/A                               0     1417
 MG      279.553          513      N/A                               0      513
 MN      257.610          920      N/A                             843       78
  K      766.491         1263      N/A                               0     1263
 NA      588.995        21864      N/A                               0    21864
```

ma3

```
2-04-1992 @ 01:26:37 -- 1



tatistics For Fitted Curve


                         Results For AL 396.152

        Low Intensity  High Intensity Intercept    Slope    Curvature
        ------------------------------------------------------------
urve 1      3592           94808       -0.97593   0.00027       0.00000

tandard   Intensity      Concen.   Calc. Con.   Con. Error  % Error   Order
------------------------------------------------------------------------
 1          3592         0.000       -0.001      -0.001               1
 2         22155         5.000        5.037       0.037      0.75     1
 3         40613        10.000       10.047       0.047      0.47     1
 4         94808        25.000       24.757      -0.243     -0.97     1

he RMS Error is    0.759%


                         Results For CA 317.933

        Low Intensity  High Intensity Intercept    Slope    Curvature
        ------------------------------------------------------------
urve 1      1389           39880       -0.90607   0.00065       0.00000

tandard   Intensity      Concen.   Calc. Con.   Con. Error  % Error   Order
------------------------------------------------------------------------
 1          1389         0.000        0.000       0.000               1
 2          9051         5.000        4.999      -0.001     -0.01     1
 3         16639        10.000        9.950      -0.050     -0.50     1
 4         39880        25.000       25.115       0.115      0.46     1

e RMS Error is    0.390%


                         Results For FE 259.940

        Low Intensity  High Intensity Intercept    Slope    Curvature
        ------------------------------------------------------------
rve 1       1417          149772       -0.23719   0.00017       0.00000

andard    Intensity      Concen.   Calc. Con.   Con. Error  % Error   Order
------------------------------------------------------------------------
 1          1417         0.000        0.000       0.000               1
 2         31650         5.000        5.059       0.059      1.18     1
 3         60949        10.000        9.962      -0.038     -0.38     1
 4        149772        25.000       24.825      -0.175     -0.70     1
```

m25

```
tatistics For Fitted Curve                        12-04-1992 @ 01:26:43 -- 2


                              Results For MG 279.553

          Low Intensity  High Intensity Intercept    Slope    Curvature
          ----------------------------------------------------------------
urve 1          513          902812       -0.01410   0.00003       0.00000

tandard    Intensity      Concen.    Calc. Con.    Con. Error  % Error    Order
-------------------------------------------------------------------------------
  1             513         0.000         0.000         0.000                1
  2          183199         5.000         5.021         0.021     0.42       1
  3          365783        10.000        10.039         0.039     0.39       1
  4          902812        25.000        24.799        -0.201    -0.80       1

he RMS Error is    0.570%


                              Results For MN 257.610

          Low Intensity  High Intensity Intercept    Slope    Curvature
          ----------------------------------------------------------------
urve 1           78          457207       -0.00420   0.00005       0.00000

tandard    Intensity      Concen.    Calc. Con.    Con. Error  % Error    Order
-------------------------------------------------------------------------------
  1              78         0.000         0.000         0.000                1
  2           93725         5.000         5.040         0.040     0.80       1
  3          187432        10.000        10.083         0.083     0.83       1
  4          457207        25.000        24.602        -0.398    -1.59       1

he RMS Error is    1.135%


                               Results For K 766.491

          Low Intensity  High Intensity Intercept    Slope    Curvature
          ----------------------------------------------------------------
urve 1         1263            3803      -12.57832   0.00992       0.00000

tandard    Intensity      Concen.    Calc. Con.    Con. Error  % Error    Order
-------------------------------------------------------------------------------
  1            1263         0.000        -0.045        -0.045                1
  2            1806         5.000         5.343         0.343     6.87       1
  3            2231        10.000         9.561        -0.439    -4.39       1
  4            3803        25.000        25.161         0.161     0.64       1

he RMS Error is    4.721%
```

m26

```
tatistics For Fitted Curve                         12-04-1992 @ 01:26:48 -- 3



                              Results For NA 588.995

       Low Intensity  High Intensity Intercept     Slope    Curvature
       --------------------------------------------------------------
urve 1      21864          292505       -1.98436   0.00009      0.00000

tandard   Intensity       Concen.   Calc. Con.   Con. Error  % Error   Order
------------------------------------------------------------------------------
 1          21864          0.000       -0.012       -0.012               1
 2          79520          5.000        5.190        0.190     3.81      1
 3         133075         10.000       10.022        0.022     0.22      1
 4         292505         25.000       24.407       -0.593    -2.37      1

he RMS Error is    2.593%
```

m27

```
nalyze Samples                                        12-04-1992 @ 01:27:39 -- 1



lculate Dilution Correction ?  Y

 HIGH STD



IGH STD

gin Analysis - Sample Number 1

    Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
    Sym.  length  Position   Intensity                   Intensity

     MN  257.61
        Off Peak Int.  =      4609
        Off Peak Int.  =      3541
                      0.0004    468632                    464557
     FE  259.94      -0.0002    151020                    151020
     MG  279.553     -0.0001    898004                    898004
     CA  317.933      0.0001     40145                     40145
     AL  396.152     -0.0004     94477                     94477
     NA  588.995      0.0002    293957                    293957
     K   766.491     -0.0004      3794                      3794

alculating Concentrations for Sample Number 1

lem. Wave-    Net Peak    Calculated    Interference      Net           Dilution
ym. length   Intensity  Concentration   Correction   Concentration     Correction

L 396.152       94477       24.667                        24.667          24.667
A 317.933       40145       25.288                        25.288          25.288
E 259.94       151020       25.033                        25.033          25.033
G 279.553      898004       24.667                        24.667          24.667
N 257.61       464557       24.998                        24.998          24.998
  766.491        3794       25.071                        25.071          25.071
A 588.995      293957       24.538                        24.538          24.538
 ICV



CV
```

m28

```
nalyze Samples                                              12-04-1992 @ 01:30:34 -- 2


gin Analysis - Sample Number 2

   Ele.  Wave-   Mean Peak  Mean Peak                    Net Peak
   Sym.  length  Position   Intensity                    Intensity

    MN  257.61
        Off Peak Int.  =     2412
        Off Peak Int.  =     1915
                      0.0001   189872                     187708
    FE  259.94       -0.0001    60510                      60510
    MG  279.553      -0.0001   365769                     365769
    CA  317.933      -0.0002    16966                      16966
    AL  396.152      -0.0003    40626                      40626
    NA  588.995       0.0001   134344                     134344
    K   766.491      -0.0001     2225                       2225

alculating Concentrations for Sample Number 2

lem. Wave-     Net Peak   Calculated    Interference     Net             Dilution
ym. length   Intensity  Concentration  Correction   Concentration      Correction

L 396.152        40626        10.051                        10.051            10.051
A 317.933        16966        10.164                        10.164            10.164
E 259.94         60510         9.888                         9.888             9.888
G 279.553       365769        10.039                        10.039            10.039
N 257.61        187708        10.098                        10.098            10.098
  766.491         2225         9.501                         9.501             9.501
A 588.995       134344        10.137                        10.137            10.137
 ICB



CB


gin Analysis - Sample Number 3

   Ele.  Wave-   Mean Peak  Mean Peak                    Net Peak
   Sym.  length  Position   Intensity                    Intensity

    MN  257.61
        Off Peak Int.  =      842
        Off Peak Int.  =      855
                   No Peak!       909                         60
    FE  259.94     No Peak!      1401                       1401
    MG  279.553    No Peak!       446                        446
    CA  317.933    No Peak!      1363                       1363
```

```
alyze Samples                                              12-04-1992 @ 01:35:54 -- 3


     AL   396.152    No Peak!        3598                       3598
     NA   588.995     -0.0002       24281                      24281
     K    766.491    No Peak!        1233                       1233


lculating Concentrations for Sample Number 3

em. Wave-   Net Peak   Calculated    Interference      Net           Dilution
m. length   Intensity  Concentration  Correction  Concentration     Correction

 396.152        3598         0.001                        0.001          0.001
 317.933        1363        -0.017                 <      0.010 <        0.010
 259.94         1401        -0.003                 <      0.010 <        0.010
 279.553         446        -0.002                 <      0.050 <        0.050
 257.61           60        -0.001                 <      0.000 <        0.000
 766.491        1233        -0.343                 <      0.050 <        0.050
 588.995       24281         0.206                        0.206          0.206


CB


gin Analysis - Sample Number 4

    Ele.   Wave-    Mean Peak  Mean Peak                    Net Peak
    Sym.   length   Position   Intensity                    Intensity

     MN   257.61
          Off Peak Int.   =     854
          Off Peak Int.   =     852
                   No Peak!        885                          32
     FE   259.94   No Peak!       1397                        1397
     MG   279.553  No Peak!        412                         412
     CA   317.933  No Peak!       1371                        1371
     AL   396.152  No Peak!       3561                        3561
     NA   588.995   -0.0001      27414                       27414
     K    766.491  No Peak!       1226                        1226

lculating Concentrations for Sample Number 4

em. Wave-   Net Peak   Calculated    Interference      Net           Dilution
m. length   Intensity  Concentration  Correction  Concentration     Correction

 396.152        3561        -0.009                 <      0.000 <        0.000
 317.933        1371        -0.012                 <      0.010 <        0.010
 259.94         1397        -0.003                 <      0.010 <        0.010
 279.553         412        -0.003                 <      0.050 <        0.050
```

ma9

```
nalyze Samples                                              12-04-1992 @ 01:41:59 -- 4


N 257.61          32          -0.002                         <     0.000 <          0.000
 766.491        1226          -0.412                         <     0.050 <          0.050
A 588.995      27414           0.489                               0.489            0.489
 ICS A

nter Sample Weight    2

nter Sample Volume    50



CS A


gin Analysis - Sample Number 5

    Ele.  Wave-   Mean Peak  Mean Peak                   Net Peak
    Sym.  length  Position   Intensity                   Intensity

     MN  257.61
         Off Peak Int.  =      891
         Off Peak Int.  =      869
                   No Peak!         922                          42
     FE  259.94      0.0003       48344                       48344
     MG  279.553     0.0003      714603                      714603
     CA  317.933     0.0002       32039                       32039
     AL  396.152     0.0003       75439                       75439
     NA  588.995     0.0001       25766                       25766
     K   766.491   No Peak!        1221                        1221


lculating Concentrations for Sample Number 5

lem. Wave-    Net Peak    Calculated     Interference      Net             Dilution
m. length    Intensity  Concentration   Correction   Concentration       Correction

L 396.152      75439          19.500                          19.500            487.500
A 317.933      32039          19.999                          19.999            499.975
E 259.94       48344           7.852                           7.852            196.300
G 279.553     714603          19.627                          19.627            490.675
N 257.61          42          -0.002                     <     0.000 <          0.000
 766.491        1221          -0.462                     <     0.050 <          0.050
A 588.995      25766           0.340                           0.340            8.500
 ICS AB
```

m30

```
alyze Samples                                          12-04-1992 @ 01:45:08 -- 5


CS AB


gin Analysis - Sample Number 6

   Ele.  Wave-   Mean Peak  Mean Peak                       Net Peak
   Sym.  length  Position   Intensity                       Intensity

    MN   257.61
            Off Peak Int.  =       883
            Off Peak Int.  =       884
                      -0.0003       1284                          400
    FE   259.94        0.0000      48304                        48304
    MG   279.553       0.0002     703698                       703698
    CA   317.933       0.0003      31173                        31173
    AL   396.152       0.0001      75426                        75426
    NA   588.995      -0.0001      24815                        24815
    K    766.491     No Peak!       1247                         1247


lculating Concentrations for Sample Number 6

lem. Wave-    Net Peak    Calculated      Interference      Net              Dilution
ym. length    Intensity   Concentration   Correction   Concentration        Correction

l 396.152       75426        19.496                          19.496          487.400
A 317.933       31173        19.434                          19.434          485.850
E 259.94        48304         7.846                           7.846          196.150
G 279.553      703698        19.327                          19.327          483.175
N 257.61          400         0.017                           0.017            0.425
  766.491        1247        -0.204                    <      0.050 <          0.050
A 588.995       24815         0.255                           0.255            6.375
 CCV

nter Sample Weight    1

nter Sample Volume    1



CV


gin Analysis - Sample Number 7

   Ele.  Wave-   Mean Peak  Mean Peak                       Net Peak
   Sym.  length  Position   Intensity                       Intensity
```

m31

```
nalyze Samples                                         12-04-1992 @ 01:48:09 -- 6


    MN   257.61
         Off Peak Int.   =       2421
         Off Peak Int.   =       1883
                       -0.0001     185943                     183791
    FE   259.94         0.0000      60921                      60921
    MG   279.553        0.0001     354290                     354290
    CA   317.933        0.0001      16460                      16460
    AL   396.152        0.0001      39378                      39378
    NA   588.995        0.0003     129885                     129885
    K    766.491       -0.0002       2255                       2255

lculating Concentrations for Sample Number 7

lem. Wave-     Net Peak    Calculated     Interference      Net              Dilution
ym. length   Intensity  Concentration   Correction   Concentration      Correction

L 396.152        39378          9.712                          9.712           9.712
A 317.933        16460          9.834                          9.834           9.834
E 259.94         60921          9.957                          9.957           9.957
G 279.553       354290          9.723                          9.723           9.723
N 257.61        183791          9.887                          9.887           9.887
  766.491         2255          9.799                          9.799           9.799
A 588.995       129885          9.735                          9.735           9.735
 CCB



CB


gin Analysis - Sample Number 8

   Ele.   Wave-     Mean Peak   Mean Peak                 Net Peak
   Sym.   length    Position    Intensity                 Intensity

    MN   257.61
         Off Peak Int.   =        848
         Off Peak Int.   =        864
                    No Peak!          890                       34
    FE   259.94     No Peak!         1404                     1404
    MG   279.553    No Peak!          445                      445
    CA   317.933    No Peak!         1363                     1363
    AL   396.152    No Peak!         3602                     3602
    NA   588.995     -0.0003        24437                    24437
    K    766.491    No Peak!         1246                     1246
```

m 32

```
lyze Samples                                     12-04-1992 @ 01:52:58 -- 7


lculating Concentrations for Sample Number 8

em. Wave-   Net Peak   Calculated    Interference      Net              Dilution
m. length  Intensity  Concentration  Correction   Concentration         Correction

 396.152        3602         0.002                       0.002              0.002
 317.933        1363        -0.017                 <     0.010 <            0.010
 259.94         1404        -0.002                 <     0.010 <            0.010
 279.553         445        -0.002                 <     0.050 <            0.050
 257.61           34        -0.002                 <     0.000 <            0.000
 766.491        1246        -0.214                 <     0.050 <            0.050
 588.995       24437         0.220                       0.220              0.220
 PBW

ter Sample Weight    100

ter Sample Volume    100



W


gin Analysis - Sample Number 9

   Ele.  Wave-   Mean Peak  Mean Peak                  Net Peak
   Sym.  length  Position   Intensity                  Intensity

    MN  257.61
       Off Peak Int.  =      850
       Off Peak Int.  =      855
                 No Peak!        881                        28
    FE  259.94   No Peak!       1401                      1401
    MG  279.553  No Peak!        434                       434
    CA  317.933  No Peak!       1358                      1358
    AL  396.152  No Peak!       3591                      3591
    NA  588.995   -0.0003      24338                     24338
    K   766.491  No Peak!       1253                      1253

lculating Concentrations for Sample Number 9

em. Wave-   Net Peak   Calculated    Interference      Net              Dilution
m. length  Intensity  Concentration  Correction   Concentration         Correction

 396.152        3591        -0.001                 <     0.000 <            0.000
 317.933        1358        -0.020                 <     0.010 <            0.010
 259.94         1401        -0.003                 <     0.010 <            0.010
```

m33

```
alyze Samples                                         12-04-1992 @ 01:55:20 -- 8


  279.553        434         -0.002                  <      0.050 <       0.050
N 257.61          28         -0.003                  <      0.000 <       0.000
  766.491       1253         -0.144                  <      0.050 <       0.050
A 588.995      24338          0.212                         0.212         0.212
 28958-1



958-1


gin Analysis - Sample Number 10

   Ele.  Wave-   Mean Peak  Mean Peak                  Net Peak
   Sym.  length  Position   Intensity                  Intensity

    MN  257.61
       Off Peak Int.  =        948
       Off Peak Int.  =        931
                      0.0002      7874                      6934
    FE  259.94        0.0000     83312                     83312
    MG  279.553       0.0003    376714                    376714
    CA  317.933       0.0001    131095                    131095
    AL  396.152       0.0001     28051                     28051
    NA  588.995     OVER RANGE!  Retrying Integration and Read:  Retry Number 1
VER RANGE!  Retrying Integration and Read:  Retry Number 2
ttempted Integration and Read:  Failed 3 times
ntegration and Read Aborted with INTENSITY OVER RANGE Error
verflow
    K   766.491       0.0001      2876                      2876


lculating Concentrations for Sample Number 10

lem. Wave-    Net Peak   Calculated    Interference     Net            Dilution
ym. length   Intensity  Concentration  Correction  Concentration      Correction

L 396.152      28051         6.638                         6.638          6.638
A 317.933     131095        84.630                        84.630         84.630
E 259.94       83312        13.704                        13.704         13.704
G 279.553     376714        10.340                        10.340         10.340
N 257.61        6934         0.369                         0.369          0.369
  766.491       2876        15.962                        15.962         15.962
A 588.995    Overflow
 28958-1 DUP
```

m34

```
lyze Samples                                           12-04-1992 @ 02:00:40 -- 9


958-1 DUP

in Analysis - Sample Number 11

    Ele.  Wave-   Mean Peak  Mean Peak                 Net Peak
    Sym.  length  Position   Intensity                 Intensity

     MN  257.61
        Off Peak Int.   =       957
        Off Peak Int.   =       924
                    -0.0003       7630                      6689
     FE  259.94     -0.0002      83622                     83622
     MG  279.553     0.0000     377093                    377093
     CA  317.933     0.0004     130701                    130701
     AL  396.152     0.0001      27959                     27959
     NA  588.995    OVER RANGE!  Retrying Integration and Read:  Retry Number 1
VER RANGE!  Retrying Integration and Read:  Retry Number 2
ttempted Integration and Read:  Failed 3 times
ntegration and Read Aborted with INTENSITY OVER RANGE Error
verflow
     K   766.491    -0.0002       3660                      3660


lculating Concentrations for Sample Number 11

lem. Wave-   Net Peak   Calculated    Interference     Net          Dilution
ym. length  Intensity  Concentration  Correction  Concentration    Correction

L 396.152       27959         6.613                        6.613         6.613
A 317.933      130701        84.373                       84.373        84.373
E 259.94        83622        13.755                       13.755        13.755
G 279.553      377093        10.350                       10.350        10.350
N 257.61         6689         0.356                        0.356         0.356
  766.491        3660        23.742                       23.742        23.742
A 588.995    Overflow
 28958-1 MS



8958-1 MS


egin Analysis - Sample Number 12

    Ele.  Wave-   Mean Peak  Mean Peak                 Net Peak
    Sym.  length  Position   Intensity                 Intensity
```

```
    MN  257.61
        Off Peak Int.  =       1390
        Off Peak Int.  =       1205
                     -0.0001      55531                     54233
    FE  259.94       -0.0002      97629                     97629
    MG  279.553       0.0000     469712                    469712
    CA  317.933       0.0002     134965                    134965
    AL  396.152       0.0001      37762                     37762
    NA  588.995    OVER RANGE!  Retrying Integration and Read:  Retry Number 1
VER RANGE!  Retrying Integration and Read:  Retry Number 2
ttempted Integration and Read:  Failed 3 times
ntegration and Read Aborted with INTENSITY OVER RANGE Error
verflow
    K   766.491      -0.0004       4799                      4799


lculating Concentrations for Sample Number 12

lem. Wave-    Net Peak   Calculated    Interference      Net           Dilution
ym. length   Intensity  Concentration   Correction   Concentration    Correction

L 396.152       37762        9.273                          9.273          9.273
A 317.933      134965       87.155                         87.155         87.155
E 259.94        97629       16.099                         16.099         16.099
G 279.553      469712       12.896                         12.896         12.896
N 257.61        54233        2.915                          2.915          2.915
  766.491        4799       35.044                         35.044         35.044
A 588.995    Overflow
 28958-1 MSD



8958-1 MSD


gin Analysis - Sample Number 13

   Ele.  Wave-    Mean Peak  Mean Peak                 Net Peak
   Sym.  length   Position   Intensity                 Intensity

    MN  257.61
        Off Peak Int.  =       1387
        Off Peak Int.  =       1220
                      0.0000      57987                     56683
    FE  259.94       -0.0002     100151                    100151
    MG  279.553       0.0000     476865                    476865
    CA  317.933       0.0006     131744                    131744
```

m36

```
lyze Samples                                          12-04-1992 @ 02:09:35 -- 11


    AL  396.152    0.0001      38922                  38922
    NA  588.995   OVER RANGE!  Retrying Integration and Read:  Retry Number 1
.0009      426376              426376
    K   766.491    0.0004      2012                   2012

lculating Concentrations for Sample Number 13

em. Wave-   Net Peak   Calculated     Interference      Net           Dilution
m. length   Intensity  Concentration  Correction   Concentration     Correction

 396.152      38922        9.588                          9.588          9.588
 317.933     131744       85.054                         85.054         85.054
 259.94      100151       16.521                         16.521         16.521
 279.553     476865       13.092                         13.092         13.092
 257.61       56683        3.046                          3.046          3.046
 766.491       2012        7.388                          7.388          7.388
 588.995     426376       36.485                         36.485         36.485
LCS I



S I


gin Analysis - Sample Number 14

   Ele.  Wave-    Mean Peak  Mean Peak                    Net Peak
   Sym.  length   Position   Intensity                    Intensity

    MN  257.61
        Off Peak Int.  =      1349
        Off Peak Int.  =      1153
                     -0.0002     56033                      54782
    FE  259.94       -0.0001     18702                      18702
    MG  279.553      -0.0001    107530                     107530
    CA  317.933       0.0005      5979                       5979
    AL  396.152       0.0001     14544                      14544
    NA  588.995       0.0002    204456                     204456
    K   766.491       0.0002      2262                       2262

lculating Concentrations for Sample Number 14

em. Wave-   Net Peak   Calculated     Interference      Net           Dilution
m. length   Intensity  Concentration  Correction   Concentration     Correction

 396.152      14544        2.972                          2.972          2.972
```

m37

```
alyze Samples                                        12-04-1992 @ 02:13:13 -- 12


 317.933        5979          2.995                            2.995          2.995
 259.94        18702          2.892                            2.892          2.892
 279.553      107530          2.941                            2.941          2.941
 257.61        54782          2.944                            2.944          2.944
 766.491        2262          9.869                            9.869          9.869
 588.995      204456         16.463                           16.463         16.463
28958-2



958-2


gin Analysis - Sample Number 15

   Ele.  Wave-   Mean Peak  Mean Peak                Net Peak
   Sym.  length  Position   Intensity                Intensity

    MN  257.61
        Off Peak Int.  =       912
        Off Peak Int.  =       905
                     0.0004       3040                   2131
    FE  259.94       0.0002      30216                  30216
    MG  279.553      0.0001     239547                 239547
    CA  317.933      0.0004      62660                  62660
    AL  396.152     -0.0001      13210                  13210
    NA  588.995   OVER RANGE!  Retrying Integration and Read:  Retry Number 1
ER RANGE!  Retrying Integration and Read:  Retry Number 2
tempted Integration and Read:  Failed 3 times
tegration and Read Aborted with INTENSITY OVER RANGE Error
erflow
    K   766.491      0.0003       2113                   2113


lculating Concentrations for Sample Number 15

em. Wave-    Net Peak   Calculated   Interference     Net            Dilution
m. length   Intensity  Concentration  Correction  Concentration     Correction

 396.152      13210         2.609                          2.609          2.609
 317.933      62660        39.978                         39.978         39.978
 259.94       30216         4.819                          4.819          4.819
 279.553     239547         6.570                          6.570          6.570
 257.61        2131         0.110                          0.110          0.110
 766.491       2113         8.390                          8.390          8.390
 588.995    Overflow
28958-3
```

m38

```
958-3

gin Analysis - Sample Number 16

   Ele.  Wave-    Mean Peak  Mean Peak              Net Peak
   Sym.  length   Position   Intensity              Intensity

    MN   257.61
         Off Peak Int.   =     881
         Off Peak Int.   =     867
                   -0.0001       1807                     933
    FE   259.94    -0.0001       8064                    8064
    MG   279.553   -0.0002     600365                  600365
    CA   317.933    0.0005      96460                   96460
    AL   396.152    0.0007       6269                    6269
    NA   588.995    0.0007     634655                  634655
    K    766.491   -0.0005       2189                    2189

lculating Concentrations for Sample Number 16

em. Wave-   Net Peak   Calculated    Interference      Net           Dilution
m. length   Intensity  Concentration  Correction  Concentration      Correction

 396.152       6269        0.726                        0.726           0.726
 317.933      96460       62.032                       62.032          62.032
 259.94        8064        1.112                        1.112           1.112
 279.553     600365       16.487                       16.487          16.487
 257.61         933        0.046                        0.046           0.046
 766.491       2189        9.144                        9.144           9.144
 588.995     634655       55.278                       55.278          55.278
28958-4



958-4

in Analysis - Sample Number 17

   Ele.  Wave-    Mean Peak  Mean Peak              Net Peak
   Sym.  length   Position   Intensity              Intensity

    MN   257.61
```

m39

```
        Off Peak Int.   =        847
        Off Peak Int.   =        843
                      0.0002       1887                    1042
     FE  259.94       0.0000      10160                   10160
     MG  279.553      0.0004     517291                  517291
     CA  317.933      0.0008      57114                   57114
     AL  396.152      0.0008       6845                    6845
     NA  588.995    OVER RANGE!  Retrying Integration and Read:  Retry Number 1
VER RANGE!  Retrying Integration and Read:  Retry Number 2
 Peak!      157472                157472
     K   766.491      0.0001       1552                    1552


lculating Concentrations for Sample Number 17

lem. Wave-    Net Peak   Calculated    Interference     Net             Dilution
ym. length    Intensity  Concentration  Correction  Concentration      Correction

L 396.152        6845       0.882                         0.882           0.882
A 317.933       57114      36.359                        36.359          36.359
E 259.94        10160       1.463                         1.463           1.463
G 279.553      517291      14.203                        14.203          14.203
N 257.61         1042       0.052                         0.052           0.052
  766.491        1552       2.823                         2.823           2.823
A 588.995      157472      12.224                        12.224          12.224
ff

n

 28958-5



958-5


gin Analysis - Sample Number 18

    Ele.  Wave-    Mean Peak  Mean Peak                 Net Peak
    Sym.  length   Position   Intensity                 Intensity

     MN  257.61
        Off Peak Int.   =        849
        Off Peak Int.   =        851
                      0.0002       2057                    1207
     FE  259.94       0.0003      11182                   11182
     MG  279.553      0.0006     533550                  533550
     CA  317.933      0.0010      65929                   65929
```

m40

```
alyze Samples                                          12-04-1992 @ 02:25:51 -- 15


    AL  396.152     0.0005      7483                   7483
    NA  588.995   OVER RANGE!  Retrying Integration and Read:  Retry Number 1
ER RANGE!  Retrying Integration and Read:  Retry Number 2
0.0033      419242               419242
    K   766.491     0.0000      1550                   1550

lculating Concentrations for Sample Number 18

em. Wave-   Net Peak   Calculated    Interference    Net              Dilution
m. length   Intensity  Concentration  Correction   Concentration      Correction

 396.152       7483         1.055                       1.055             1.055
 317.933      65929        42.111                      42.111            42.111
 259.94       11182         1.634                       1.634             1.634
 279.553     533550        14.650                      14.650            14.650
 257.61        1207         0.061                       0.061             0.061
 766.491       1550         2.803                       2.803             2.803
 588.995     419242        35.842                      35.842            35.842
CCV



V


gin Analysis - Sample Number 19

   Ele.  Wave-   Mean Peak  Mean Peak               Net Peak
   Sym.  length  Position   Intensity               Intensity

    MN  257.61
       Off Peak Int.  =     2206
       Off Peak Int.  =     1819
                    0.0003    175632                 173619
    FE  259.94      0.0002     56893                  56893
    MG  279.553     0.0002    334388                 334388
    CA  317.933     0.0002     15336                  15336
    AL  396.152     0.0003     37621                  37621
    NA  588.995     0.0005    204264                 204264
    K   766.491     0.0002      2410                   2410

lculating Concentrations for Sample Number 19

em. Wave-   Net Peak   Calculated    Interference    Net              Dilution
m. length   Intensity  Concentration  Correction   Concentration      Correction
```

m41

```
lyze Samples                                            12-04-1992 @ 02:30:12 -- 16


 396.152        37621         9.235                        9.235          9.235
 317.933        15336         9.100                        9.100          9.100
 259.94         56893         9.283                        9.283          9.283
 279.553       334388         9.176                        9.176          9.176
 257.61        173619         9.340                        9.340          9.340
 766.491         2410        11.337                       11.337         11.337
 588.995       204264        16.445                       16.445         16.445


V


gin Analysis - Sample Number 20

   Ele.  Wave-   Mean Peak  Mean Peak                    Net Peak
   Sym.  length  Position   Intensity                    Intensity

CCB



B


gin Analysis - Sample Number 20

   Ele.  Wave-   Mean Peak  Mean Peak                    Net Peak
   Sym.  length  Position   Intensity                    Intensity

    MN  257.61
        Off Peak Int.  =      820
        Off Peak Int.  =      798
                   No Peak!       834                          25
    FE  259.94     No Peak!      1343                        1343
    MG  279.553    No Peak!       416                         416
    CA  317.933    No Peak!      1310                        1310
    AL  396.152    No Peak!      3404                        3404
    NA  588.995      0.0006     67846                       67846
    K   766.491    No Peak!      1366                        1366

lculating Concentrations for Sample Number 20

em. Wave-    Net Peak   Calculated    Interference     Net            Dilution
m. length   Intensity  Concentration  Correction  Concentration      Correction

 396.152       3404        -0.052                   <     0.000 <         0.000
```

m42

```
alyze Samples                                          12-04-1992 @ 02:36:01 -- 17


 317.933             1310             -0.051                   <       0.010 <          0.010
 259.94              1343             -0.012                   <       0.010 <          0.010
 279.553              416             -0.003                   <       0.050 <          0.050
 257.61                25             -0.003                   <       0.000 <          0.000
 766.491             1366              0.977                           0.977            0.977
 588.995            67846              4.137                           4.137            4.137
28958-6



958-6


gin Analysis - Sample Number 21

    Ele.  Wave-   Mean Peak  Mean Peak                Net Peak
    Sym.  length  Position   Intensity                Intensity

     MN  257.61
        Off Peak Int.  =      837
        Off Peak Int.  =      811
                      0.0001       1718                    894
     FE  259.94       0.0001       9475                   9475
     MG  279.553     -0.0001     726530                 726530
     CA  317.933      0.0003     114954                 114954
     AL  396.152      0.0006       6255                   6255
     NA  588.995      0.0006     860031                 860031
     K   766.491      0.0000       2147                   2147

lculating Concentrations for Sample Number 21

em. Wave-    Net Peak    Calculated    Interference      Net           Dilution
m. length   Intensity  Concentration  Correction  Concentration      Correction

 396.152       6255          0.722                        0.722           0.722
 317.933     114954         74.099                       74.099          74.099
 259.94        9475          1.348                        1.348           1.348
 279.553     726530         19.954                       19.954          19.954
 257.61         894          0.044                        0.044           0.044
 766.491       2147          8.727                        8.727           8.727
 588.995     860031         75.612                       75.612          75.612
28958-6 SER DIL

ter Sample Weight     1

ter Sample Volume     4
```

m43

```
nalyze Samples                                          12-04-1992 @ 02:41:57 -- 18



958-6 SER DIL

gin Analysis - Sample Number 22

   Ele.  Wave-    Mean Peak  Mean Peak                    Net Peak
   Sym.  length   Position   Intensity                    Intensity

    MN  257.61
       Off Peak Int.   =       823
       Off Peak Int.   =       806
                    0.0000        1088                        273
    FE  259.94      0.0001        3483                       3483
    MG  279.553     0.0001      193562                     193562
    CA  317.933     0.0009       31037                      31037
    AL  396.152    No Peak!       4084                       4084
    NA  588.995     0.0006      268731                     268731
    K   766.491    No Peak!       1405                       1405

lculating Concentrations for Sample Number 22

lem. Wave-    Net Peak    Calculated    Interference       Net           Dilution
m. length    Intensity  Concentration   Correction   Concentration      Correction

 396.152         4084         0.133                         0.133           0.532
 317.933        31037        19.345                        19.345          77.380
 259.94          3483         0.346                         0.346           1.384
 279.553       193562         5.306                         5.306          21.224
 257.61           273         0.010                         0.010           0.040
 766.491         1405         1.364                         1.364           5.456
 588.995       268731        22.262                        22.262          89.048
ICS A

ter Sample Weight     2

ter Sample Volume     50



S A


in Analysis - Sample Number 23
```

m44

```
lyze Samples                                   12-04-1992 @ 02:44:47 -- 19


   Ele.  Wave-   Mean Peak  Mean Peak               Net Peak
   Sym.  length  Position   Intensity               Intensity

    MN  257.61
        Off Peak Int.  =     837
        Off Peak Int.  =     829
                  No Peak!         873                      40
    FE  259.94     0.0002        55766                   55766
    MG  279.553    0.0002       788665                  788665
    CA  317.933    0.0015        36344                   36344
    AL  396.152    0.0014        88012                   88012
    NA  588.995    0.0008        64757                   64757
    K   766.491   No Peak!        1284                    1284

lculating Concentrations for Sample Number 23

em. Wave-   Net Peak   Calculated    Interference    Net             Dilution
m. length   Intensity  Concentration  Correction  Concentration      Correction

 396.152      88012       22.912                       22.912          572.800
 317.933      36344       22.808                       22.808          570.200
 259.94       55766        9.094                        9.094          227.350
 279.553     788665       21.662                       21.662          541.550
 257.61          40       -0.002                  <     0.000 <          0.000
 766.491       1284        0.163                        0.163            4.075
 588.995      64757        3.858                        3.858           96.450
ICS AB



S AB


gin Analysis - Sample Number 24

   Ele.  Wave-   Mean Peak  Mean Peak               Net Peak
   Sym.  length  Position   Intensity               Intensity

    MN  257.61
        Off Peak Int.  =     890
        Off Peak Int.  =     863
                   0.0006         1334                     457
    FE  259.94     0.0003        53991                   53991
    MG  279.553    0.0003       788365                  788365
    CA  317.933    0.0014        34949                   34949
    AL  396.152    0.0013        84661                   84661
    NA  588.995    0.0007        64219                   64219
```

m45

```
lyze Samples                                      12-04-1992 @ 02:49:24 -- 20


   K   766.491   No Peak!        1326                     1326

lculating Concentrations for Sample Number 24

em. Wave-    Net Peak   Calculated    Interference      Net              Dilution
m. length   Intensity  Concentration  Correction   Concentration        Correction

 396.152       84661       22.003                        22.003           550.075
 317.933       34949       21.897                        21.897           547.425
 259.94        53991        8.797                         8.797           219.925
 279.553      788365       21.654                        21.654           541.350
 257.61          457        0.020                         0.020             0.500
 766.491        1326        0.580                         0.580            14.500
 588.995       64219        3.810                         3.810            95.250
 CCV



V


in Analysis - Sample Number 25

  Ele.   Wave-   Mean Peak  Mean Peak                   Net Peak
  Sym.   length  Position   Intensity                   Intensity

   MN  257.61
       Off Peak Int.   =    2456
       Off Peak Int.   =    2095
                    0.0005     213361                    211085
   FE  259.94       0.0002      68368                     68368
   MG  279.553      0.0001     392345                    392345
   CA  317.933      0.0015      18501                     18501
   AL  396.152      0.0009      44016                     44016
   NA  588.995      0.0009     182757                    182757
   K   766.491      0.0011       2388                      2388

lculating Concentrations for Sample Number 25

em. Wave-    Net Peak   Calculated    Interference      Net              Dilution
m. length   Intensity  Concentration  Correction   Concentration        Correction

 396.152       44016       10.971                        10.971           274.275
 317.933       18501       11.165                        11.165           279.125
 259.94        68368       11.203                        11.203           280.075
 279.553      392345       10.769                        10.769           269.225
```

```
N 257.61        211085        11.356                            11.356        283.900
 766.491          2388        11.119                            11.119        277.975
A 588.995       182757        14.505                            14.505        362.625
nter Sample Weight    1

nter Sample Volume    1



CV


gin Analysis - Sample Number 26

     Ele.  Wave-   Mean Peak  Mean Peak                  Net Peak
     Sym.  length  Position   Intensity                  Intensity

      MN   257.61
          Off Peak Int.   =    2538
          Off Peak Int.   =    2076
                       0.0003    203935                    201628
      FE   259.94      0.0001     66129                     66129
      MG   279.553     0.0006    383586                    383586
      CA   317.933     0.0016     18334                     18334
      AL   396.152     0.0008     42974                     42974
      NA   588.995     0.0010    178581                    178581
      K    766.491     0.0006      2424                      2424

lculating Concentrations for Sample Number 26

lem. Wave-    Net Peak   Calculated    Interference     Net           Dilution
ym. length   Intensity  Concentration   Correction  Concentration    Correction

L 396.152        42974       10.688                         10.688        10.688
A 317.933        18334       11.056                         11.056        11.056
E 259.94         66129       10.828                         10.828        10.828
G 279.553       383586       10.529                         10.529        10.529
N 257.61        201628       10.847                         10.847        10.847
 766.491          2424       11.476                         11.476        11.476
A 588.995       178581       14.128                         14.128        14.128


CV


gin Analysis - Sample Number 27
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M47

```
nalyze Samples                                         12-04-1992 @ 03:00:21 -- 22


   Ele.  Wave-    Mean Peak  Mean Peak                    Net Peak
   Sym.  length   Position   Intensity                    Intensity

    MN   257.61
        Off Peak Int.   =     2500
        Off Peak Int.   =     2117
                      0.0004    197815                      195506
    FE   259.94       0.0002     65340                       65340
    MG   279.553      0.0003    379071                      379071
    CA   317.933      0.0012     17778                       17778
    AL   396.152      0.0007     41144                       41144
    NA   588.995      0.0011    170057                      170057
    K    766.491      0.0016      2399                        2399

lculating Concentrations for Sample Number 27

lem. Wave-    Net Peak   Calculated    Interference    Net             Dilution
ym. length   Intensity  Concentration  Correction  Concentration      Correction

l 396.152       41144        10.191                       10.191          10.191
A 317.933       17778        10.694                       10.694          10.694
E 259.94        65340        10.696                       10.696          10.696
G 279.553      379071        10.405                       10.405          10.405
N 257.61       195506        10.518                       10.518          10.518
  766.491        2399        11.228                       11.228          11.228
A 588.995      170057        13.359                       13.359          13.359
 CCB




CB



gin Analysis - Sample Number 28

   Ele.  Wave-    Mean Peak  Mean Peak                    Net Peak
   Sym.  length   Position   Intensity                    Intensity

    MN   257.61
        Off Peak Int.   =     948
        Off Peak Int.   =     957
                    No Peak!      1025                          72
    FE   259.94     No Peak!      1574                        1574
    MG   279.553      0.0001       603                         603
    CA   317.933    No Peak!      1521                        1521
    AL   396.152    No Peak!      3934                        3934
```

m48

```
alyze Samples                                              12-04-1992 @ 03:04:29 -- 23


      NA  588.995     0.0009       58817                       58817
      K   766.491    No Peak!       1309                        1309

lculating Concentrations for Sample Number 28

em. Wave-    Net Peak   Calculated    Interference     Net              Dilution
m. length   Intensity  Concentration  Correction  Concentration        Correction

 396.152        3934         0.092                         0.092             0.092
 317.933        1521         0.086                         0.086             0.086
 259.94         1574         0.026                         0.026             0.026
 279.553         603         0.002                  <      0.050 <           0.050
 257.61           72         0.000                         0.000             0.000
 766.491        1309         0.411                         0.411             0.411
 588.995       58817         3.322                         3.322             3.322


CB

gin Analysis - Sample Number 29

     Ele.  Wave-    Mean Peak  Mean Peak                  Net Peak
     Sym.  length   Position   Intensity                  Intensity

      MN   257.61
           Off Peak Int.  =      924
           Off Peak Int.  =      910
                      No Peak!        964                        47
      FE   259.94     No Peak!       1542                      1542
      MG   279.553    No Peak!        466                       466
      CA   317.933    No Peak!       1495                      1495
      AL   396.152    No Peak!       3938                      3938
      NA   588.995     0.0007       56029                     56029
      K    766.491    No Peak!       1305                      1305

lculating Concentrations for Sample Number 29

em. Wave-    Net Peak   Calculated    Interference     Net              Dilution
m. length   Intensity  Concentration  Correction  Concentration        Correction

 396.152        3938         0.093                         0.093             0.093
 317.933        1495         0.069                         0.069             0.069
 259.94         1542         0.021                         0.021             0.021
 279.553         466        -0.001                  <      0.050 <           0.050
 257.61           47        -0.002                  <      0.000 <           0.000
```

m49

```
Analyze Samples                                        12-04-1992 @ 03:07:09 -- 24

  766.491        1305        0.372                            0.372          0.372
A 588.995       56029        3.071                            3.071          3.071
```

TITLE TSS

PROJECT NO. GC1

BOOK NO. 1931

SAMPLE	ID	AMT.	Wt. # 1	Wt. # 2	Wt. # 3	X̄ INITIAL Wt.
Blank	A	100ml	2.1795	2.1794		
28958-1	B	100ml	2.1060	2.1058		
-1 dup	C	100ml	2.1895	2.1893		
-2	D	100ml	2.1957	2.1955		
-3	E	100ml	2.1924	2.1922		
-4	F	100ml	2.2011	2.2008		
-5	G	100ml	2.0668	2.0664		
28959-1	H	100ml	2.3407	2.3403		
28967-1	I	100ml	1.9418	1.9414		
28969-	J	25ml ~~100ml~~	2.1162	2.1158		
			N. Sufian Rollins			11/18/92
Blank	K	100ml	2.0928	2.0930		
28981-4	L	100ml	2.1804	2.1805		
-4 dup	M	100ml	2.1103	2.1105		
-3	N	100ml	2.0332	2.0334		
28977-2	O	100ml	2.0919	2.0920		
-3	P	20ml	2.1706	2.1708		
-4	Q	100ml	2.0531	2.0533		
28970-1	R	70ml	2.1780	2.1781		
28972-1	S	100ml	2.1636	2.1637		
28978-1	T	100ml	2.1276	2.1278		
-2	U	100ml	2.1854	2.1856		
8987-1	V	100ml	2.0974	2.0975		
			N. Sufian Rollins		11/19/92	

GRAPHIC PRODUCTS CHICAGO

SIGNATURE | DATE

DISCLOSED TO AND UNDERSTOOD BY | DATE | WITNESS | DATE

GC2

TITLE

PROJECT NO.

BOOK NO. 1931

FINAL Wt.

ID	Wt. #1	Wt #2	Wt. #3	$\bar{X}$ FINAL WT. ~~Wt #4~~	PPB
A	2.1791	2.1791			3000
B	2.1687	2.1689			629,000
C	2.2523	2.2524			630,000
D	2.2683	2.2684			728,000
E	2.1931	2.1930			7,000
F	2.2013	2.2012			2,000
G	2.0743	2.0743			77,000
H	2.3407	2.3406			1,000
I	1.9419	1.9416			2,000
J	2.1290	2.1288			286,667
K	2.0928	2.0928			1,~~0~~00 10,000
L	2.1806	2.1804			~~0~~ ~~1,000~~ ↓
M	2.1105	2.1103			~~0~~
N	2.0335	2.0334			1,000
O	2.1003	2.1001			82; 000
P	2.2512	2.2512			4,025,000
Q	2.0567	2.0565			34,000
R	2.1894	2.1892			161,429
S	2.1698	2.1696			61,000
T	2.1286	2.1284			8,000
U	2.1892	2.1890			36,000
V	2.1112	2.1110			137,000

11/19/92

...TIFIC BINDERY PRODUCTS CHICAGO

SIGNATURE **DATE**

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TITLE Hardness

PROJECT NO. GC3

BOOK NO. 1925

continued from Page ______

N EDTA = 0.02 => chk 0.0198

Sample	Amt	Initial Titrant	Final Titrant	Total Titrant	Hardness (ppb)
Blank	50	0.00	0.01	0.01	10004
$CaCO_3$ chk	10	0.00	10.08	10.08	0.0198
28980-1	50 ~~50~~ 40	0.00	3.10	3.10	61,380
28958-1	25	2.00 ~~0.00~~ 40	7.00	5.00	198,000
-2	25	0.00	4.00	4.00	158,400
-3	25	5.00	11.30	6.30	249,480
-4	25	0.00	4.50	4.50	178,200
-5	25	0.00	4.80	4.80	190,080
-6	25	5.00	11.00	6.00	237,600
28980-1 Dup	25	0.00	1.80	1.80	71,280

Yvette O'Hara 12/1/92

Work continued to Page ______

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DATE

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DATE

WITNESS

DATE

GC4

TITLE Sulfate

PROJECT NO.

BOOK NO. 1790

STD	Absorbance	Blank corrected
Blank	0.069	–
1.0	0.087	0.018
5.0	0.136	0.067
15	0.249	0.180
30	0.405	0.336
40	0.496	0.427

Corr = 0.9991
Slope = 0.011
y int = 0.0144

Sample	Amt	F.V.	D.F.	Abs.	Blank Corrected	PPB	Comments
28942-1	1.0	50	1:50	0.334	0.265	1192,660	20g/20mls
-1MS	↓	↓	↓	0.462	0.393	(31.26) 100%	(31.46)
-1MSD	↓	↓	↓	0.460	0.391	(31.07) 99% 1% RPD	↓ 2
28958-1	0.5	50	1:100	0.435	0.366	3346,557	
-1MS	↓	↓	↓	0.493	0.424	(32.29) 103%	(31.42)
-1MSD	↓	↓	↓	0.491	0.422	(32.10) 102%	1% RPD 2
-2	0.5	50	1:100	0.551	0.482	~~4450,550~~	
-3	25	50	1:2	0.413	0.344	62,744	
-4	1.0	50	1:50	0.230	0.161	697,767	
-5	1.0	50	1:50	0.239	0.170	740,594	
-6	25	50	1:2	0.459	0.390	71,499	
-2RR	0.25 40 ~~[illegible]~~	50	1:200	0.330	0.261	4494,504	Report this YO
Plasma Chem STD	50	50	–	0.399	0.330	98% (30.04)	30 ppm (30.61)

spk = 40 mls of 610 ppm
~~1810 mls of sample~~ YO
10 mls of sample

SCIENTIFIC BINDERY PRODUCTS CHICAGO

SIGNATURE Yvette O Garro
DATE 12/2/92

DISCLOSED TO AND UNDERSTOOD BY
DATE
WITNESS
DATE

TITLE TDS

PROJECT NO. GC5

BOOK NO. 1745

SAMPLE	ID	Amt.	Wt. 1	Wt. 2	Wt. 3	$\bar{X}$ FINAL Wt
28917-2	D9	100 ml	69.7992	69.7992		
28919-3	Z7	100 ml	68.9360	68.9360		
-4	AM	100 ml	73.4501	73.4500		
-5	Cr	100 ml	70.6216	70.6214		
28920-1	Q	100 ml	60.1713	60.1712		
28934-1	G_2	100 ml	77.5386	77.5396	77.5394	
	~~Yb~~		~~68.6990~~	~~68.6998~~	~~Yb 68.6997~~	
	~~G~~		~~67.0502~~ ~~[illegible]~~	~~67.0509~~	~~67.0505~~	Void NSR
	~~Q_2~~		~~76.1079~~	~~76.1086~~	~~76.1083~~	
			N. Sufian Rollin		11/13/92	
Blank	33	100 ml	78.5730	78.5727		
28937-1	34	~~100~~ 50 ml	78.7238	78.7236		
-1 dup	36	50 ml	78.1683	78.1686		
	~~B2~~		~~73.2614~~	~~73.2618~~	Void NSR	
			N. Sufian Rollin		11/16/92	
Blank	B_2	100 ml	73.2620	73.2620		
28958-1	30	100 ml	76.7408	76.7405		
-1 dup	K	100 ml	75.2030	75.2029		
-2	31	100 ml	74.5443	74.5443		
-3	PM	100 ml	72.6180	72.6170	72.6172	
-4	H_2	100 ml	76.3585	76.3583		
-5	32	100 ml	73.4069	73.4066		
			N. Sufian Rollin		11/18/92	
28987-2	Sb	100 mls	67.9900	67.9900	—	67.9900
3	AM	100 mls	69.1679	69.1679	=	69.1679
4	F	100 mls	69.1673	69.1673	=	69.1673

SIGNATURE R

DATE

DISCLOSED TO AND UNDERSTOOD BY

DATE

WITNESS

DATE

TITLE TDS

PROJECT NO. GC6

BOOK NO. 1745

ID	wt #1	wt #2	wt #3	wt. #4	$\bar{x}$ FINAL	PPB
D9	69.8296	69.8292				302,000
27	68.9985	68.9985				625,000
AM	73.4667	73.4665				166,000
Cr	70.6499	70.6498				283,000
Q	60.2230	60.2226				516,000
G2	77.5601	77.5598				205,000
33	78.5724	78.5735	78.5738			7,500
34	78.7296	78.7318	78.7324	78.7327		178,000
36	78.1755	78.1773	78.1778			184,000
B2	73.2616	73.2618				3,000
30	77.8880	77.8881				1,473,000
K	76.3499	76.3499				1,469,000
31	76.2150	76.2150				16,707,000
PM	72.6620	72.6622				450,000
H_2	76.6043	76.6043				2,459,000
32	73.6600	73.6601				2,533,000
Sb	68.0183	68.0183				283,000
AM	69.2164	69.2164				485,000
P	69.1968	69.1968				295,000

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DATE

DISCLOSED TO AND UNDERSTOOD BY

DATE

WITNESS

DATE

TITLE pH

PROJECT NO. GC7

BOOK NO.

Date	Sample	PH	Calibration
11/17/92	28969-1	7.18 ①	4.00-set 7.00 set 10.00 → 9.96
	28967-1	8.39 ①	10-set ~~4.00 set~~ 7.00 set ↓ · 4.00 - 4.02
	28958-1	9.36 ②	
	-2	9.39 ②	
	-3	~~[illegible]~~ ① ⇒ 7.67	
	-3dup	~~[illegible]~~ ①	
	4	8.48 ①	
	5	8.75 ②	

11/17/92

11/18/92	28808-11	10.65		Calibration
	28887-2	6.56	50.10 gm	① 7.00-set, 4.00-set
	28805-25	7.67	20.01g	10 - 10.10
	28805-26	7.92	20.03g in 50 ml DI H_2O	
	28902-1	7.82	50.06g	

② 7.00-set
10.0 set
4.00 - 3.88

11/18/92	28977-1	7.28	② ↓
	-3	7.04	
	-4	7.49	
	28976-1	6.03	
	-2	6.47	
	-3	6.52	

Next page

SIGNATURE

DATE

DISCLOSED TO AND UNDERSTOOD BY

DATE

WITNESS

DATE 12/7/92

APPENDIX C

12.3 Adirondack Environmental Laboratory Report

AnalytiKEM An American NuKEM Company

28 Springdale Road
Cherry Hill, New Jersey 08003
(609) 751-1122 • (215) 923-2068
Fax: (609) 751-0824

Chain-of-Custody

454 South Anderson Road BTC 532
Rock Hill, South Carolina 29730
(803) 329-9690
Fax: (803) 329-9689

Client RICH SCHLAUCH

Project: SALT KILL

NORLITE ~~AnalytiKEM~~ Contact DICK FRANKLIN

SAMPLE DESIGNATION	DATE	MATRIX	40 ml vials	950 ml Org. Pres.	ml Unpres.	ml Unpres.	ml HNO_3	ml H_2SO_4	ml H_2SO_4	ml NaOH			PARAMETERS
C 2	11/23/92	SOLID POWDER	X										EDS ANALYSIS FOR COMPOUNDS PER ATTACHED SHEET ($CaCO_3$ as a Minimum)
E 2	11/23/92	SOLID POWDER	X										EDS ANALYSIS FOR COMPOUNDS PER ATTACHED SHEET ($CaCO_3$ as a Minimum)
F 1	11/23/92	SOLID GRANULAR	X										EDS ANALYSIS PER ATTACHED SHEET
F 2	11/23/92	SOLID POWDER	X										EDS ANALYSIS PER ATTACHED SHEET

I. Field Measurements:

Data Sheets: Y N

Filtered: Y Not Required

II. Field Conditions/Comments: All samples have been separated from creek water by laboratory filtration and dried at 104° C.

III. Special Instructions: Note: If all compounds per attached sheet cannot be analyzed
(Detection Limits, Data Package, etc.)
due to limited sample quantity for C2 & E2, analyze $CaCO_3$ as the priority compound.

Relinquished By:	Time/Date:	Received By:	Time/Date:
R. Schlauch	11:00 AM Nov. 23, 1992		

TO: Dick Franklin
Norlite

FROM: Rich Schlauch
THERMALKEM

DATE: Oct. 20, 1992

PAGES: 1

IF THIS FAX IS RECEIVED INCOMPLETE, PLEASE CALL RICH
AT 803/324-5310.

THANK YOU!

Dick; Please have the lab give price for the following by x-ray diffraction (etc.) as an alternative to individual elements.
Determine percentages of following compounds plus total carbon in oven dried sediment.

---

calcium carbonate - $CaCO_3$
magnesium oxide - MgO
manganese dioxide - MnO_2
aluminum oxide - Al_2O_3
iron(III) oxide - Fe_2O_3

calcium sulfite - $CaSO_3 \cdot \frac{1}{2} H_2O$
calcium sulfate - $CaSO_4$
magnesium metasilicate - $MgSiO_3$
manganese metasilicate - $MnSiO_3$
iron orthosilicate - Fe_2SiO_4
aluminum silicate - $Al_2O_3 \cdot SiO_2$

Total Carbon - T-C

Thanks,
Rich

Adirondack Environmental Services, Inc.
314 North Pearl Street
Albany, New York 12207
518-434-4546/434-0891 FAX

A full service analytical research laboratory offering solutions to environmental concerns

LABORATORY REPORT

for

Norlite Corporation
628 Saratoga Street
Cohoes, New York 12047

Attention: Mr. Dick Franklin

Report Date: 01/19/93
Number of samples analyzed:04
AES Project ID:921208LC

Adirondack
Environmental Services, Inc.

314 North Pearl Street
Albany, New York 12207
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X-RAY DIFFRACTION ANALYSIS OF POWDER SPECIMENS

ABSTRACT

Four powder specimens designated C-2, E-2, F-1 and F-2 were submitted for analysis using x-ray diffraction (XRD) techniques. The purpose of the analysis was to (1) determine chemical composition and (2) report quantitative data relative to twelve compounds of specific interest for each powder specimen.

TEST RESULTS

The following information was provided during examination of the powder specimens:

EDS: Energy dispersive x-ray spectroscopy (EDS) analysis is performed prior to x-ray diffraction (XRD) to expedite diffractogram interpretation. The EDS elemental profiles are presented with the diffractograms within this report. All four powder specimens produced EDS data which indicates calcium and silicon concentrations with traces of magnesium, aluminum, sulfur, potassium, titanium, manganese and iron.

XRD: Calcium carbonate and quartz concentrations were positively identified for all four powder specimens; quantitative determinations are provided in Figure One within this report. Identification and/or quantification for the other 10 compounds of interest could not be obtained using standard XRD procedures since these concentrations are less than the limit of detection (3% by weight).

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XRD QUANTITATIVE DATA

Compound	Smpl. C-2	Smpl. E-2	Smpl. F-1	Smpl. F-2
$CaCO_3$	78.73%	7.83%	52.14%	31.32%
SiO_2	12.29%	58.32%	26.25%	43.12%
MgO	BDL	BDL	BDL	BDL
MnO_2	BDL	BDL	BDL	BDL
Al_2O_3	BDL	BDL	BDL	BDL
Fe_2O_3	BDL	BDL	BDL	BDL
$CaSO_3$	BDL	BDL	BDL	BDL
$CaSO_4$	BDL	BDL	BDL	BDL
$MgSiO_3$	BDL	BDL	BDL	BDL
$MnSiO_3$	BDL	BDL	BDL	BDL
Fe_2SiO_4	BDL	BDL	BDL	BDL
Al_2O_3	BDL	BDL	BDL	BDL

BDL - Below Detection Limit of 3% by weight

FIGURE ONE

Adirondack Environmental Services, Inc.
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Albany, New York 12207
518-434-4546/434-0891 FAX

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SPECIMEN PREPARATION

Representative powder sample was packed into graphite crucibles and subjected to energy dispersive x-ray spectroscopy (EDS) analysis in the scanning electron microscope. These sample mounts were then submitted for x-ray diffraction (XRD) analysis.

XRD ANALYSIS

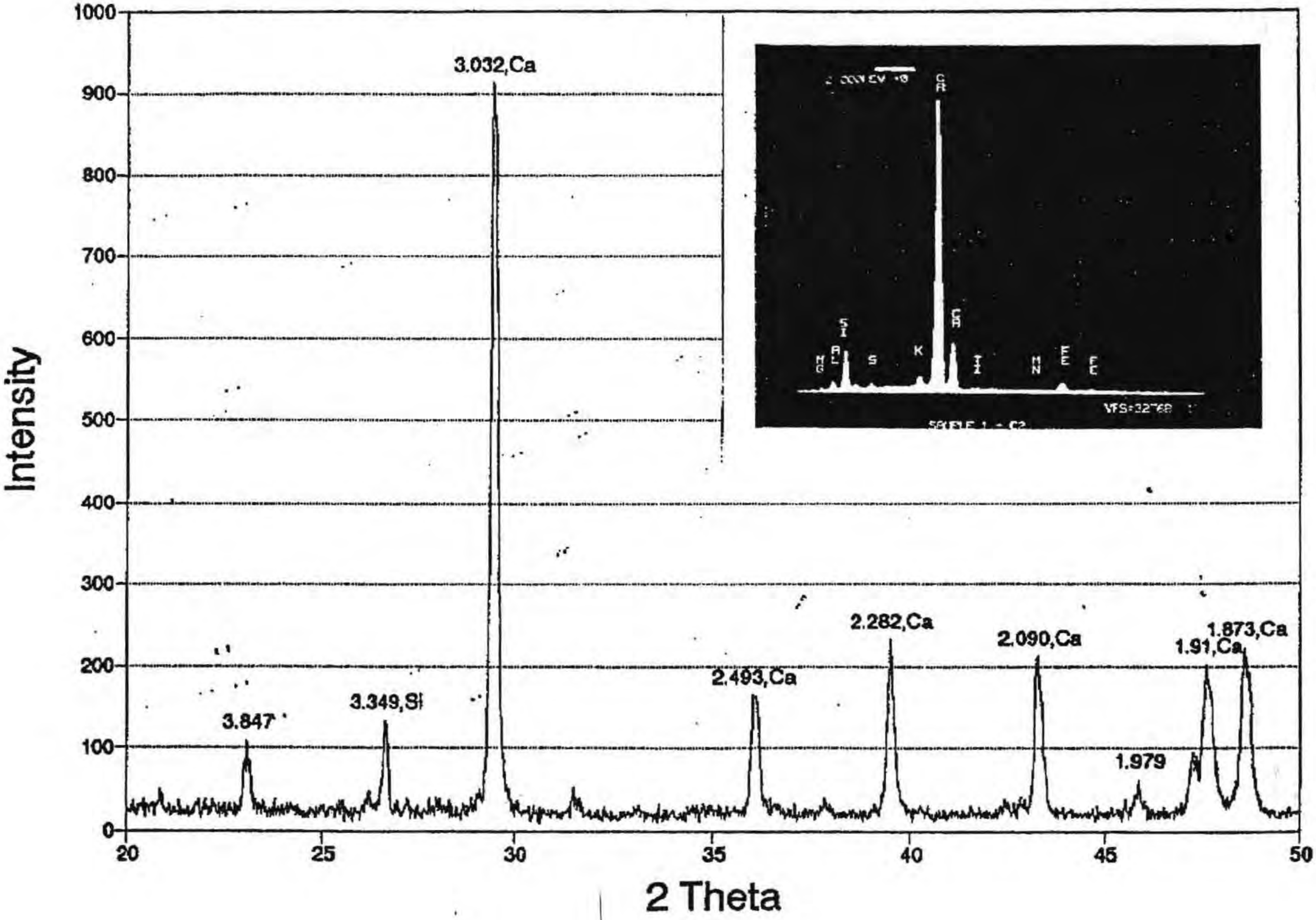
The samples were subjected to a 40kV copper x-ray source from 20 through 50 degrees two-theta. The JCPDS indexing system was used to identify the peaks recorded on the XRD diffractograms (Figures Two through Five). A computer program was implemented to transfer reported integral counts beneath the XRD peak positions to concentration data.

Adirondack Environmental Services, Inc.

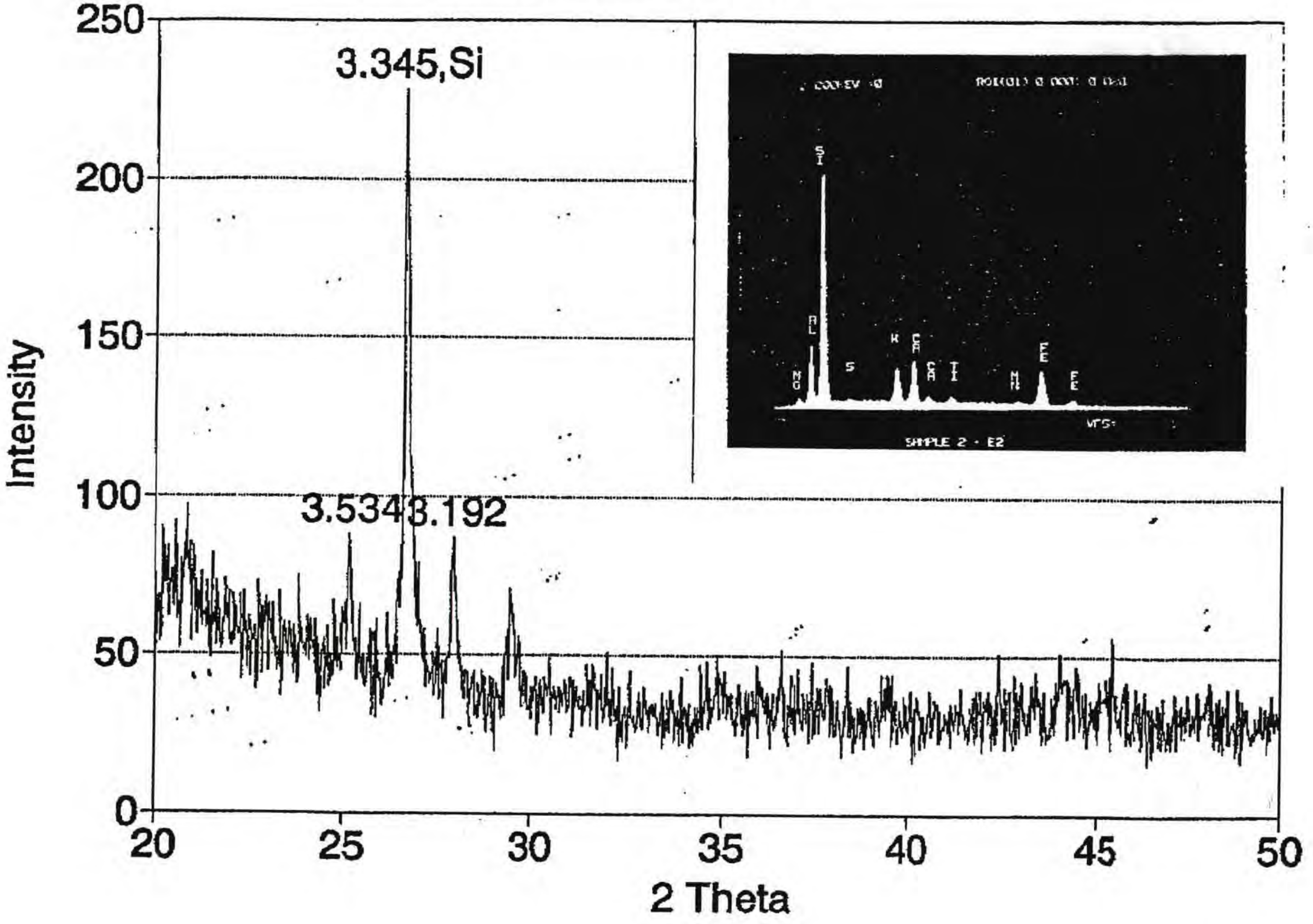
Thomas K. Ware
Laboratory Manager

Norlite Corporation
AES Report No. 921208LC

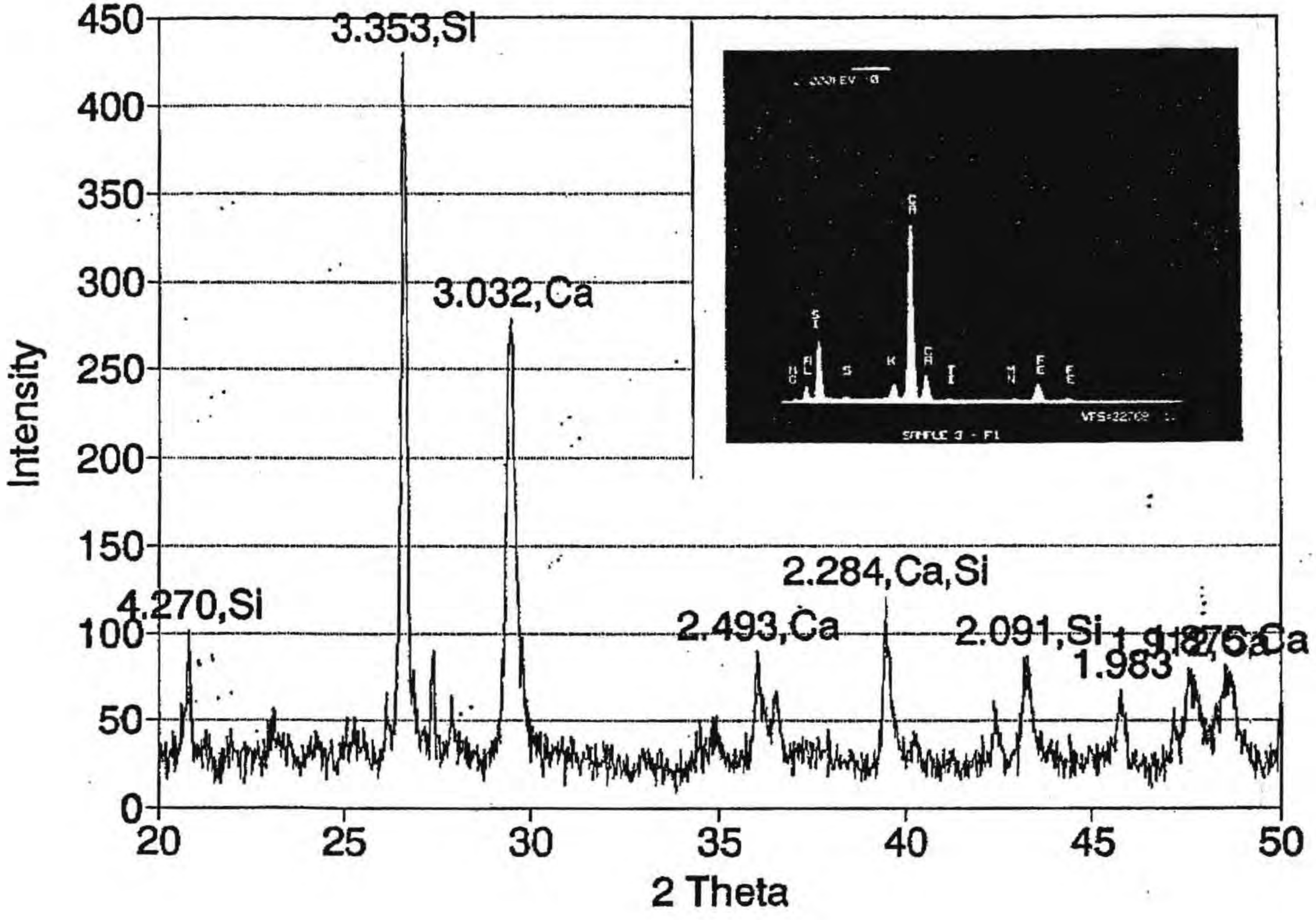
921208 LC 01


Intensity
1000
900
800
700
600
500
400
300
200
100
0
20
25
30
35
40
45
50
2 Theta
3.032,Ca
3.847
3.349,Si
2.493,Ca
2.282,Ca
2.090,Ca
1.979
1.91,Ca
1.873,Ca
CA
SI
AL
MG
S
K
CA
TI
MN
FE
FE
VFS=32768

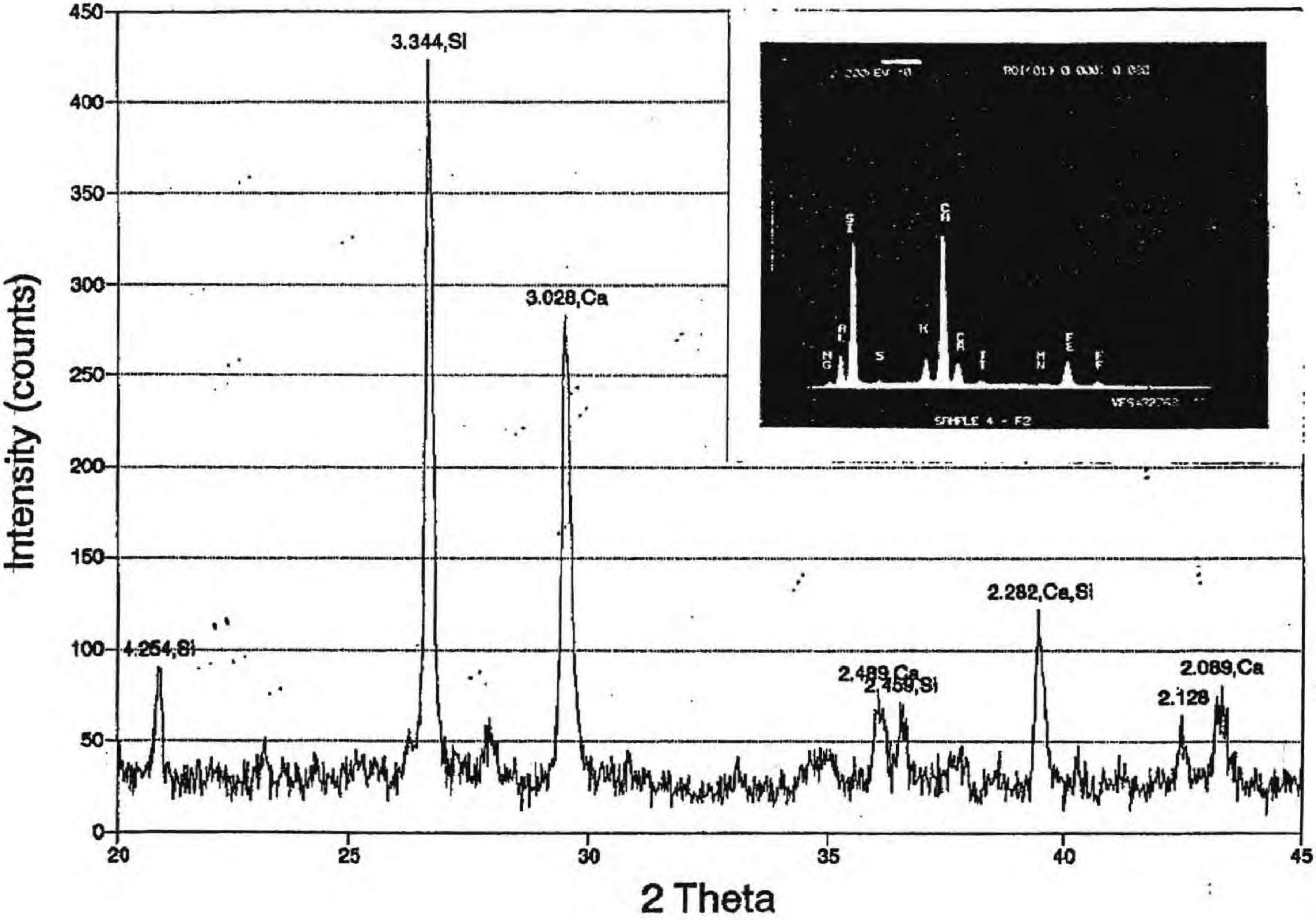
921208 LC 02


Intensity
250
200
150
100
50
0
20
25
30
35
40
45
50
2 Theta
3.345,Si
3.534
3.192
SI
AL
MG
S
K
CA
CA
TI
MN
FE
FE
VFS=
SAMPLE 2 - E2

911208 LC 03


Intensity
450
400
350
300
250
200
150
100
50
0
20
25
30
35
40
45
50
2 Theta
3.353,Si
3.032,Ca
4.270,Si
2.493,Ca
2.284,Ca,Si
2.091,Si
1.983
1.875,Ca
SI
AL
S
K
CA
CA
TI
MN
FE
FE
VFS=22708
SAMPLE 3 - F1

921208 LC 04



Intensity (counts)
450
400
350
300
250
200
150
100
50
0
20
25
30
35
40
45
2 Theta
3.344,Si
3.028,Ca
4.254,Si
2.489,Ca
2.459,Si
2.282,Ca,Si
2.128
2.089,Ca
SI
CA
AL
MG
S
K
CA
TI
MN
FE
FE
SAMPLE 4 - F2

AES NO: 921208 LC

Adirondack Environmental Services, Inc.

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Albany, New York 12207
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CHAIN OF CUSTODY RECORD

CLIENT NAME NORLITE CORPORATION

PROJECT NAME (Location)

SAMPLERS' (Name) FRANK W. KOVACS

ADDRESS Cohoes, N.Y. 12047

PO NUMBER

SAMPLERS: (Signature) Frank W Kovacs

AES SAMPLE NUMBER	CLIENT SAMPLE IDENTIFICATION & LOCATION	DATE SAMPLED	TIME A=a.m. P=p.m.	SAMPLE TYPE MATRIX	COMP	GRAB	NUMBER OF CONT'S	ANALYSIS REQUIRED
921208LC01,2	C-7 & E-7	11-23-92	A P	?		X	2	Calcium Carbonate
LC03,4	E7 & F2	11-23-92	A P	?		X	2	*See Below

Analysis for the following MATERIAL VIA XRD

* $CaCO_3$; MgO; MnO_2; $CaSO_3$;
Al_2O_3; Fe_2O_3; Calcium Sulfites;
$CaSO_4$; $MgSiO_3$; $MnSiO_3$;
Fe_2SiO_4; $Al_2O_3 \cdot SiO_2$

*If ANY Question
CALL FRANK KOVACS
Thank you
FWK

Turnaround Time 10 DAYS

Laboratory Approval:

Relinquished by: (Signature)	**Received by:** (Signature)	**Date/Time**
Relinquished by: (Signature)	**Received by:** (Signature)	**Date/Time**
Relinquished by: (Signature)	**Received by:** (Signature)	**Date/Time**

Dispatched by: (Signature)	**Date/Time**	**Received for Laboratory by:**	**Date/Time** 12/7/92 | 3:30
Method of Shipment:		**Send Report To:** Dick Franklin	**Client Phone No.:** 235-0401

The Laboratory reserves the right to return hazardous samples to the client or may levy a fee of $10.00 per container for disposal.

WHITE - Lab Copy YELLOW - Sampler Copy PINK - Generator Copy

Adirondack Environmental Services, Inc.

APPENDIX D

12.4 Laboratory Bench Test and Jar Test Data American NuKEM Wastewater Treatment Laboratory, Rock Hill, SC

AnalytiKEM An American NuKEM Company

28 Springdale Road
Cherry Hill, New Jersey 08003
(609) 751-1122 • (215) 923-2068
Fax: (609) 751-0824

Chain-of-Custody

454 South Anderson Road BTC 532
Rock Hill, South Carolina 29730
(803) 329-9690
Fax: (803) 329-9689

Client: RICH SCHLAUCH

Project: SALT Kill

NORLITE ~~AnalytiKEM Contact~~: R.H. FRANKLIN

SAMPLE DESIGNATION	DATE	MATRIX	40 ml vials	950 ml Org. Pres.	ml Unpres.	ml Unpres.	ml HNO_3	ml H_2SO_4	ml H_2SO_4	ml NaOH	1GAL UNPRES		PARAMETERS
C	11/13/92	WATER									X		
B1	11/13/92										X		Sent to analytiKEM Cherry Hill after receipt.
E	11/13/92										X		
F	11/13/92										X		

Note: Due to missing sample of B.1 in package sent from Norlite to analytiKEM Cherry Hill N.J. I am Federal Expressing most of the above 1-gallon of B.1 to analytiKEM for general chemistry and metals analysis indicated on attached table

I. Field Measurements:

Data Sheets: Y N

Filtered: Y Not Required

II. Field Conditions/Comments: RICH THESE ARE THE SAMPLES YOU REQUESTED. 11/13/92

III. Special Instructions:
(Detection Limits, Data Package, etc.)

Relinquished By:	Time/Date:	Received By:	Time/Date:
	5:30 11/13/92	FED X-PRESS Richard Schlauch	Nov. 17, 1992 / 1:30 PM
B.1 only R. Schlauch	9:00 AM 11/19/92		

PROJECT Study of Precipitate Observed in Salt Kill Creek

Continued From Page

Scrubber Blowdown (Outfall 005) and Salt Kill Water + bottom sediments study. Samples collected 11/9-13/92 By Norton Staff (i.e. Rick Franklin & Frank Kovacs).

Sample Measurement and Analysis upon receipt at ThermalKEM WWT Lab, Rock Hill SC (Supernatants) Nov. 17 1992 2:00 PM

Sample	ICP Ca++ ppm as CaCO3	pH	Temp	Conductivity
B.1	175 ppm	8.46 ~~[illegible] µS/cm~~	10.5 ~~11~~ °C	750 ~~[illegible]~~ µS/cm
C.		8.82	10.5°C	2870 µS/cm
E.		8.30	10.5°C	675 µS/cm
F.		8.88	11.0°C	3,590 µS/cm

Liquid - Solids Separations Nov. 18, 1992

~~Wet~~

Coarse Solids (+100 mesh or > 0.15 mm dia.)

Sample	Settled Solids Vol	Supernatant Liquid Volume ~~[illegible]~~	Wet solids wt.	104°C Dry solids wt.
C.1	0.35 ml/l	3650 ml	Al dish = 153.266g Dish + solids = none (Diff) Solids = observed	none observed
E.1	< 0.1 ml/l	3600 ml	Al Dish = 152.277 ~~152.278~~ Dish + solids = mostly H2O 153.128 (Diff) Solids = 0.841g	Trace 152.284 ~~152.[illegible]~~
F.1	950 ml/l	3200 ml	Al dish = 151.999 Dish + solids = 467.583 (Diff) Solids =	345.426g

Continued on Page

Read and Understood By

Richard Schlenck Nov. 19, 1992 | Peter J. Carter Nov. 23, 1992

Signed Date Signed Date

PROJECT Study of Precipitate Observed in Salt Kill Cells

Notebook No. APCSS-1

Continued From Page 17

Liquid-Solid Separations (continued)

Whatman GF/A 12.5 cm paper

Fine Solids (-100 mesh + 1.6 micron or 0.0016 to 0.15 mm)

104°C

Sample	Vol of Settled Solids Filtered	Vol of Filtrate	Wet Cake Wt	Dry Cake Wt.
C.2		0.674 153.270 ~~[illegible]~~ g 159.464 5.52 g	wt filter = 0.096 g ~~[illegible]~~5 g wt pan = 1.439 g total solids + pan + filter = 2.129 g (Diff) solids = 0.594	1.553 g - 1.535 g = 0.018 g 154.294 g - 153.944 = 0.350 total dry wt = 0.368 g
E.2		+ 0.354 g	wt filter 0.096 ~~0.356~~ g wt pan = 1.444 g total solids + pan + filter = 3.025 g (Diff) solids =	2.000 g - 0.450 g (2 filters) 1.55 g - 1.444 g total dry wt 0.106 g
F.2			wt filter = 0.685 g wt pan = 152.855 g total solids + pan + filter = ~~[illegible]~~ 428.614 g (Diff) solids =	350.165 ~~[illegible]~~ g - 196.625 g

Continued on Page

Read and Understood By

Richard Schlesinger Nov. 19, 1992
Signed Date

Pete J Carter Nov. 23, 1992
Signed Date

PROJECT Study of Precipitate Observed in Salt Kill Notebook No. AFCSS-1

Continued From Page 18

Sample. Calculations of Total Suspended Solids

C. Initial Volume of Sample = 3.65 liters

Total dry wt of precipitated solids = 0.368 g

$$\frac{0.368\,g}{3.65\,liter} = \frac{0.1008\,g}{liter} \times 1000 = \frac{100.8\,mg}{liter}\ TSS$$

E. Initial Volume of Sample = 3.6 liters

Total dry wt of suspended = 0.106 g

$$\frac{0.106}{3.6} = \frac{0.0294\,g}{liter} \times 1000 = \frac{29.4\,mg}{liter}\ TSS$$

F. Initial Volume of Sample = 3.2 liters

Total dry wt of suspended solids = 196.625 g

$$\frac{196.625\,g}{3.2\cancel{00}\,L} \cdot \frac{61.445\,g}{L} = 6.1\ \%\ solids$$

Continued on Page

Read and Understood By

Richard Schlauch Nov. 20, 1992 Nov. 23, 1992

Signed Date Signed Date

PROJECT Study of Precipitate Observed in Salt Kill Creek

Notebook No. APCSS-1

Continued From Page 19

Upstream Sample E. Filtrate 3600 ml + ~500 ml of B-1
Jar Tests

ICP Test # 1 Room Temp Variable Na_2CO_3 Dosages

ICP Ca ppm as $CaCO_3$		Samp #	375 ml pH	Na_2CO_3 soln		After mix ~~and settle~~ at Equilibrium pH	~~Equilibrium~~	TSS
A 20.9	71°F	1	8.14	+ 50 ml @ 0.5% (= 0.25 g Na_2CO_3)	440 ml	10.21	filt + pan = 1.769 g total dry = 1.825 g } $\frac{0.056}{0.44}$	= 127 mg/l ~~149 mg/l~~
B 15.1 ppm	71°F	2	8.15	+ 50 ml of 2.0% (= 1 g Na_2CO_3)	440 ml	10.76	filt + pan. = 1.725 g 1.792 g } $\frac{0.067}{0.44}$	= 152 mg/l ~~153 mg/l~~
C 16.3 ppm	71°F	3	8.15	+ 50 ml @ 5.0% (= 2.5 g Na_2CO_3)	435 ml	10.96	filt + pan = 1.791 g 1.861 g } $\frac{0.070}{0.44}$	= 159 mg/l ~~160~~ ~~167~~

Mix 20 min let settle min. About 5 min mixing before ppt is evident.
measure pH
Filter for TSS & filtrate metals analysis

ICP Ca++ ppm as $CaCO_3$

Test # 2 ~~120~~ 110 °F Const. Na_2CO_3 Dosage Var. pH

	375 ml Samp #	pH	NA_2CO_3 soln	pH		TSS
51.5 ppm A	4	8.1	+ 50 ml @ 0.5%	8.14	0.1 ml HCl ~~added HCl~~	filt + pan = 1.765 g total dry = 1.812 g } $\frac{0.047}{0.44}$ = 107 ppm
14.8 ppm B	5		+ 50 ml @ 0.5%	8.96		filt + pan = 1.721 g total dry = 1.786 g } $\frac{0.065}{0.44}$ = 148 ppm
4.4 ppm C	6		+ 50 ml @ 0.5%	9.88		filt + pan = 1.792 g total dry = 1.861 g } $\frac{0.069}{0.44}$ = 157 ppm

Note: Precipitation evident after 15 to 30 seconds of mix.

ICP Ca++ ppm as $CaCO_3$

Test # 3 110°F Var. pH w/ NaOH

	pH	Samp			pH	TSS
73.5 ppm D	8.2	7	300 ml add 26% NaOH		8.61	filt + pan = 1.721 g total dry = 1.751 g } $\frac{0.03}{0.3}$ = 100 mg/l
5.4 ppm E	8.2	8	300 ml add 26% NaOH		10.13	filt + pan = 1.795 g total dry = ~~1.848~~ 1.846 g } $\frac{0.051}{0.3}$ ~~0.053~~ 170 ~~177~~ mg/l
170 ppm F		9	200 ml Raw	filtered	8.15	filt + pan = 1.758 g total dry = 1.759 g } $\frac{0.001}{0.2}$ = 5 mg/l

Precipitation evident after 30 seconds of mixing

Continued on Page

Read and Understood By

Richard Schlander Nov. 23, 1992 Peter Carter Nov 23 1992

Signed Date Signed Date

PROJECT Study of Precipitate Observed in Salt Kiln
Notebook No. ______
Continued From Page ______

Dec. 4, 1992

Simulated Scrubber ~~Blowdown~~ Solution Neutralization with Caustic soda (NaOH) vs soda ash (Na_2CO_3).

Scrubber BD/Make-up = 60 GPM = 31,226 lbs/hr.
avg Cl_2 in LGF = 3.5% of LGF = 338 lbs/hr Cl^- in B.D.

$\frac{338 \text{ lbs}}{31,226 \text{ lbs}}$ = 0.0108 = 1.1% chloride solution.

HCl feed solution = 36% NaOH = 24% (approx)
Prepare 10% Na_2CO_3 solution by dissolving 10 grams of [illegible] soda ash in 100 ~~grams of~~ ml of H_2O.

Prepare 1.1% HCl solution by diluting 3 ml HCl to 100 ml w/H_2O
∴ Prepare 400 ml of 1.1% HCl by diluting 12 ml HCl to 100 ml w/H_2O.

Titration of 200 mls 1.1% HCl solution pH = 0.36 at 130°F to 150°F with:

24% ~~24%~~ NaOH solution			10% Na_2CO_3 solution					
pH	temp °F	mls titrant	pH	temp °F	mls titrant	pH	temp °F	mls titrant
0.35	120°F	0	0.35	120°F	0	8.85	150°F	38.0 mls
1.04	130°F	6.4 mls	0.45	132°F	6.0 mls	8.99	150°F	38.4 mls
2.40	132°F	7.9 mls	0.52	136°F	10.0 mls	9.16	150°F	39.0 mls
3.50	135°F	7.95 mls	0.60	137°F	14.0 mls	9.26	150°F	39.5 mls
10.70	136°F	8.1 mls	0.75	144°F	20.0 mls	9.76	147°F	46.0 mls
			0.89	147°F	24.0 mls	9.80	147°F	47.0 mls
			1.10	148°F	28.0 mls	9.83	147°F	48.0 mls
			1.25	150°F	30.0 mls	9.89	147°F	50.0 mls
			1.53	152°F	32.0 mls	9.94	147°F	52.0 mls
			2.07	151°F	34.0 mls	9.98	147°F	54.0 mls
			5.25	152°F	35.1 mls	10.01	147°F	56.0 mls
			6.21	152°F	36.0 mls	10.04	147°F	58.0 mls
			7.10	151°F	36.8 mls	10.07	147°F	60.0 mls
			7.50	151°F	37.0 mls	10.12	148°F	66.0 mls
			8.10	151°F	37.15 mls	10.13	150°F	68.0 mls
			8.52	151°F	37.50 mls	10.14	150°F	70.0 mls

Continued on Page

Read and Understood By

Richard Schlanck	Dec 4, 1992		
Signed	Date	Signed	Date

PROJECT Study of Precipitate Observed in Salt Kill Creek

Notebook No. APC SS-1

Continued From Page 21

Titration test for pH adjustment
of Scrubber solution from neutral
to pH 9.5 with Na_2CO_3 vs NaOH
at Thermal KEM S.C. WWT Lab

Jan 18, 1992
9:00 AM
collect sample 500 ml of
scrubber solution.

500 ml sample = cond 53.6 mS at 127°F TDS = ~ 4.1%

pH = 10.05

Add 0.9 ml 35% HCl = pH 7.03 at 144°F

Sodium Carbonate 10% solution (100mg/ml)

mls	ppm	pH	Temp °F
0.5	100	7.60	147
1.0	200	8.06	150
1.5	300	8.33	150
2.0	400	8.50	150
2.5	500	8.63	150
3.0	600	8.73	150
3.5	700	8.82	150
4.0	800	8.88	150
4.5	900	8.94	148
5.0	1000	9.00	145
5.5	1100	9.04	145
6.0	1200	9.08	144
6.5	1300	9.12	144
7.0	1400	9.15	144
7.5	1500	9.18	144
8.0	1600	9.21	144
8.5	1700	9.24	144
9.0	1800	9.26	144
9.5	1900	9.28	144
10	2000	9.30	145
11	2200	9.35	145
12	2400	9.38	146
14	2800	9.42	146
15	3000	9.44	146
16	3200	9.47	147
17	3400	9.50	147
18	3600	9.52	147

Titrate scrubber sample from Na_2CO_3 titration
w/ 35% HCl from pH 9.52 to 6.95 with
1.8 mls HCl @ 149°F ≈ 1440 ppm as HCl
× 1.37 ≈ 1973 ppm as $CaCO_3$
× 1.06 ≈ 2091 ppm as Na_2CO_3

Sodium Hydroxide 21% solution (250mg/ml)

mls	ppm	pH	Temp °F
0.05	25	7.32	150
0.10	50	7.55	150
0.15	75	7.79	150
0.20	100	7.99	150
0.25	125	8.15	150
0.30	150	8.28	150
0.35	175	8.35	150
0.45	225	8.53	150
0.50	250	8.60	150
0.60	300	8.69	150
0.70	350	8.79	150
0.80	400	8.89	150
0.90	450	8.98	150
1.0	500	9.06	150
1.1	550	9.14	150
1.2	600	9.21	150
1.3	650	9.28	150
1.4	700	9.35	150
1.5	750	9.42	150
1.6	800	9.49	150
1.7	850	9.56	

Continued on Page 50

Read and Understood By

Richard Schlaach — Signed
Jan 18, 1993 — Date

Signed

Date

PROJECT Study of Precipitate in Salt Kill

Notebook No. APCSS-1

Continued From Page 22

Titration of Club Soda (ie saturated CO_2 solution) Jan 26, 1993

pH at 68 °F = 5.55

400 ml

68°F

Titrate w 21% NaOH

mls NaOH	ppm	pH	
0	0	5.56	69°F
0.1	65	5.72	
0.2	129	5.84	
0.3	194	5.97	
0.4	258	6.08	
0.5	323	6.19	
0.6	388	6.30	
0.7	452	6.40	
0.8	517	6.53	
0.9	581	6.60	
1.0	646	6.67	
1.1	711	6.74	
1.2	775	6.88	
1.3	840	7.08	70°F
1.4	904	7.24	
1.5	969	7.68	
1.6	1034	8.48	
1.7	1098	8.93	
1.8	1163	9.24	
1.9	1227	9.44	
2.0	1292	9.59	

assume soda is saturated w/CO_2 at 140°F = 576 ppm CO_2

Titrate w/21% NaOH at 140°F

mls	ppm	pH	Temp
0	0	6.02	130°F
0.15	97	6.38	136°F
0.30	194	6.80	139°F
0.40	258	7.34	144°F
0.50	323	8.73	146°F
0.60	388	9.01	147°F
0.70	452	9.42	150°F
0.80	517	9.62	150°F

21% NaOH = 259 g/l

= 259 mg/ml

$\overline{0.4\ l}$

1 ml = 646 ppm

10% NaOH = 100 g/l

= 100 mg/ml

$\overline{0.4\ l}$

1 ml = 250 ppm

Titrate w/10% Na_2CO_3 at 140°F

mls	ppm	pH	Temp
0	0	5.95	130°F
0.1	25	5.98	133°F
0.2	50	6.05	136°F
0.3	75	6.12	138°F
0.4	100	6.16	140°F
0.5	125	6.20	140°F
0.6	150	6.25	142°F
0.7	175	6.30	144°F
0.8	200	6.36	146°F
0.9	225	6.42	147°F
1.0	250	6.47	148°F
1.1	275	6.52	150°F
1.3	325	6.62	150°F
1.5	375	6.71	150°F
1.7	425	6.81	151°F
1.9	475	6.91	151°F
2.1	525	7.00	152°F
2.5	625	7.25	150°F
3.0	750	7.72	150°F
3.5	875	8.39	150°F

mls	ppm	pH	Temp
4.0	1000	8.77	149°F
4.5	1125	8.98	148°F
5.0	1250	9.10	148°F
5.5	1375	9.19	147°F
6.0	1500	9.27	147°F
6.5	1625	9.34	146°F
7.0	1750	9.39	146°F
7.5	1875	9.44	146°F

Continued on Page

Read and Understood By

Richard Schlauch Jan 26, 1993

Signed Date

Signed Date

Norlite
Salt Kill Test
11/21/92
3410-"B"
"Bomb" SAF
ICP Metals Analyses

```
[illegible] ICP

Begin Analysis -- Sample Number 2

   Elem Wave-   Mean Peak  Mean Peak    % RSD     Net Peak
   Sym.  length Position   Intensity              Intensity

    S   180.731
      Off Peak Int.  =        714 ♦    688
      Peak Intensity =       3799 ♦   3903
                -0.0001      3851     1.910        3150
    SB  187.115
      Off Peak Int.  =        618 ♦    586
      Peak Intensity =       1674 ♦   1662
                 0.0000      1668     0.509        1066
    Ti  190.864
```

```
Analyze Samples                         11-21-1992 @ 12:14:43 -- 4

      Off Peak Int.  =       1473 ♦   1423
      Peak Intensity =       4613 ♦   4562
                 0.0007      4588     0.786        3140
    AS  193.759
      Off Peak Int.  =       1107 ♦   1177
      Off Peak Int.  =       1124 ♦   1143
      Peak Intensity =       5973 ♦   5766
                 0.0001      5672     2.553        4734
    HG  194.227
      Off Peak Int.  =       1118 ♦   1120
      Peak Intensity =       1138 ♦   1134
                 No Peak!    1136     0.249          17
    SE  196.09
      Off Peak Int.  =        831 ♦    822
      Peak Intensity =       3978 ♦   4010
                 0.0006      3994     0.567        3167
    SB  206.833
      Off Peak Int.  =        795 ♦    816
      Peak Intensity =       4840 ♦   4967
                -0.0001      4904     1.831        4098
    ZN  213.856
      Off Peak Int.  =        466 ♦    470
      Off Peak Int.  =        292 ♦    293
      Peak Intensity =      29932 ♦  30304
                 0.0001     30118     0.873       29737
    PB  220.353
      Off Peak Int.  =       1161 ♦   1161
      Off Peak Int.  =       1183 ♦   1200
      Peak Intensity =       5771 ♦   5783
                -0.0004      5777     0.147        4600
    CD  228.88
      Off Peak Int.  =       1037 ♦   1022
      Peak Intensity =      55798 ♦  57581
                -0.0003     56690     2.224       55660
    NI  231.604
      Off Peak Int.  =        421 ♦    422
      Peak Intensity =       4504 ♦   4583
                 0.0002      4544     1.229        4122
    FE  259.94
      Off Peak Int.  =        816 ♦    804
      Off Peak Int.  =        769 ♦    780
      Peak Intensity =      16837 ♦  16354
                -0.0001     16596     2.058       15803
    CR  267.716
      Off Peak Int.  =        885 ♦    882
      Peak Intensity =      13801 ♦  13720
                 0.0000     13761     0.416       12877
    V   292.402
```

```
analyze Samples                          11-21-1992 @ 12:19:05 -- 5

        Off Peak Int.  =      3583 ♦   3532
        Peak Intensity =     45358 ♦  44013
                       -0.0002      44686    2.128       41128
    BE  313.042
        Off Peak Int.  =       488 ♦    500
        Peak Intensity =     76006 ♦  74930
                        0.0005      75469    1.010       74975
    CU  324.754
        Off Peak Int.  =       895 ♦    904
        Peak Intensity =     16287 ♦  15684
                        0.0003      15986    2.667       15086
    AG  328.068
        Off Peak Int.  =       753 ♦    762
        Peak Intensity =     15033 ♦  14448
                       -0.0002      14741    2.806       13983
    CA  422.673
        Off Peak Int.  =      1308 ♦   1317
        Peak Intensity =      9399 ♦   9263
                        0.0003       9331    1.031        8018
    BA  455.403
        Off Peak Int.  =       586 ♦    584
        Peak Intensity =     46350 ♦  47671
                        0.0007      47011    1.987       46426

Calculating Concentrations for Sample Number 7

Elem. Wave-   Net Peak  Calculated    Interference    Net            Dilution
Sym. length   Intensity Concentration Correction   Concentration   Correction

AG 328.068      13983      5.364                      5.364           5.364
AS 193.759       4734      5.241                      5.241           5.241
BA 455.403      46426      5.335                      5.335           5.335
BE 313.042      74975      5.405                      5.405           5.405
CD 228.80       55660      5.297                      5.297           5.297
CR 267.716      12877      5.266                      5.266           5.266
PB 220.353       4600      5.287                      5.287           5.287
HG 194.227         17      0.012                      0.050 <         0.050
NI 231.604       4122      5.135                      5.135           5.135
SB 187.115       1066      5.545                      5.545           5.545
SR 206.833       4098      5.848                      5.848           5.848
SE 196.09        3167      5.429                      5.429           5.429
TL 190.864       3140      5.125                      5.125           5.125
S  180.731       3150      3.678                      3.678           3.678
V  292.402      41128      5.202                      5.202           5.202
CU 324.754      15086      5.256                      5.256           5.256
ZN 213.856      29737      5.280                      5.280           5.280
FE 259.94       15803      5.111                      5.111           5.111
CA 422.673       8018      5.225                      5.225           5.225
```

5 ppm metals standard
0 ppm Hg

```
    Peak Intensity =      839 ♦    882
               No Peak!       861     3.531         156
 SB  187.115
    Off Peak Int.  =      611 ♦    624
    Peak Intensity =      708 ♦    703
               No Peak!       706     0.501          88
 TI  190.864
    Off Peak Int.  =     1434 ♦   1445
    Peak Intensity =     1425 ♦   1419
               No Peak!      1422     0.298         -18
 AS  193.759
    Off Peak Int   =     1079 ♦   1095
    Off Peak Int.  =     1079 ♦   1096
    Peak Intensity =     1121 ♦   1089
               No Peak!      1105     2.048          17
 HG  194.227
    Off Peak Int.  =     1110 ♦   1158
    Peak Intensity =     8159 ♦   8120
              -0.0002        8140     0.339        7006
 SE  196.09
    Off Peak Int.  =      825 ♦    790
    Peak Intensity =      811 ♦    818
               No Peak!       815     0.607           7
 SB  206.833
    Off Peak Int.  =      796 ♦    812
    Peak Intensity =      893 ♦    890
               No Peak!       892     0.238          88
 ZN  213.856
    Off Peak Int.  =      269 ♦    268
    Off Peak Int.  =      270 ♦    267
    Peak Intensity =      381 ♦    380
               0.0001         381     0.186-        112
 PB  220.353
```

```
Analyze Samples                       11-21-1992 @ 12:25:15 -- 7


    Off Peak Int.  =     1152 ♦   1161
    Off Peak Int.  =     1186 ♦   1176
    Peak Intensity =     1161 ♦   1157
               No Peak!      1159     0.244         -10
 CD  228.88
    Off Peak Int.  =      916 ♦    925
    Peak Intensity =      950 ♦    942
               No Peak!       946     0.598          25
 NI  231.604
    Off Peak Int.  =      408 ♦    407
    Peak Intensity =      411 ♦    410
               No Peak!       411     0.172           3
 FE  259.94
    Off Peak Int.  =      754 ♦    753
    Off Peak Int.  =      756 ♦    768
    Peak Intensity =      810 ♦    808
               No Peak!       809     0.175          51
 CR  267.716
    Off Peak Int.  =      869 ♦    875
    Peak Intensity =      866 ♦    865
               No Peak!       866     0.082          -6
 V   292.402
    Off Peak Int.  =     3350 ♦   3321
    Peak Intensity =     3335 ♦   3358
               No Peak!      3347     0.486          11
 BE  313.042
    Off Peak Int.  =      315 ♦    319
    Peak Intensity =      351 ♦    350
               No Peak!       351     0.201          34
 CU  324.754
    Off Peak Int.  =      873 ♦    897
    Peak Intensity =      898 ♦    892
               No Peak!       895     0.474          10
 AG  328.068
    Off Peak Int.  =      712 ♦    708
    Peak Intensity =      715 ♦    713
               No Peak!       714     0.198           4
 CA  422.673
    Off Peak Int.  =     1282 ♦   1291
    Peak Intensity =     1305 ♦   1294
               No Peak!      1300     0.598          13
 BA  455.403
    Off Peak Int.  =      478 ♦    478
    Peak Intensity =      493 ♦    488
               No Peak!       491     0.220          13

Calculating Concentrations for Sample Number 3
```

```
Analyze Samples                              11-21-1992 @ 12:29:34 -- 8

Elem Wave-   Net Peak  Calculated    Interference       Net          Dilution
Sym. length  Intensity Concentration Correction  Concentration      Correction

AG 328.068          4      -0.001               <     0.010 <        0.010
AS 193.759         17      -0.009               <     0.125 <        0.125
BA 455.403         13       0.001               <     0.002 <        0.002
BE 313.042         34       0.001                     0.001 <        0.001
CD 228.88          25       0.002                     0.002          0.002
CR 267.716         -6      -0.006               <     0.015 <        0.015
PB 220.353        -10      -0.014               <     0.100 <        0.100
HG 194.227       7006       3.637                     3.637          3.637
NI 231.604          3       0.001               <     0.020 <        0.020
SB 187.115         88       0.199                     0.199          0.199
SB 206.833         88       0.075                     0.075          0.075
SE 196.09           7       0.031               <     0.250 <        0.250
TI 190.864        -18      -0.074               <     0.250 <        0.250
S  180.731        156       0.068                     0.068          0.068
V  292.402         11       0.007               <     0.025 <        0.025
CU 324.754         10      -0.003               <     0.010 <        0.010
ZN 213.856        112       0.015                     0.015          0.015
FE 259.94          51       0.014                     0.014          0.014
CA 422.673         13       0.007               <     0.150 <        0.150
Enter Sample Weight   9.7

Enter Sample Volume   10


SAMPLE B.1


SAMPLE B.1


Begin Analysis - Sample Number 4

    Ele. Wave-   Mean Peak  Mean Peak    % RSD     Net Peak
    Sym. length  Position   Intensity              Intensity

     S   180.731
       Off Peak Int.   =      736 ♦    758
       Peak Intensity =     12680 ♦  12721
                   -0.0001     12701     0.228        11954
     SB  187.115
       Off Peak Int.   =      607 ♦    600
       Peak Intensity =       665 ♦    677
                  No Peak!       671     1.265           67
     TI  190.864
```

0 ppm metals std.

3 ppm Hg std.

```
Analyze Samples                              11-21-1992 @ 12:31:37 -- 9


       Off Peak Int.  =     1491 ♦   1541
       Peak Intensity =     1473 ♦   1463
                  No Peak!      1468    0.482       /   -48
     AS  193.759
       Off Peak Int.  =     1330 ♦   1296
       Off Peak Int.  =     1274 ♦   1262
       Peak Intensity =     1276 ♦   1278
                  No Peak!      1277    0.111           -14
     HG  194.227
       Off Peak Int.  =     1189 ♦   1220
       Peak Intensity =     1246 ♦   1230
                  No Peak!      1238    0.914            33
     SE  196.09
       Off Peak Int.  =      814 ♦    809
       Peak Intensity =      837 ♦    843
                  No Peak!       840    0.505            28
     SB  206.833
       Off Peak Int.  =      787 ♦    813
       Peak Intensity =      817 ♦    819
                  No Peak!       818    0.173            18
     ZN  213.856
       Off Peak Int.  =      267 ♦    273
       Off Peak Int.  =      276 ♦    279
       Peak Intensity =      363 ♦    360
                    0.0002       362    0.586            88
     PB  220.353
       Off Peak Int.  =     1162 ♦   1166
       Off Peak Int.  =     1166 ♦   1173
       Peak Intensity =     1180 ♦   1175
                  No Peak!      1178    0.300            1
```

```
         Off Peak Int.  =         747 ♦     754
         Off Peak Int.  =         762 ♦     761
         Peak Intensity =        1549 ♦    1512
                        0.0001       1531     1.309        774
     CR  267.716
         Off Peak Int.  =         866 ♦     864
         Peak Intensity =         862 ♦     872
                    No Peak!          867     0.816          2
     V   292 402

Analyze Samples                               11-21-1992 @ 12:35:58 -- 10

         Off Peak Int.  =        3315 ♦    3309
         Peak Intensity =        3354 ♦    3341
                    No Peak!         3348     0.275         36
     BE  313.042
         Off Peak Int.  =         323 ♦     327
         Peak Intensity =         342 ♦     343
                    No Peak!          343     0.206         18
     CU  324.754
         Off Peak Int.  =         876 ♦     876
         Peak Intensity =         900 ♦     896
                    No Peak!          898     0.315         22
     AG  328.068
         Off Peak Int.  =         717 ♦     716
         Peak Intensity =         710 ♦     712
                    No Peak!          711     0.199         -6
     CA  422.673
         Off Peak Int.  =        1552 ♦    1557
         Peak Intensity =      104107 ♦  107258
                        0.0005     105683     2.108     104128
     BA  455.403
         Off Peak Int.  =         482 ♦     477
         Peak Intensity =        1219 ♦    1207
                        0.0007       1213     0.700        733

Calculating Concentrations for Sample Number 4

Elem. Wave-   Net Peak   Calculated   Interference      Net          Dilution
Sym. length  Intensity  Concentration  Correction  Concentration    Correction

AG 328.068        -6        -0.005                   <    0.010 <      0.010
AS 193.759       -14        -0.043                   <    0.125 <      0.125
BA 455.403       733         0.084                        0.084        0.087
BE 313.042        18         0.000                   <    0.001 <      0.001
CD 228.88         14         0.001                        0.001        0.001
CR 267.716         2        -0.002                   <    0.015 <      0.015
PB 220.353        11         0.010                   <    0.100 <      0.100
HG 194.227        33         0.021                   <    0.050 <      0.050
NI 231.604         0        -0.002                   <    0.020 <      0.020
SR 187.115        67         0.084                        0.084        0.087
SB 206.833        18        -0.026                   <    0.000 <      0.000
SE 196.09         28         0.067                   <    0.250 <      0.250
TL 190.864       -48        -0.123                   <    0.250 <      0.250
S  180.731     11954        14.294                       14.294       14.736
V  292.402        36         0.010                   <    0.025 <      0.025
CU 324.754        22         0.001                   <    0.010 <      0.010
ZN 213.856        88         0.011                        0.011        0.011
FE 259.94        274         0.248                        0.248        0.256
CA 422.673    104128        67.885                       67.885       69.985
```

= 70 ppm Ca++ x 2.5 = 175 mg/l CaCO3

SAMPLE B.1
upstream

```
Analyze Samples                               11-21-1992 @ 12:38:23 -- 11

 SAMPLE #1

SAMPLE #1

Begin Analysis - Sample Number 5
```

```
Analyze Samples                              11-21-1992 @ 12:38:23 -- 11

 SAMPLE #1


SAMPLE #1

Begin Analysis - Sample Number 5

   Ele.  Wave-   Mean Peak  Mean Peak    % RSD    Net Peak
   Sym.  length  Position   Intensity             Intensity

    S   180.731
      Off Peak Int.   =      770 ♦    771
      Peak Intensity  =    11625 ♦  11788
                    0.0001     11707     0.985     10936
    SB  187.115
      Off Peak Int.   =      637 ♦    652
      Peak Intensity  =      700 ♦    698
                  No Peak!       699     0.202        54
    TL  190.864
      Off Peak Int.   =     1649 ♦   1673
      Peak Intensity  =     1538 ♦   1525
                  No Peak!      1532     0.600      -129
    AS  193.759
      Off Peak Int.   =     1530 ♦   1559
      Off Peak Int.   =     1501 ♦   1488
      Peak Intensity  =     1539 ♦   1535
                  No Peak!      1537     0.184        17
    HG  194.227
      Off Peak Int.   =     1290 ♦   1339
      Peak Intensity  =     1334 ♦   1340
                  No Peak!      1337     0.317        22
    SE  196.09
      Off Peak Int.   =      865 ♦    851
      Peak Intensity  =      885 ♦    883
                  No Peak!       884     0.160        26
    SR  206.833
      Off Peak Int.   =      820 ♦    800
      Peak Intensity  =      835 ♦    844
                  No Peak!       840     0.758        30
    ZN  213.856
      Off Peak Int.   =      271 ♦    281
      Off Peak Int.   =      276 ♦    279
      Peak Intensity  =      301 ♦    302
                  No Peak!       302     0.234        25
    PB  220.353




Analyze Samples                              11-21-1992 @ 12:41:59 -- 12

      Off Peak Int.   =     1197 ♦   1174
      Off Peak Int.   =     1189 ♦   1202
      Peak Intensity  =     1193 ♦   1175
                  No Peak!      1184     1.075        -7
    CD  228.88
      Off Peak Int.   =      933 ♦    955
      Peak Intensity  =      948 ♦    950
                  No Peak!       949     0.149         5
    NI  231.604
      Off Peak Int.   =      415 ♦    418
      Peak Intensity  =      416 ♦    420
                  No Peak!       418     0.677         1
    FE  259.94
      Off Peak Int.   =      763 ♦    763
      Off Peak Int.   =      754 ♦    759
      Peak Intensity  =      960 ♦    958
                    0.0001       959     0.147       199
    CR  267.716
      Off Peak Int.   =      868 ♦    876
      Peak Intensity  =      877 ♦    876
                  No Peak!       877     0.081         5
    V   292.402
      Off Peak Int    =  [illegible] ♦   2380
```

```
ze Samples                          11-21-1992 @ 12:41:59 -- 12

   Off Peak Int.  =        1197 ♦    1174
   Off Peak Int.  =        1189 ♦    1202
   Peak Intensity =        1192 ♦    1175
                No Peak!       1184     1.075          -7
CD  228.88
   Off Peak Int.  =         933 ♦     955
   Peak Intensity =         948 ♦     950
                No Peak!        949     0.149           5
NI  231.604
   Off Peak Int.  =         415 ♦     418
   Peak Intensity =         416 ♦     420
                No Peak!        418     0.677           1
FE  259.94
   Off Peak Int.  =         763 ♦     763
   Off Peak Int.  =         754 ♦     759
   Peak Intensity =         960 ♦     958
                0.0001          959     0.147         199
CR  267.716
   Off Peak Int.  =         868 ♦     876
   Peak Intensity =         877 ♦     876
                No Peak!        877     0.081           5
V   292.402
   Off Peak Int.  =        3337 ♦    3380
   Peak Intensity =        3336 ♦    3369
                No Peak!       3353     0.696          -6
BF  313.042
   Off Peak Int.  =         326 ♦     321
   Peak Intensity =         343 ♦     345
                No Peak!        344     0.411          20
CU  324.754
   Off Peak Int.  =         870 ♦     880
   Peak Intensity =         911 ♦     906
                No Peak!        909     0.389          34
AG  328.068
   Off Peak Int.  =         719 ♦     708
   Peak Intensity =         707 ♦     713
                No Peak!        710     0.598          -4
CA  422.673
   Off Peak Int.  =        1297 ♦    1310
   Peak Intensity =       13294 ♦   13554
                0.0004        13424     1.370       12120
BA  455.403
   Off Peak Int.  =         469 ♦     476
   Peak Intensity =         811 ♦     807
                0.0007          809     0.350         336

lating Concentrations for Sample Number 5
```

SAMPLE #1 Jar Test

+ 5.88 g/l Na_2CO_3
pH = 10.21 Temp = 71°F

```
ze Samples                          11-21-1992 @ 12:46:18 -- 13

Wave-   Net Peak  Calculated    Interference      Net          Dilution
length  Intensity Concentration Correction    Concentration    Correction

3.068       -4      -0.004               <     0.010 <        0.010
1.759       17      -0.009               <     0.125 <        0.125
5.403      336       0.038                     0.038          0.039
3.042      -20       0.000               <     0.001 <        0.001
3.88         5       0.000                     0.000          0.000
7.716       -5      -0.001               <     0.015 <        0.015
1.353       -7      -0.010               <     0.100 <        0.100
.227        22       0.015               <     0.050 <        0.050
.604         1      -0.001               <     0.020 <        0.020
.115        54       0.013                     0.013          0.013
.833        30      -0.008               <     0.000 <        0.000
.09         26       0.063               <     0.250 <        0.250
1.864     -129      -0.257               <     0.250 <        0.250
1.731    10936      13.066                    13.066         13.470
.402        -6       0.005               <     0.075 <        0.025
.754        34       0.005               <     0.010 <        0.010
.256        75       0.000               <     0.005 <        0.005
.94        199       0.061                     0.061          0.063
.673     12120       7.900                     7.900          8.144
LE #7
```

x 2.5 = 20.36 ppm as $CaCO_3$

```
#7

Analysis - Sample Number 6
```

```
SAMPLE #2

Begin Analysis - Sample Number 6

   Ele.  Wave-   Mean Peak  Mean Peak    % RSD    Net Peak
   Sym.  length  Position   Intensity             Intensity

   S    180.731
      Off Peak Int.   =      840 ♦     815
      Peak Intensity  =    10616 ♦   10336
                     0.0001     10476     1.890       9648
   SB   187.115
      Off Peak Int.   =      736 ♦     692
      Peak Intensity  =      749 ♦     751
                   No Peak!       750     0.189         36
   TL   190.864
      Off Peak Int.   =     2196 ♦    2229
      Peak Intensity  =     1796 ♦    1817
                   No Peak!      1807     0.822       -406
   AS   193.759




Analyze Samples                         11-21-1992 @ 12:47:48 -- 14


      Off Peak Int.   =     2711 ♦    2694
      Off Peak Int.   =     2489 ♦    2471
      Peak Intensity  =     2617 ♦    2617
                   No Peak!      2617     0.000         25
   HG   194.227
      Off Peak Int.   =     1872 ♦    1828
      Peak Intensity  =     1800 ♦    1837
                   No Peak!      1819     1.438        -31
   SE   196.09
      Off Peak Int.   =      969 ♦     942
      Peak Intensity  =     1035 ♦    1028
                   No Peak!      1032     0.480         76
   SB   206.833
      Off Peak Int.   =      858 ♦     879
      Peak Intensity  =      907 ♦     889
                   No Peak!       896     1.026         27
   ZN   213.856
      Off Peak Int.   =      294 ♦     294
      Off Peak Int.   =      302 ♦     300
      Peak Intensity  =      314 ♦     318
                   No Peak!       316     0.895         18
   PB   220.353
      Off Peak Int.   =     1255 ♦    1247
      Off Peak Int.   =     1267 ♦    1280
      Peak Intensity  =     1270 ♦    1259
                   No Peak!      1265     0.615          2
   CD   228.88
      Off Peak Int.   =      994 ♦     994
      Peak Intensity  =     1013 ♦    1012
                   No Peak!      1013     0.070         19
   NI   231.604
      Off Peak Int.   =      437 ♦     438
      Peak Intensity  =      435 ♦     440
                   No Peak!       438     0.807          0
   FE   259.94
      Off Peak Int.   =      811 ♦     796
      Off Peak Int.   =      802 ♦     797
      Peak Intensity  =      912 ♦     910
                   No Peak!       911     0.155        109
   CR   267.716
      Off Peak Int.   =      918 ♦     913
      Peak Intensity  =      916 ♦     909
                   No Peak!       913     0.542         -3
   V    292.402
      Off Peak Int.   =     3487 ♦    3419
      Peak Intensity  =     3452 ♦    3487
                   No Peak!      3467     0.612         14
   BE   313.042









Analyze Samples                         11-21-1992 @ 12:52:09 -- 15
```

```
SAMPLE #2
Begin Analysis - Sample Number 6

    Ele.  Wave-   Mean Peak  Mean Peak    % RSD    Net Peak
    Sym.  length  Position   Intensity             Intensity

     S   180.731
       Off Peak Int.  =       840 ♦    815
       Peak Intensity =     10616 ♦  10336
                   0.0001      10476     1.890         9648
     SB  187.115
       Off Peak Int.  =       736 ♦    692
       Peak Intensity =       749 ♦    751
                 No Peak!        750     0.189           36
     TL  190.864
       Off Peak Int.  =      2196 ♦   2229
       Peak Intensity =      1796 ♦   1817
                 No Peak!       1807     0.822         -406
     AS  193.759




Analyze Samples                          11-21-1992 @ 12:47:48 -- 14


       Off Peak Int.  =      2711 ♦   2694
       Off Peak Int.  =      2489 ♦   2471
       Peak Intensity =      2617 ♦   2617
                 No Peak!       2617     0.000           25
     HG  194.227
       Off Peak Int.  =      1872 ♦   1828
       Peak Intensity =      1800 ♦   1837
                 No Peak!       1819     1.438          -31
     SE  196.09
       Off Peak Int.  =       969 ♦    942
       Peak Intensity =      1035 ♦   1028
                 No Peak!       1032     0.480           76
     SB  206.833
       Off Peak Int.  =       858 ♦    879
       Peak Intensity =       902 ♦    889
                 No Peak!        896     1.026           27
     ZN  213.856
       Off Peak Int.  =       294 ♦    294
       Off Peak Int.  =       302 ♦    300
       Peak Intensity =       314 ♦    318
                 No Peak!        316     0.895           18
     PB  220.353
       Off Peak Int.  =      1255 ♦   1247
       Off Peak Int.  =      1267 ♦   1280
       Peak Intensity =      1270 ♦   1259
                 No Peak!       1265     0.615            2
     CD  228.80
       Off Peak Int.  =       994 ♦    994
       Peak Intensity =      1013 ♦   1012
                 No Peak!       1013     0.070           19
     NI  231.604
       Off Peak Int.  =       437 ♦    438
       Peak Intensity =       435 ♦    440
                 No Peak!        438     0.807            0
     FE  259.94
       Off Peak Int.  =       811 ♦    796
       Off Peak Int.  =       802 ♦    797
       Peak Intensity =       912 ♦    910
                 No Peak!        911     0.155          109
     CR  267.716
       Off Peak Int.  =       916 ♦    913
       Peak Intensity =       916 ♦    909
                 No Peak!        913     0.542           -3
     V   292.402
       Off Peak Int.  =      3487 ♦   3419
       Peak Intensity =      3452 ♦   3482
                 No Peak!       3467     0.612           14
     BE  313.042




Analyze Samples                          11-21-1992 @ 12:52:09 -- 15
```

```
     Off Peak Int.  =      [illegible] ♦  [illegible]
     Peak Intensity =       916 ♦   909
              No Peak!          913     0.542          -3
 V   292.402
     Off Peak Int.  =      3437 ♦   3419
     Peak Intensity =      3452 ♦   3482
              No Peak!         3467     0.612          14
 BF  313.042
```

```
Analyze Samples                              11-21-1992 @ 12:52:09 -- 15


     Off Peak Int.  =       332 ♦   336
     Peak Intensity =       353 ♦   354
              No Peak!          354     0.200          20
 CU  324.754
     Off Peak Int.  =       914 ♦   903
     Peak Intensity =       951 ♦   951
              No Peak!          951     0.000          42
 AG  328.068
     Off Peak Int.  =       741 ♦   741
     Peak Intensity =       735 ♦   733
              No Peak!          734     0.193          -7
 CA  422.673
     Off Peak Int.  =      1337 ♦  1332
     Peak Intensity =     10381 ♦ 10275
               0.0004         10328     0.726        8993
 BA  455.403
     Off Peak Int.  =       489 ♦   492
     Peak Intensity =       759 ♦   763
               0.0008           761     0.372         270

Calculating Concentrations for Sample Number 6

Elem. Wave-   Net Peak  Calculated     Interference     Net           Dilution
Sym. length  Intensity  Concentration  Correction  Concentration    Correction

AG 328.068        -7       -0.005                   <     0.010 <      0.010
AS 193.759        25        0.000                   <     0.125 <      0.125
BA 455.403       270        0.031                         0.031        0.032
BE 313.042        20        0.000                   <     0.001 <      0.001
CD 228.88         19        0.002                         0.002        0.002
CR 267.716        -3       -0.005                   <     0.015 <      0.015
PB 220.353         2        0.000                   <     0.100 <      0.100
HG 194.227       -31       -0.012                   <     0.050 <      0.050
NI 231.604         0       -0.002                   <     0.020 <      0.020
SB 187.115        36       -0.086                   <     0.000 <      0.000
SB 206.833        27       -0.013                   <     0.000 <      0.000
SE 196.09         76        0.149                   <     0.250 <      0.250
TL 190.864      -406       -0.713                   <     0.250 <      0.250
S  180.731      9648       11.513                        11.513       11.869
V  292.402        14        0.007                   <     0.025 <      0.025
CU 324.754        42        0.008                   <     0.010 <      0.010
ZN 213.856        18       -0.001                   <     0.005 <      0.005
FE 259.94        109        0.032                         0.032        0.033
CA 422.673      8993        5.861                         5.861        6.042
  SAMPLE #3
```

SAMPLE #2 Jar Test

x 2.5 = 15.1 ppm as CaCO3

```
Analyze Samples                              11-21-1992 @ 12:54:25 -- 16


SAMPLE #3

Begin Analysis - Sample number 7

   Ele.  Wave-   Mean Peak  Mean Peak   % RSD    Net Peak
   Sym.  length  Position   Intensity            Intensity

   S    180.731
     Off Peak Int.  =      [illegible] ♦  [illegible]
```

```
Analyze Samples                          11-21-1992 @ 12:58:30 -- 17

      Off Peak Int.  =        1072 ♦    1083
      Peak Intensity =        1087 ♦    1089
                 No Peak!         1088    0.230          10
   NI  231.604
      Off Peak Int.  =         480 ♦     480
      Peak Intensity =         473 ♦     473
                 No Peak!          473    0.000          -7
   FE  259.94
      Off Peak Int.  =         850 ♦     845
      Off Peak Int.  =         843 ♦     859
      Peak Intensity =         946 ♦     953
                 No Peak!          950    0.521         100
   CR  267.716
      Off Peak Int.  =         985 ♦     972
      Peak Intensity =         976 ♦     983
                 No Peak!          980    0.505           1
   V   292.402
      Off Peak Int.  =        3642 ♦    3648
      Peak Intensity =        3649 ♦    3649
                 No Peak!         3649    0.000           4
   BE  313.042
      Off Peak Int.  =         348 ♦     357
      Peak Intensity =         371 ♦     372
                 No Peak!          372    0.190          19
   CU  324.754
      Off Peak Int.  =         966 ♦     955
      Peak Intensity =        1003 ♦    1009
                 No Peak!         1006    0.422          45
   AG  328.068
      Off Peak Int.  =         768 ♦     784
      Peak Intensity =         778 ♦     777
                 No Peak!          778    0.091           2
   CA  422.673
      Off Peak Int.  =        1413 ♦    1421
      Peak Intensity =       11103 ♦   11211
                   0.0005        11157    0.684        9740
   BA  455.403
      Off Peak Int.  =         512 ♦     511
      Peak Intensity =         913 ♦     919
                   0.0011          916    0.463         404

Calculating Concentrations for Sample Number 7

Elem. Wave-  Net Peak   Calculated    Interference      Net          Dilution
Sym. length  Intensity  Concentration  Correction  Concentration    Correction

AG 328.068         2        -0.002                <   0.010 <       0.010
AS 193.759        27         0.002                <   0.125 <       0.125
```

SAMPLE #3 Jar Test

```
Analyze Samples                          11-21-1992 @ 13:07:24 -- 18

BA 455.403       404         0.046                    0.046         0.047
BE 313.042        19         0.000                <   0.001 <       0.001
CD 228.80         10         0.001                    0.001         0.001
CR 267.716         1        -0.003                <   0.015 <       0.015
PB 220.353        -1        -0.003                <   0.100 <       0.100
HG 194.227       -52        -0.023                <   0.050 <       0.050
NI 231.604        -7        -0.011                <   0.020 <       0.020
SB 182.115        62         0.056                    0.056         0.058
SB 206.833        65         0.042                    0.042         0.043
SE 196.09        264         0.470                    0.470         0.485
TL 190.864      -651        -1.116                <   0.250 <       0.250
S  180.731     11021        13.169                   13.169        13.576
V  292.402         4         0.006                <   0.025 <       0.025
CU 324.754        45         0.009                <   0.010 <       0.010
ZN 213.856        21        -0.001                <   0.005 <       0.005
FE 259.94        100         0.029                    0.029         0.030
CA 422.673      9740         6.348                    6.348         6.544
 SAMPLE #4
```

x2.5 = 16.25 ppm as CaCO3

```
SAMPLE #4

Begin Analysis - Sample Number 8
```

```
SAMPLE #4 [illegible]

Begin Analysis - Sample Number 2

    Ele.  Wave-   Mean Peak  Mean Peak    % RSD    Net Peak
    Sym.  length  Position   Intensity             Intensity

     S   180.731
         Off Peak Int.  =      765 ♦    786
         Peak Intensity =    10726 ♦  10634
                       0.0002     10680    0.609      9904
     SB  187.115
         Off Peak Int.  =      621 ♦    641
         Peak Intensity =      691 ♦    684
                    No Peak!        688    0.719        57
     TL  190.864
         Off Peak Int.  =     1644 ♦   1642
         Peak Intensity =     1518 ♦   1517
                    No Peak!       1518    0.047      -125
     AS  193.759
         Off Peak Int.  =     1528 ♦   1558
         Off Peak Int.  =     1486 ♦   1496
         Peak Intensity =     1510 ♦   1498
                    No Peak!       1504    0.564       -13
     HG  194.227



Analyze Samples                        11-21-1992 @ 13:04:49 -- 19


         Off Peak Int.  =     1335 ♦   1275
         Peak Intensity =     1301 ♦   1324
                    No Peak!       1313    1.239         8
     SE  196.09
         Off Peak Int.  =      850 ♦    862
         Peak Intensity =      879 ♦    861
                    No Peak!        870    1.463        14
     SB  206.833
         Off Peak Int.  =      804 ♦    793
         Peak Intensity =      825 ♦    822
                    No Peak!        824    0.257        25
     ZN  213.856
         Off Peak Int.  =      268 ♦    269
         Off Peak Int.  =      278 ♦    284
         Peak Intensity =      300 ♦    302
                    No Peak!        301    0.470        26
     PB  220.353
         Off Peak Int.  =     1157 ♦   1190
         Off Peak Int.  =     1149 ♦   1158
         Peak Intensity =     1161 ♦   1166
                    No Peak!       1164    0.304         0
     CD  228.88
         Off Peak Int.  =      932 ♦    901
         Peak Intensity =      923 ♦    928
                    No Peak!        926    0.382         9
     NI  231.604
         Off Peak Int.  =      399 ♦    399
         Peak Intensity =      405 ♦    403
                    No Peak!        404    0.350         5
     FE  259.94
         Off Peak Int.  =      737 ♦    731
         Off Peak Int.  =      737 ♦    732
         Peak Intensity =     1068 ♦   1049
                       0.0003      1059    1.769       374
     CR  267.716
         Off Peak Int.  =      839 ♦    829
         Peak Intensity =      841 ♦    842
                    No Peak!        842    0.084         8
     V   292.402
         Off Peak Int.  =     3265 ♦   3266
         Peak Intensity =     3232 ♦   3220
                    No Peak!       3226    0.263       -40
     BE  313.042
         Off Peak Int.  =      315 ♦    313
         Peak Intensity =      331 ♦    332
                    No Peak!        332    0.213        18
     CU  324.754
         Off Peak Int.  =      854 ♦    861
```

```
Analyze Samples                                11-21-1992 @ 13:09:11 -- 20


      Peak Intensity =        881 ♦     877
                 No Peak           879     0.241            21
    AG  328.068
      Off Peak Int   =        692 ♦     692
      Peak Intensity =        692 ♦     693
                 No Peak!          693     0.102             2
    CA  422.673
      Off Peak Int.  =       1325 ♦    1325
      Peak Intensity =      31604 ♦   32297
                0.0006           31951     1.534         30625
    BA  455.403
      Off Peak Int.  =        462 ♦     462
      Peak Intensity =        993 ♦     989
                0.0010             991     0.285           528


Calculating Concentrations for Sample Number 8

Elem. Wave-   Net Peak   Calculated    Interference      Net           Dilution
Sym.  length  Intensity Concentration  Correction  Concentration      Correction

AG 328.068          2       -0.002                  <    0.010 <         0.010
AS 193.759        -13       -0.042                  <    0.125 <         0.125
BA 455.403        528        0.060                       0.060           0.062
BE 313.042         18        0.000                  <    0.001 <         0.001
CD 228.80           9        0.001                       0.001           0.001
CR 267.716          8        0.000                  <    0.015 <         0.015
PB 220.353          0       -0.002                  <    0.100 <         0.100
HG 194.227          8        0.008                  <    0.050 <         0.050
NI 231.604          5        0.004                  <    0.020 <         0.020
SR 187.115         57        0.029                       0.029           0.030
SB 206.833         25       -0.016                  <    0.000 <         0.000
SE 196.09          14        0.043                  <    0.250 <         0.250
TL 190.864       -125       -0.250                  <    0.250 <         0.250
S  180.731       9904       11.822                      11.822          12.188
V  292.402        -40        0.001                  <    0.025 <         0.025
CU 324.754         21        0.000                  <    0.010 <         0.010
ZN 213.856         26        0.000                  <    0.005 <         0.005
FE 259.94         324        0.102                       0.102           0.105
CA 422.673      30625       19.964                      19.964          20.581
   SAMPLE #5


SAMPLE #5

Begin Analysis - Sample Number 9
```

SAMPLE #4 Jar Test

x 2.5 = 51.45 ppm as CaCO3

```
Analyze Samples                                11-21-1992 @ 13:10:55 -- 21


    Ele.  Wave-    Mean Peak  Mean Peak    % RSD     Net Peak
    Sym.  length   Position   Intensity              Intensity

     S   180.731
       Off Peak Int.  =        746 ♦     776
       Peak Intensity =      11859 ♦   11423
                  0.0001           11641     2.648       10880
     SR  187.115
       Off Peak Int.  =        633 ♦     629
       Peak Intensity =        699 ♦     690
                  No Peak!           695     0.916          64
     TL  190.864
       Off Peak Int.  =       1599 ♦    1585
       Peak Intensity =       1505 ♦    1487
                  No Peak!          1496     0.851         -96
     AS  193.759
       Off Peak Int.  =       1375 ♦    1370
       Off Peak Int.  =       1372 ♦    1365
       Peak Intensity =       1390 ♦    1384
                  No Peak!          1387     0.306          16
     HG  194.227
       Off Peak Int.  =       1230 ♦    1294
       Peak Intensity =       1266 ♦    1264
                  No Peak!          1265     0.112           3
     SE  196.09
       Off Peak Int.  =        828 ♦     836
       Peak Intensity =        867 ♦     868
                  No Peak!           868     0.081          36
     SB  206.833
       Off Peak Int.  =  [illegible] ♦   241
       Peak Intensity =  [illegible] ♦   [illegible]
```

```
Ele.  Wave-   Mean Peak  Mean Peak    % RSD     Net Peak
Sym.  length  Position   Intensity              Intensity

 S  180.731
   Off Peak Int.  =        746 ♦    776
   Peak Intensity =      11859 ♦  11423
                0.0001      11641    2.648       10880
 SR  187.115
   Off Peak Int.  =        633 ♦    629
   Peak Intensity =        699 ♦    690
                No Peak!      695    0.916          64
 TL  190.864
   Off Peak Int.  =       1599 ♦   1585
   Peak Intensity =       1505 ♦   1487
                No Peak!     1496    0.851         -96
 AS  193.759
   Off Peak Int.  =       1375 ♦   1370
   Off Peak Int.  =       1372 ♦   1365
   Peak Intensity =       1390 ♦   1384
                No Peak!     1387    0.306          16
 HG  194.227
   Off Peak Int.  =       1230 ♦   1294
   Peak Intensity =       1266 ♦   1264
                No Peak!     1265    0.112           3
 SE  196.09
   Off Peak Int.  =        828 ♦    836
   Peak Intensity =        867 ♦    868
                No Peak!      868    0.081          36
 SB  206.833
   Off Peak Int.  =        816 ♦    841
   Peak Intensity =        874 ♦    832
                No Peak!      828    0.683          -2
 ZN  213.856
   Off Peak Int.  =        270 ♦    273
   Off Peak Int.  =        281 ♦    283
   Peak Intensity =        296 ♦    294
                No Peak!      295    0.479          18
 PB  220.353
   Off Peak Int.  =       1147 ♦   1174
   Off Peak Int.  =       1198 ♦   1201
   Peak Intensity =       1184 ♦   1201
                No Peak!     1193    1.006          12
 CO  228.88
   Off Peak Int.  =        933 ♦    938
   Peak Intensity =        946 ♦    954
                No Peak!      950    0.595          14
 NI  231.604
```

```
Analyze Samples                          11-21-1992 @ 13:15:23 -- 22

   Off Peak Int.  =        417 ♦    413
   Peak Intensity =        420 ♦    416
                No Peak!      418    0.677           3
 FE  259.94
   Off Peak Int.  =        776 ♦    758
   Off Peak Int.  =        755 ♦    766
   Peak Intensity =        957 ♦    963
                0.0006        960    0.442         196
 CR  267.716
   Off Peak Int.  =        877 ♦    884
   Peak Intensity =        878 ♦    877
                No Peak!      878    0.081          -3
 V   292.402
   Off Peak Int.  =       3339 ♦   3404
   Peak Intensity =       3393 ♦   3375
                No Peak!     3384    0.376          13
 BE  313.042
   Off Peak Int.  =        328 ♦    333
   Peak Intensity =        344 ♦    345
                No Peak!      345    0.205          14
 CU  324.754
   Off Peak Int.  =        878 ♦    885
   Peak Intensity =        915 ♦    901
                No Peak!      908    1.090          26
 AG  328.068
   Off Peak Int.  =        717 ♦    711
   Peak Intensity =        716 ♦    714
                No Peak!      715    0.198           1
 CA  422.673
   Off Peak Int.  =       1297 ♦   1311
   Peak Intensity =      10182 ♦   9999
                0.0006      10091    1.282        8787
 BA  455.403
   Off Peak Int.  =        471 ♦    475
   Peak Intensity =        825 ♦    822
                0.0012        824    0.257         351
```

SAMPLE #5

SAMPLE #5 Jar Test

```
   Peak Intensity =       [illegible] ♦   [illegible]
                  0.0006       10091    1.282        8787
 BA  455.403
     Off Peak Int.  =      471 ♦     475
     Peak Intensity =      825 ♦     822
                  0.0012        824     0.257         351


Calculating Concentrations for Sample Number 9

Elem Wave-    Net Peak  Calculated     Interference     Net          Dilution
Sym. length  Intensity  Concentration  Correction  Concentration    Correction

AG 328.068        1        -0.002                 <    0.010 <       0.010
AS 193.759       16        -0.010                 <    0.175 <       0.175
BA 455.403      351         0.040                      0.040         0.041
BE 313.042       14         0.000                 <    0.001 <       0.001
CD 226.50        14         0.001                      0.001         0.001
CR 267.716       -3        -0.005                 <    0.015 <       0.015




Analyze Samples                               11-21-1992 @ 13:18:55 -- 23


PB 220.353       12         0.011                 <    0.100 <       0.100
HG 194.227        3         0.005                 <    0.050 <       0.050
NI 231.604        3         0.001                 <    0.020 <       0.020
SB 187.115       64         0.067                      0.067         0.069
SB 206.833       -2        -0.055                 <    0.000 <       0.000
SE 196.09        36         0.080                 <    0.250 <       0.250
TI 190.864      -96        -0.202                 <    0.250 <       0.250
S  180.731    10880        12.999                     12.999        13.401
V  292.402       13         0.007                 <    0.025 <       0.025
CU 324.754       26         0.002                 <    0.010 <       0.010
ZN 213.856       18        -0.001                 <    0.005 <       0.005
FE 259.94       196         0.061                      0.061         0.063
CA 422.673     8787         5.727                      5.727         5.904
  SAMPLE #6
```

x 2.5 = 14.75 ppm as CaCO3

```
SAMPLE #6

Begin Analysis - Sample Number 10

  Ele. Wave-   Mean Peak  Mean Peak    % RSD     Net Peak
  Sym. length  Position   Intensity              Intensity

  S   180.731
     Off Peak Int.  =      750 ♦     756
     Peak Intensity =    11659 ♦   12269
                  0.0002      11964     3.605       11196
  SB  187.115
     Off Peak Int.  =      663 ♦     638
     Peak Intensity =      685 ♦     698
                No Peak!        692     1.328          41
  TI  190.864
     Off Peak Int.  =     1709 ♦    1626
     Peak Intensity =     1521 ♦    1523
                No Peak!       1522     0.093        -146
  AS  193.759
     Off Peak Int.  =     1573 ♦    1623
     Off Peak Int.  =     1560 ♦    1567
     Peak Intensity =     1561 ♦    1545
                No Peak!       1553     0.729         -28
  HG  194.227
     Off Peak Int.  =     1318 ♦    1314
     Peak Intensity =     1350 ♦    1363
                No Peak!       1357     0.677          41
  SE  196.09




Analyze Samples                               11-21-1992 @ 13:21:36 -- 24


     Off Peak Int   =      876 ♦     853
     Peak Intensity =      [illegible] ♦   [illegible]
```

```
      Off Peak Int.  =      1182 ♦   1177
      Peak Intensity =      1203 ♦   1191
               No Peak!         1197    0.709        12
   CD  228.88
      Off Peak Int.  =       955 ♦    960
      Peak Intensity =       951 ♦    956
               No Peak!          954    0.371        -4
   NI  231.604
      Off Peak Int.  =       410 ♦    412
      Peak Intensity =       423 ♦    418
               No Peak!          419    0.338         8
   FF  259.94
      Off Peak Int.  =       769 ♦    765
      Off Peak Int.  =       771 ♦    762
      Peak Intensity =       898 ♦    930
               No Peak!          914    2.476       147
   CR  267.716
      Off Peak Int.  =       883 ♦    867
      Peak Intensity =       879 ♦    875
               No Peak!          877    0.323         2
   V   292.402
      Off Peak Int.  =      3402 ♦   3409
      Peak Intensity =      3400 ♦   3399
               No Peak!         3400    0.021        -1
   BF  313.042
      Off Peak Int.  =       324 ♦    327
      Peak Intensity =       343 ♦    342
               No Peak!          343    0.206        17
   CU  324.754
      Off Peak Int.  =       892 ♦    893
      Peak Intensity =       915 ♦    910
               No Peak!          913    0.387        20
   AG  328.068
      Off Peak Int.  =       725 ♦    737
```

```
Analyze Samples                              11-21-1992 @ 13:25:58 -- 25


      Peak Intensity =       717 ♦    719
               No Peak!          718    0.197       -13
   CA  422.673
      Off Peak Int.  =      1291 ♦   1307
      Peak Intensity =      4139 ♦   4237
                 0.0006         4188    1.655      2889
   BA  455.403
      Off Peak Int.  =       486 ♦    480
      Peak Intensity =       721 ♦    724
                 0.0011          723    0.293       240

Calculating Concentrations for Sample number 10

Elem. Wave-   Net Peak   Calculated    Interference     Net           Dilution
Sym.  length  Intensity  Concentration  Correction  Concentration    Correction

AG 328.068       -13        -0.008                  <   0.010 <       0.010
AS 193.759       -28        -0.059                  <   0.125 <       0.125
BA 455.403       240         0.027                      0.027         0.028
BE 313.042        17         0.000                  <   0.001 <       0.001
CD 228.88         -4         0.000                      0.000         0.000
CR 267.716         2        -0.002                  <   0.015 <       0.015
PB 220.353        12         0.011                  <   0.100 <       0.100
HG 194.227        41         0.025                  <   0.050 <       0.050
NI 231.604         8         0.007                  <   0.020 <       0.020
SR 187.115        41        -0.058                  <   0.000 <       0.000
SB 206.833        33        -0.004                  <   0.000 <       0.000
SE 196.09         23         0.058                  <   0.250 <       0.250
TI 190.864      -146        -0.285                  <   0.250 <       0.250
S  180.731     11196        13.380                     13.380        13.794
V  292.402        -1         0.005                  <   0.025 <       0.025
CU 324.754        20         0.000                  <   0.010 <       0.010
ZN 213.856        16        -0.002                  <   0.005 <       0.005
FE 259.94        147         0.045                      0.045         0.046
CA 422.673      2889         1.882                      1.882         1.940
  SAMPLE #7

SAMPLE #7

Begin Analysis - Sample Number 11

   Ele.  Wave-   Mean Peak  Mean Peak    % RSD    Net Peak
   Sym.  length  Position   Intensity             Intensity
```

SAMPLE #6 Jar Test

x2.5 = 4.8 ppm as $CaCO_3$

```
Analyze Samples                             11-21-1992 @ 13:27:52 -- 26

  S   180.731
     Off Peak Int.  =       756 ♦    768
     Peak Intensity =     12892 ♦  12566
                0.0002     12729     1.811        11967
  SR  187.115
     Off Peak Int.  =       629 ♦    612
     Peak Intensity =       692 ♦    677
              No Peak!       685     1.548           64
  TL  190.864
     Off Peak Int   =      1558 ♦   1540
     Peak Intensity =      1482 ♦   1505
              No Peak!      1494     1.089          -55
  AS  193.759
     Off Peak Int   =      1312 ♦   1251
     Off Peak Int   =      1231 ♦   1269
     Peak Intensity =      1255 ♦   1241
              No Peak!      1248     0.793          -18
  HG  194.227
     Off Peak Int.  =      1225 ♦   1200
     Peak Intensity =      1204 ♦   1203
              No Peak!      1204     0.059           -9
  SE  196.09
     Off Peak Int.  =       835 ♦    839
     Peak Intensity =       847 ♦    860
              No Peak!       854     1.076           17
  SB  206.833
     Off Peak Int.  =       797 ♦    797
     Peak Intensity =       817 ♦    816
              No Peak!       817     0.087           20
  ZN  213.856
     Off Peak Int.  =       265 ♦    270
     Off Peak Int.  =       270 ♦    276
     Peak Intensity =       296 ♦    299
              No Peak!       298     0.712           27
  PB  220.353
     Off Peak Int.  =      1173 ♦   1175
     Off Peak Int.  =      1178 ♦   1150
     Peak Intensity =      1166 ♦   1161
              No Peak!      1164     0.304           -5
  CD  228.88
     Off Peak Int.  =       932 ♦    936
     Peak Intensity =       930 ♦    938
              No Peak!       934     0.606            0
  NI  231.604
     Off Peak Int.  =       411 ♦    412
     Peak Intensity =       414 ♦    413
              No Peak!       414     0.171            2
  FE  259.94
```

```
Analyze Samples                             11-21-1992 @ 13:32:13 -- 27

     Off Peak Int.  =       750 ♦    760
     Off Peak Int.  =       747 ♦    765
     Peak Intensity =      1002 ♦   1008
                0.0002      1005     0.422          249
  CR  267.716
     Off Peak Int.  =       864 ♦    866
     Peak Intensity =       864 ♦    867
              No Peak!       866     0.245            1
  V   292.402
     Off Peak Int.  =      3357 ♦   3315
     Peak Intensity =      3364 ♦   3359
              No Peak!      3362     0.105           26
  BE  313.042
     Off Peak Int.  =       322 ♦    323
     Peak Intensity =       341 ♦    340
              No Peak!       341     0.207           18
  CU  324.754
     Off Peak Int.  =       862 ♦    889
     Peak Intensity =       908 ♦    916
              No Peak!       912     0.620           36
  AG  328.068
     Off Peak Int.  =       709 ♦    715
     Peak Intensity =       713 ♦    715
              No Peak!       714     0.198            2
```

```
                  0.0002     1005     0.472        243
   CR 267.716
      Off Peak Int.  =        864 ♦     866
      Peak Intensity =        864 ♦     867
                No Peak!        866     0.245          1
   V  292.402
      Off Peak Int.  =       3357 ♦    3315
      Peak Intensity =       3364 ♦    3359
                No Peak!       3302     0.105         26
   BE 313.042
      Off Peak Int.  =        322 ♦     323
      Peak Intensity =        341 ♦     340
                No Peak!        341     0.207         18
   CU 324.754
      Off Peak Int.  =        862 ♦     889
      Peak Intensity =        908 ♦     916
                No Peak!        912     0.620         36
   AG 328.068
      Off Peak Int.  =        709 ♦     715
      Peak Intensity =        713 ♦     715
                No Peak!        714     0.198          2
   CA 422.673
      Off Peak Int.  =       1415 ♦    1403
      Peak Intensity =      44999 ♦   45341
                 0.0007       45170     0.535      43761
   BA 455.403
      Off Peak Int.  =        480 ♦     483
      Peak Intensity =       1137 ♦    1128
                 0.0011        1133     0.562        651


Calculating Concentrations for Sample Number 11

Elem. Wave-   Net Peak   Calculated   Interference     Net          Dilution
Sym. length  Intensity Concentration  Correction  Concentration   Correction

AG 328.068         2        -0.002                 <    0.010 <        0.010
AS 193.759       -18        -0.048                 <    0.125 <        0.125
BA 455.403       651         0.074                      0.074          0.076
BE 313.042        18         0.000                 <    0.001 <        0.001
CD 228.88          0         0.000                      0.000          0.000
CR 267.716         1        -0.003                 <    0.015 <        0.015
PB 220.353        -5        -0.008                 <    0.100 <        0.100
HG 194.227        -9        -0.001                 <    0.050 <        0.050
NI 231.604         2         0.030                 <    0.020 <        0.020
SB 187.115        64         0.067                      0.067          0.069
```

SAMPLE #7 Jar Test

```
Analyze Samples                             11-21-1992 @ 13:35:22 -- 28


SB 206.833        20        -0.023                 <    0.000 <        0.000
SE 196.09         17         0.048                 <    0.250 <        0.250
TL 190.864       -55        -0.135                 <    0.250 <        0.250
S  180.731     11967        14.309                     14.309         14.752
V  292.402        26         0.009                 <    0.025 <        0.025
CU 324.754        36         0.006                 <    0.010 <        0.010
ZN 213.856        27         0.000                 <    0.005 <        0.005
FE 259.94        249         0.078                      0.078          0.080
CA 422.673     43761        28.528                     28.528         29.410
  SAMPLE #8
```

x 2.5 = 73.53 ppm as $CaCO_3$

```
SAMPLE #8


Begin Analysis - Sample Number 12

   Ele.  Wave-   Mean Peak  Mean Peak     % RSD     Net Peak
   Sym.  length  Position   Intensity               Intensity

   S  180.731
      Off Peak Int.  =        750 ♦     755
      Peak Intensity =      12794 ♦   13031
                 0.0002       12913     1.298      12160
   SB 187.115
      Off Peak Int.  =        609 ♦     637
      Peak Intensity =        681 ♦     686
                No Peak!        684     0.517         61
   TL 190.864
      Off Peak Int.  =       1515 ♦    1512
      Peak Intensity =       1484 ♦    1478
                No Peak!       1481     0.286        -33
   AS 193.759
      Off Peak Int.  =       1209 ♦    1207
      Off Peak Int.  =       1245 ♦    1211
      Peak Intensity =       1236 ♦    1244
                No Peak!       1240     0.456         22
   HG 194.227
      Off Peak Int.  =       [illegible] ♦    [illegible]
```

```
 S   180.731
     Off Peak Int.  =      750 ♦     755
     Peak Intensity =    12794 ♦   13031
              0.0332     12913     1.296          12160
  SR  187.115
     Off Peak Int.  =      609 ♦     637
     Peak Intensity =      681 ♦     686
            No Peak!       684     0.517            61
  TL  190.864
     Off Peak Int   =     1515 ♦    1512
     Peak Intensity =     1484 ♦    1478
            No Peak!      1481     0.286           -33
  AS  193.759
     Off Peak Int.  =     1209 ♦    1207
     Off Peak Int.  =     1245 ♦    1211
     Peak Intensity =     1236 ♦    1244
            No Peak!      1240     0.456            22
  HG  194.227
     Off Peak Int   =     1206 ♦    1164
     Peak Intensity =     1195 ♦    1181
            No Peak!      1188     0.833             3
  SE  196.09
     Off Peak Int.  =      361 ♦     341
     Peak Intensity =      346 ♦     355
            No Peak!       851     0.748             0
  SB  206.833



Analyze Samples                               11-21-1992 @ 13:38:22 -- 29


     Off Peak Int.  =      814 ♦     828
     Peak Intensity =      819 ♦     821
            No Peak!       820     0.172            -1
  ZN  213.856
     Off Peak Int.  =      270 ♦     276
     Off Peak Int.  =      283 ♦     279
     Peak Intensity =      291 ♦     289
            No Peak!       290     0.488            13
  PB  220.353
     Off Peak Int.  =     1205 ♦    1157
     Off Peak Int.  =     1183 ♦    1192
     Peak Intensity =     1182 ♦    1209
            No Peak!      1196     1.596            11
  CD  228.88
     Off Peak Int.  =      941 ♦     936
     Peak Intensity =      958 ♦     941
            No Peak!       950     1.265            11
  NI  231.604
     Off Peak Int.  =      412 ♦     417
     Peak Intensity =      419 ♦     417
            No Peak!       418     0.338             3
  FE  259.94
     Off Peak Int.  =      759 ♦     759
     Off Peak Int.  =      769 ♦     772
     Peak Intensity =      795 ♦     796
            No Peak!       796     0.089            31
  CR  267.716
     Off Peak Int.  =      864 ♦     870
     Peak Intensity =      869 ♦     876
            No Peak!       873     0.567             6
  V   292.402
     Off Peak Int.  =     3373 ♦    3315
     Peak Intensity =     3364 ♦    3355
            No Peak!      3360     0.189            16
  BE  313.042
     Off Peak Int.  =      327 ♦     324
     Peak Intensity =      341 ♦     341
            No Peak!       341     0.000            18
  CU  324.754
     Off Peak Int.  =      881 ♦     888
     Peak Intensity =      897 ♦     902
            No Peak!       900     0.393            15
  AG  328.068
     Off Peak Int.  =      707 ♦     717
     Peak Intensity =      712 ♦     708
            No Peak!       710     0.398            -2
  CA  422.673
     Off Peak Int.  =     1286 ♦    1302
```

```
     Off Peak Int.  =        [illegible] ♦    [illegible]
     Peak Intensity =        897 ♦    902
                 No Peak!        900     0.393
 AG  328.068
     Off Peak Int.  =        707 ♦    717
     Peak Intensity =        717 ♦    708
                 No Peak!        710     0.398          -2
 CA  422.673
     Off Peak Int.  =       1286 ♦   1302



Analyze Samples                              11-21-1992 @ 13:42:45 -- 30


     Peak Intensity =       5117 ♦   5070
               0.0005       5094     0.652        3800
  BA  455.403
     Off Peak Int.  =        476 ♦    476
     Peak Intensity =        689 ♦    680
               0.0031        685     0.929         209

Calculating Concentrations for Sample Number 12
```

SAMPLE #8 Jar Test

```
Elem. Wave--  Net Peak   Calculated   Interference     Net          Dilution
Sym.  length  Intensity Concentration  Correction  Concentration    Correction

AG 328.068         -2        -0.003                 <    0.010 <       0.010
AS 193.759         22        -0.003                 <    0.125 <       0.125
BA 455.403        209         0.024                      0.024         0.025
BE 313.042         18         0.000                 <    0.001 <       0.001
CD 228.88          11         0.001                      0.001         0.001
CR 267.716          6        -0.001                 <    0.015 <       0.015
PB 220.353         11         0.010                 <    0.100 <       0.100
HG 194.227          3         0.005                 <    0.050 <       0.050
NI 231.604          3         0.001                 <    0.020 <       0.020
SB 187.115         61         0.051                      0.051         0.053
SB 206.833         -1        -0.053                 <    0.000 <       0.000
SE 196.09           0         0.019                 <    0.250 <       0.250
TL 190.864        -33        -0.099                 <    0.250 <       0.250
S  180.731      12160        14.542                     14.542        14.992
V  292.402         16         0.008                 <    0.025 <       0.025
CU 324.754         15        -0.002                 <    0.010 <       0.010
ZN 213.856         13        -0.002                 <    0.005 <       0.005
FE 259.94          31         0.007                 <    0.010 <       0.010
CA 422.673       3800         2.475                      2.475         2.552
```

x2.5 = 5.4 ppm as $CaCO_3$

```
  SAMPLE #9



SAMPLE #9

Begin Analysis - Sample Number 13

   Ele.  Wave-   Mean Peak  Mean Peak    % RSD    Net Peak
   Sym.  length  Position   Intensity             Intensity

   S   180.731
     Off Peak Int.  =        754 ♦    793
     Peak Intensity =      12889 ♦  12516
               0.0002      12703     2.076        11929



Analyze Samples                              11-21-1992 @ 13:44:36 -- 31


   SB  187.115
     Off Peak Int.  =        641 ♦    632
     Peak Intensity =        686 ♦    685
                 No Peak!        686     0.103          49
   TL  190.864
     Off Peak Int.  =       1544 ♦   1546
     Peak Intensity =       1477 ♦   1480
                 No Peak!       1479     0.143         -66
   AS  193.759
     Off Peak Int.  =       [illegible] ♦   [illegible]
```

```
Analyze Samples                          11-21-1992 @ 13:44:36 -- 31

  SB  187.115
     Off Peak Int.  =      641 ♦     632
     Peak Intensity =      686 ♦     685
              No Peak!         686      0.103        49
  TL  190.864
     Off Peak Int.  =     1544 ♦    1546
     Peak Intensity =     1477 ♦    1480
              No Peak!        1479      0.143       -66
  AS  193.759
     Off Peak Int.  =     1339 ♦    1311
     Off Peak Int.  =     1328 ♦    1334
     Peak Intensity =     1298 ♦    1325
              No Peak!        1312      1.455       -21
  HG  194.227
     Off Peak Int.  =     1232 ♦    1223
     Peak Intensity =     1231 ♦    1237
              No Peak!        1234      0.344         6
  SE  196.09
     Off Peak Int.  =      828 ♦     850
     Peak Intensity =      864 ♦     859
              No Peak!         862      0.410        23
  SB  206.833
     Off Peak Int.  =      796 ♦     817
     Peak Intensity =      818 ♦     824
              No Peak!         821      0.517        14
  ZN  213.856
     Off Peak Int.  =      270 ♦     278
     Off Peak Int.  =      280 ♦     272
     Peak Intensity =      343 ♦     345
               0.0009          344      0.411        69
  PB  220.353
     Off Peak Int.  =     1192 ♦    1146
     Off Peak Int.  =     1174 ♦    1171
     Peak Intensity =     1179 ♦    1178
              No Peak!        1179      0.060         8
  CD  228.88
     Off Peak Int.  =      931 ♦     939
     Peak Intensity =      950 ♦     947
              No Peak!         949      0.224        14
  NI  231.604
     Off Peak Int.  =      411 ♦     414
     Peak Intensity =      411 ♦     415
              No Peak!         413      0.685         0
  FE  259.94
     Off Peak Int.  =      754 ♦     754
     Off Peak Int.  =      763 ♦     775
     Peak Intensity =     1195 ♦    1202
               0.0005         1199      0.413       437
  CR  267.716

Analyze Samples                          11-21-1992 @ 13:48:57 -- 32

     Off Peak Int.  =      884 ♦     873
     Peak Intensity =      875 ♦     876
              No Peak!         876      0.081        -3
  V   292.402
     Off Peak Int.  =     3396 ♦    3380
     Peak Intensity =     3382 ♦    3365
              No Peak!        3374      0.356       -14
  BE  313.042
     Off Peak Int.  =      324 ♦     328
     Peak Intensity =      342 ♦     341
              No Peak!         342      0.207        16
  CU  324.754
     Off Peak Int.  =      877 ♦     889
     Peak Intensity =      928 ♦     920
              No Peak!         924      0.612        41
  AG  328.068
     Off Peak Int.  =      714 ♦     712
     Peak Intensity =      715 ♦     714
              No Peak!         715      0.099         2
  CA  422.673
     Off Peak Int.  =     1549 ♦    1557
     Peak Intensity =   102892 ♦  102034
               0.0007       102463      0.592    100910
  BA  455.403
     Off Peak Int.  =      477 ♦     480
     Peak Intensity =     1562 ♦    1630
```

```
       Off Peak Int.  =      931 ♦    939
       Peak Intensity =      950 ♦    947
                No Peak!         949      0.224         14
    NT  231.604
       Off Peak Int   =      411 ♦    414
       Peak Intensity =      411 ♦    415
                No Peak!         413      0.685          0
    FF  259.94
       Off Peak Int.  =      754 ♦    754
       Off Peak Int.  =      763 ♦    775
       Peak Intensity =     1195 ♦   1202
                  0.0005        1199      0.413        437
    CR  267.716
```

```
Analyze Samples                        11-21-1992 @ 13:48:57 -- 32

       Off Peak Int.  =      884 ♦    873
       Peak Intensity =      875 ♦    876
                No Peak!         876      0.021         13
    V  292.402
       Off Peak Int.  =     3396 ♦   3380
       Peak Intensity =     3382 ♦   3365
                No Peak!        3374      0.356        -14
    BE  313.042
       Off Peak Int.  =      324 ♦    328
       Peak Intensity =      342 ♦    341
                No Peak!         342      0.207         16
    CU  324.754
       Off Peak Int.  =      877 ♦    889
       Peak Intensity =      928 ♦    920
                No Peak!         924      0.612         41
    AG  328.068
       Off Peak Int.  =      714 ♦    712
       Peak Intensity =      715 ♦    714
                No Peak!         715      0.099          2
    CA  422.673
       Off Peak Int.  =     1549 ♦   1557
       Peak Intensity =   102892 ♦ 102034
                  0.0007      102463      0.592     100910
    BA  455.403
       Off Peak Int.  =      477 ♦    480
       Peak Intensity =     1563 ♦   1600
                  0.0011        1582      1.654       1103

Calculating Concentrations for Sample Number 13

Elem. Wave-   Net Peak  Calculated    Interference      Net         Dilution
Sym.  length  Intensity Concentration Correction   Concentration   Correction

AG 328.068        2       -0.002                  <  0.010 <       0.010
AS 193.759      -21       -0.051                  <  0.125 <       0.125
BA 455.403     1103        0.126                     0.126         0.130
BE 313.042       16        0.000                  <  0.001 <       0.001
CD 228.88        14        0.001                     0.001         0.001
CR 267.716       -3       -0.005                  <  0.015 <       0.015
PB 220.353        8        0.007                  <  0.100 <       0.100
HG 194.227        6        0.007                  <  0.050 <       0.050
NT 231.604        0       -0.002                  <  0.020 <       0.020
SB 187.115       49       -0.015                  <  0.000 <       0.000
SB 206.833       14       -0.031                  <  0.000 <       0.000
SE 196.09        23        0.058                  <  0.250 <       0.250
TI 190.864      -66       -0.153                  <  0.250 <       0.250
S  180.731    11929       14.264                    14.264        14.705
V  292.402      -14        0.004                  <  0.025 <       0.025
```

SAMPLE #9 Jor Test

```
Analyze Samples                        11-21-1992 @ 13:51:42 -- 33

CU 324.754       41        0.007                  <  0.010 <       0.010
ZN 213.856       69        0.008                     0.008         0.008
FE 259.94       437        0.139                     0.139         0.143
CA 422.673   100910       65.787                    65.787        67.822
  5PPM ICV
```

x 2.5 – 169.6 ppm $CaCO_3$