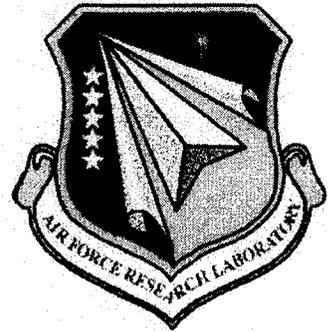


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**STUDY OF FACTORS RELATED TO MAGNETIC  
TREATMENT OF CALCIUM CARBONATE  
SATURATED WATER**

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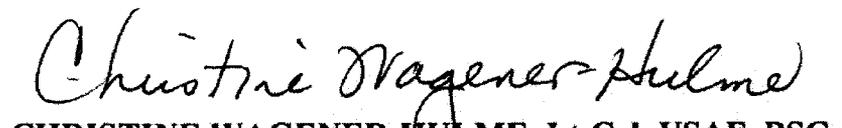
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GRADUATE COMMITTEE APPROVAL

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This thesis has been read and approved by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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## ABSTRACT

# STUDY OF FACTORS RELATED TO MAGNETIC TREATMENT OF CALCIUM CARBONATE SATURATED WATER

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Magnetic water treatment to reduce scale formation in industrial equipment has been shown alternatively to have little or no effect or to be successful in field trials. Laboratory studies have also shown mixed results historically. Recent research shows promising results for effects of magnetic treatment on calcium carbonate crystals and suspensions. If and as this technology is proven beneficial, proper application guidelines must be developed for this technology to achieve wider application in yielding significant economic and environmental benefits.

The research reported herein summarizes the design and operation of a test system to produce calcium carbonate crystals for analysis with or without magnetic fields applied. Aqueous and solid sampling were performed. System parameters varied during testing include water temperature, flow rate, test duration, and the number of magnetic devices attached. Crystal residue was examined by XRD for relative proportions of calcite and aragonite. Filter residue was also examined by XRF for the presence of transition metals and elements known to substitute for calcium in known carbonate scale formers. Aqueous samples were tested for zeta potential of charged particles and by flame ionization atomic absorption for iron concentrations.

The percent calcite in the sample residues showed little change relative to the estimated error of the method, and the changes were not consistent with any one system test parameter. Visual examination of filter residues did show effects of magnetic treatment versus non-magnetic treatment for certain test parameters. XRF analysis showed a consistent decreasing trend in iron content in the solid filter residue with increasing number of magnetic devices attached. The zeta potential measurements indicate decreased magnitude surface potential with the presence of magnetic devices. Particle size distribution analysis showed increased counts roughly in the range of 6 – 35 microns.

The background section briefly discusses why there is so much controversy on this topic and gives examples of how results can be misinterpreted either in favor of or against the use of these devices. A brief introduction to proposed mechanisms is presented.

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# STUDY OF FACTORS RELATED TO MAGNETIC TREATMENT OF CALCIUM CARBONATE SATURATED WATER

## 1.0 INTRODUCTION

While chemical additives usually control the scaling of heat transfer surfaces, this imposes significant costs and maintenance. Where the chemicals do not completely solve the problem, acid cleaning, physical scraping or replacement of equipment is required, at additional financial and environmental costs and logistical support. A number of benefits accrue from the non-chemical suppression of scaling: decreased chemical purchasing, handling, use and disposal; reduced energy consumption due to scale-free heat transfer surfaces; lower labor requirements to perform chemical-based prevention and cleaning treatment; lower atmospheric emissions due to lower fuel consumption; reduced water use due to lowered system drainage requirements to remove scale-forming constituents; and extended service lifetimes of equipment. These environmental and economic benefits are not reliably predicted because the factors determining success or failure of non-chemical means such as magnetic treatment have either not been identified or are poorly defined.

A small sampling of the literature on the subject shows examples of successful field applications (MacGarva, 1993; Simpson, 1980; Raisen 1984) and measured effects due to magnetic treatment in the laboratory (Duncan, 1995; Busch and Busch, 1996). Other researchers have shown no effect or inconclusive evidence for the commercial magnetic devices tested (Lawrence, 1984; Limpert and Raber, 1985; Hasson and Bramson, 1985). For a larger discussion of the literature see Baker and Judd (1996). Broad conclusions that may be drawn from reading a lot of the literature is that it is probable that the commercial devices do not work equally well and that there may be numerous situations where none will work due to inappropriate conditions for use. This is no different than looking at the success of other processes or equipment where improperly applied. Several problems exist with the use of magnetic treatment devices (MTDs) for anti-scale magnetic treatment (AMT) including: lack of successful replication of many experiments, poor field trial controls, lack of definitive causal mechanisms and clear cut success in all claimed applications. However, sufficient evidence indicates well-defined changes in laboratory experiments and successful applications exist to merit further research. The second international symposium held in England in 1996 addressed principally by university researchers is ample evidence of the respectable attention afforded the subject by some in the international community.

## 2.0 LITERATURE SURVEY AND BACKGROUND

The literature review gives an overview of laboratory research and field experience with magnetic treatment devices (MTDs) both in the United States and in foreign countries over about the last 45 years. The concentration is on research from the last fifteen years. While some of the information is applicable to many forms of scale, the information presented here focuses on calcium carbonate scale specifically.

### 2.1 Brief History

There is very little in the open literature in the U.S. prior to the 1950s regarding the examination of magnetic water devices. In the first half of the 1950s several U.S. engineers and scientists wrote articles attacking the statements of sales literature prevalent at that time, but no attempt was made to test the devices. The second half of the 1950s saw several serious attempts by researchers to test scale-preventing magnetic devices. None of the tests showed any success in preventing scale formation. There is very little U.S. published literature on the subject in the U.S. between 1960 and 1977. I believe the device testing of the late 1950s convinced many that the devices did not work. However, many articles came out in Europe and the former Soviet Union during the 1970s (O'Brien, 1979), generally indicating from moderate to considerable success in reducing adherent scale formation and removal of existing scales using magnetic water treatment devices. Field testing, as reported by water-treatment magnetic-device-marketing companies and occasionally by customers, has continued to show successful applications of these devices. Unsuccessful field trials were rarely reported by these sources.

Starting in the late 1970s serious independent research in the U.S. began again to examine the effectiveness of magnetic treatment of water to prevent scaling. Until the mid 1980s essentially all the independent laboratory tests and field trials showed little or no effect on measured parameters due to the use of MTDs. Since the mid 1980s more U.S. (Raison, 1984) and foreign (Donaldson, 1990) researchers have found significant, measurable changes in several calcium carbonate crystal parameters. Scale reduction has been verified in some instances (Duffy, 1977) and scale removal has been reported occasionally. However, some research has continued to show no measurable changes in water characterization parameters or scaling due to the use of magnetic devices (Hasson and Bramson, 1985; Lawrence, 1984). During the mid-1990's there has been continued international interest in the subject with the second international symposium for scientists and engineers being held at Cranfield University in the United Kingdom in March 1996. The following list includes the majority of reported successful applications of these devices in reducing adherent scale: boilers, cooling towers, steam generators, air-conditioning condensers, sugar-processing plants, oil field production, and residential hot water heaters (Baker and Judd, 1996).

## 2.2 Experimental Results

The most obvious questions examined in the literature have been whether magnetic water conditioning devices reduce scale formation on pipe or heat exchange surfaces and whether they remove or "soften" existing scale from these surfaces. Many other water and calcium carbonate crystal parameters have been examined as part of the effort to prove or disprove the claimed phenomenon and to understand underlying mechanisms that may explain its functioning. Measuring parameters other than direct formation of scale not only helps in the search for understanding the phenomenon, but in some cases is a quicker and easier means to look for magnetic effects in the aqueous solutions tested. The listing here will provide a quick look at the various parameters examined in the published literature.

Scale surface deposition. Some research and field trials have shown success in reducing scale formation and some have even shown reduction in existing scale deposits (Donaldson, 1990).

Corrosion. The use of an MTD has been reported to increase corrosion of steel and (Duffy, 1977; Eliassen and Skrinde, 1957) iron. Other data suggest inhibition of iron or steel corrosion due to the presence of an operating MTD (Baker and Judd, 1996). No consensus has been reached about the effect on iron and steel. Data show increased corrosion for active state titanium but reduced corrosion of aluminum and zinc due to the presence of operating MTDs (Baker and Judd, 1996). If an existing scale layer on an iron pipe is removed due to AMT, then corrosion should increase due to loss of the protective layer.

Electrical properties. One report shows voltage and current changes measured in conducting fluids treated with MTDs relative to the same fluids operated without MTDs (Busch, et al., 1986).

Crystal phases. This has been a significant area of research on the question of anti-scale magnetic treatment (AMT) of water. Several researchers in different countries have reported measurable changes in the calcium carbonate crystal phase (Baker and Judd, 1996; Pandolfo, 1987). Calcium carbonate is frequently found in two polymorphic forms, which are identical in chemical composition, but differ in density and crystal structure and shape. These two crystalline phases are calcite and aragonite. A third crystalline phase, vaterite, is infrequently found. The changes most commonly reported in the literature for precipitated calcium carbonate crystals are noted below.

Crystals precipitated from aqueous solutions without AMT are composed principally of calcite (Duffy, 1977) (70 - 80% is the most commonly reported range), (Deren, 1985; Donaldson, 1990) the remainder being aragonite. After the solutions flow through MTDs and precipitated crystals are examined, they are found to be primarily aragonite (Higashitani, et al., 1993) (70 - 80% has been reported by several publications) with the balance composed of calcite. Adherent scale removed from pipe and heat exchanger surfaces has generally been determined to be composed mostly of the calcite phase. However, Cowan and Weintritt (1976) indicate that it is principally composed of aragonite. Precipitated crystals removed from the bulk fluid (by filtration or settling in quiescent zones) generally have been shown to be mostly aragonite. With different crystalline shapes, densities, and ions that can substitute into the respective crystal lattices for calcite and aragonite, there are some significant differences between these two phases. Some researchers believe that this noticeable effect is tied to the scale reduction phenomenon.

Other crystal factors. Other changes in the precipitated crystals that have been noted include size, number and crystal shapes. While published results have shown increases and decreases in both crystal size and number, it appears that the majority of the reports favor an increase in crystal size (Deren, 1985) accompanied by a decrease in crystal numbers (Higashitani, et al, 1993) due to the effect of AMT. Many changes in crystal shape after AMT have been reported (Kronenberg, 1985).

pH. Ellingsen and Fjeldsend (1982) discuss the impact of pH on the solubility of CaCO<sub>3</sub>. Parsons (1996) showed that controlling the pH of the solution eliminated any AMT effect. Others have not measured in change in pH during AMT testing while others have noted small changes.

Zeta potential. Few researchers have measured zeta potential, but this parameter indicates a potentially powerful argument for changes due to AMT. The maximum reduction in zeta potential measured for an MTD treated solution was 25%. Reduced potential allows charged particles closer proximity, facilitating coagulation of colloid particles (Parsons, 1996; Higashitani, 1996).

Impurities. Some researchers have argued that reduced scaling due to the use of MTDs derives solely from the presence of certain known scale -reducing ions, especially iron. These researchers proposed that corrosion of the MTD itself or of the adjacent pipes supplied the small concentrations of iron necessary to suppress scale formation. Hasson and Bramson (1985) showed the addition of 1.2 - 1.4 ppm of Fe suppressed scale formation by as much as 40% (without regard to AMT) and the removal of sulfite (a scale inhibitor) could increase the scaling rate by up to 60%. Some researchers argue that iron and various colloids are necessary for the successful application of AMT. They showed that the use of AMT with small concentrations of iron and colloids reduced scale formation significantly more than without AMT. Some research shows that the presence of iron favors the presence of the aragonite phase (Pandolfo, 1987) and inhibits the aragonite to calcite transition (Herzog, et al., 1989). Thirty-four chemicals were tested in the mid 1980s in one study (Meyer, 1984) alone for their effect on calcium carbonate crystal growth kinetics. Some impurities are used industrially as scale suppressants (Ellingsen and Fjeldsend, 1982).

Solubilization rate. One study showed the solubilization rate of calcium carbonate to increase as much as 43% due to the use of MTDs (Baker and Judd, 1996).

Conductivity and dissolved solids. Both these parameters have been measured at less than a 10 % reduction due to AMT. Some tests have shown no change to these parameters (Baker and Judd, 1996).

Suspended solids and infrared absorbance. Some tests showed no change to these two (Bernardin and Chan, 1991) parameters. Other tests have shown a significant (25-30 %) change in value due to magnetic treatment. Some later researchers proposed that the significant changes measured were the result of the presence of impurities not noted by the those observing these larger changes.

Physical water parameters. No significant changes have been reliably measured in many physical water characteristics such as density, viscosity, boiling and freezing points, visible light transmission and reflection (Martynova and Gusev, 1974).

Memory effect. This is an important and characteristic feature that frequently occurs when magnetic treatment has been reported to produce significant, measurable changes. Whatever characteristic

or parameter produces a measurable change is shown to persist for several hours up to about a week after magnetic treatment is terminated (Belova, 1972; Higashitani, et al, 1993; Pandolfo, 1987). This is both an important practical effect for successful AMT and tied to understanding the underlying mechanism.

### 2.3 Parameters Affecting Magnetic Device Testing

A large number of factors have been reported by one or more authors to have a significant effect on the testing of MTDs. They are briefly introduced here to indicate the types of factors that must be controlled or measured for successful testing of MTDs. Successful results as used here solely indicate that AMT was able to demonstrate a significant, measurable change in the parameters examined. It does not necessarily mean that scale deposition was noticeably reduced, as this parameter was not always measured.

Calcium carbonate saturation level. This is the most-commonly accepted requirement (Martynova and Gusev, 1974; O'Brien, 1979) for an MTD device to show successful results. The solution must be supersaturated with respect to calcium carbonate at the time and point of application of the magnetic device. The supersaturated condition may be determined using the Langelier Saturation and Ryznar Indices (Cowan and Weintritt, 1976).

Magnetic field strength or intensity. Several reports show that increasing magnetic field strength increases whatever (Belova, 1972; Higashitani, et al., 1993; Martynova and Gusev, 1974) effect is being measured up to a cutoff point. This point of no additional effect occurred about 0.3 to 0.5 tesla (T) (3000 - 5000 gauss (G)).

Magnet design and field orientation. (Belova, 1972) Electromagnets are commonly used in the former Soviet Union but have been infrequently investigated in this country. Promoters of MTDs defend the importance of different arrangements of permanent magnets which include pole arrangement and spacing. Whatever the design, the magnetic force lines should be perpendicular to the flow velocity. This produces the largest Lorentz forces induced by the magnetic field. Lorentz forces are thought by some to be the causative factor underlying the magnetic effect (Baker and Judd, 1996).

Magnet installation. Another possible effect is whether the magnet is installed in-line (the solution flows around the surface of the magnet) or whether it is installed external to any pipes. The in-line style produces flow blockage and turbulence (thought by some to assist the magnetic effect or coagulation process) but is more difficult to install and remove. In-line may also introduce chemical effects (corrosion) which may add or obscure scaling mechanisms.

Wetted surfaces. The piping and heat exchanger construction materials may affect test results if they supply small quantities of impurities that affect scale formation or crystal nucleation or growth kinetics. Different surface finishes also affect crystal nucleation on the solid surfaces. For example: scale does not adhere as readily to the smoother surfaces of PVC pipes (Cowan and Weintritt, 1976).

Time effects. The total exposure time of the fluid to the magnetic field has been shown several times to affect the outcome of AMT tests (Higashitani, et al., 1993). The exposure time is influenced by fluid velocity, number and length of the devices used and the number of passes recirculated water makes

through the magnetic field. Also important is the length of time since magnetic exposure before a solution is examined. This is tied to the memory effect (Kronenberg, 1985).

Fluid properties. Fluid temperature and pH very significantly affect the solubility of calcium carbonate (Kronenberg, 1985). Fluid pressure is significant only in highly pressurized systems.

Flow conditions. Flow velocity affects the magnetic exposure time and the magnitude of the Lorentz forces. High velocities can affect crystal nucleation on side walls and can produce a scouring effect, limiting the total adherent scale thickness. Several published reports indicate an influence due to fluid turbulence, whether due to the system design or fluid velocity or artificially created by an in-line magnet. The Russians especially have commented on this factor. Some results indicate successful AMT above the laminar range. If more than one phase is present in the flowing solution, crystal nucleation can be impacted. Nucleation is affected by vapor-liquid interfaces such as vapor bubble surfaces.

Impurities. Many impurities, some at very small concentrations, have a large impact on crystal growth kinetics. Many inorganic and some organic impurities (Duncan, 1995; Kazmierczak, 1978) have an effect, mostly to inhibit crystal growth rates. Even some proteins are reported to affect the calcite-aragonite transition (Wu, 1997). Different impurities substitute into the calcite and aragonite crystal structures, affecting both their growth rates and transformations between the two phases (Baker and Judd, 1996; Heffner, 1976).

Heat load / specific heat rate. A few researchers have shown the rate of heat transfer supplied by the heat exchange equipment can significantly affect the AMT effect on scaling (Hasson and Bramson, 1985; Martynova and Gusev, 1974).

Specimen preparation. One of the popular techniques for examining calcium carbonate crystals is X-ray diffraction (XRD). Grinding and storage of the scale specimens can affect the composition of the crystal phase measured (calcite vs. aragonite) (Criado and Trillo, 1975; Gammage and Glasson, 1975).

Measurement methodologies. The measurement methodologies used don't change the crystal parameters affected by the use of AMT, but in some cases may change the interpretation of the noted results. Specimen preparation is one example of this phenomenon.

#### 2.4 "Unsuccessful" and "Successful" Magnetic Device Testing

Examining specific examples of both "successful" and "unsuccessful" laboratory tests or field trials can be very instructive in understanding why there are so many conflicting results and conclusions reported in the literature. It is very important to look at how the tests were conducted, what parameters were measured, and how the results were interpreted.

Controlled tests were run on both non-magnetic and magnetic water treatment devices in tube heat exchangers between 1975 and 1984 (Limpert and Raber, 1985). Two electromagnetic devices and two permanent magnetic devices were tested. The published report concluded that none of the magnetic devices significantly reduced scale. This is the same conclusion reached by independent laboratory and field tests reported in 1977 and the late 1950s.

The published data for this research showed that two of the MTDs tested showed scale reductions of 14 - 16%. While this is not a large reduction, it is large enough to be confidently measured, and may in fact show successful treatment given the parameters to be discussed next. Several parameters currently considered important in successful AMT applications were in ranges during this research that would indicate at best a very marginal application for successful scale reduction due to AMT. These include very low levels of iron in the treated water, significant temperature variations, a single-pass system with short magnetic exposure times, and problematic calcium carbonate saturation levels. The published data were used to calculate Langelier Saturation and Ryznar Indices. These indicate that the water was likely not supersaturated with calcium carbonate at the point of exposure to the magnetic field and reached marginal supersaturation levels only in the effluent from the heat-transfer equipment. It may well be that the particular conditions of this testing severely limited the potentially successful application of the MTDs used in this study. The small scale reduction of two of the devices may in fact be all they were able to do given the marginal operating conditions.

A summary of two "successful" applications follows. The U.S. Coast Guard (Simpson, 1980) had a land-based boiler that experienced 40% area reduction in its piping due to adherent scale. An MTD was installed and after several months of operation there was a 41% fuel savings due to reduced boiler fuel requirements, the pipe scale was cleared out, and the exit water temperature increased by more than 20° F. A large quantity of loose, soft scale was removed from a stagnant point in the system. The Coast Guard also applied MTDs to six boilers on six ships (MacGarva, 1993). They measured alkalinity, chlorides and scale before and after chemical conditioning was terminated and magnetic treatment was begun. Begun in 1989 and continuing through at least the end of 1992, the Coast Guard was very satisfied with the results.

As with the previously discussed test results, it is instructive to examine the test controls and reporting. In these published reports there was only a small amount of direct comparison of measured test results with and without AMT. The operating water was poorly characterized and there was little direct control of the experiments so it is difficult to say that the MTDs operated under the same conditions as did the chemical treatment. Also, on the land-based boiler, a special blowdown schedule was instituted. This type of blowdown schedule is known to retard scale formation and is a commonly reported procedure used when magnetic device marketers have a say in the operation of the system for comparison testing. So it is difficult to use these reported results to really give AMT a passing grade for scale prevention, although it looked quite convincing.

## 2.5 Discussion of Reasons for Conflicting Results

It becomes evident that many reported results from AMT testing have had very different results reported for the same parameters from tests performed by different researchers. I believe that this confusion is due to several factors. 1) There are so many inter-related variables. Different parameters dominate solution chemistry, and crystal nucleation and growth under different operating conditions. 2) Many of the reported tests or field trials indicate a lack of control of many of the influential factors or poor

characterization of the tested water. Some of the tests measured parameters that in fact do not change even under reported successful AMT applications. 3) There is incomplete understanding of the many variables that influence potentially successful applications of AMT. This misunderstanding generally causes the lack of control or characterization of experiments. Sometimes this is due to lack of the ability to control or measure certain parameters due to a particular system configuration or lack of funds for measurement equipment. Two very recent examples serve to illustrate these issues.

A utility power plant attached an MTD to a pipe that carried 1% of the total system flow to a holding lagoon where the water cooled. After several days this water was added to the rest of the system flow. The plant manager reported that the MTD was completely unsuccessful in reducing scale. But an understanding of current research indicates that there are at least three problems with this application as tested. 1) The magnetic field was applied to water just before it entered a lagoon for cooling. The problem: low temperature at this point may have indicated an undersaturated calcium carbonate solution. 2) The several-day time delay may have negated any potentially successful water conditioning by the MTD due to the memory effect. 3) Treated water does not somehow magically cure the rest of the water it is mixed with. So at most, one would have observed no more than a 1% scale reduction (probably not even noticeable) even if the AMT had been 100% effective.

A federal government agency (Ferrigan, 1997) recently completed a two-year field test of four magnetic devices. Verbally reports indicated that none of the devices had shown successful results. In particular it was reported that one system was doing so poorly that filtration had to be added to remove all the precipitated calcium carbonate crystals flowing in the fluid. If accurately reported this actually indicates one successful application of AMT. If calcium carbonate is in the water, it can only go three places: 1) remain dissolved in solution, 2) precipitate out as adherent scale or 3) precipitate out as non-adherent crystals that remain in the bulk fluid. If precipitated crystals that remain free floating in a recirculating system are removed with filtration, then the calcium carbonate concentrations in the bulk fluid can gradually be reduced. If the bulk-fluid concentration is reduced, this condition may lead to dissolution of existing adherent scale on pipe surfaces.

## 2.6 Classification of Proposed Mechanisms

Many mechanisms have been proposed to explain scale amelioration through the use of AMT. These different mechanisms have been organized into two different kinds of classification systems. One classification system groups the theories as follows: A) Interatomic effects, B) Contamination effects, C) Intermolecular/ionic effects, D) Interfacial effects (Baker and Judd, 1996). Another classification system groups the different theories into three different categories: 1) Physical/structural water changes, 2) Effect of iron impurities, 3) Lorentz force effect on ions and colloids (Hasson and Bramson, 1985). Multiple theories are also discussed by Ellingsen and Feldsend (1982), Herzog, et al., (1989) and others.

### **3.0 PREMISE AND PROBLEM DEFINITION**

The premise of this effort is that at least one design of MTD does produce changes in water or solid residue (crystalline  $\text{CaCO}_3$ ) parameters that could be tied to plausible explanations for hard water scale minimization in industrial systems. Direct measurement of scale build-up in pipes due to changes in system parameters (principally due to the presence of MTDs) was deemed unmanageable from a cost and time duration standpoint for this effort. A principal distinguishing feature of this study is the design for system water recirculation, commonly found in industrial systems but not common in residential systems.

The two goals of the present research were 1) demonstrating measurable changes in water or crystal parameters potentially tied to hard water scaling and the use of MTDs and 2) conducting testing and analysis to define selection of probable mechanisms. This was a rather broad approach. These goals were supported by objectives focusing on changes in two measurement criteria: 1) the relative proportion of calcite and aragonite (chemically identical forms of calcium carbonate, but different polymorphic crystalline forms, also called crystal phase) and 2) changes in the zeta potential (a measure of surface potential). The change in zeta potential (which affects colloid coagulation) was to be backed up with particle size distribution measurements to look for verification of colloid agglomeration. These objectives required completion of three major tasks: 1) design and construction of a test system that would mimic a circulatory system passing  $\text{CaCO}_3$  laden water through MTDs, allowing for aqueous and crystalline sampling, 2) selection of the evaluation criteria, technologies and analytical approach and 3) development of sample preparation techniques. To look for changes in the noted measurement criteria seven factors were selected for examination. These factors were selected based on both an extensive literature review and consideration of the test capabilities. These seven factors are briefly described below.

- 1) Number of magnets. This impacts the number (or total time) of magnetic exposures that the circulating solution is exposed to.
- 2) Water temperature. This factor significantly impacts chemical solubility, reaction rates and crystal initiation and growth.
- 3) Calcium carbonate concentration at initial mixing time. The saturation level of  $\text{CaCO}_3$  in the tested solution has been implicated by a number of researchers as to whether any positive results are seen or not. It is generally believed that the solution must be "supersaturated" in  $\text{CaCO}_3$ .
- 4) Total circulating test time prior to sampling. This affects the total exposure time to the magnetic field.
- 5) Pumping rate. This factor affects the solution flow velocity which several researchers have implied as having an impact on the magnetic effect. The flow velocity potentially comes into play in two different areas: a) the Lorentz Force on charged particles flowing through a magnetic field is proportional to the particle velocity, b) the flow regime (ie. laminar vs. turbulent) may have an impact on crystal nucleation in bulk solution and on solid surfaces.

- 6) Time between removal of the magnetic field and sampling. This factor may confirm what some researchers (Higashitani, 1996) call the "memory effect" which shows that the measured impact persists some time after removal of the magnetic field.
- 7) Iron concentration. The iron concentration certainly may help explain why a magnetic field impacts MTD testing and why there is a difference in test results between natural waters (frequently containing moderate to low levels of iron) and pure waters containing little or no iron.

A few significant occurrences during test system operation modified some of the above factor manipulations during testing. Originally, lab filtered pure water (16 M $\Omega$ -cm resistivity) was to be used with appropriate amounts of CaCO<sub>3</sub> and iron added. System tests were run with this water but great difficulty was experienced in getting reliable zeta potential readings and producing sufficient residue for crystal examination. Examination of several different source waters with CaCO<sub>3</sub> added led to the use of tap water.

The original intent was to use pump rates that allowed for laminar (Reynolds Number, Re < 2000) as well as mixed or turbulent flow. Unsteady operation at higher flow rates and pump freeze ups at low flow rates prevented system testing beyond a fairly narrow range (1 gpm = 6800 Re, 3 gpm = 20,500 Re, both are turbulent flow) - limiting the usefulness of this factor for interpretative purposes.

Fairly low concentrations of iron are known to greatly affect CaCO<sub>3</sub> crystal nucleation (Meyer, 1984). To look at the effect of iron it was decided to look at iron accumulation in the solid residue filtered from solution. It was anticipated that if the iron in the solid samples could be shown to significantly change in a consistent pattern tied to AMT application then this would point a direction for plausible mechanism development and further research.

The selection of the measurement criteria were based on reported changes in zeta potential and particle sizes (Parsons, et al., 1997; Busch and Busch, 1996) or in the crystal habit (Deren, 1985; Donaldson and Grimes, 1988) among others.

#### **4.0 DESIGN OF TEST SYSTEM**

A test system to perform the desired functions was designed to meet the following requirements:

- a) Allow equilibration of CaCO<sub>3</sub> in solution at different concentrations.
- b) Allow heating of the solution to 105° F and maintaining a relatively constant temperature during the test. 105° F was suggested to represent average cooling tower temperatures. A heat exchanger with removeable pipe sections was beyond the scope of the current project
- c) Allow flow rate variation from laminar to mixed laminar/turbulent flow through the piping system.
- d) Include temperature, pressure and flow measurement and control.

- e) Allow pH measurement and aqueous sampling for alkalinity, hardness and Zeta-Meter measurements.
- f) Physical scale and construction to simulate a piping circulatory system.
- g) Include the ability to capture  $\text{CaCO}_3$  crystals in the size range of 2  $\mu\text{m}$  up to about 35  $\mu\text{m}$  (the expected size range estimated from the literature) from the solution stream without plugging the line during tests.
- h) Have multiple, identical systems to allow side-by-side testing of parameters.
- i) No continuous water-metal contact was to be allowed in the entire system. This was to prevent the possibility of contamination with common metals used in piping system components: iron, copper, zinc.
- j) The pump should not risk crushing agglomerated crystal groups circulating through the system..
- k) The system should be a recirculating system, mimicking cooling tower recirculation.
- l) Pressure fluctuations should be kept to a minimum (desired to be less than four psi).
- m) Provide flow split flexibility between the main pipe line and the bypass tubing line.

Non-technical requirements also had major impacts on the design.

1) Budgeted costs. The entire system was designed and parts ordered prior to submitting the final research grant proposals. Additional funds availability was in no way certain at design and ordering time. The original budget was far more limited. The biggest impact the original equipment budget had on system design and operation was the elimination of automatic controls, principally for temperature control.

2) Timing of equipment orders. The orders were first placed prior to returning to the University where location and equipment questions had yet to be fully resolved, requiring additional design flexibility.

3) Regulations governing which companies could be ordered from and whether a specific item was currently in stock (and therefore could be ordered) affected many component decisions and in a few cases forced design changes to allow for available components.

The above requirements were generally met through use of the following design decisions and components. Component specifics are listed in a subsequent section of the thesis.

A.  $\text{CaCO}_3$  mixing and equilibration took place in a 30 gallon plastic reservoir.

B. Heating of the aqueous solution took place in the 30 gallon plastic reservoir through the use of a 300 W fused quartz immersion heater suspended from a hanging instrumentation rack suspended above the water surface. The failure of one of the heaters required replacement with a 400 W heater due to unavailability of the 300 W heater within the United States at the time of replacement. Initial system testing showed the necessity of insulating the reservoirs to allow reaching 105° F within a reasonable timeframe and to maintain a semi-constant temperature during system operation. The reservoir (tank) was insulated with fiberglass insulation such as is used in building insulation. Voltage controllers were added to allow manual control of the heat rate of the immersion heaters. The budget available at design time did not allow for the use of automatic temperature controllers.

C. An air operated double diaphragm pump was selected to provide approximately the flow rate variation desired, no metal contact, ease of operation off of laboratory air supply and to minimize potential damage to any circulating agglomerated  $\text{CaCO}_3$  crystals. Of all pump types that nominally met the other requirements, the double diaphragm pump was deemed the least likely to damage crystals that had not yet strongly attached themselves to one another. The desired flow rate range in the published pump curves was not achieved in practice. Only a 3 to 1 ratio was achieved with 3 and 1 gpm flow rates being used. These flow rates correspond to velocities in the pipes of 0.83 ft/sec (1 gpm) and 2.48 ft/sec (3 gpm).

D. System temperature response was initially tested with thermometers in both the influent and effluent pipes from the reservoir and compared against an iron-constantan thermocouple installed inside the tank. Once the tank was insulated and the circulating water temperature reached  $105^\circ\text{F}$  it was found that the influent and effluent pipe water temperature measurement was no longer needed and was abandoned. The thermocouple (T/C) was inserted through a plastic tube to prevent the mixing current from pushing the T/C bead up against the tank wall. The T/C bead was coated with nail polish to prevent shorting and to prevent any metal leaching. The T/C bead protruded about 1/2 inch below the bottom of the protective tubing and about 1 – 1 1/2 inches below the water surface, several inches from the tank wall, opposite the side of the heater. The plastic tube was supported by the suspended instrumentation support structure. Thermocouple readings were provided by a digital thermometer external to the tank.

Pressure gages were installed in five locations throughout the main piping line and the bypass tubing line. This provided valuable system operation information such as pressure fluctuations (due to the diaphragm pump), progression of filter plugging (which of the two in-line filters were plugging most rapidly) and an occasional valve or tubing pinch off problem. During initial system checkout, the pressure gauge showed the need for more surge suppression in line, downstream of the pump.

Flow measurement was provided by ball float flow meters in both the main line and the bypass line. Two ranges of flow meters were provided for the bypass line to provide for the flow rate ranges anticipated with the control valve. The pump rate was controlled through the use of air flow metering valves going to the pumps. The air supply also was provided with pressure regulating air filters upstream of the air metering valves.

E. Aqueous sampling was accomplished by removal of the tank lid. The pH probe was hung from the suspended equipment support inside the tank with the wiring leading to an external handheld meter accurate to  $\pm 0.1$  units.

F. The tank capacity was 30 gallons, but for a variety of reasons was operated with 15 gallons. One of the reasons was to allow side entry of a mixer shaft to assure complete mixing of the  $\text{CaCO}_3$ . The water travel path through the main pipe line makes up a total of about 23 feet. The bypass line accounted for about seven feet. The bottom of the tank was sloped. The bottom of the sloped tank cone was attached to sampling tubing, valves and a drain spigot. The sampling port was used to check the settling characteristics of the undissolved  $\text{CaCO}_3$  (which served as an indicator of differences in the mixing action in the two tanks) but crystals from the bottom were never examined by XRD.

G. Capture of solid  $\text{CaCO}_3$  crystals was accomplished through side-stream filtration. Initial system testing with a number of filter membrane materials, styles and pore sizes showed either early plugging or pore sizes too large to trap the desired crystal size range (2--35  $\mu\text{m}$ ). To reduce plugging, a partial size range compromise was required with a 10  $\mu\text{m}$  pore size selected. The early plugging problem was also alleviated by installing a second upstream depth filter with no pores (random fibers provide filtration). It was intended to filter out any large crystals or contaminants that entered the system. A second, very important requirement for the downstream filter was to allow easy removal of the crystals without damage for examination by XRD. This was accomplished by using a smooth surface membrane with tightly controlled diameter pores etched through the membrane.

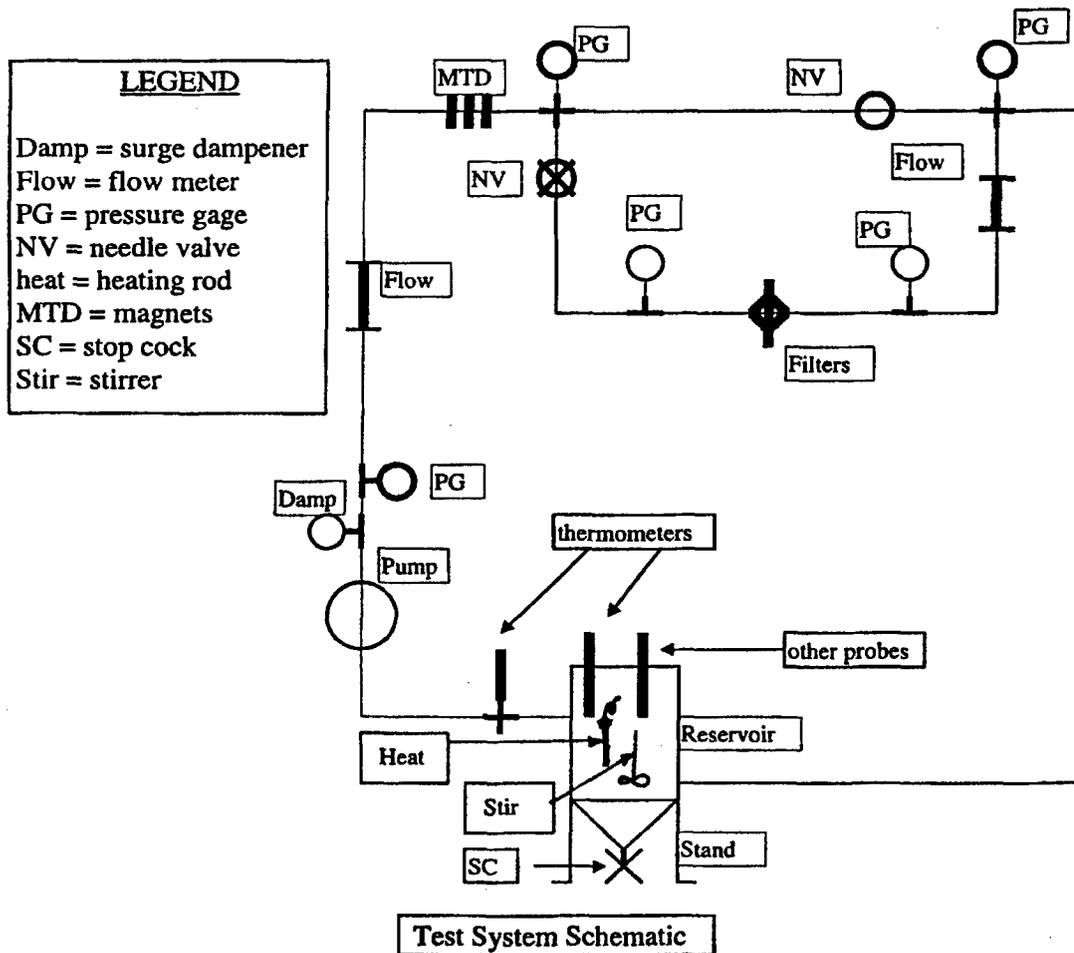
H. Dual systems were designed with construction being in a mirror image mode to allow the use of a single air supply to drive the two pumps. While all overall piping dimensions were measured within 1/2 inch of one another on the two systems (after construction) and all components had identical specifications, the two systems still operated somewhat differently. The differences occurred in hydrodynamic operation, heating rate and temperature control, mixing and in solid residue collection. Some of the differences can be explained (see Discussion section) while others never were explained.

I. To avoid metal-water contact the piping and most of the plumbing fixtures were selected of PVC. A pump was selected with internal surfaces entirely of plastic. The mixer shaft and propeller were entirely coated with plastic. The suspended equipment support inside the tank was a heavy gage wire rack entirely coated with rubber. There was momentary metal contact (seconds duration total per test) of a heavy wire gage support used to dip the aqueous sampler bottles. This wire metal support was spray coated and dried three times (on top of a painted coating) with an organic, aerosol spray, art coating.

J. Flow split flexibility between the main pipe line and the bypass tubing line was provided by two needle valves, one on each line. In operation, it was found that all the necessary control was achieved by the single valve on the bypass line. The main line valve was left fully open after initial system tests were complete.

K. Pressure fluctuations downstream of the pump were greatly reduced through the use of two different surge suppressor devices, each designed to handle different surge pressure ranges.

A schematic of the test system is illustrated in Figure 1 while overall views of the test systems are shown in Figures 2 and 3. Design drawings and additional photographs can be found in Appendix A. The arrangement of the magnets in the commercial device and how they are mounted to the pipe is illustrated in Figure 4. The south poles of the magnet are oriented radially inward. Sets of magnetic devices were spaced about one half inch apart when multiple sets were installed. According to some manufacturers, the particular arrangement of the magnets, and their spacing can be important. The research literature does distinguish between externally mounted magnets and in-line (internally mounted) magnets. The internally mounted magnets influence flow properties locally and in some cases affect the release of iron to the water.



## 5.0 MATERIALS, EQUIPMENT AND METHODOLOGY

### 5.1 Materials

calcium carbonate,  $\text{CaCO}_3$ , chelometric standard, assay 99.97% pure, Certified Lot Analysis

calcium nitrate tetrahydrate,  $\text{Ca}(\text{NO}_3)_2 \cdot 4 \text{H}_2\text{O}$ , reagent grade, assay minimum 99.0% pure

hydrogen peroxide ( $\text{H}_2\text{O}_2$ ), 50% solution

sodium carbonate monohydrate,  $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$ , reagent grade

trichloroacetic acid (TCA) -  $\text{Cl}_3\text{CCO}_2\text{H}$ , crystals, reagent grade, assay 99% minimum

R601 Min-U-Sil Test Colloid, Zeta-Meter, Inc. (used to verify equipment and technique for zeta potential)

NBS Traceable Polymer Microspheres, diameters: 29.9 +/- 0.20, 20.49 +/- 0.20, 7.040 +/- 0.051, 3.004 +/- 0.029 microns (used for particle counter operation and technique verification)

Hach Alkalinity test kit (5-400 mg/L) Model - AL-AP MG-L

Hach Total and Calcium Hardness test kit (10-4000 mg/L) Model HAC-DT

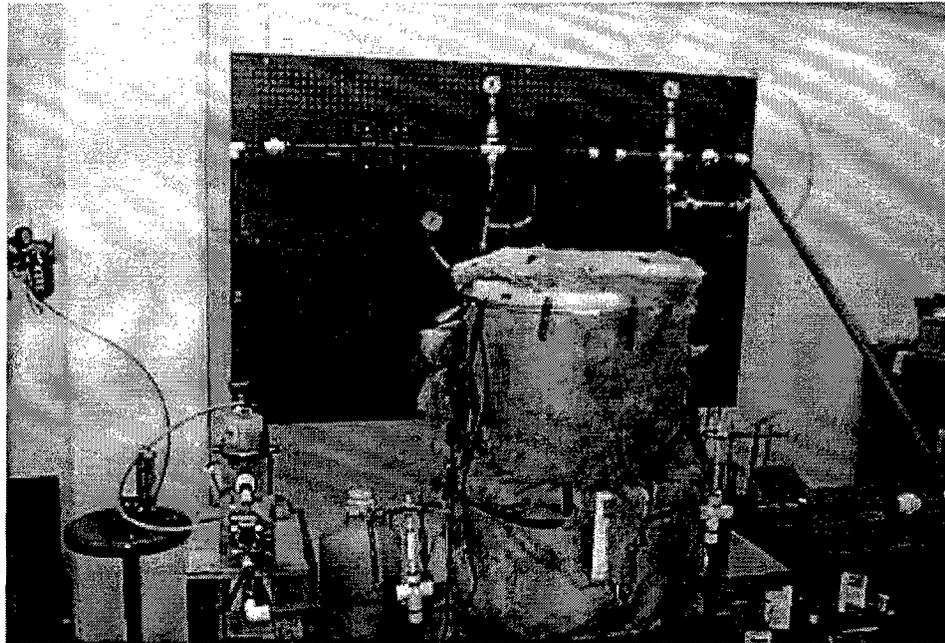


Figure 2 Overall view of test system 1. Insulation covers the tank. Digital thermometer on right

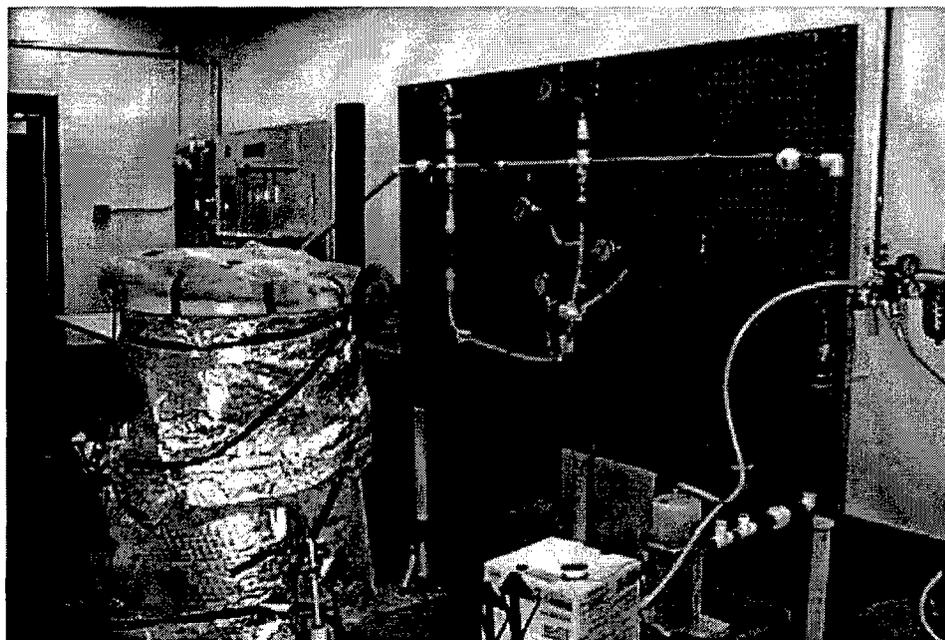
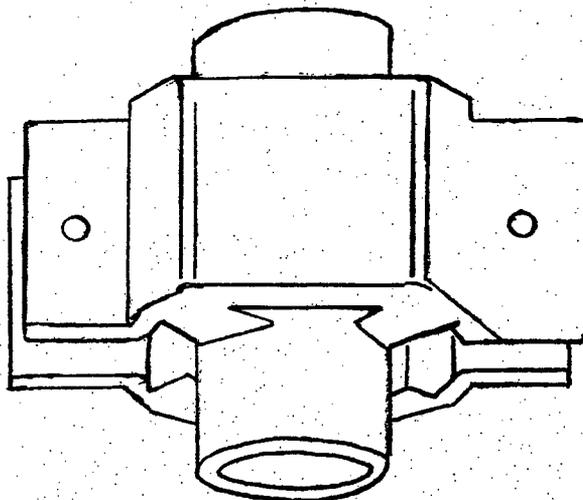
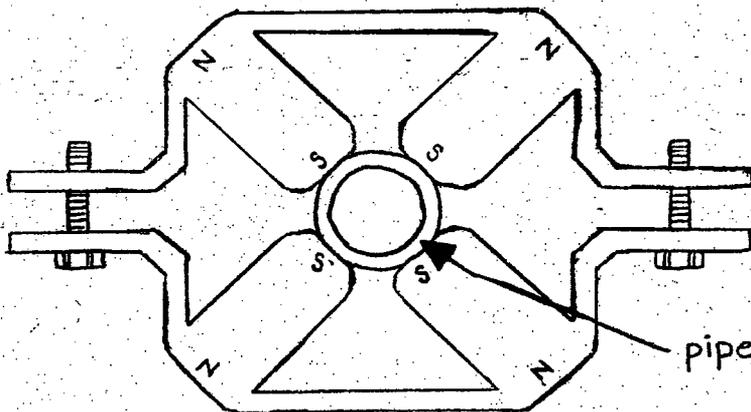


Figure 3 Overall view of test system 2. Insulated box over pump for noise attenuation.



a) Side view of magnetic device mounted on pipe



b) Cross-sectional view of magnetic device mounted on pipe

Figure 4 Views of magnetic device attached to section of pipe.

### 5.2 Test System Equipment (significant components only)

Wilden air operated, double diaphragm pump, designation: M.025/PPPD/WF/WF/PWF

The Equalizer (TM), Wilden automatic surge dampener, Wilden Pump & Engineering Co.

Mini-Trol Model 500 shock suppressor, Amtrol, Inc.

filter membrane: Nuclepore polycarbonate, 10.0  $\mu\text{m}$  pore, track etched, 47 mm diameter

depth filter (for upstream pre-screening): Osmonics polyester drain disc, 42 mm diameter

fused quartz, Red Hot Immersion Heater, 300 and 400 watt BD series, Electrothermal Engineering Ltd.

Robotemp, heat controller Model No. 315, George Ulanet Co.

Barnant Series 10 variable speed mixer motor

Magnetic device model number M1-C, The Magnetizer Group, Inc.

handheld pH meter: pH Testr BNC, ordered through Cole-Parmer

Fluke 51 K/J digital thermometer

### 5.3 Analytical Test Equipment

Scanning Electron Microscope (SEM): Zeiss DSM 960 (Tyndall AFB , FL)

Scanning Electron Microscope (SEM): Japanese Electron Optics Laboratory (JEOL) JSM-840A (BYU)

X-ray Diffraction (XRD): XDS 2000, Scintag Inc., USA

X-ray Fluorescence (XRF): Siemens SRS 303

Zeta Meter 3.0, Zeta-Meter, Inc.

Hiac Royco ABS2 sampler, 8000A controller/counter, particle counter (BYU CE environmental laboratory)

Hiac Royco Particle Size Analyzer Model PC-320 (Orem treatment plant laboratory)

Hach DR/4000U Spectrophotometer

Flame Ionization Atomic Absorption (FIAA): Thermo Jarrell Ash model number 11

Modulab, Laboratory Research Grade Water (filter/purifier) System, Continental Water Systems Corp.

### 5.4 Operation of Sample Production and Filtration Test System

The immersion heaters (one in each tank) raised the average water temperature to 105° F to simulate an average temperature in a cooling tower circuit. Insulation around the plastic tank allowed this water temperature to be maintained by a lower setting on the heat controller than required to heat the water initially. Monitoring the water temperature and adjusting the heat controllers (to govern the immersion heaters) was done manually. Water temperature was measured about one inch below the water surface, about two to three inches from the tank wall and about nine inches from the heater rod. It was measured by a chromel/alumel thermocouple (T/C) bead with temperature readout on a digital thermometer. The T/C bead was coated with finger nail polish to prevent shorting across the bare wires. The T/C insulated wire leads were fed through a several inch section of flexible plastic tubing just ahead of the T/C bead. This tubing allowed for attachment to the instrument support rack mounted internally to the reservoir and kept

the bead submerged below the water surface against the current generated by the stirrer. Accurate temperature readings on this digital thermometer with this T/C bead required setting it in the "J" mode. Initial system thermal operation was monitored using glass thermometers mounted in the pipelines leading to and from the reservoir. These were used to acquire thermal operating experience for the system. This information was used to determine that the PVC piping did not require insulation but that the reservoir did. After temperatures stabilized, and the tanks were insulated, the flow coming out of the reservoir was about one degree different than the water temperature measured in the tank. Hot water circulating in the PVC piping generally dropped a degree or less from outlet to inlet to the tank. This was about the accuracy of the thermometers used. With these readings matching the tank water temperature closely, the use of the glass thermometers to measure system water temperatures was discontinued. The immersion heaters were operated with and without the heat controllers depending on heat rate requirements. The immersion heaters required occasional cleaning to prevent the hard film (scale) build up from significantly reducing heat transfer. Generally the heater controllers had to be adjusted a number of times during each test.

The propeller mixers provided a good chemical and thermal mix of the 15 gallons of water in each of the two tanks. Two levels of  $\text{CaCO}_3$  supersaturation were selected for testing: 25 and 75mg/L of  $\text{CaCO}_3$  added to the existing tap water content (typical winter water supply total hardness range: 150 - 200 mg/L as  $\text{CaCO}_3$ ). Supersaturation is used here as it is frequently used in the literature on magnetic descaling. Strictly speaking, the aqueous solutions were not supersaturated but only contained an excess amount of  $\text{CaCO}_3$  above saturation levels which were circulated throughout the system as a suspended solid. The excess solid chemical maintained the  $\text{CaCO}_3$  saturation concentration during the test while the bypass line filters removed  $\text{CaCO}_3$ . Fresh  $\text{CaCO}_3$  powder was added at the start of each test in an amount matching the dry weight of the filter residue removed from the system during the previous test.

Bacterial growth interferes with particle counting in the smaller size range of interest (below three or four microns). So 10 mg/L of hydrogen peroxide was added to each fresh batch of water to minimize bacterial growth. Hydrogen peroxide was selected as the disinfectant least likely to interfere with the  $\text{CaCO}_3$ . Filter membrane holders were checked and cleaned as necessary between tests. The fine pore downstream filter was replaced each test while the coarser prefilter could be cleaned and reused several times. After each test all filter membranes containing any significant amount of residue were placed in dessicators for at least one day. The filter residue was then removed from the membrane and weighed. The residue was saved in plastic petri dishes with tight fitting lids for later XRD and XRF analyses.

Hydrodynamic properties flow rate, pressure and temperature were recorded to monitor system operation and watch for the onset of filter plugging. On a few occasions near the completion of system testing, pump #1 began sticking if the flow rate dropped below 1 gpm. So the last test conducted at this flow rate was run at 1.1 gpm for system 1 to prevent possible pump seizure. Two interchangeable flow meters were available to measure bypass line flow over two different flow ranges. As system operation became better understood, only the lower range flow meter was used to help monitor filter plugging.

Water chemistry (pH, alkalinity, calcium and total hardness) was tested near the beginning and

end of each test. As the alkalinity and hardness patterns developed (there was no reason to suspect that they should change significantly during the test), the alkalinity and hardness titrations were only performed near the end of each system test. The titrations were performed using the portable Hach test kits. The titrations were started and completed generally within 45 minutes of sampling. When a thermometer was available, the sample temperatures were measured at the beginning of each titration. The tip of the pH probe was inserted in each tank to a depth of one half to two inches below the water surface, roughly midway between the stirrer shaft and the immersion heater. No attempt was made to sample different locations to determine spatial pH variations (if any). The pH digital readout was allowed to stabilize for at least a minute at one value before recording. In a few instances the readout continued to fluctuate between two adjacent readings in which case the midpoint pH value was recorded. At the start of each new series of system tests the pH meter was calibrated at pH 7.0 and 10.0, bracketing the actual measurement range. Calibrations conducted with room temperature standard solutions usually required pH adjustments of 0.0 – 0.1 units. A calibration using hot standard solutions also required meter adjustments of 0.0 – 0.1 units. The meter accuracy was 0.1 pH units.

Water samples were also collected for use with the Zeta-Meter, AA and the particle counter. These water samples were allowed to cool (sometimes refrigerated briefly) to near room temperature because of the thermal effects on the zeta potential measurement. After the titrations were performed, aqueous sampling completed, and final system variables recorded, the systems were shut down. The filter membranes were removed (and in some cases the filter housings) and placed in dessicators for drying. The dried residue was removed from the membranes and housings, examined visually and weighed. The residue weights were used to prepare more  $\text{CaCO}_3$  to mix back into the tanks to maintain approximately the same supersaturation level. The dissolved  $\text{CaCO}_3$  removed during aqueous sampling (250 – 550 ml, depending on the titration) was not calculated and replaced in the tanks for subsequent test runs. The  $\text{CaCO}_3$  lost during aqueous sampling was minimal compared to the total amount in the reservoir.

When a series of tests were completed the system was drained, the  $\text{CaCO}_3$  residue was rinsed from the tank, then wiped out. Fresh tap water (from tap on east wall of the CE Fluids Lab) was placed in the system and circulated through the PVC piping and bypass tubing (without filter membranes installed) to flush out the entire system. This was then drained. Depending on the situation, the tanks were then wiped down with a mild hydrogen peroxide solution and re-rinsed. Later, fresh water was added, then new  $\text{CaCO}_3$  and hydrogen peroxide added to prepare for the next round of tests.

Due to the logistics involved of cleaning the circulatory system, preparing the new solution and reheating the water in the 30 gallon tank (the entire process could take over eight hours for the two systems), this process was not performed between every individual test. It was performed between series of tests. Between each individual test, fresh  $\text{CaCO}_3$  was mixed in to replace that which had been removed from the bypass filters, fresh makeup water was added as necessary and the temperature was brought back up (for those tests run at 105° F). Generally 12 hours up to several days passed between subsequent tests to allow the memory effect to dissipate. Unfortunately, no one currently knows how long the memory effect

lasts or whether its effects diminish exponentially, linearly or in some other fashion. For those tests run without magnetic devices, there is no memory effect, and so the waiting time was not important, except to allow equilibration of any newly added  $\text{CaCO}_3$  and thermal equilibrium to be reached.

### 5.5 Sample Evaluation Techniques

Aqueous samples were held in glass stoppered, glass bottles with dust caps. These bottles had been washed and sterilized in an autoclave prior to use. Aqueous samples were removed from the tanks using plastic sampler bottles lowered 1 – 3 inches below the water surface at two or three separate locations. The plastic samplers were lowered into the tank with a heavy gauge metal wire handle. This handle had been painted and spray coated three times with an organic art coating to prevent metal particles (from the wire or the paint) from entering the tank. These samples were immediately transferred to the glass sample bottles. Thus each glass bottle held water sampled from two or three locations within the tank. After the solid filter residue was removed from filter holders it was held in tight fitting, lidded, plastic petri dishes. The residue was dried in dessicator chambers prior to weighing.

5.5.1 Scanning Electron Microscope (SEM): Two different SEM (at different laboratories, operated by experienced personnel) provided pictures and dimensional analysis of  $\text{CaCO}_3$  crystals prepared at different times by different techniques. This analysis provided some very beneficial information for two purposes: filter membrane selection and crystal powder preparation for XRD calibration. The first SEM work showed the longer crystal dimension to vary from about 2 to 12 microns for crystals precipitated by the method of Wray and Daniels (1957). This drove original attempts to use filter membranes with pore sizes in the 1 to 2 micron range (which plugged rapidly). The later SEM work showed crystal lengths in excess of 100 microns in some cases. These crystals prepared by the method of Rao and Yoganarasimhan (1965) indicated that crystals of much larger dimensions than shown by the original SEM work might be present. This information coupled with the early filter plugging problem drove the decision to use 10.0 micron pore size filters. The range in crystal sizes seen in the two SEM efforts likely explains the problems originally encountered in packing powder samples in XRD sample holders. The second SEM analysis included some hand ground specimens as well as the original unground samples. This revealed the need for machine grinding to reduce the crystal aspect ratio which was causing preferred orientation problems in the early XRD work. All remaining XRD samples were machine ground due to this second round of SEM work.

Dry powder clumps were lightly broken up and mixed with a glass stir rod to prepare a loose powder. Sticky tape was used to hold a very light sprinkling of powder on the SEM stem sample holder. The surfaces were scanned at different locations and with different magnifications to find a good cross section of crystal sizes, habits and morphology. Crystal dimensional measurements were taken straight from the computer screen. A sampling of images were saved, some of which are reproduced in this thesis. The imaging work (reproduced in this thesis) was done at the BYU Microscopy Laboratory. The earlier SEM work was performed at Wright Laboratory, Tyndall Air Force Base, Florida.

5.5.2 Spectrophotometer and Flame Ionization Atomic Absorption (AA): Standard Method 3500 D (Eaton, 1995) was followed with a spectrophotometer to first measure the ferrous (Fe<sup>++</sup>) and total iron content of three water sources considered for use in the test system. Regular and deionized tap water were both measured against ultra-pure water (resistivity 16 MΩ-cm) obtained from the MODULAB lab filter unit. Later system testing led to the decision to use tap water in the test system. Additional source water analysis provided by the City of Provo (Table B3 of Appendix B) implicated lower iron concentrations than measured by the spectrophotometer method so additional iron concentration analysis was performed by flame ionization atomic absorption (FIAA). The AA was expected to provide more accurate total iron concentrations at the anticipated lower levels. The minimum, reliable detection level for Fe for this machine and method were about 40 ppb. The AA analyses were conducted by an experienced operator. A series of concentrations were conducted on the aqueous samples to provide two or three iron concentration levels for more accurate AA work. Concentrations were performed by heating the samples to 10 – 20° F below the boiling point. Unfortunately, the concentrated samples provided meaningless results for the iron as the iron was not preserved using acid. If iron is not preserved during the heating/evaporation stage, it is converted to a form that is not compatible with the FIAA determination for total iron. The preservation step was not mentioned in discussions with three separate individuals, all of whom had worked with metals determination by AA analysis and so was missed. The unconcentrated aqueous samples provided iron concentrations by AA. The AA analysis was performed by an experienced laboratory operator.

Other methods considered for element determination in the aqueous samples were EDX and inductively coupled plasma (ICP). EDX was abandoned due to a lack of detection capability/accuracy in the low ppm range. While ICP would have provided a quick scan for many elements in the water, the AA analysis was available for iron for no cost while the ICP was not and iron was the only required element. Also, the AA operator was far more experienced than the ICP operator.

5.5.3 Particle Counters: The purpose of the particle counters was to provide particle size distributions in aqueous samples taken during system testing. An increase in particle sizes with a concurrent decrease in particle counts would confirm that particle agglomeration was taking place. This would serve as supporting evidence that a decrease in zeta potential was leading to particle agglomeration. Two particle counters were used at different times, as both malfunctioned at different times with different problems. As both counters were not functioning properly during most of the testing, most planned comparisons were not made. A few early tests and the last series of system tests were successfully analyzed for particle size distribution on the repaired BYU CE environmental laboratory particle counter.

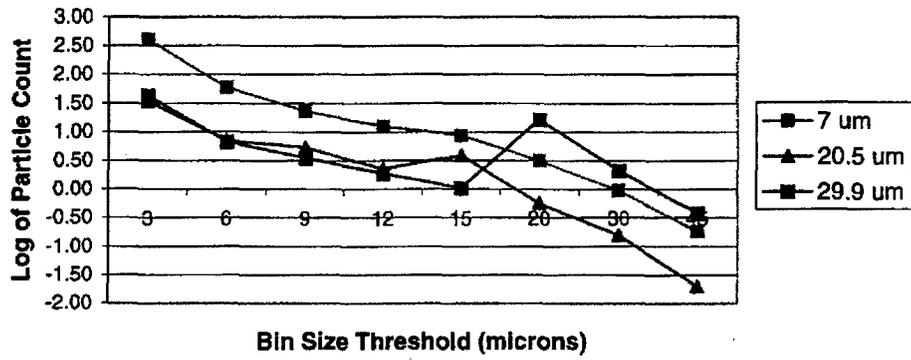
The BYU CE particle counter controller was powered up at least one half hour prior to use to thermally stabilize the electronic circuitry. The auto adjust screen command on the controller was run after thermal stabilization but several minutes before sampling began, for accurate results. Particle bin sizes, screen and print output options were also set using the controller keypad and screen. A pump may be used

to drive the sampler, but I used laboratory compressed air to drive the sampler. While the instruction manual does not state this, the particle sampler must have the "Pump On" button depressed for the sampler to function, even though a pump is not being used. A bottle of tap deionized (DI) water (from the environmental lab) was run through the particle counter until low counts were obtained (one - three sample passes) to flush out the laser counter and associated tubing. A magnetic stir bar was rinsed with DI water and placed in a newly obtained aqueous sample bottle which was then secured in the particle sampler. The magnetic stirrer was set at "3" on the dial. Use of the magnetic stirrer did make a significant difference in the results for the system test samples, but only a small difference in the DI water particle counts. Use of the magnetic stirrer raised particle counts in the same sample. Usually two to three (rarely four) sampling events were conducted with each separate sample. Between each run the results were printed on the controller paper tape output. These were compared from run to run until subsequent runs provided fairly similar results. The sample bottle was removed and replaced with the bottle containing the tap DI water to flush the system out prior to running a different system test sample.

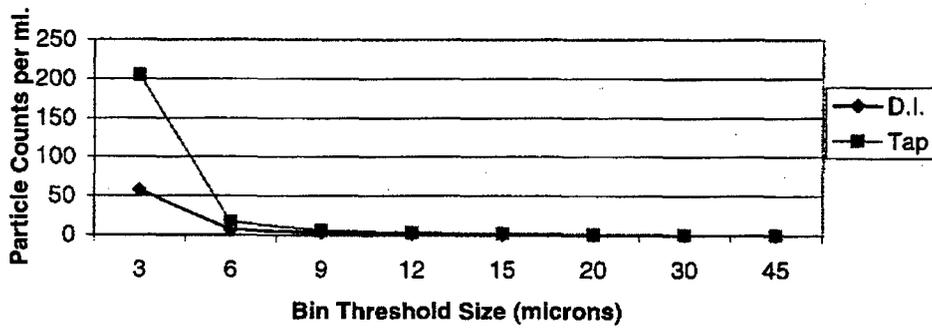
The accuracy of the particle counter (BYU CE laboratory) was checked against ultra-pure water spiked with NBS traceable micro-sphere standards in three sizes (7.0 - 29.9  $\mu\text{m}$ ). The data is plotted in Figure 5. The log of the particle counts was plotted because it better illustrated singular peaks in the data as well as the possible influence of three micron size particles. No spike in the graph shows for the 7.0  $\mu\text{m}$  standard, possibly due to the overpowering influence of bacteria in the slightly smaller size range. (It was later discovered that the tubing exiting the filtration unit delivering the ultra-pure water supplied sizeable numbers of bacterial contamination.) There are spikes for both the 20.5 and 29.9  $\mu\text{m}$  size standards although they appear to fall in the threshold size bins one size smaller than they should. However, it is a consistent trend. Had the bin sizes that were selected more closely bracketed the known size particles it is anticipated that the size analysis would have more closely matched the specified sizes. The error was judged a systematic one that should not affect qualitative comparisons of general particle size distributions.

Based on discussions with a microbiology researcher (Christiansen, 1998) and a water treatment laboratory manager (Dodds, 1998), it was believed that large numbers of both bacteria and tiny air bubbles up to at least the three micron size range (or slightly larger) should be expected. The potentially large numbers of these bacteria and air bubbles would be expected to obscure anything else I was looking for in this small size range. To examine this hypothesis, the average of 52 different D.I. tap water flush runs (through the BYU CE particle counter) were averaged and plotted. Also, four samples of the water (from the CE Fluids Lab east wall tap, with connected hose) used in the system tests were run through the particle counter. The data is shown in Figures 6 and 7. What is observed is a very steep drop in particle counts in the three to six micron size range. Starting with six microns there is an exponential drop in the particle counts as particle size increases. This appears to agree more readily with a natural decrease in random particle counts as the size increases. Based on this information, the three micron size particle counts were not plotted for any of the test system results, although this data is included in the results data tables contained in Appendix B.

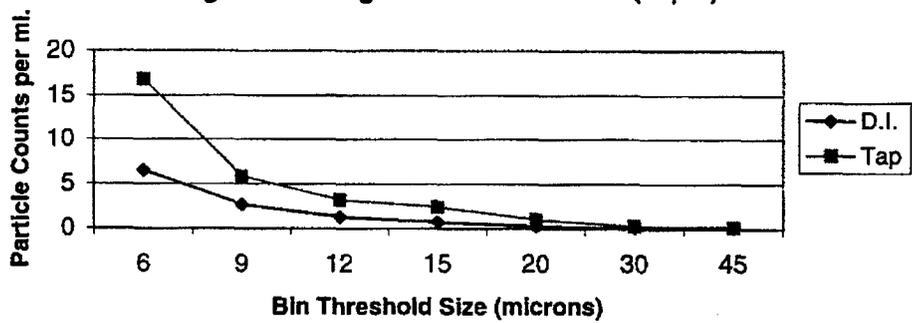
**Figure 5 Particle Counts for Calibration Standards**



**Figure 6 Background Water Counts**



**Figure 7 Background Water Counts (-3 μm)**

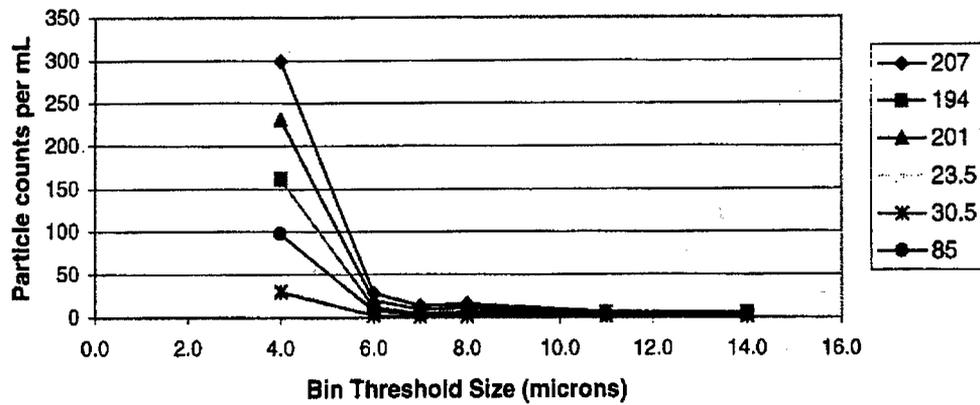


Particle size analysis of different source waters conducted during the process and analysis development stage provided useful information used later during the system testing phase. The data plotted in Figures 8 and 9 examined the influence of using the magnetic stirrer or not, the effect of water storage, the delivery tubing (new and clean vs. existing) and the water source (DI – tap vs. ultra-pure from the filtration unit). Figure 8 samples were analyzed over a narrow size range to give better definition to the smaller sizes. It shows that large variations in the small size ranges (to 4.0 microns) can be expected if care is not exercised on the delivery of purified water (for particle distribution analysis), and depending on the source. Much of the difference is attributed to bacterial contamination. Figure 9 shows analysis of the same source samples over a greater particle size range to confirm the expected size range for filtration and analysis purposes. Sizeable differences in counts were obtained for the same sample sources between the two analyses exhibited in these two figures. This implies some random variation in analysis results or the impact of procedural control. The analyses plotted here were obtained before my sampling procedure was refined and set. In retrospect, I would set the bottom bin threshold size at four (or five) microns rather than the three microns which I used. This bottom bin size should not be used for data comparison purposes. This would provide more assurance that the counts in the next larger bin size represented significantly more than bacteria or small air bubbles.

5.5.4 Zeta-Meter: The Zeta-Meter measures charged particle velocities. This information coupled with specific conductivity is used to calculate the zeta potential which comprises the majority of the surface potential of the charged particles in fresh water samples (Zeta Meter, Inc., 1993). These values are then ratioed to a normalized value at a standard 22.5°C temperature. Measurements were taken as soon as the aqueous sample temperature approached room temperature. While temperature correction ratios are provided by the manufacturer, a problem occurs when temperatures differ very much from room temperature, in that the sample approaches room temperature during preparation and measurement (which can take up to 12 minutes). No current capability exists for monitoring the sample temperature during this time. If the sample started at a temperature much above ambient, the measured temperature (used to select a correction factor) may differ markedly from the actual test temperature and introduce an error of as much as 20%. Min-U-Sil test colloids were used to prepare standard dilutions (used similar to calibration standards) to develop operating experience with the equipment. No zeta meter operators were found locally with experience in the types of waters (and hence test problems) encountered on this project. Use of the test colloid standard dilutions showed that the measured zeta potential of waters maintained in glass bottles declined noticeably within 24 hours after standard preparation. This was confirmed with the manufacturer. The situation was worse if the sample were stored in plastic containers. This led to the consistent measurement of aqueous samples as soon as they neared room temperature (one half to two hours after sampling).

The sample holder was filled carefully to preclude the presence of air bubbles which adversely affects the measurements. This was done by completely filling the holder and allowing the excess water to

**Figure 8 Particle Counts For Different Source Waters**



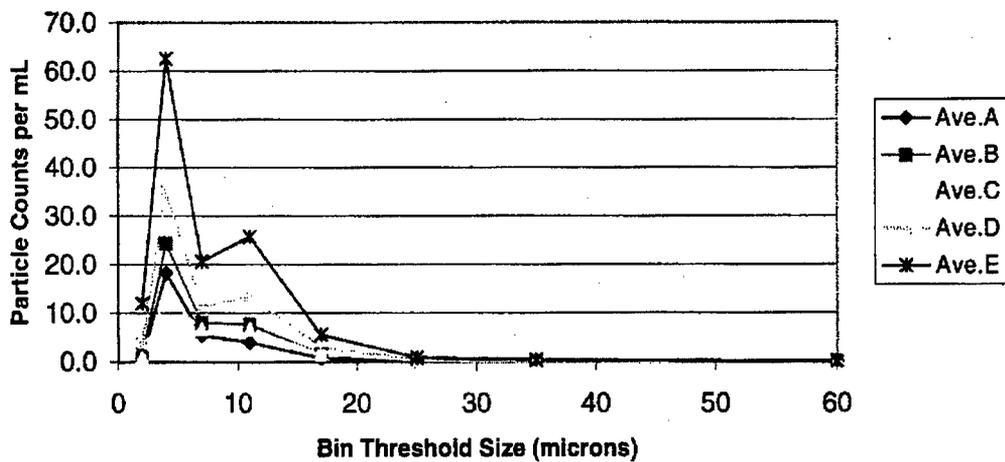
**LEGEND:** A = DI water, stirrer off  
 B = filter water, old tube, stir off  
 C = filter water, old tube, stir on  
 D = filter water, new tube, stir off  
 E = filter water, new tube, stir on  
 F = stored, filter water, old tube, stirrer on

**NOTES:**

BYU CE Enviro. Lab - Hiac Royco particle counter - Tests run 1/5/98  
 D.I. = deionized water from mid counter tap in main enviro. Lab  
 old tube = old, dirty tubing on lab water filtration unit, new tube = new, clean tube  
 filter = water from enviro. Lab filtration unit, stirrer at 50% = stirr knob set between 4 & 5  
 stored = water originally from old tube, lab filter unit, stored in plastic can for 4-8 weeks  
 without addition of hydrogen peroxide

Chan = channel #, Diff. Count = differential particle counts/mL thesplot.xls, sht 2

**Figure 9 Counts For Different Source Waters - Larger Size Range**



**LEGEND:** A = DI water, stirrer on  
 B = filter water, old tube, stirrer on  
 C = filter water, new tube, stirrer on  
 D = filter water, no tube, stirrer on  
 E = stored filter water, new tube, stir on

spill out the top as the anode (first) and cathode were threaded into place. The anode was cleaned periodically to remove oxidation products when the anode became discolored (blue-black). The sample holder was triple rinsed with tap DI water between each different aqueous sample measured. On recommendation of the manufacturer to improve accuracy, 50 individual particles were tracked for each different system test sample. This occurred after a number of tests had already been run. To preclude heating the water sample in the holder (due to lights and applied voltage), the water was changed out, generally between 20 and 30 readings, without resetting the zeta meter counters. In this manner the zeta meter would automatically average all the readings taken including both water volumes from the same system test sample. Zeta potential readings were analyzed for the impact of this technique. No consistent effect was noted on the data scatter by using the second, fresh water sample, ie. the data standard deviation did not change significantly one way or another using the fresh water half way through tracking 50 particles. However, the zeta potential measured for the second (fresh water) sample from the same sample bottle always yielded higher values (1 – 32% higher, with an average of 13%). It was not determined what this effect was attributable to. But this technique continued to be used based on the manufacturer's recommendation.

When the tube in the fused quartz block became cloudy, it was cleaned with one of the special cleaner rods provided by Zeta Meter. The sample specific conductivity was first measured and then the applied voltage was selected, prior to taking actual measurements. The selection of which voltage to apply for measurements was dependent on two factors: 1) the maximum recommended in the manual for a given specific conductivity and 2) how low a particle velocity was acceptable to the individual making the measurements. Acceptable particle velocity partly depended on the observer's patience. Low velocities favored more curved particle trajectories, making particle tracking along the microscopic scale more difficult. However, slower velocities (with some straight particle trajectories) allowed more accurate timing of when particles cross scale tick marks. Selection of the applied voltage became a tradeoff between these different factors. Some variability in measured zeta potential (for the same system test sample) was noted when different applied voltages were used. Also, repeated measurements of the same sample showed some variability. The lack of high repeatability was due to the human factor and the statistical nature of particle velocities. Repeatability was improved when particle tracking was increased from 10 – 15 to 50 individual events.

The effect of using different voltage settings on the same water samples was checked. The meter is designed to automatically correct the readings for the voltage setting used, but I wished to determine if this change could have a significant impact on the readings. Two different water samples were run, twice each. In each case the sample was run first at 300 volts, left in the sample holder and then run at a reduced voltage (one sample at 200 volts, the other sample at 150 volts). In one case the average reading increased 11%, in the other instance it decreased 14%. It is possible that the change in reading is affected simply by repeatability but it may be that the different voltage settings do in fact have a small impact on the value obtained. For this reason, the later samples were almost always run at the same voltage. Occasionally

particle velocities required a change between 300 and 200 volts. Future research pursued in the area of zeta potential measurements should do an extensive evaluation of the impact of different meter settings and sampling handling techniques to give better statistical validity to data evaluation and conclusions.

As different source waters could be used in the reservoirs for the test systems, an evaluation was made of four different source waters spiked with added  $\text{CaCO}_3$  at two concentration levels. The different waters were: tap DI water, regular tap water, distilled water and water from the water purification system in the environmental lab. The zeta potential data for these evaluations are listed in Table B5 of Appendix B. Considerable difficulty was experienced in measuring the zeta potential of laboratory filtered pure water that had been used in early system tests. There were insufficient particles to yield statistically significant results. This was the principal reason for the change to using tap water for the test systems. In seven of eight paired comparisons the higher concentrations of added  $\text{CaCO}_3$  (200 – 250 mg/L) produced lower magnitude (absolute value) zeta potentials by an average of 27% than the lower concentrations of added  $\text{CaCO}_3$  (50 – 80 mg/L). This later served as a factor when comparing system test results when different concentration levels of added  $\text{CaCO}_3$  were involved. Analysis of Zeta-Meter readings revealed that tap water samples always yielded lower data scatter (standard deviation) than for DI, distilled or ultra-pure (lab filtered) water samples. The other water sources typically had data standard deviations 50 – 300% higher than for the tap water samples evaluated. Reducing data scatter for zeta potential was a second reason for using tap water in the system tests.

#### 5.5.5 X-ray Diffraction (XRD):

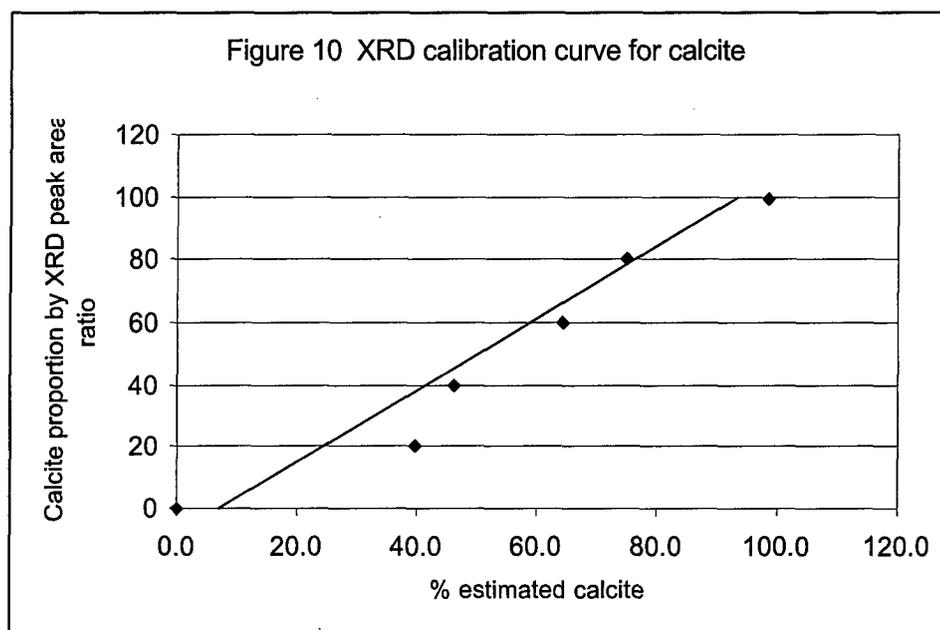
5.5.5.1 (Calibration standard powder preparation) The XRD was used to perform quantitative analysis to determine the relative proportions of calcite and aragonite in the powdered crystals obtained from the filter residue from the system tests. Appropriate techniques for producing relatively pure calcite and aragonite (which were not available commercially) for use as calibration standards were found and verified. The method of Wray and Daniels (1957) was selected to produce calcite while Rao's method (1965) was selected as producing the purest batch of aragonite. The Wray and Daniel's method has also been used in obtaining aragonite but I was unsuccessful in several attempts in obtaining relatively pure aragonite by this method. Wray and Daniels method uses calcium nitrate with sodium carbonate to precipitate calcite and aragonite (different procedures produce various mixes of the two polymorphic forms). Rao's method used calcium carbonate and trichloroacetic acid (TCA) to precipitate aragonite. Then a technique for creating a reasonably good quality calibration curve were found and tested that were suitable to this particular application.

5.5.5.2 (Powder grinding) The calibration standards (calcite and aragonite preparations) were initially hand ground and then machine ground in a Micronizing grinder for 60 – 90 seconds prior to XRD evaluation. After further SEM evaluation of the ground powders, it was decided that a slightly longer grinding time would provide a more consistent powder while avoiding the problem of converting aragonite to calcite by excessive grinding (Criado and Trillo, 1975; Gammage and Glasson, 1975; Lin and

Somasundaran, 1972). Final test system residues were ground for about three minutes. The potential aragonite/calcite conversion problem was also minimized by the use of 10 ml of isopropyl alcohol to buffer the  $\text{CaCO}_3$  powder during grinding. The powdered residue and the alcohol are placed in a plastic container filled with small, precision ground ceramic or stone rollers. When the grinding is complete, the alcohol and ground powder are poured into a glass evaporation dish. The inside of the lid and container are rinsed with an additional 5 – 10 ml of isopropyl alcohol to remove more ground powder which is also poured into the evaporation dish. The glass dish is then placed in an enclosed fume hood for fume evacuation during evaporation. This process was speeded up on occasion through placing the dishes on a pan of heated sand placed on a hot plate inside the hood. Between grinding operations, the lid, container and all the grinding rollers were thoroughly rinsed with laboratory water and placed on paper towels to dry to prevent cross contamination of samples.

5.5.5.3 (Diffraction pattern, peak height, area and intensity) The X-ray diffraction pattern provides signal peaks corresponding to compounds within the sample powder. Peak intensity, peak area and peak height have all been used to estimate the concentration of a given compound in a given sample (Bisch, 1989; Milliman, 1974). The compound concentration in the sample is estimated using peak intensity, area and then height, in order of decreasing accuracy. The difficulty of the analytical procedure increases in the reverse order. I measured peak heights for known concentration samples and found the peak height to be an inaccurate measure for the work I was doing. I used peak areas for this analysis due to it's improved accuracy (over peak height) and it's ease of use (an existing software algorithm lent itself to semi-automated analysis). Had the XRD results shown more promise, it would have justified the time to analyze the results using the peak intensities. The intensity is related to the peak area which is approximated by a curve fitting computer software algorithm. Among other factors, the peak area is a function of the amount of a given substance in the sample. The relationship between peak heights or individual peak areas is not necessarily linearly related to the concentration of calcite or aragonite. The curve fitting algorithm was the best technique discovered to yield the peak areas for this particular analysis. However, several choices in the non-automated portion of the curve fitting routine affected the calculated area for the same sample data by as much as 8%.

5.5.5.4 (Calibration function) The calibration function selected for this analysis yielded close to a linear relationship for calcite for most of the range (Figure 10). Some non-linearity, at each end of the line, is closer to reality in this situation. This assumption is based on an understanding of the actual process of obtaining the peak areas. The curve fitting routine doesn't resolve peaks where only a few percent of a compound is present. Without the resolution no peak areas are obtained for use in the calibration function. Under these particular circumstances it is estimated that about 5% of calcite or aragonite would need to be present before the curve fitting routine would pick it up. The peak areas (for low concentrations) could be done manually, but I found that my manual peak area estimates weren't as consistent with the software routine as would justify confidence in mixing these two approaches. Better quality techniques could be developed with more effort. The "calcite proportion by XRD peak area ratio" =  $(\sum A_{ci}) / ((\sum A_{ci}) + (\sum A_{ai}))$



where  $i = 1$  to 4 (for different selected peaks) and  $A_c$  and  $A_a$  are the areas of the calcite and aragonite peaks respectively. The “% estimated calcite” then becomes the estimated calcite percent in the diffracted sample. The form of the particular calibration function selected came from Milliman (1974) while the rationale for selecting numerous prominent peaks from known standards came from Bisch (1989). Selecting a larger number of prominent peaks for analysis provides for more accuracy as preferred orientation can affect different peaks by differing amounts. Taft and Harbaugh (1964) give a good example of using a calibration curve using peak intensity for calcite and aragonite.

5.5.5.5 (XRD equipment setup, hardware and software settings) One to two liters of liquid nitrogen were poured into the dewar to cool down the detector. Cool down time depended on the previous recent thermal history of the equipment. Without recent cooling it typically took two hours to cool down. The proper cool down point was achieved when the “high voltage rate meter” read -1001 to -999 for some time. Some problems were encountered while attempting to use the automated multi-sample holder and batch mode with rotation, probably due to operator inexperience (my inexperience). Sample rotation should improve the quality of the results. So samples, without rotation, were run one at a time. Source and detector slit widths, chopper increment and scan rate were selected based on recommendations of experienced operators and by making trial runs at different settings. The final source (divergent) slit widths selected were 2 and 3 mm while the detector (convergent) slit widths were 0.3 and 0.2 mm. Based on Bisch (1989, pp. 30 – 31) and calculations for the particular geometry I was using, a  $1^\circ$  angular divergence was targeted to get the largest sample exposure without targeting the sample holder. The appropriate slits were installed, and the equipment was gradually brought up to 40.0 kV and 30.1 mA. After all the runs

were complete for a given time period the equipment was returned to 10.1 kV and 2.0 mA settings.

Machine control was through the DMS 2000 software package operating on a MicroVAX 3100 computer. When the equipment was set up, the "Manual" → "General" → "Calibrate" routine was run through the computer. When the source quit moving, the "TH" and "OM" angles were visually noted and entered into the computer. The plastic sample holder was installed, the enclosure cover closed and the safety interlock (red square button) was depressed. The "DIFF" → "Continuous Scan" computer screen was called up to input the filename and file description. Then the "PROGRAM" → "Level 1" → "Background Correction" routine was run to apply the K alpha 2 stripping and the background subtraction (YES option for both). Various "GRAPHIC" options were executed to provide "Normal Display" and "Results Display" graphical output. The "Peak Finder" routine was run to find the peak areas through a curve fitting option. The "Graphics" → "Profile Fitting" routine used the Pearson VII curve type. The "Program" → "Level 1" → "Peakfinder" routine used an ESD multiplier of 0.02. Care must be exercised in always selecting net intensity files (NI file extension) for the curve fitting work rather than the raw data files (RD file extension) which the software sometimes automatically selects. The final variable selections input into the MicroVax that controlled hardware motion were: two theta range = 25.0 – 50.0° and the scan rate of 1.2° per minute. The final stepper size chopper increment was set at 0.02. The grinding and XRD equipment are maintained by the BYU Geology Department.

Figure 11 illustrates how a test diffraction pattern is compared against Joint Committee on Powder Diffraction Studies (JCPDS) standard card files to make a visual selection for a relatively pure sample. These JCPDS card files are now stored in computer memory. Different JCPDS standard patterns (up to three at a time) can be called up for comparison with the unknown powder sample. Figure 12 shows a match from a software routine designed to automatically determine the relative percent composition of an sample where two substances in the sample are identifiable or already known. Running known composition powder samples with this routine established that at least some of the time this routine gave very erroneous results. It was not determined when this routine could be trusted, so this fully automated method was abandoned. The malfunctioning of this software routine was confirmed with the equipment manufacturer. A semi automated curve fitting routine which calculated peak areas was used with a manual calibration function to determine the relative percent composition of the sample.

5.5.5.6 (XRD sample holder and powder packing) The positioning of the sample holder within the spring loaded metal frame affects accuracy and so was located similarly each time. The top and bottom sides of the plastic sample holder were wiped clean of any loose powder so as not to impact the positioning of the holder. The size and aspect ratio of the sample powder crystals affects packing in the rectangular plastic holder, as demonstrated by SEM analysis coupled with XRD results. Once the filter residue was ground and dried, the powder was packed solid (somewhat tightly) within the rectangular recess in the plastic holder. The top powder surface was smoothed with a metal spatula to achieve a consistent layer, even with the top of the recess side walls. Uneven packing, cracks and pores in the top powder layer were

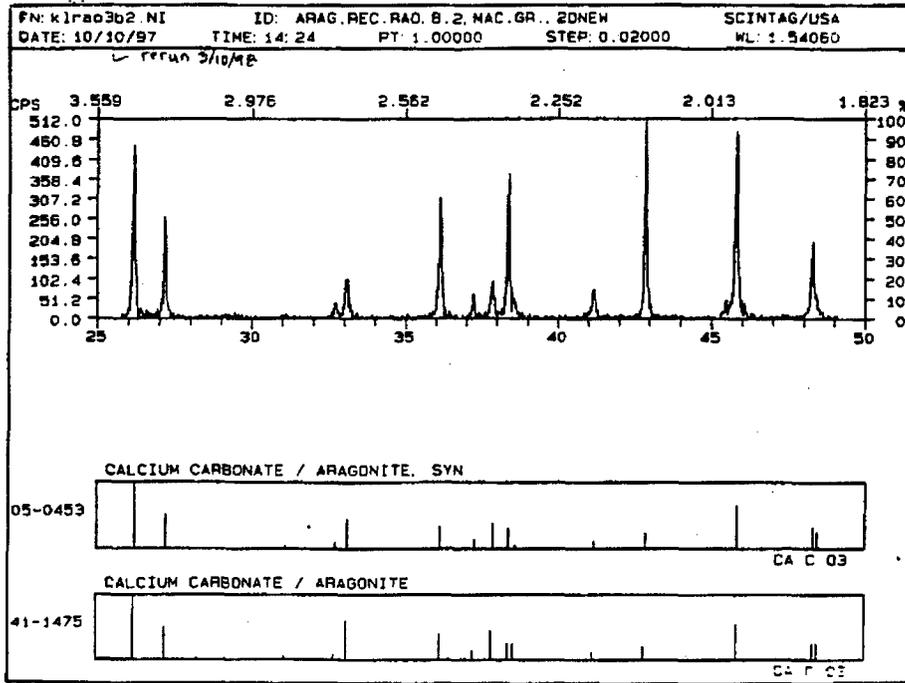


Figure 11 Diffraction pattern with JCPDS aragonite standard patterns

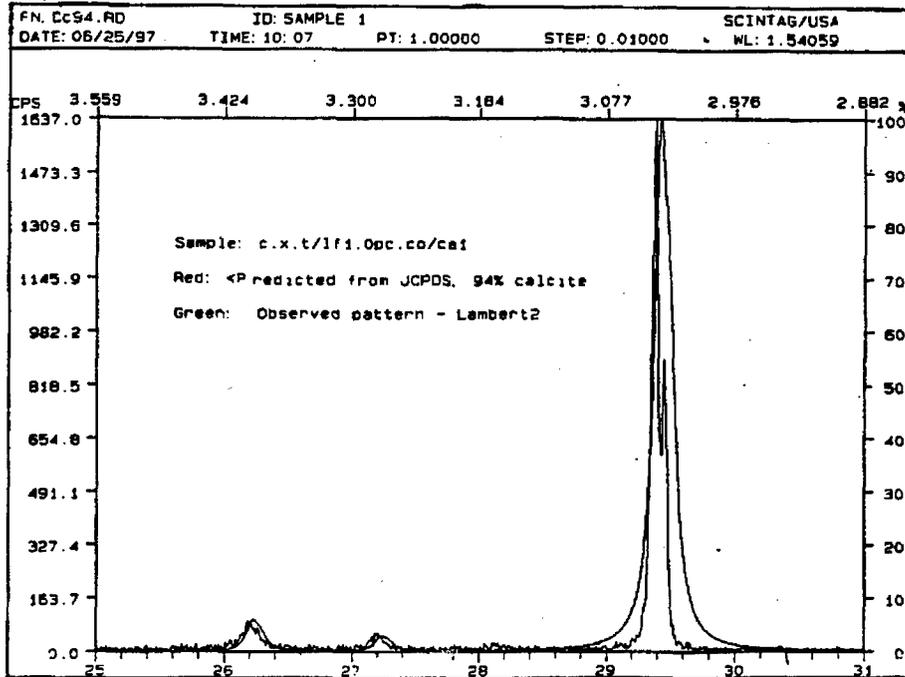


Figure 12 Curve fitting match to automatically determine relative percent composition

smoothed as much as possible to provide a good X-ray diffracted pattern. Sample holders and spatulas were cleaned between samples to prevent cross contamination. Packed sample holders were covered while awaiting placement in the equipment to minimize contamination from air borne particles. The unmodified plastic sample holders with the particular powders I was using required a minimum of 0.7 grams of powder. A few of the dried system test residue powders did not have this much material and so the sample holders were modified by inserting a small quartz or glass circular disk in the bottom of the holder. This reduced the powder requirement to a minimum of 0.3 grams. One of the samples was run with the full amount of powder (0.7 grams) and the reduced amount (using the small inserted disk) of powder to examine the impact on the diffraction pattern (see Figures D21 and D22). There was very little difference between the two patterns; about the same amount of change as observed when the identical sample were run twice with the same settings, to examine technique repeatability.

5.5.6 Energy Dispersive X-ray (EDX): As EDX was available when the first  $\text{CaCO}_3$  solid powder samples were prepared, this technique was used to verify good calibration standard preparation technique. For this purpose the EDX analysis provided an advantage of scanning for many substances (unknown beforehand), whereas the XRD is set up to look for given compounds. This analysis was conducted by a skilled user at Wright Laboratory, Tyndall Air Force Base, Florida.

5.5.7 X-ray Fluorescence (XRF): Color differences in solid residue removed from the test system bypass filters implicated the probable presence of transition metals in the  $\text{CaCO}_3$  residue. This occurred only for certain test conditions where magnetic devices were not used. XRF was used to look at 15 solid residue samples to pinpoint significant changes in any transition metals tied to any particular system test parameter changes. The chelometric standard  $\text{CaCO}_3$  powder was analyzed to serve as a comparative baseline. A quick scan was also performed on a piece of the plastic petri dish to determine any significant metals content in the plastic. The metals looked for included ones known to form carbonates (Sr, Mg, Pb, Fe) and those commonly found in industrial water systems (Zn, Pb, Fe, Cu, sometimes Cr, Ni). The scans also covered the following elements initially: Si, Al, Na, K, Rb, Au, W, Mo, Ni, Y, As, Ge, Ga, Cr, Ti, Vn, Ba. These elements either fell within the ranges scanned, for the previously mentioned metals or are found in natural waters. Nearly all these extra elements were quickly abandoned from further analysis as they showed up as non-detects or in trace amounts consistently.

Since XRF counts individual atoms of the elements encountered, each sample was prepared with the same total mass of powder (+/- 0.8%) to provide results that would imply relative concentrations. The sample masses ran 0.506 – 0.514 grams. I prepared the samples and performed all the data evaluation while the XRF equipment runs were programmed by an experienced operator. The associated computer software permitted the stripping of background signals and overlaying the signal from several different samples for easy qualitative comparison. As this software was designed to print output to a single printer (which was no longer functioning) a screen catcher program, "PZP", was used to capture the screen image

which was then saved to diskette. As this was a tedious process (for the many screen images analyzed), the peak heights were recorded manually from the computer screen for input into a computer spreadsheet.

Several scans were run using two separate analyzing crystals over different angular ranges to look for the presence of various elements as follows:

OVO55 (multi-layer silica wafer) crystal over a two theta range of 14-30° for Si, Al, Na, Mg

LiF200 crystal over a two theta range of 20-71° for Mo, Ni, Zn, Pb, Au, W, Y, Sr, Rb, As, Ge, Ga - Cr

LiF200 (Lithium Fluoride) crystal over a two theta range of 71-90 ° for Ti, Vn, Ba (rare earth metals)

LiF200 crystal over a two theta range of 132-136° for K.

## **6.0 RESULTS**

### **6.1 Test System**

The principal parameters of all the system tests (using tap water) are summarized in Table B1 (Appendix B). Earlier system testing used to confirm and refine system design are not summarized. System testing with laboratory filtered water is also not summarized as they were not used in any of the final results and conclusions. Most of the water tank temperatures were kept within about a 6 degree range near 105° F. However, without automatic temperature control, some of the longer tests (overnight or long memory-effect tests) exhibited larger temperature variations.

### **6.2 Solid Residue - Visual Examination**

Figure 13 shows sample containers with dried powder removed from filters in the test systems. Although the original shapes were not preserved, nor can the photos show the consistency of the residues personally observed by the author, they do show some color distinctions. The powders with the light tan or yellow color (on the right of the figure) were taken from filters in the test system running without MTDs. The white powders (on the left side of the figure) are from the system that was operating with MTDs attached to the piping during these tests. These changes were only noted for the series of tests with the maximum flow rate (3 gpm), at 105° F bulk temperature, with generally longer run times (10 hours). The system test in this series run for 4 hours showed some similar tendencies, although to a lesser extent. The MTDs were swapped from one system to the other and the tests repeated, with similar results. The residues removed from systems without the MTDs were cohesive (forming a solid disk in the filter holder) requiring more work to remove them. The residue removed from the systems with the MTDs attached had a pasty consistency, like wet powder and had the same color as the CaCO<sub>3</sub> crystals added to the systems. This same phenomenon was not observed (at least in this pronounced manner) in other series of tests that ran at lower flows (1 gpm), at room temperature bulk water temperature or for most shorter time periods (4 – 5 hours). The coloration was attributed to the presence of a transition metal in the residue. The cohesive nature of the residue from the non-magnetically treated systems may indicate the onset of scale formation.

The masses of the dried residue recovered from the filters are listed in Table B9 in Appendix B.

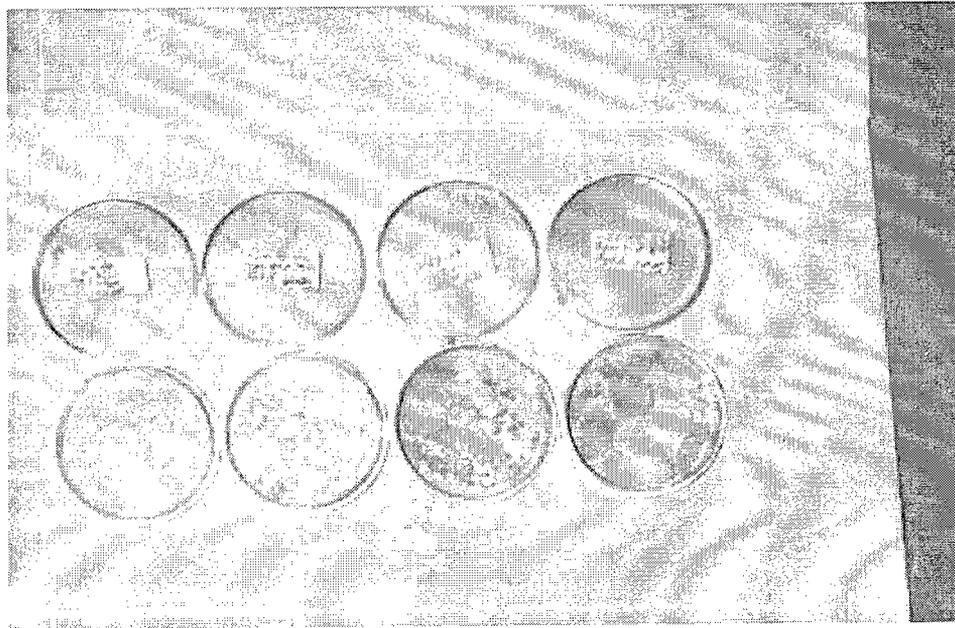


Figure 13 Filter residues from tests with and without magnets. Two samples on left from system with magnets installed. Two samples on right from system without magnets.

### 6.3 System Water Chemistry: pH, Alkalinity and Hardness

The system test pH, alkalinity, calcium and total hardness values are included in Table B2 in Appendix B. Typical chemistry for the water supply upstream of the laboratory was provided by the City of Provo. Total iron concentrations don't normally exceed 25 ppb. The complete water source analysis can be found in Table B3 (Appendix B). The pH rarely varied more than 0.1 units from beginning to end of a test. The average pH change between magnetically and non-magnetically treated water was less than 0.1 and was considered insignificant (pH meter accuracy was 0.1). Alkalinity measurements were more consistent than the hardness values. The known sources of error in the alkalinity measurements account for about +/- 5 mg/L as CaCO<sub>3</sub>. Calcium hardness data showed the greatest variation, possibly due to the more difficult nature of its titration. The titration color change for calcium hardness was the least pronounced of the three titrations performed. Total hardness generally ran 25 – 150% higher than the calcium hardness. There are a few data among these chemical measures that seem unreasonably different from comparable data at say the beginning or end of the same test or when compared to the same piece of data for a similar test. For these cases the data were noted but not considered valid for data evaluation. In a few cases no definitive value is given as the color change was passed too quickly during titration. This was due to reaching the color change point much quicker than anticipated when compared to similar tests.

#### 6.4 Purity Of CaCO<sub>3</sub> Powder Calibration Standard: EDX

Energy Dispersive X-ray (EDX) results indicated that the preparation techniques used to yield “pure” calcite or aragonite were successful in minimizing undesired elements. These crystal preparations were necessary as part of the function of developing a calibration curve of known ratios of calcite and aragonite powder mixtures to be used for the XRD analysis.

#### 6.5 Crystal Size, Habit And Phase (Aragonite or Calcite): SEM

SEM work showed significant differences between different crystal preparation techniques (for XRD calibration). Figure 14 shows calcite crystals. The calcite preparations utilizing precipitation (Wray and Daniels, 1957) showed consistent crystal production with very little aragonite found in batch 2 which was used for the calibration standard. Figure 15 shows calcite ground from a solid, pure crystal used in an attempt to provide 100% pure calcite for calibration. The distinct nature of the calcite ground from a solid crystal provided different diffraction patterns from the precipitated powders and so was abandoned as a standard. Aragonite preparations showed quite different results between methods. The aragonite crystal lengths varied a lot based on preparation technique.

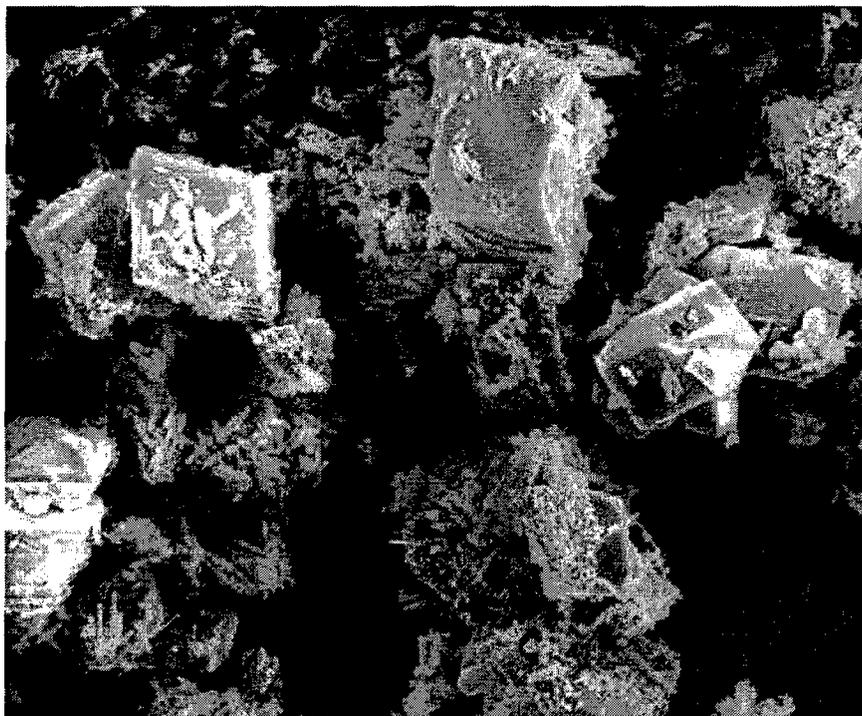


Figure 14 Calcite crystals prepared by method of Wray and Daniels. Larger crystal dimensions range from 5 to 16 microns. SEM image, 1200 X magnification.



Figure 15 Calcite after hand and machine grinding of a single, naturally occurring calcite crystal. Largest fragment dimensions about 54 x 17 microns. SEM image, 500 X magnification.

Generally, the shorter crystals were produced by the method of Wray and Daniels, 1957 (Figure 16). The longer crystals were produced by the method of Rao and Yoganarasimhan, 1965 (Figure 17).

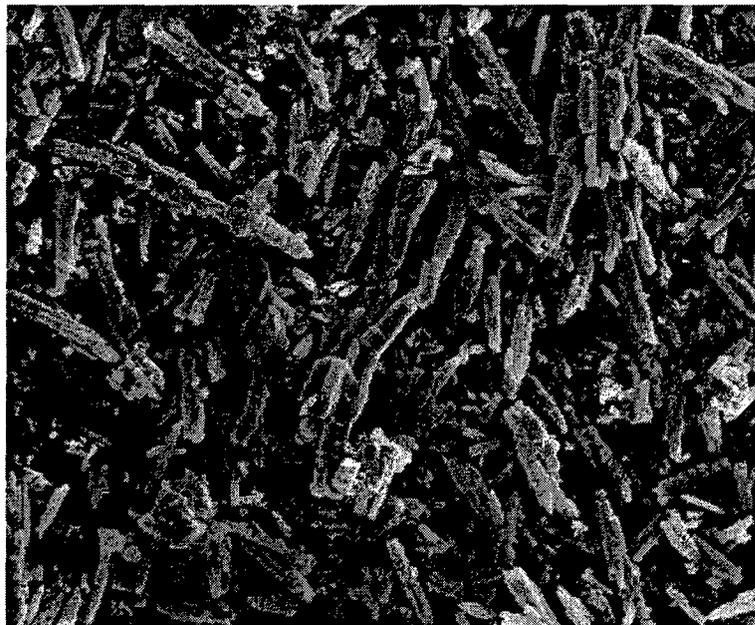


Figure 16 Aragonite crystals prepared by method of Wray and Daniels. Dimensions: widths vary 0.8 – 2 microns, lengths vary 5.4 – 22 microns. SEM image.

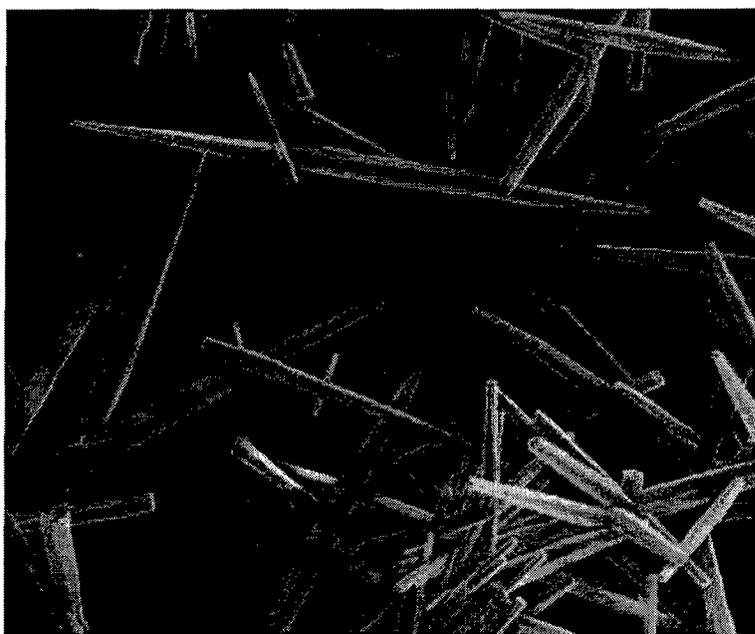


Figure 17 Aragonite crystals prepared by Rao's method. Dimensions: widths vary 0.4 – 4.6 microns, longest length about 100 microns. SEM image, 1200 X magnification.

While they both produced a similar needle or cigar shape, the crystals prepared by the second method had a greater aspect ratio and a cleaner, smoother appearance. Very few calcite crystals were found by SEM in the powders produced by Rao's method, while a small, but very noticeable percentage of the crystals produced by Wray and Daniel's method were calcite, besides the desired aragonite. The SEM findings were important in selecting filters, in selecting Rao's method to produce aragonite powder for the calibration curve and in governing the crystal powder preparation technique. It was found that even the filtered and dried crystal powders required machine grinding. SEM work on the hand ground powders showed considerable variation in size, leading to powder packing inconsistencies. This leads to preferred orientation problems in quantitative XRD work.

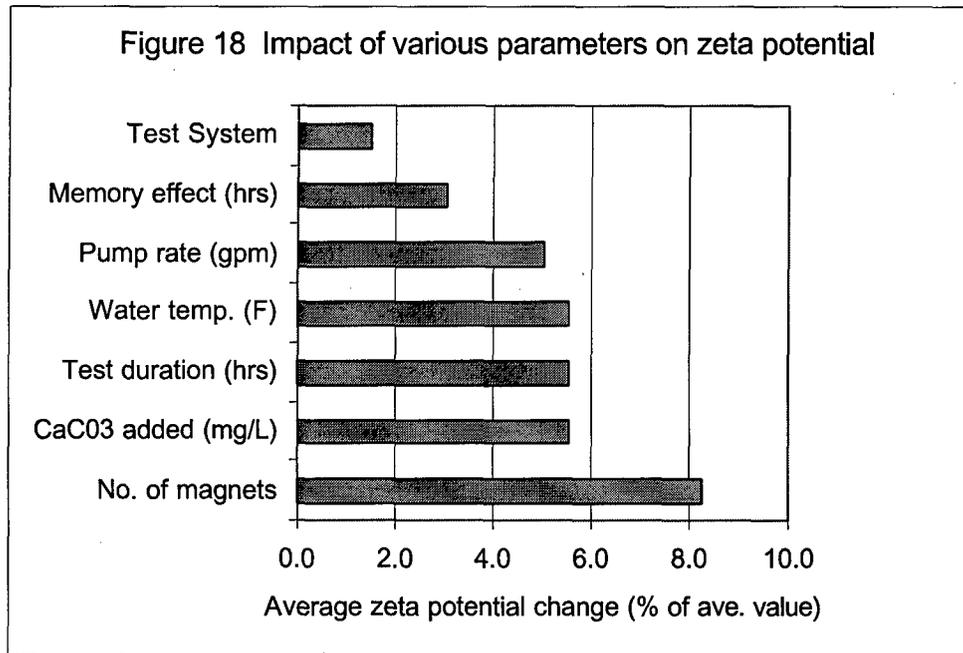
#### 6.6 Zeta Potential

The zeta potential readings were analyzed in different ways to determine the impact of various system test parameters. The most important observations are summarized in Table 1 and graphed in Figure 18. The greatest variation in zeta potential due to change in any system test parameter was tied to the presence of three installed MTDs versus no MTDs. Installation of either one or six MTDs produced less change in zeta potential than was observed for three magnets. Table 1 lists the number of test results examined to make these delta zeta potential comparisons (which gives some indication of which comparisons deserve more trust). Table 1 also lists the test system parameter values pertaining to either the higher or lower magnitude zeta potential. Other system test parameters influencing the change in zeta potential were test duration, bulk water temperature, pump rate and the amount of  $\text{CaCO}_3$  added. Memory

TABLE 1 Zeta Potential Changes vs. System Test Parameters

Test Parameter varied	Value of test parameter for:		Ave. change in zeta potential	No. of test results evaluated
	larger magnitude zeta potential	smaller magnitude zeta potential		
No. of magnets	0	3 or 6	1.63	20
CaCO <sub>3</sub> added (mg/L)	75	25	1.1	23
Test duration (hrs)	9-10.5	4-5.0	1.1	19
Water temp. (F)	75	105	1.1	12
Pump rate (gpm)	3	1	1.0	12
Memory effect (hrs)	40	20	0.6	8
Test System	2	1	0.3	36
Ave. zeta potential reading = 19.8 mV			zetapot1.xls, sht 2	

Figure 18 Impact of various parameters on zeta potential



effect shows little impact as does which test system was used. Pump rate, water temperature, test duration and the amount of CaCO<sub>3</sub> added all show some intermediate impact.

Table B4 ( Appendix B) lists the specific conductivity and zeta potential values measured, the standard deviation, and the mean values of zeta potential corrected for temperature for the system tests.

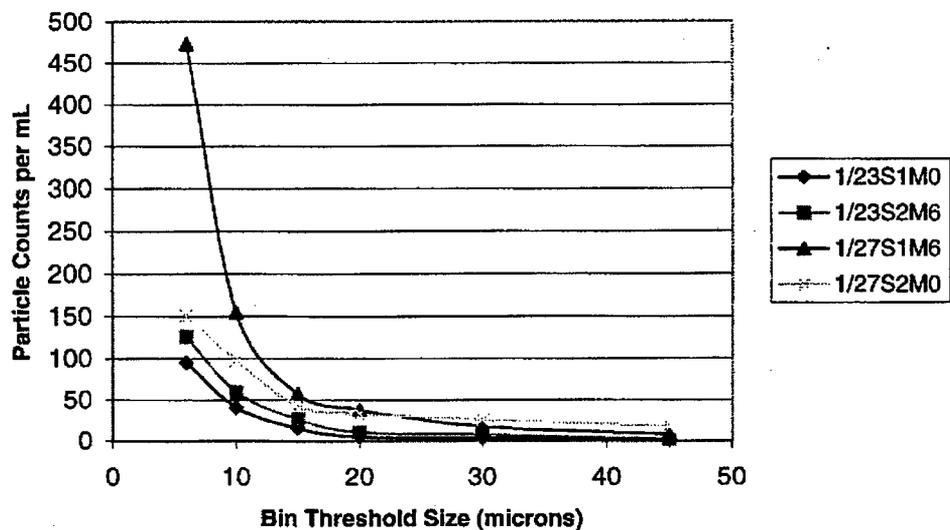
## 6.7 Particle Size Distribution

Due to the malfunction of the particle samplers used during the system testing, only a few of the desired parameters were examined by this technique. The number of magnets attached and the memory effect were the two evaluated parameters. Also, for data evaluation purposes, data was compared for aqueous samples taken at the start and end of each test and from each of the two tanks. Figures 19 and 20 show the size distributions obtained for early system tests obtained prior to particle sampler malfunction. The sampler was repaired prior to the last series of tests. These data are shown in Figures 21 – 25. All the system tests (3/31 – 4/17/98) run for particle size distribution analysis were run at the following conditions: flow rate = 3 gpm, water temperature  $\cong$  105° F, 75 mg/L of CaCO<sub>3</sub> added to tap water and a pumping duration of 10 – 10 1/3 hours (except for memory effect tests). Appendix B contains the individual particle count data tables for the DI water flush runs, calibration standard runs and the system test runs.

Table C3 (Appendix C) contains the averaged particle size distributions for the system test runs exclusive of the memory effect tests. Each distribution in this table is the average of two to three particle sampler runs on the same system test sample. This data does not include the 3  $\mu$ m data (as explained in the procedures section). The data in this table has the average background DI water particle counts subtracted out from each bin size range. This data is plotted in Figures 21 – 25. Each plot contains the data for one pair of tests, including samples from both test systems and from the start and end of each test. Examination of these plots yields the following observations: 1) Nine of ten pairs of data show that the particle counts are higher across the size spectrum for the sample at the start of the test versus at the end of the system test. The tenth pair shows similar counts for most of the sizes. This may be explained by the fact that a certain amount of suspended CaCO<sub>3</sub> is trapped in both the filter units (intentionally) and in a few system crevices (unintentionally). 2) Mixed results when comparing which system the sample came from. This is good, indicating that for particle counts there is not a strong influence of one test system over the other. 3) Comparison of the number of magnetic units installed showed that the higher number of Magnetic Treatment Devices (MTDs) yielded higher particle counts across the size range tested in eight of ten data pairs. In one data pair the counts were very similar and in one data pair the trend was reversed.

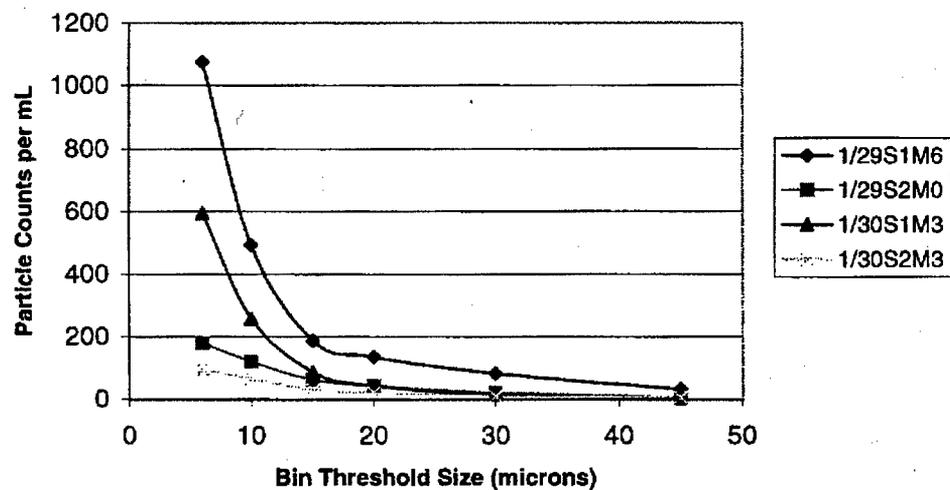
Figures 19 and 20 show that the average counts for tests with both six and three MTDs attached are higher than the average counts for the tests with zero MTDs attached. Figure 21 shows that the system with six MTDs installed had higher counts than systems with zero MTDs below particle sizes of about 23 microns. Above this size, there are mixed results. If the data for the three MTDs installed, shown in Figure 22, were averaged for the two system tests, then the particle counts would decrease for systems with six, three and zero MTDs installed for particle sizes up to 20 microns. Above this size, the sample particle counts from three and zero MTDs are about the same. Particle counts for the pure water system tests (during the preliminary system test checkout stage) also showed higher counts for samples from systems operated with magnets versus those with no magnets.

**Figure 19 System Test Particle Counts, 6 vs 0 Magnets, 10 hour Test**



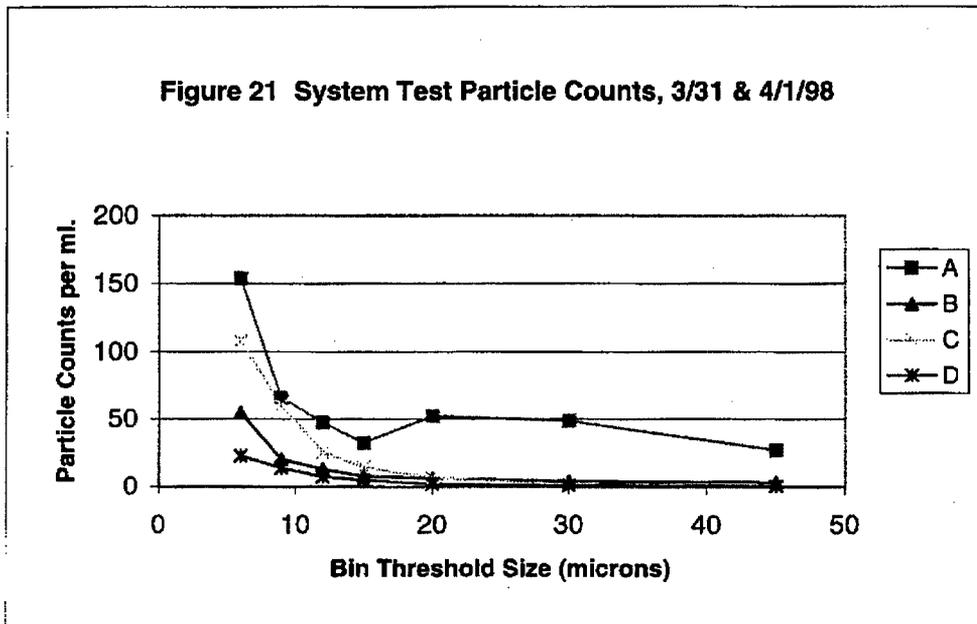
LEGEND NOTE: 1/23 = 1/23/98 system test date, S1 = system 1, M0 = 0 magnets

**Figure 20 System Test Particle Counts, 6, 3 & 0 Magnets, 4 hour Test**



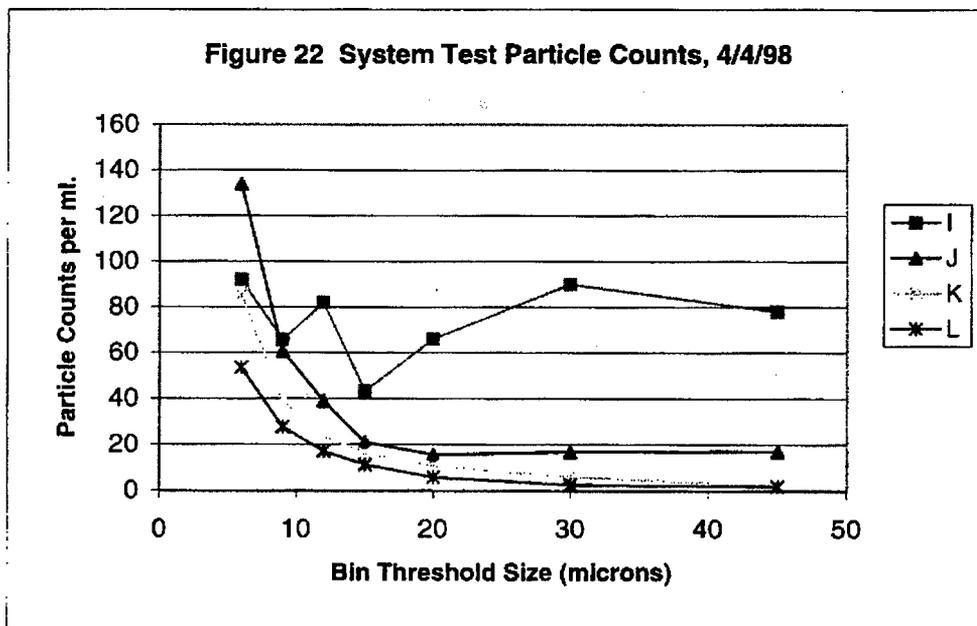
LEGEND NOTE: 1/29 = 1/29/98 system test date, S1 = system 1, M6 = 6 magnets

**Figure 21 System Test Particle Counts, 3/31 & 4/1/98**

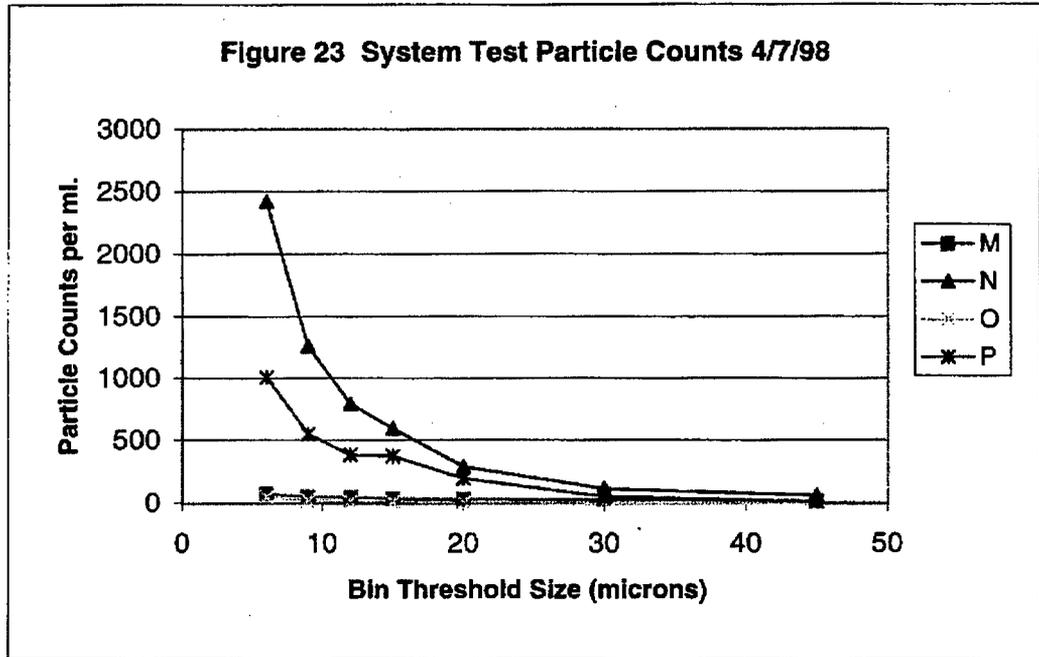


LEGEND: A = 3/31, start, system 1, 6 magnets; B = 3/31, start, system 2, 0 magnets  
 C = 4/1/98, end, system 1, 6 magnets; D = 4/1, end, system 2, 0 magnets

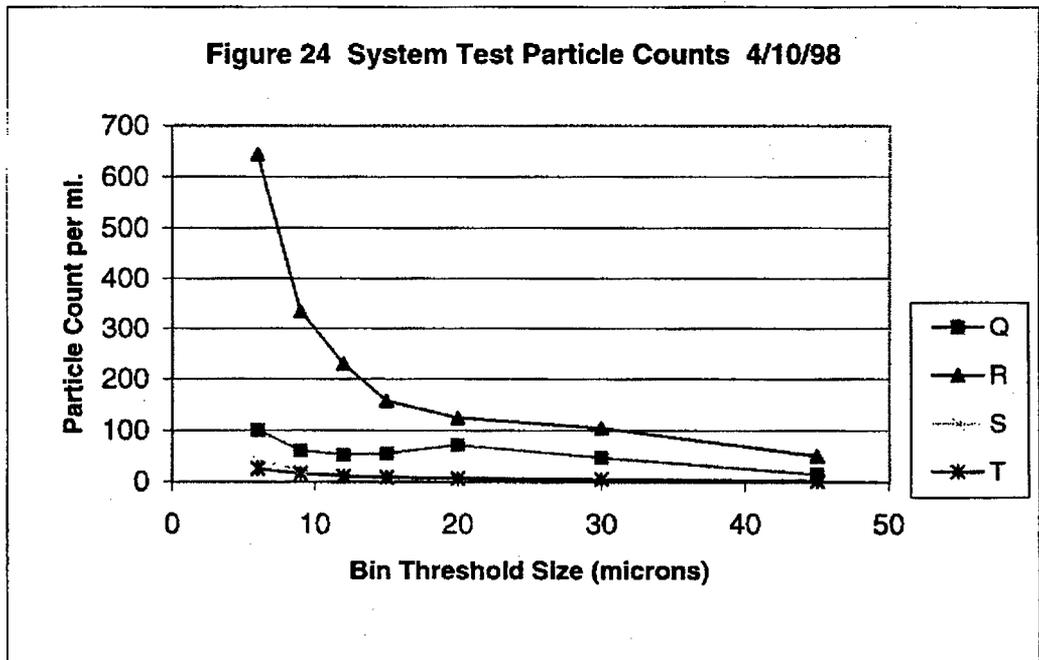
**Figure 22 System Test Particle Counts, 4/4/98**



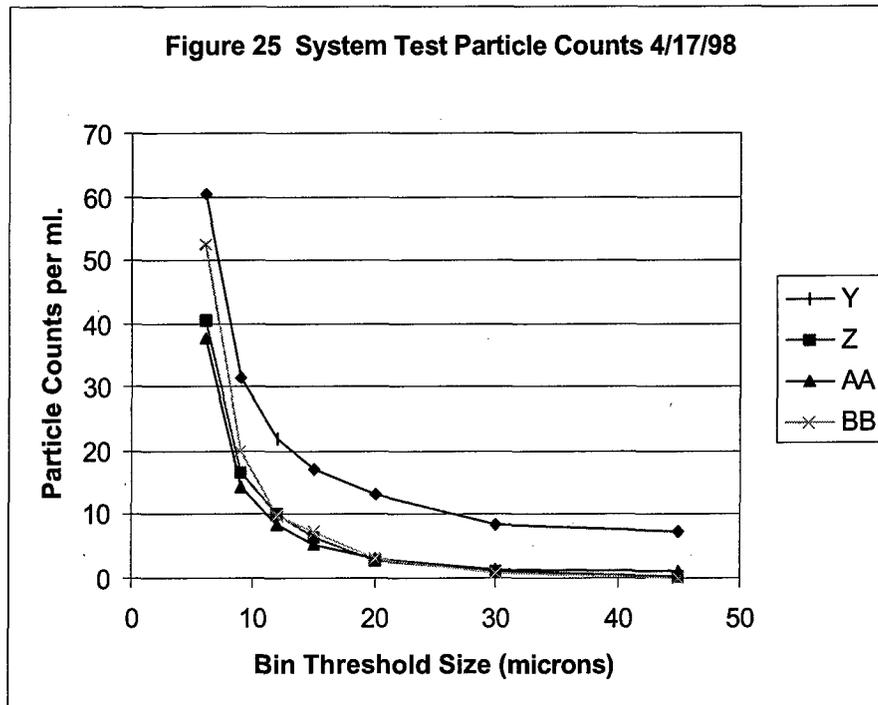
LEGEND: I = 4/4/98, start, system 1, 3 magnets; J = 4/4, start, system 2, 0 magnets  
 K = 4/4/98, end, system 1, 3 magnets; L = 4/4, end, system 2, 0 magnets



LEGEND: M = 4/7/98, start, system 1, 1 magnet; N = 4/7, start, system 2, 3 magnets  
 O = 4/7/98, end, system 1, 1 magnet; P = 4/7, end, system 2, 3 magnets



LEGEND: Q = 4/10, start, system 1, 0 magnets; R = 4/10, start, system 2, 6 magnets  
 S = 4/10/98, end, system 1, 0 magnets; T = 4/10, end, system 2, 6 magnets



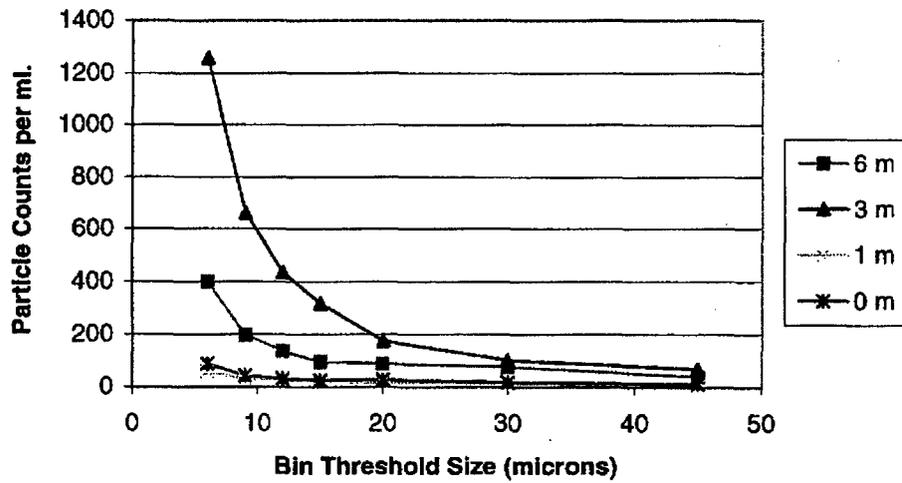
LEGEND: Y = 4/17/98, start, system 1, 0 magnets; Z = 4/17/98, start, system 2, 1 magnet  
 AA = 4/17/98, end, system 1, 0 magnets; BB = 4/17/98, end, system 2, 1 magnet

Figures 26 – 27 present data (from Table C3, Appendix C) that has been averaged for two to four data pairs from system tests that match for the number of MTDs installed and whether the sample was from the start or end of the test. These two plots present the data from the previous five figures in different combinations. This additional analysis looks more closely at the effect of the presence of magnetic devices on particle size distributions. The start-of-test sample data is plotted in Figure 26 while the end-of-test sample data is shown in Figure 27. The particle counts for the tests with “3 m” (3 installed MTDs) are much, much higher than for any of the other data. This is due to three sets of particle counts that appear excessively high. No probable cause or error was discovered to explain the very high counts, so the data was accepted “as is.” The counts for three or six MTDs installed were always higher than for one or no MTD installed. The particle counts for one MTD installed was generally slightly lower or about the same as for no MTD installed.

There was little evidence of an increase in particle counts in one size range at the expense of a decrease in counts in a different size range. This occurred only for the 1/27/98 test data shown in Figure 19 where there was a larger particle count for the smaller size range for the system with 6 magnets (versus 0) but a lower count for larger sizes. The rest of the data showed an increase in counts (or essentially the same) across the particle size spectrum.

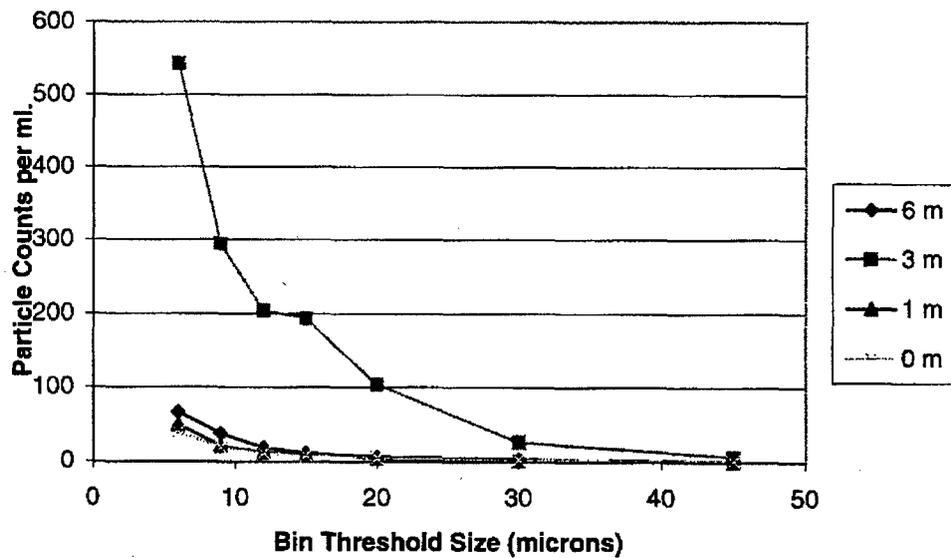
Figures 28 and 29 show the impact of the “memory effect” (time since removal of the MTDs from the system piping) on particle counts. In the first of these figures the system with six MTDs consistently

Figure 26 Particle Counts by No. of Magnets (start)



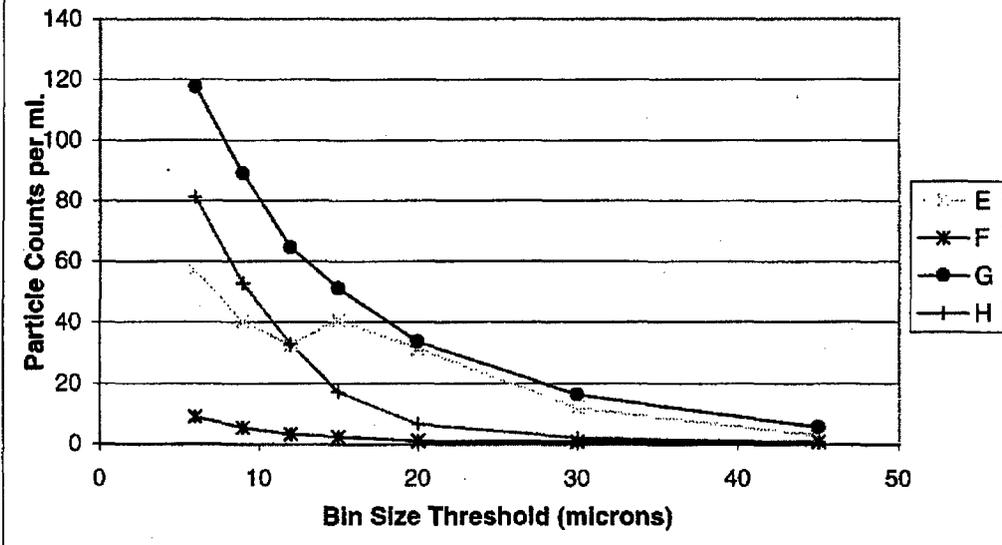
NOTE: 6, 3, 1, 0 m refers to numbers of MTDs installed

Figure 27 Particle Counts by No. of Magnets (end)



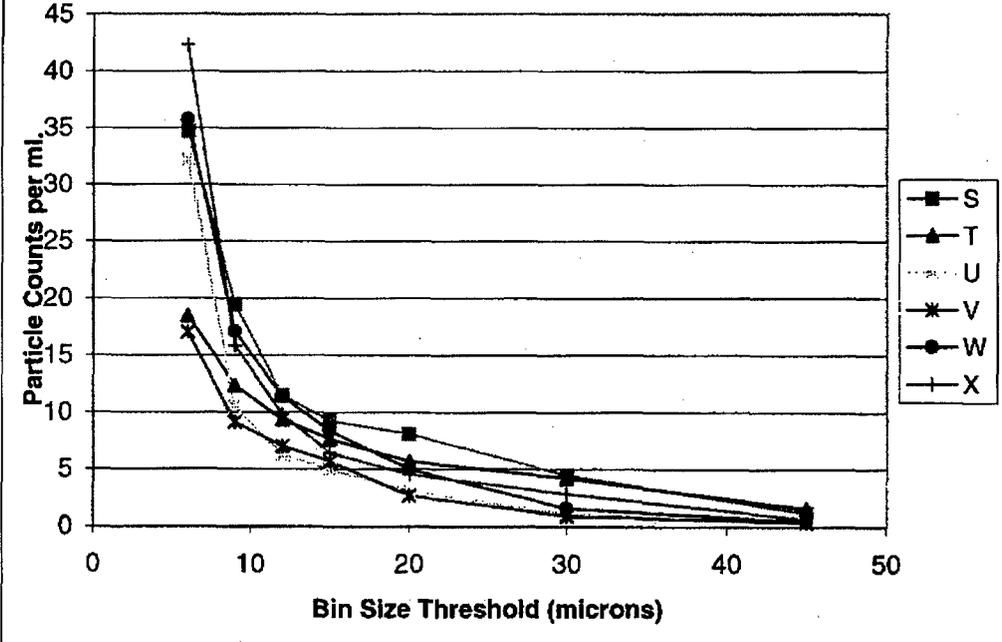
NOTE: 6, 3, 1, 0 m refers to numbers of MTDs installed

**Figure 28 Particle Counts: Memory Effect 4/2 & 4/3/98**



E = 4/2/98, sys. 1, 6 magnets, 0 hrs.;      F = 4/2/98, sys. 2, 0 magnets, 0 hrs.  
 G = 4/3/98, sys. 1, 6 magnets, 28 hrs.;      H = 4/3/98, sys. 2, 0 magnets, 28 hrs.

**Figure 29 Particle Counts: Memory Effect 4/10,4/11 & 4/13/98**



S = 4/10/98, sys. 1, 0 magnets, 0 hrs.;      T = 4/10/98, sys. 2, 6 magnets, 0 hrs.  
 U = 4/11/98, sys. 1, 0 magnets, 23.5 hrs.;      V = 4/11/98, sys. 2, 6 magnets, 23.5 hrs.  
 W = 4/13/98, sys. 1, 0 magnets, 72 hrs.;      X = 4/13/98, sys. 2, 6 magnets, 72 hrs.

had higher counts than the system with zero MTDs. In the second figure, the system samples with zero MTDs had more or about the same counts as the system with six MTDs. This is nearly the opposite results as shown in the first figure. Examination of the number of hours the water was circulated without MTDs installed versus the particle counts (system number and number of MTDs previously installed remaining constant) also shows inconsistent results. No consistent trend was observed.

#### 6.8 Calcite/Aragonite Relative Proportions: XRD

Figure 30 shows different peaks corresponding to the four most prominent angular positions for both calcite and aragonite (identified as c = calcite, a = aragonite). The peak height and area are tabulated below the plot. Figure 31 shows both the peak height and the planar "D" spacing for the crystals. Appendix D contains the remaining diffraction patterns (Figures D1 – D22) for the analyzed system test filter residues. It also contains the additional patterns for the prepared sample powders used to develop the XRD calibration curve. The four calcite and four aragonite peak areas from the diffraction patterns for all the samples are listed in Table D1 in the same appendix. The filename at the top left of each diffraction pattern may be matched up with an appropriate system test or prepared sample powder by referring to Table D1.

Table 2 (below) lists the estimated percent of calcite in the given sample residue, based on the Table D1 data and the calibration curve. The remaining powder content is aragonite crystals. Evidence of a small concentration of an unknown substance in many of the XRD patterns were ignored for this analysis.

TABLE 2 System Test XRD Results: Calcite Percentage

XRD File Name	Sys No.	No. Mags	Temp (F)	Added CaCo3 (mg/L)	corrected Calcite %	Syst Test Date	Test Time (hrs)
klaast.ni	1	6	hot	75	90%	1/27	10.5
klbbst.ni	2	0	hot	75	98%	1/27	10.5
klccst.ni	2	0	hot	75	90%	1/29	4
klddst.ni	1	3	hot	75	95%	1/30	4
kleest.ni	1	6	hot	75	94%	1/29	4
klffst.ni	2	3	hot	75	86%	1/30	4
klggst.ni	1	0	hot	75	100%	1/23	10
klhhst.ni	2	1	hot	75	100%	2/2	4
kljst.ni	1	0	room	75	93%	2/9	9.25
klkkst.ni	1	0	hot	25	100%	2/13	20
klilst.ni	1	3	room	75	98%	2/10	9
klmmst.ni	1	1	hot	75	99%	2/2	4
kloost.ni	2	0	hot	75	93%	2/20	23
klppst1.ni	1	0	hot	75	89%	2/17	9.25
klqqst1.ni	1	1	hot	25	79%	1/31	4
klqqst2.ni	1	1	hot	75	81%	1/31	4
klrrst2.ni	2	1	hot	75	71%	1/31	4

xrdpeak1.xls

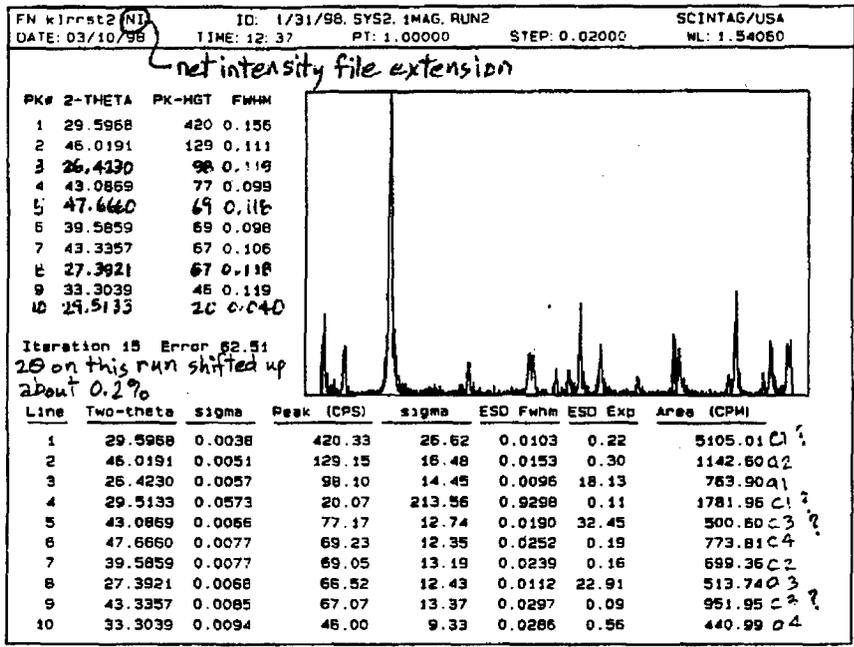


Figure 30 Profile curve fit of XRD pattern with peak areas: system 2 test date 1/31/98, 1 magnet about 0.3 gr. powder in sample holder with glass disk

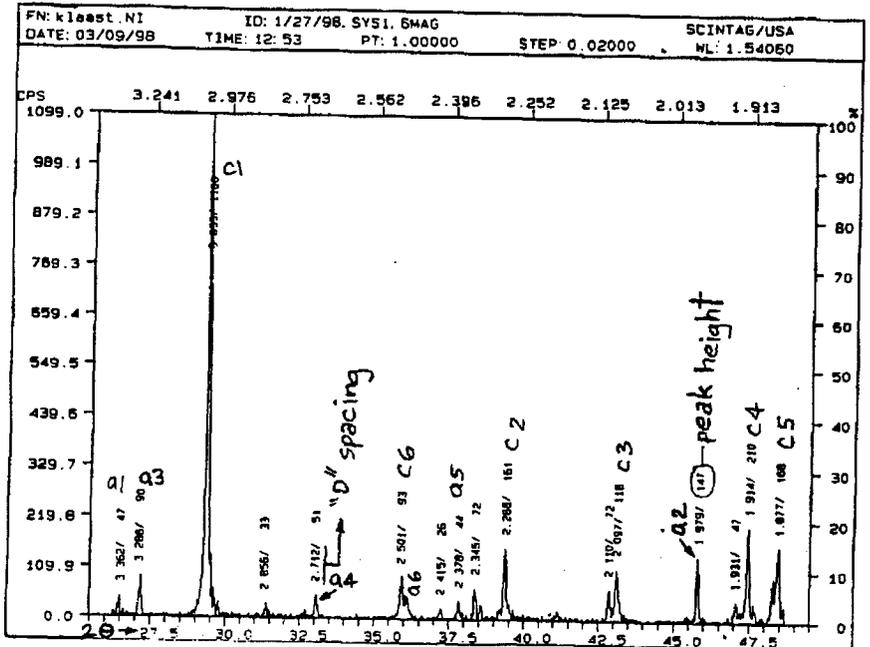


Figure 31 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 1/27/98, 6 magnets

All but one test condition yielded calcite percentages in the 80-100% range. Comparison of changes in the calcite percentage between different sets of test conditions yielded very small changes on average (usually less than 5% change). The longer test times favored calcite (7% greater calcite content on average). There was no consistent trend of calcite proportion versus number of magnets installed. The best estimate for potential error in these readings is about 20% (+/- 10%).

#### 6.9 Iron Content in Solid Residue: XRF

Two of the screen images used for elemental analysis are reproduced in Figures 32 and 33. The first figure shows an "over line" comparison, without background stripping, of the CaCO<sub>3</sub> used in the system (used as a baseline) against two of the test system filter residues. The tallest peak is for zinc (Zn) and the smaller peak to the right half of the curves is the major iron (Fe) peak. Other elements scanned using this same crystal and angular range were copper (Cu), lead (Pb) and strontium (Sr). This type of chart was used for a quick scan for the significant presence of these elements and for relative amounts of a particular element for a given set of system test conditions. Once particular areas of interest were determined using this first screen image, then a zoom in function was used to concentrate on specific elemental peaks, as is illustrated in the second figure. This second figure shows the major peak region for Fe for several filter residues. This image illustrates that Fe content in the residue decreased for an increasing number of installed MTDs and that the chelometric standard had a very low iron content.

The only element to show a consistent pattern with any of the system test parameters was iron (Fe), which changed with the presence of magnets. Figure 34 (Table 3 data) illustrates the change in Fe content in the samples with a change in the number of magnets attached to the pipes. It shows a consistent drop of iron in the filter residue with the presence of an increasing number of magnets used. The biggest change in Fe content occurred between the points with no magnetic presence and one magnet attached. Table B6 in Appendix B lists the counts, indicative of the relative amount of Fe, Zn, Sr, Cu, Pb and Mg in the filter residue. Other elements tested are not listed in Table B6 as they only showed non-detect or trace levels in all the samples tested. A quick scan of a sample of the plastic petri dish showed the presence of Zn (which is not uncommon in this type of plastic). The presence of Zn in the plastic sample containers

TABLE 3 Average Iron Content in Filter Residue: XRF Results

No. of magnets	No. of data pts.	Average Fe counts (cps)	Comments
0	9	1288	
1	3	614	
3	6	571	
6	4	567	
0	8	994	Eliminates 1 very high data point
Note: these residues were taken from system tests run at 3 gpm with 75 mg/L of CaCO <sub>3</sub> added. Test duration and system number varies.			
xrfrest3.xls			

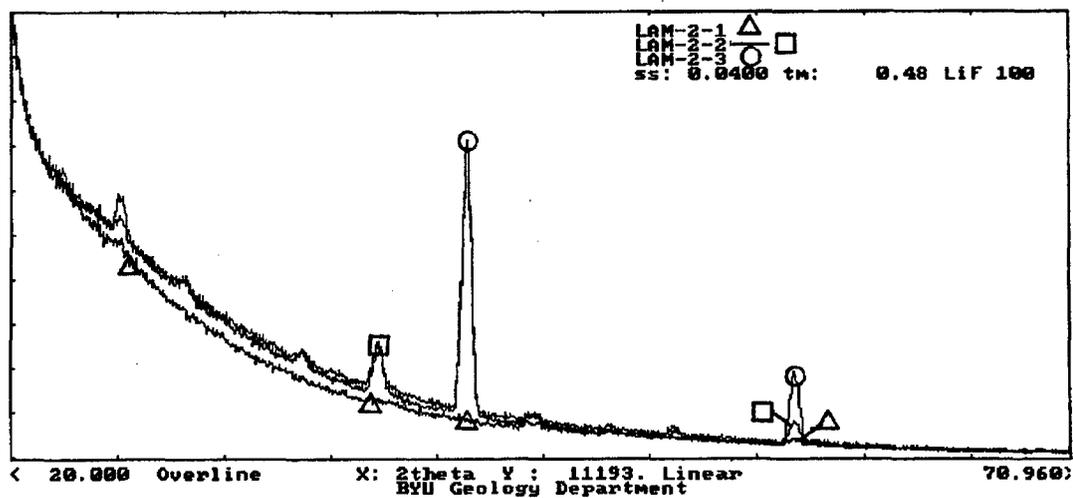


Figure 32 XRF Overline comparison of chelometric standard versus two system test filter residues.

LAM-2-1 = calcium carbonate chelometric standard  
 LAM-2-2 = 1/23/98, sys. 1, 0 magnets, 10 hours, 105° F  
 LAM-2-3 = 1/27/98, sys. 2, 0 magnets, 10.5 hours, 105° F

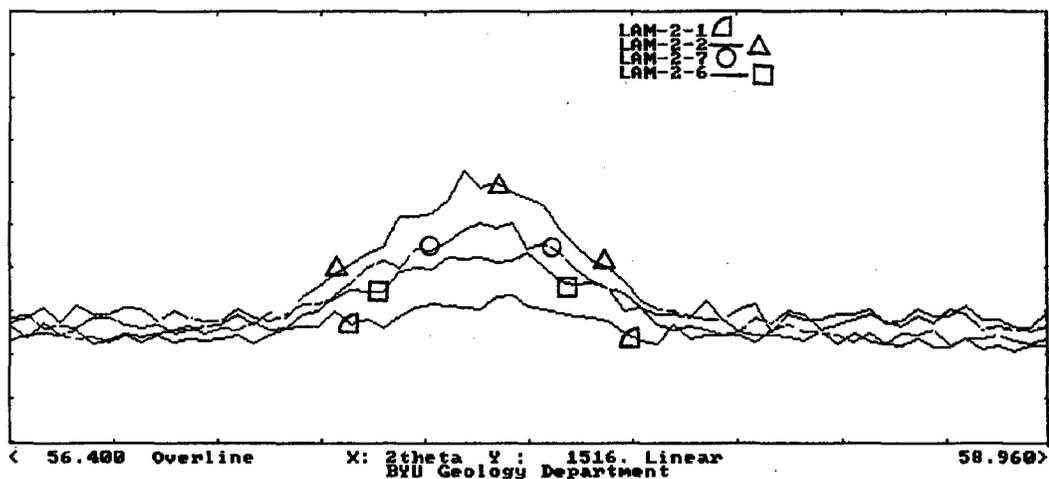
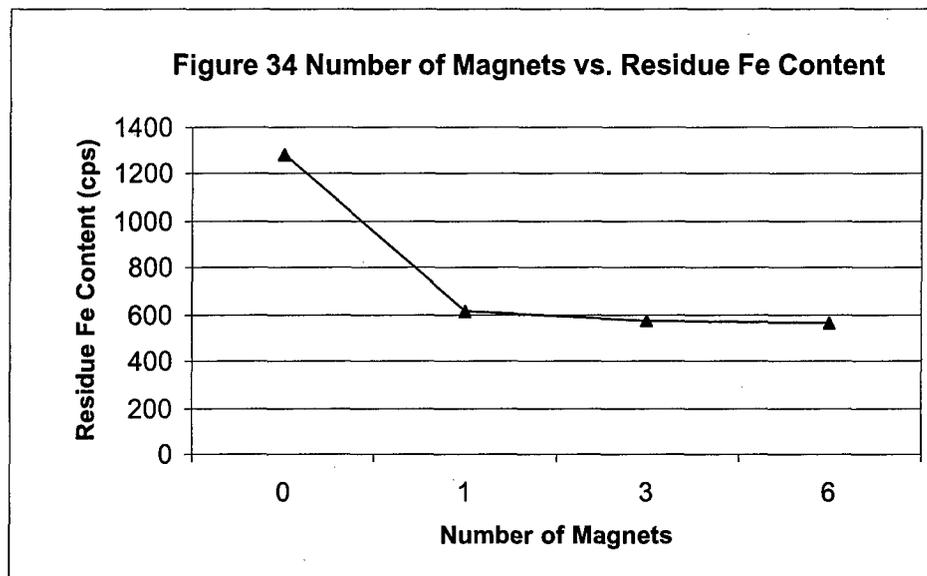


Figure 33 XRF Zoom in view of iron peak for chelometric standard versus three system test filter residues.

LAM-2-1 = calcium carbonate chelometric standard  
 LAM-2-2 = 1/23/98, sys. 1, 0 magnets, 10 hours, 105° F  
 LAM-2-7 = 1/30/98, sys. 2, 3 magnets, 4 hours, 105° F  
 LAM-2-6 = 1/29/98, sys. 1, 6 magnets, 4 hours, 105° F

may explain its presence in the XRF samples, since Zn concentration in both the source water and in the chelometric standard were minimal. The experienced XRF operator indicated that it is not unusual for elements in the container to be scraped off and enter the sample in small quantities.



#### 6.10 Iron Content in Aqueous Samples: Spectrophotometer and FIAA

Table 4 lists the total iron concentrations for water samples analyzed by flame ionization atomic absorption. These values are for the unconcentrated system test samples. Table 5 shows the iron concentrations in DI and regular tap water originally considered for use as measured by spectrophotometer. The iron concentration in the regular tap water measured by the spectrophotometer falls just below the mid range given by FIAA, which adds credibility to the FIAA results. The raw FIAA data with explanatory notes are listed in Table B8 of Appendix B.

TABLE 4 Flame Ionization AA Total Iron Results for the unconcentrated samples

Sample ID	Mean Concentration (ppb)	Standard Deviation (ppb)	Relative Standard Deviation (%)	Description/Comments
AO	69	59	85.5	2/13/98 hose tap H2O, 0 mag, 0 gpm, 0 hrs
BO	13	37	28.5	2/25/98 hose tap H2O+75mg/L, 0 mag, 0 gpm, 0 hrs
EO	69	50	72.8	2/20/98 sys 2, tap H2O+75mg/L, 0 mag, 3 gpm, 23 hrs
FO	44	48	109	2/20/98 sys 1, tap+75mg/L, 3 mag, 3 gpm, 10.25 hrs
GO	87	49	56.1	1/27/98 sys 2, tap H2O+75mg/L, 0 mag, 3 gpm, 10.5hrs
HO	78	56	71.2	1/23/98 sys 2, tap H2O +75mg/L, 6 mag, 3 gpm, 10 hrs

Oremp1nt1.xls, sht 2

TABLE 5 Spectrophotometer Results for Iron

Iron Test	Deionized Water (ppb)	Regular Tap Water (ppb)
Fe ++	-14.9	-9.4
Total Fe	113.9	41.6
Notes: 1) Averages for three samples 2) Negative values for Fe++ indicate unreliable data below detection limit.		
oremplnt1.xls, sht 2		

## 7.0 DISCUSSION OF RESULTS

### 7.1 Iron in the Solid Residue

Although not part of the original evaluation plan, examination of the solid residue provided the most intriguing of clues as to whether the magnetic devices lead to changes in suspended crystalline matter. This led to the XRF analysis which showed a consistent drop in iron content in the residue (for certain tests) for an increasing number of installed MTDs. This has potential implications from two perspectives. First, iron concentrations in aqueous solutions can have a large inhibitory effect on  $\text{CaCO}_3$  crystal nucleation (Meyer, 1984) and growth. The removal of iron was cited by Belova (1972) as contributing significantly to the effectiveness of scale reduction in combination with anti-scaling magnetic treatment (AMT). One of the authors reviewed by O'Brien (1979) claims that iron oxides must be present for AMT to work successfully. These references potentially present conflicting conclusions on this subject. On the one hand, iron is said to be required at least in small quantities to inhibit  $\text{CaCO}_3$  crystal nucleation and growth, while on the other hand, iron removal contributes to the success of AMT. The exact conditions and iron levels in these different studies need to be examined more closely. It may be that it deals with an effect of non-monotonically changing iron concentrations. Secondly, Fe substitutes for Ca and forms iron carbonate (siderite) a known scale component. Whether this affects scale formation on heat transfer surfaces is as yet unknown. These combined results (colored, cohesive residue plus XRF) may implicate iron as a significant component of the magnetic treatment effect. It is possible that the magnets simply retain the colloidal iron along the pipe, preventing it from entering the residue. Or the magnetic fields may influence the formation of a compound involving both Fe and  $\text{CaCO}_3$  that affect adherent scale formation. The colored residue implies not only the presence of a transition metal but the formation of chemical bonds, apparently tied to iron.

Figure 32 shows that the Fe content of the residue was quite a lot higher than what was in the chelometric standard used to seed the system water tanks. This may imply that something about magnetic

treatment affects the concentration of iron in suspended solid calcium carbonate crystals.

Since the total iron in the water as determined by AA was usually in excess of the maximum expected from the source water (plus a minimal contribution of Fe impurity in the CaCO<sub>3</sub> powder) the additional iron may be attributable to iron piping or components.

It was not determined if the Fe in the residue was siderite (iron carbonate). The Fe was in such low concentrations that the compound was not accurately detected using XRD analysis, which can detect compounds. While XRF detected the low concentrations of Fe, XRF only detects individual elements.

## 7.2 Zeta Potential

The most significant impact on zeta potential came when comparing results for three installed MTDs versus no MTDs. The drop in zeta potential of 8% from untreated samples to those treated with three magnets compares with an average drop of 16% measured by Parsons (1996). The difference due to the one installed MTD was smaller. Very little change was noted between six and no installed MTDs when the data for all the early test system data was compared. But when paired comparisons (with all other parameters held constant) of later (3/31 – 4/17/98) tests were made, the change in zeta potential for six MTDs versus none was actually slightly greater than for three MTDs versus none. In summary, three and six MTDs may have similar impact on zeta potential whereas one of these particular MTDs had only about 60% of this impact.

Added CaCO<sub>3</sub> concentration, test duration, water temperature and pump rate were considered in my judgement to provide a small effect on zeta potential. The added CaCO<sub>3</sub> concentration effect is not unexpected as the ion concentration level impacts zeta potential (Zeta Meter, Inc., 1993). Water temperature affects saturation levels and both test duration and flow rate impact the total exposure time to the magnetic field. The magnitude of the zeta potential change due to memory effect (hours of circulating water after termination of magnetic treatment) was minimal, and depending on the comparison showed inconsistent results.

Each test system was run with the same test parameters fixed. These paired comparison results differed by 1.6% of the mean value on average, indicating little impact on zeta potential due to which system was used. Another evaluation made to check data consistency was comparing zeta potential measured from samples taken from the beginning and end of the same test. The average difference was 0.5% indicating consistent results, at least for the tests run from 3/31 to 4/17/98, when my techniques had been improved.

Approximately 50 particles were tracked for each test value recorded. This large number provides a sizeable statistical base for comparing averages. The standard deviation, for individual particle tracking from the same sample, typically ran 20 – 30% of the mean value. This indicates considerable variation in particle velocities and charge. Sampling of repeat tests showed differences in zeta potential of about 9% (for tests run 3/31 – 4/17/98). This imprecision lends difficulty to reliable data interpretation for changes in zeta potential on the order of 5 – 9% of the mean value.

### 7.3 Particle Size Distribution.

There appeared to be a consistent trend of higher particle counts for magnetically treated samples. Data evaluation could not attribute this trend to the system used or the amount of CaCO<sub>3</sub> residue deposited in the filters. However, the trend is not consistent for the number of MTDs installed. A possible explanation for the data for one and zero MTD being so close to one another is that one MTD installed is insufficient to cause significant enough change to overcome data variation with the small number of samples taken. The data for three MTDs was plotted against six MTDs without the inclusion of the three sets of data containing the very high counts. This brought the particle counts for three MTDs close to the counts for six installed MTDs. This may indicate that after a certain level of impact (between one and three MTDs) there may be no additional benefit from added magnetic devices. The lack of a larger database for statistical evaluation lowers the confidence level in this conclusion.

The general shape of the particle size distribution curves were nearly identical for magnetically treated and untreated samples. Due to mass balance considerations one might anticipate that a larger particle count in one size range would necessitate a lower particle count at a different size range. This was not generally observed. This observation lessens confidence in the conclusion that higher particle counts were due to the effect of MTDs. However, there was no other explanation found, other than the presence of three or six MTDs (versus zero), to explain the higher counts.

Frequently, absolute particle counts for sizes above about 30 microns were relatively small. Due to data variation observed in particle counts (from what should have been similar samples) there is not a lot of confidence in the small differences in absolute particle counts for many of the larger particle sizes.

It was noted that the particle size distributions (and the amount of solid residue trapped in the filters) was significantly influenced by which test system the sample was taken from. It is believed that this was due to slight differences in the positioning of the mixer propeller and in the angle of the mixer shaft. For this reason, particle size distributions were either compared for the same test system, or data was obtained with the same number of magnets on both systems (different test runs) to counteract the influence of the test system sampled. Results evaluation indicated that the presence of six versus zero magnets had a significantly stronger influence on particle counts than did the system from which the sample was taken.

### 7.4 Calcite vs. Aragonite: XRD.

The XRD results found in this research imply little variation in the calcite/aragonite composition when analyzed against the number of magnets used (including none). This is in stark contrast with some researcher's reported results (Deren, 1985 and Donaldson, 1988) that show an 80/20 mix of calcite and aragonite can nearly reverse itself after magnetic treatment. However, this phenomenon has only been observed by a few researchers. Several have said that they have not seen this crystal change.

### 7.5 Magnesium Content.

No water analysis was performed for Mg concentration and so no independent confirmation can be

made regarding the Mg content implied by the significant difference between total and calcium hardness values. The Mg content in the source water analysis implies a lower Mg content than the hardness values indicate. If one of the hardness values is to be doubted, it is the calcium hardness. The calcium titration endpoint was less distinct and data evaluation suggests unexplained variations in the calcium hardness. Magnesium can be important in this research as it substitutes for Ca and forms scale forming carbonates. Magnesium can also inhibit  $\text{CaCO}_3$  crystal growth.

#### 7.6 Water Chemistry: pH, alkalinity, hardness.

These measures were taken principally for monitoring purposes, not because any trend was expected to be observed. Nevertheless, various ratios were calculated to look for any possible trends or for any particular operating system problems that might show up. The ratios calculated were: alkalinity to both calcium and total hardness, calcium to total hardness, and the test start to test end value for all three parameters for those tests that were analyzed at both the beginning and end. These calculated ratios are listed in Table B7 of Appendix B. The data showed more variation than expected for the ratios comparing alkalinity and the two different hardnesses. On average, the start to end ratio of hardness and alkalinity remained near one, but there were sizeable variations in individual test samplings. This may be due to inconsistencies in the mixing mechanism or the sampling or titration procedures. While there was frequently considerable quantities of  $\text{CaCO}_3$  removed by filtration, there was apparently enough left in the tank to maintain saturation levels. No particular trends in the chemistry was observed relative to changes in system test parameters, but this data was not as carefully analyzed in this respect as were the other analytical results. pH remained quite constant for a given test. Plummer and Busenberg (1982) are a good source of information on the solubilities of calcite and aragonite (which are different) as well as the impact of  $\text{CO}_2$  in the water. The  $\text{CO}_2$  concentration in the water should be examined as it has a considerable impact on equilibrium concentrations of carbonates and bicarbonates.

### **8.0 INTRODUCTION TO POSSIBLE MECHANISMS**

There are many possible mechanisms suggested in the literature, from unbelievable to potentially defensible. Those papers and articles that propose mechanisms generally only briefly introduce them. The solid theoretical and microscopic scale test verification is lacking to date. Three of the more plausible (in my opinion) mechanisms that have been advanced are briefly introduced here. A fourth approach mentioned here is not truly a causal mechanism directly but may be an indicator of some crystal effect that some authors have sought to advance.

Numerous authors have mentioned the Lorentz force as a possible explanation. It is an accepted principal that applies to charged particles and is proportional to the particle charge, the strength of the magnetic field and the particle velocity through the magnetic field. As it is a vector product, the largest Lorentz force is generated when the particle traverses the field orthogonally to the field lines. Some

authors argue that the minimal forces generated by the low flow velocities encountered in a typical industrial facility would be insufficient to overcome repulsive forces of charged particles. However, it is the only force proposed to date that is known to tie velocity, particle charge and magnetic field together. It has not been adequately explained how this force would influence scale reduction except through crystal nucleation or particle coagulation through forcing additional particle collisions. If this phenomenon occurred primarily in the bulk fluid flow then the crystals might successfully compete with nucleation sites on solid surfaces such as pipes and heat transfer tubes.

A second proposed mechanism, that was addressed in the current research, deals with surface charge of charged particles. Figure 35 illustrates the charged layers surrounding a negatively charged colloid. For fresh water (low ionic strength) the zeta potential is a fairly good approximation of the total surface potential (Figure 36) and the zeta potential is far easier to measure than the surface potential (Zeta Meter, Inc., 1993). The reduction of zeta potential lowers the energy barrier (Figure 37) fostering coagulation in the bulk fluid which may provide the nucleus around which crystal growth begins. This may provide competitive sites for calcium carbonate crystal growth as opposed to heat transfer surfaces. Further information on zeta potential may be found in Sawyer, et al. (1994) or Zeta Meter, Inc. (1993).

Many impurities reduce calcium carbonate crystal nucleation and growth (Meyer, 1984). One of the most effective is iron. It has been suggested by several authors that iron must be present for AMT to be effective. It may be that the magnetic field affects the colloidal iron that may then affect crystal nucleation and growth. It is not necessary that this effect eliminates calcium carbonate formation but that it provides competing nucleation sites in the bulk fluid so that the crystals are carried to a slow flow point in the system to drop out rather than form scale on the heat transfer surfaces. If this happens, system design changes, such as side stream filtration (with cyclone separation of heavier particles) can be incorporated to clean out the system. With a recirculating system the calcium carbonate can then be gradually removed, leaving only a saturated solution. This may then lead to gradual removal of built up scale. This in fact has been reported in a number of field trials. Crystal surface energy, effect of impurities, solubility and the effect of alkalinity and carbon dioxide on calcite and aragonite crystals is discussed by Fyfe and Bischoff (1964). Homogeneous and heterogeneous crystal nucleation are discussed by Reimers et al. (1986). While these sources provide some useful thoughts to get started on this line of research, it will require a very different experimental approach to delve into crystal nucleation because of the physical scale, equipment and processes used.

Several researchers have observed large differences in the relative proportions of calcite and aragonite in the  $\text{CaCO}_3$  with and without magnetic treatment. Some claim that this is significant due to some reports that aragonite predominates in the loose, non-adherent sludge while calcite dominates in the adherent form as scale. This does not agree with Cowan and Weintritt (1976) that state that aragonite is the predominant form in scale. No explanation has been advanced to explain why the different polymorphic forms would favor different solid manifestations of  $\text{CaCO}_3$ . But conclusive research in this area would direct future research in different paths.

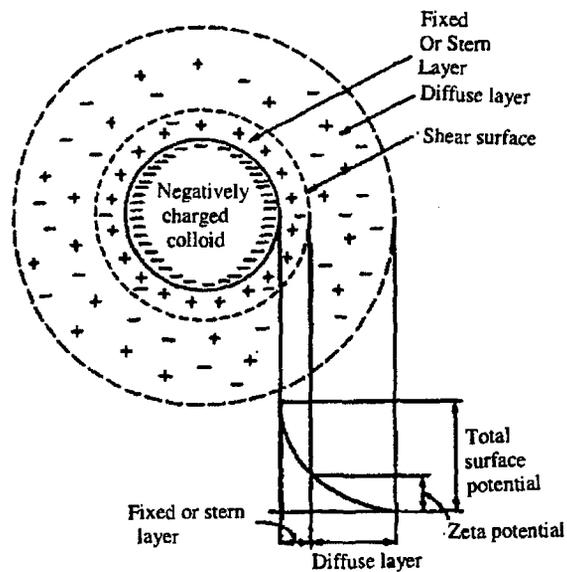


Figure 35 Electrical double layer of a negatively charged colloid.  
 (From Sawyer, et. al., *Chemistry for Environmental Engineering, Fourth Edition*.  
 Copyright © 1994. Reproduced with permission of McGraw-Hill Companies.)

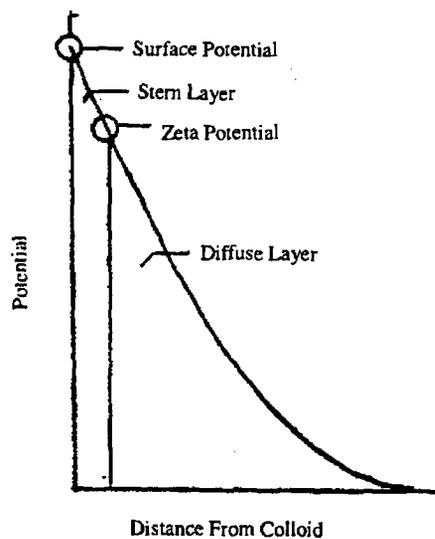
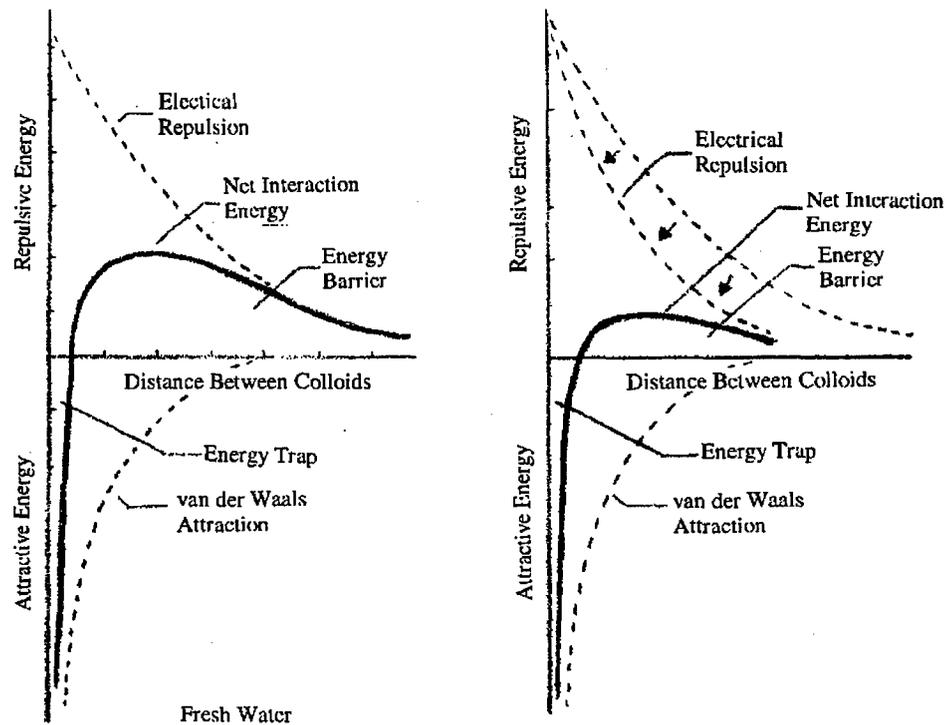


Figure 36 Zeta potential vs. surface potential. In fresh water  
 Zeta potential is a good approximation of the surface potential.  
 (From Zeta-Meter, Inc., 1993. Used by permission.)



**Interaction**  
The net interaction curve is formed by subtracting the attraction curve from the repulsion curve.

**Compression**  
Double layer compression squeezes the repulsive Energy curve reducing its influence. Further compression would completely eliminate the energy barrier.

a) Net interaction curve

b) Compression reduces the energy barrier

Figure 37 The energy barrier to colloidal flocculation.  
(From Zeta-Meter, Inc., 1993. Used with permission.)

Crystal nucleation energy potential favors nucleation sites on surfaces rather than in free space (in the bulk fluid), which partially explains the development of scale on piping and heat exchanger surfaces. To favor the development of a loose sludge ( $\text{CaCO}_3$  crystals as a suspended solid in the bulk fluid) over adherent scale, a mechanism must provide preferential nucleation sites in the bulk flow. Whether this mechanism is due to the presence of certain suspended impurities in the bulk flow or to preferentially affecting the surface energy of particles in the bulk fluid versus side walls has yet to be determined.

## **9.0 BRIEF COMMENTS ON MAGNETIC FIELDS AND DEVICES**

Many authors treating this subject mention the importance of having the particulate laden flow going in a direction orthogonal to the magnetic field lines. This makes sense if the phenomenon is tied to the Lorentz Force or some similarly acting force. The construction of a magnetic force field line diagram for a three dimensional field produced by an array of magnets spatially equi-distant circumferentially about a pipe is not the easy task that a two dimensional field is, due to interactions. In attempting this, it was observed that for typical MTD layouts there are portions of the flow that pass parallel to, perpendicular to and angularly anywhere between these two extremes, relative to magnetic lines at some point in the field.

The strength and distribution of the magnetic field produced by the MTD used in this research was greatly affected by the type of pipe it was installed on. A non-magnetic pipe material such as PVC allowed for a fairly narrow magnetic field which gradually dropped to zero magnitude near the pipe center. The magnetic field did not extend axially along the pipe for any sizeable dimension relative to the dimensions of the MTD. When placed on a magnetic material pipe such as iron the magnetic field changed drastically. The field strength dropped very rapidly in a radial direction towards the pipe axis as it left the pipe wall. The field extended axially along the pipe somewhat. In essence, the magnetic pipe material served to diffuse and reduce the magnetic field interior to the pipe. Thus, the use of iron or steel pipe significantly alters the magnetic field inside the pipe which likely impacts the AMT effect.

While the Magnetizer Group, Inc. does not provide any numbers for the strength of the magnetic field of their MTDs, they did provide a data sheet on the magnets used in the device manufacture. These magnets were listed as having nominal properties of residual induction  $B_r = 3900$  Gauss (0.39 Tesla), and coercive force  $H_c = 3200$  Oersteds (255 kA/m)

## **10.0 CONCLUSIONS**

The principal research goals have been met in that some effects of magnetic treatment have been demonstrated and some lines of reasoning, for causal mechanisms, have received support, while others have not. The reliability of much of the results are not as strong as desired, principally due to the broad based approach taken. This level of effort minimized the depth of analysis achievable in a more narrowly focused study. The current research study implies that pursuit of the relative proportions of calcite and aragonite versus magnetic treatment as determined by XRD quantitative analysis is unproductive. Zeta potential appears a somewhat promising approach based both on theoretical considerations and current research results. Particle size distribution results did show a general trend with MTDs installed, however sample collection and analysis would have to be improved to provide more reliable results. The presence of iron in filter-retained residue provided good evidence of a line of research worth pursuing. Iron is both magnetic and known to significantly influence calcium carbonate crystal nucleation and growth.

The impact of flow rate was not effectively examined due to pump operating limitations (actual operation was in a narrower range than pump operating curves indicated). However, flow rate, test duration and water temperature all played a part in determining residue collection. Insufficient residue for XRD examination was collected from tests involving low flow rates, room temperature or short test times. Generally any two of these parameters in combination were sufficient to cause insufficient residue retention. Minor influences were noted due to test length and water temperature. Significant influences were noted due to the presence of magnets and iron. More in depth comments follow.

The maximum change in relative proportions of calcite and aragonite was about 8% for a procedure with an estimated error of about +/- 10%. The change in the relative crystal forms was not consistent with changes in the test parameters. This research did not indicate the relative proportion of calcite as a viable indicator of magnetic water treatment.

Results showed a consistent pattern of higher particle counts for tests with three and six MTDs attached versus particle counts for system tests with one and zero attached MTDs. Data variation, mass balance considerations and unexplained particle count trends versus the number of magnetic devices installed make definitive conclusions difficult. No adequate explanation was found for the increase in particle counts across the entire size spectrum examined for tests with six and three MTDs installed.

The presence of installed magnetic devices did lower the zeta potential, which fosters particle coagulation and flocculation. This may explain the phenomenon of particulate  $\text{CaCO}_3$  settling out in low flow regions of operating systems as reported by a number of field trials. However, the data variation for repeat tests is on the same order as many of the changes measured. This does not lend itself to a great deal of credibility in these particular conclusions for zeta potential. I believe that with some procedural refinements, that this line of research merits continued examination. Particle count distributions would provide a supportive background for this line of research. Particle size increases (accompanied by fewer counts) due to flocculation could easily be tied to reduced zeta potential.

The solid residue removed from the filters for the hot water, longer term tests with higher levels of  $\text{CaCO}_3$  present (all factors known to favor scaling) indicate that at least in a number of repeated tests that these particular magnetic devices did indeed make a difference in the accumulated solid. This was mainly evidenced by the very cohesive residue in the non-magnetically treated system versus the soft paste accumulated in the system with magnetic treatment. Although no long term tests were run to confirm scale reduction - there is evidence that this might be possible. The color in the residue pointed to the presence of a transition metal which XRF analysis evidenced as being tied to iron in this instance. The amount of iron in the residue was tied to the number of magnets attached to the system.

## 11.0 RECOMMENDATIONS

For research pursued using any of the above techniques, concentrated efforts should be made by different individuals to refine each evaluation technique to improve the accuracy and repeatability. The operation of the test systems could be refined slightly, especially in the replacement of fresh water for each individual test. The sampling procedure could be made more exact in the surface planar position and depth of the sampling. Some mid depth (about nine inches below the surface) sampling yielded particle counts from 67% lower to 180% higher than samples taken just below the surface. The much deeper sampling always yielded higher counts than the surface sampling in the smaller size ranges. Review of the Procedures section will yield specific areas within each technique that could be refined. Focusing on fewer test variables and fewer analytical techniques would allow for more test repetition and analytical sampling within time and cost constraints. For more focused testing I recommend the following: 1) Don't test room temperature water, different flow rates or test durations of less than 8 hours. 2) Eliminate crystal phase evaluation (XRD). 3) Combining particle size distribution with zeta potential for one approach or residue and aqueous sample evaluation for consistent changes in elements such as iron as a different approach; each to be pursued at different times or with different personnel.

One line of research that may be worth pursuing is the evaluation of the iron in the water and the solid residue collected in the filters. The residue could be evaluated to determine if the iron was in the form of siderite or iron oxides. AA analysis could be used to determine before and after iron contents in the water. The XRF analysis of solid residue could be compared with a mass balance of the AA results on the liquid samples to confirm iron transition from the colloidal state to potentially scale forming compounds. Additional literature review on crystallography and the effects of impurities on crystal nucleation and growth would be beneficial in this line of study.

It would be very beneficial to locate field studies where the participants feel that magnetic treatment has successfully removed scale and produced a soft, easily removable sludge at a slow flow point in the boiler or cooling tower system. Scale formed on heat transfer surfaces or piping should be sampled, along with the softened sludge and analyzed chemically to characterize the scale (i.e. Sr, Mg, Fe or other scale components) from the two sources. They should especially be evaluated for iron content form (i.e. oxides or carbonates) and concentration. The best source I am aware of for background on real-world scale composition is Cowan and Weintritt, 1974.

I believe a test system should be used to test these MTDs for somewhat longer time periods to look for effects on the solid residue. This likely requires larger pore size filters (or intermittent changing) to prevent premature plugging and would greatly benefit from the addition of automatic temperature control.

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**APPENDIX A**

Test System Photographs And Drawings

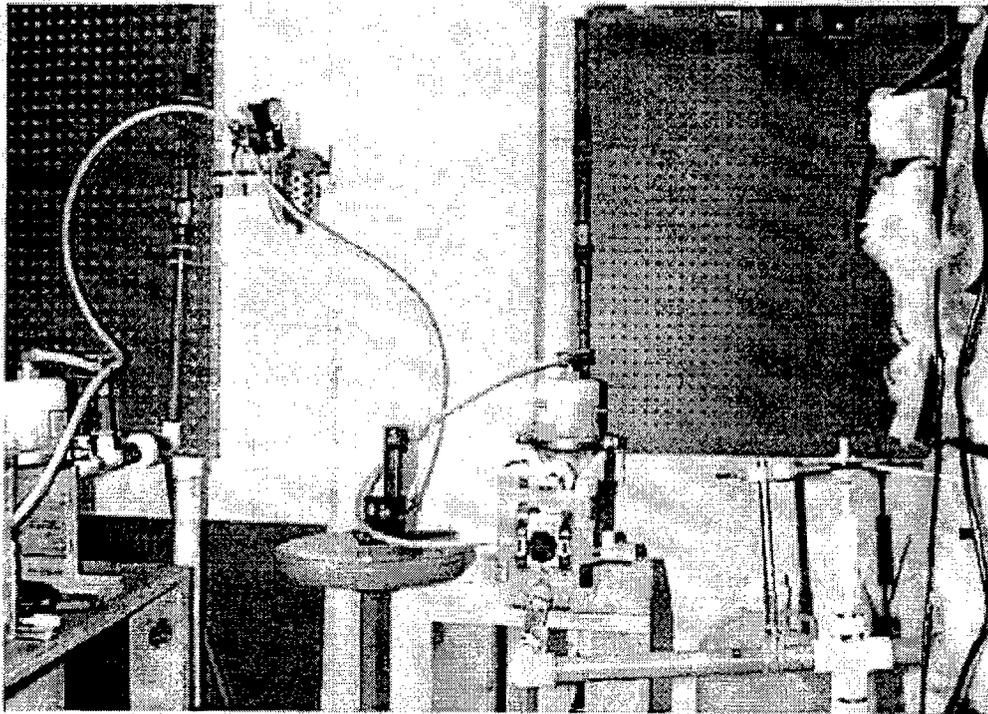


Figure A1 View of air pressure and flow regulators, air driven pump and surge dampener.

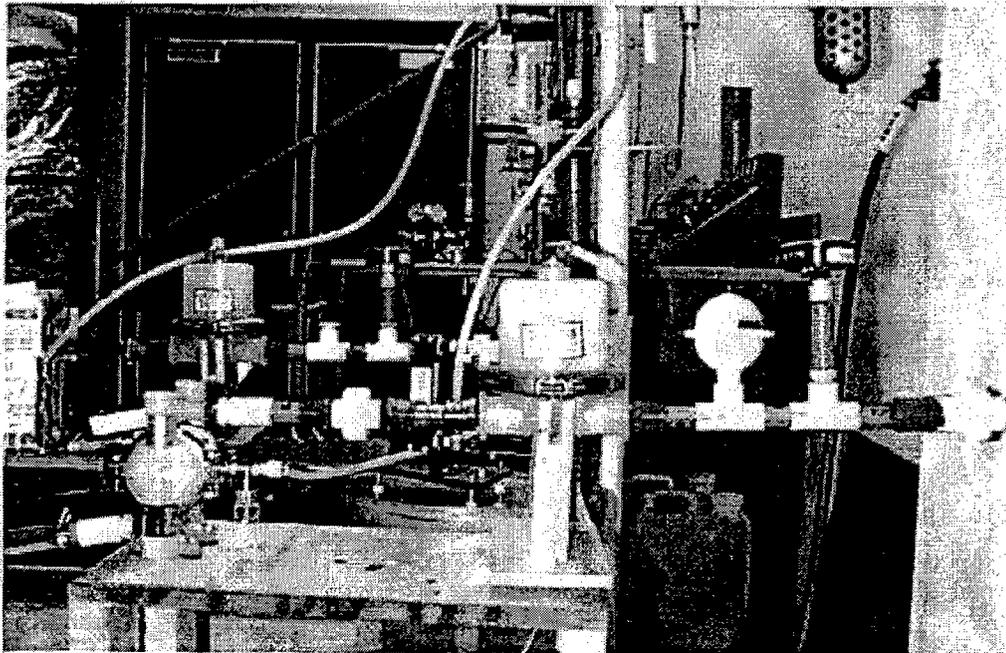


Figure A2 View of air driven diaphragm pump, surge dampener, shock suppressor, pressure gage.

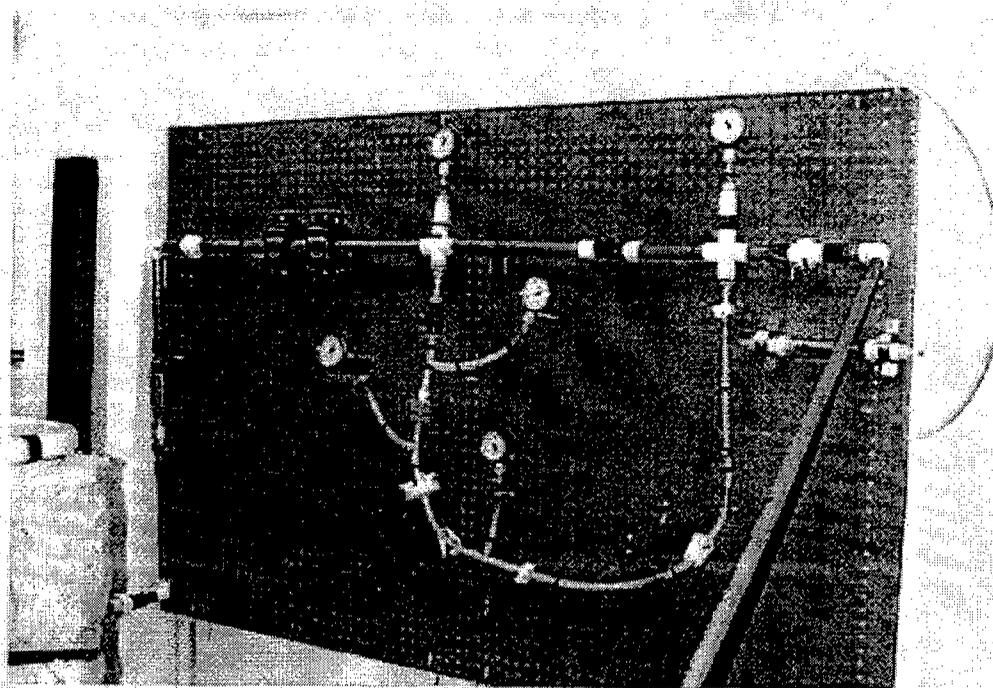


Figure A3 Support frame, MTDs, bypass line with filters, flow meter and pressure gages.

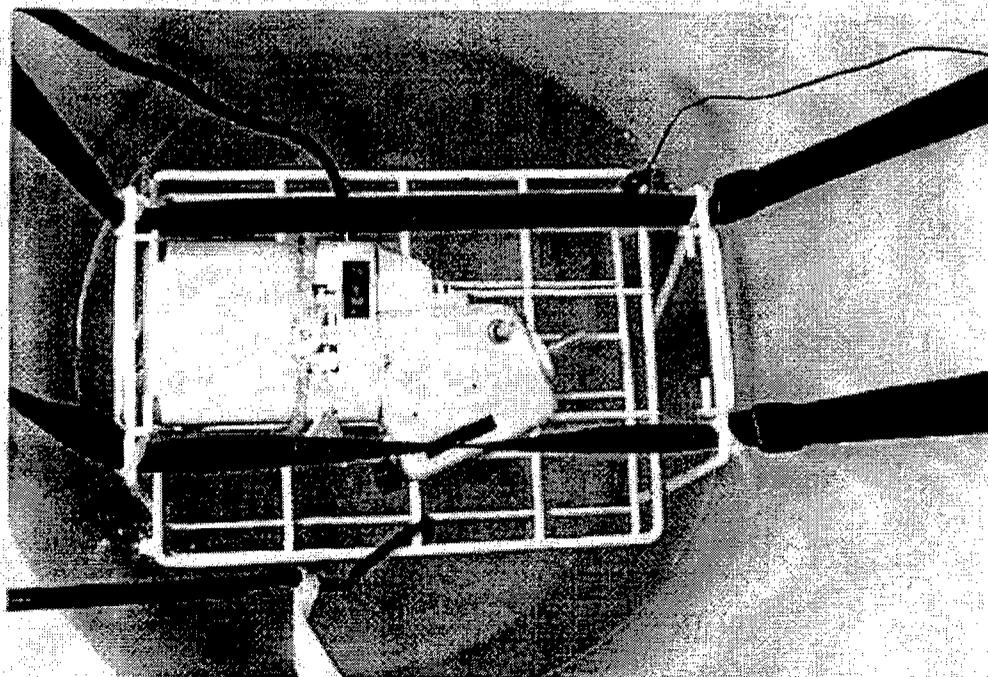
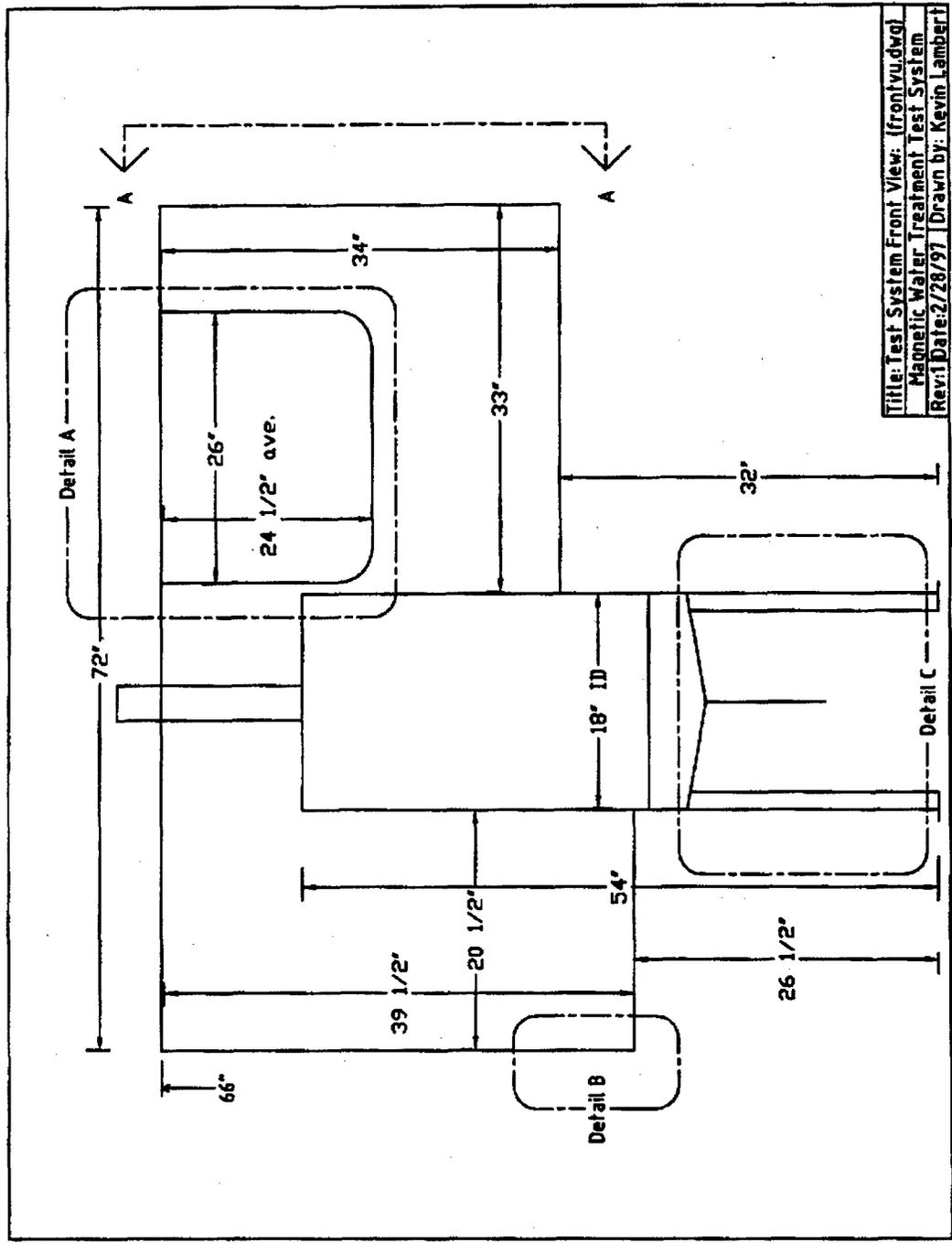


Figure A4 Equipment support rack inside tank with BYU stir motor (later replaced with external motor).

	90 elbow, slip x slip		needle valve, for pipe or tubing		spigot for reservoir
	reducer/adaptor, male thread x slip		stopcock for reservoir		pressure gage
	bulk head fitting for reservoir		union, 1/2 or 3/4 pipe		magnets
	reducing elbow, 1/2 F, thread x 3/4 slip		adapter, slip x female thread		thread connector, male
	tee fitting, slip x slip x slip		adapter, male thread x barb		thread connector, female
	tee fitting, slip x slip x female thread		reducer/adaptor, female thread x slip		adapter, female thread x barb
	tee, barb ends x 3		hose clamp for tubing		endcap
	cross, PVC, slip ends x 4		flow meter, female thread		flow meter, male thread
	reducer, 3/4 thread x 1/2 thread		straight connector, slip x slip		male adapter, thread x slip
	barb reducer, 3/8 x 1/4 or 1/4 x 3/16		filter for tube bypass line		

Title: Symbol Definition (symbols.dwg)  
Magnetic Water Treatment Test System  
Rev:2 Date:2/26/97 | Drawn by: Kevin Lambert

Figure A5 Symbol definition



Title: Test System Front View: (frontvu.dwg)  
 Magnetic Water Treatment Test System  
 Rev:1 Date:2/28/97 | Drawn by: Kevin Lambert

Figure A6 Front view

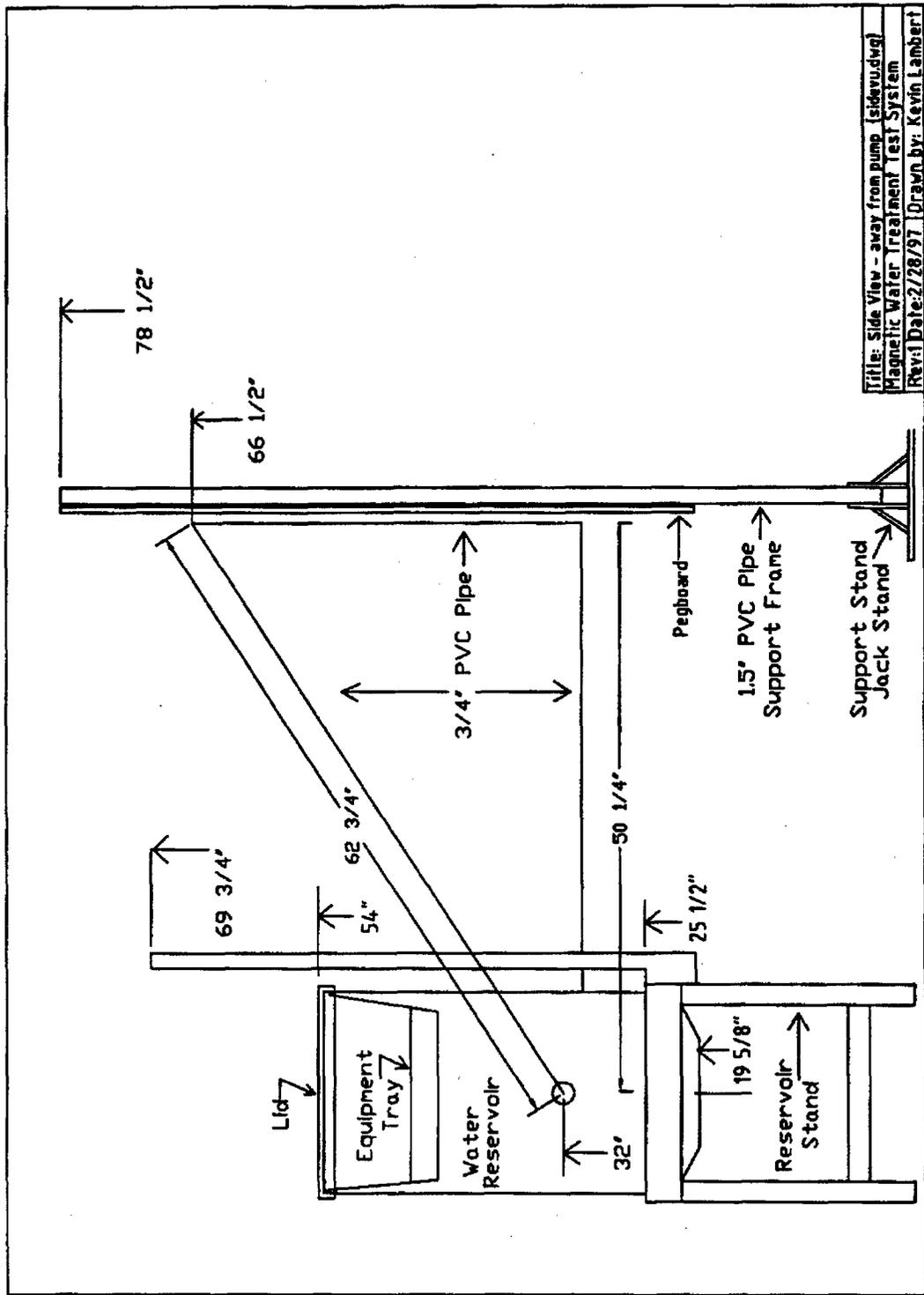


Figure A7 Side view

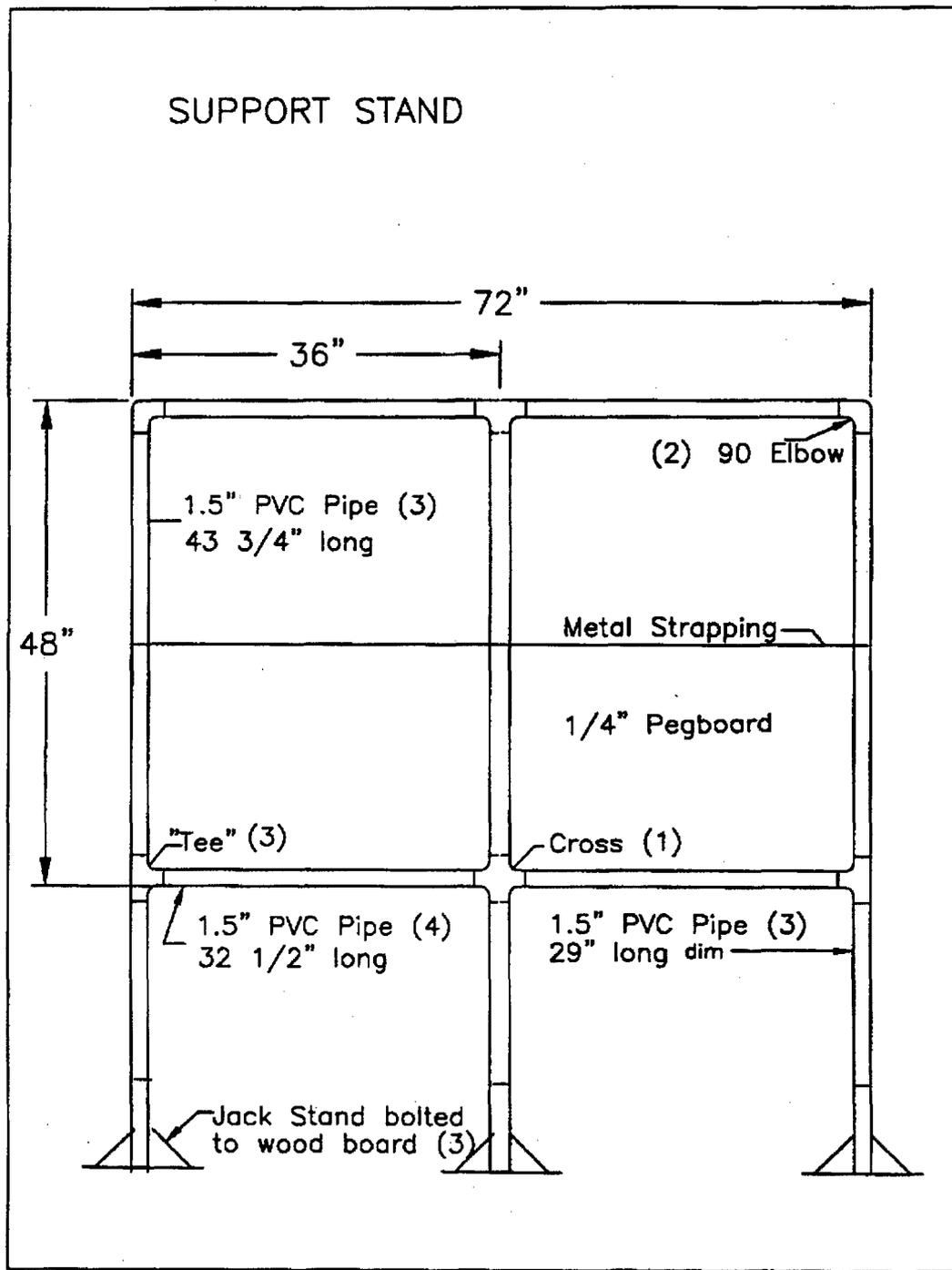


Figure A8 Support stand

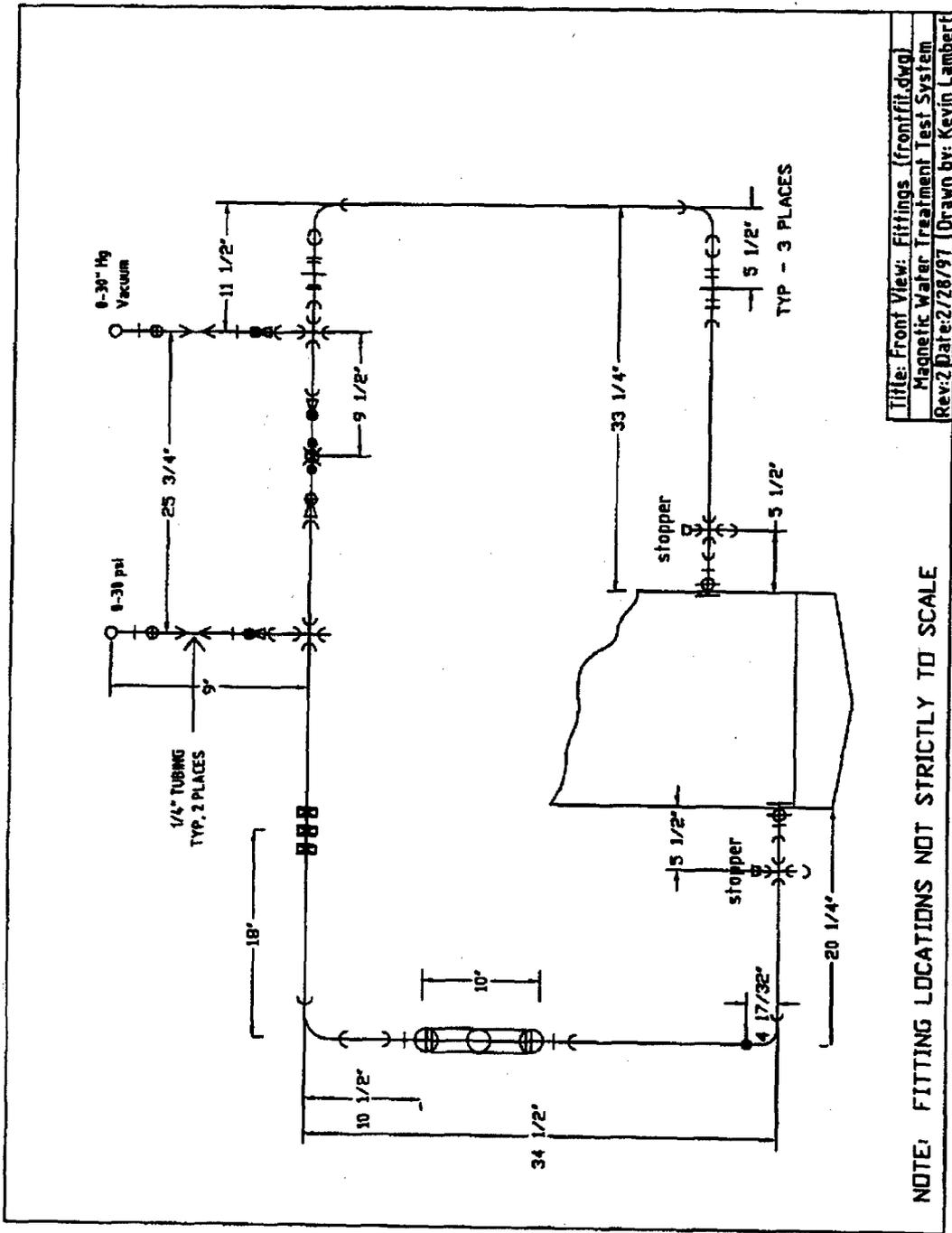


Figure A9 Front view: Fittings



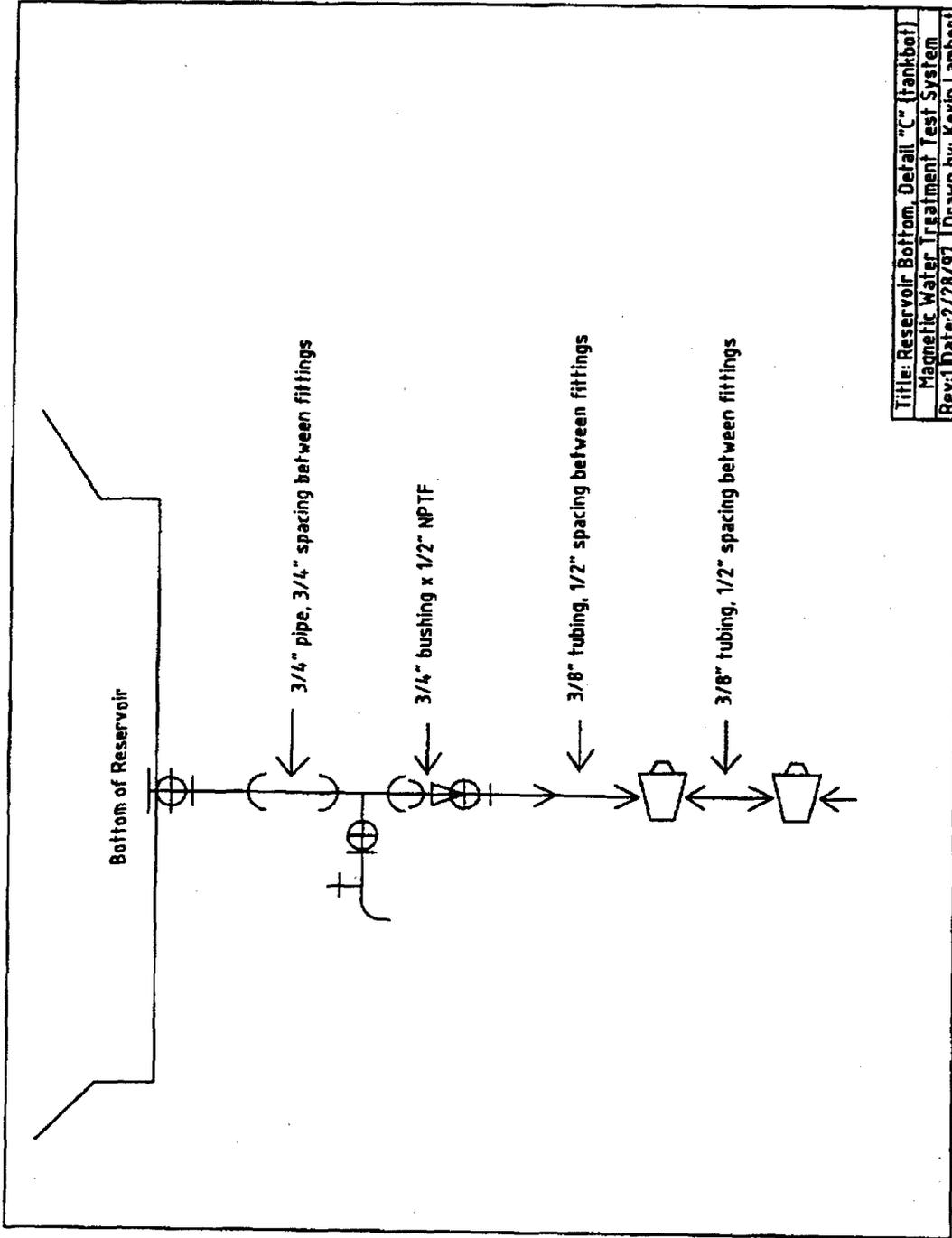


Figure A11 Reservoir bottom detail

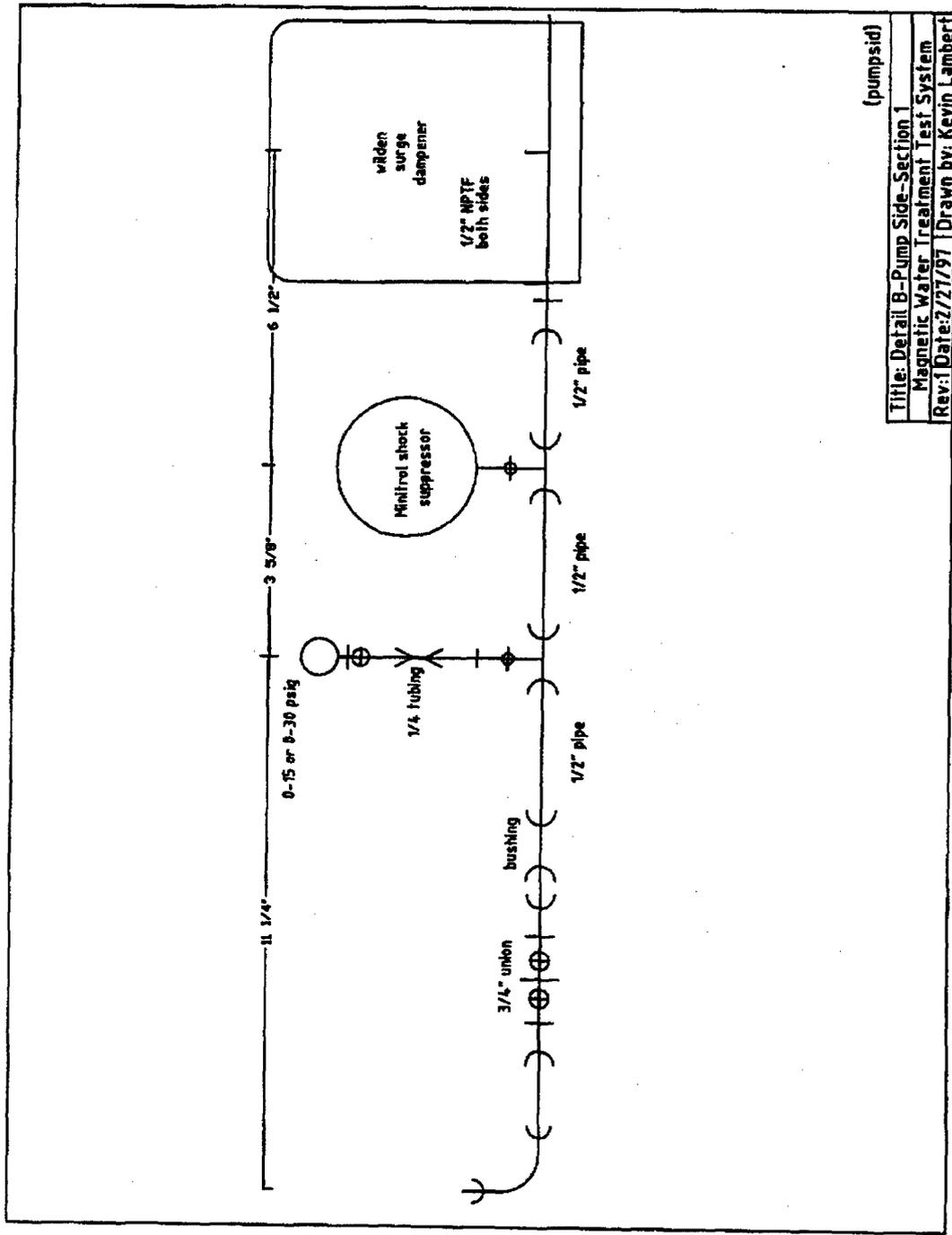
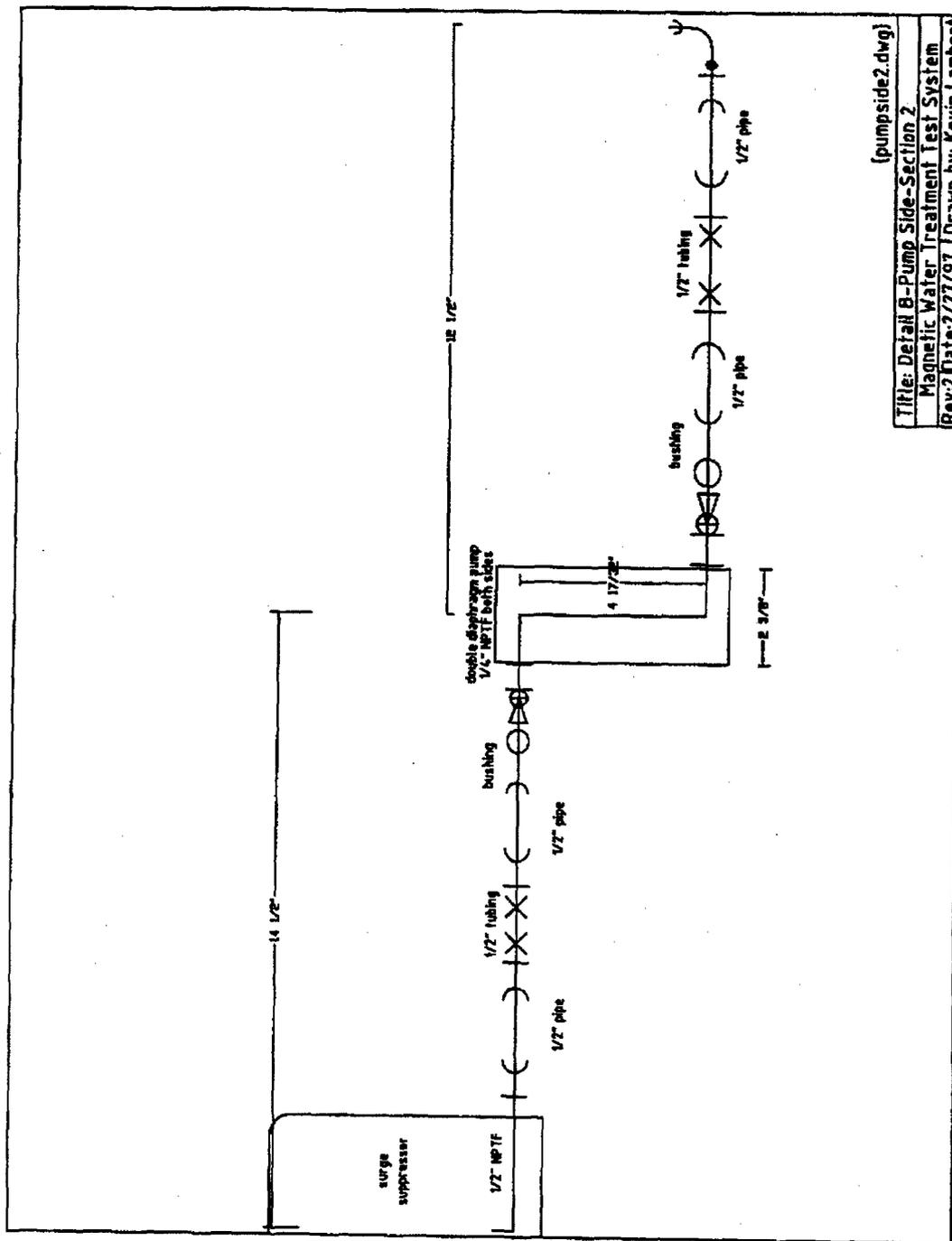


Figure A12 Detail "B" - Pumpsid, Section 1



(pumpsid2.dwg)  
 Title: Detail B-Pump Side-Section 2  
 Magnetic Water Treatment Test System  
 (Rev:2 Date:2/27/97) Drawn by: Kevin Lambert

Figure A13 Detail "B" – Pumpside, Section 2

**APPENDIX B**

**(Miscellaneous Results and Analyses)**

System Test Parameter Summary

Water Chemistry

Provo City's Drinking Water Analysis

Zeta Potential

XRF Results

Water Chemistry Calculations

Results of FIAA Iron Analysis

Filter Residue Mass Recovered

TABLE BI System Test Parameter Summary								
Test	Syst.	Test Time	Number of	Added	Water	Pump		
date	No.	(hrs)	Magnets	CaCO3 (mg/L)	Temp. ( F)	Rate (gpm)	Comments	
1/23/98	1	10	0	75	103-105	3.0	colored residue	
1/23/98	2	10	6	75	104-106	3.0	white paste residue	
1/27/98	1	10 1/2	6	75	96-110	3.0	white paste residue	
1/27/98	2	10 1/2	0	75	94-105	3.0	cohesive, colored residue	
1/29/98	1	4	6	75	103-105	3.0		
1/29/98	2	4	0	75	104-112	3.0		
1/30/98	1	4	3	75	100-112	3.0		
1/30/98	2	4	3	75	99-105	3.0		
1/31/98	1	4	1	75	103-106	3.0		
1/31/98	2	4	1	75	105-115	3.0		
2/2/98	1	4	1	75	104-107	3.0		
2/2/98	2	4	1	75	94-113	3.0	tubing separated, water lost	
2/6/98	1	4 1/4	3	75	103-104	1.0		
2/6/98	2	4 1/4	3	75	104-106	1.0		
2/7/98	1	5	0	75	102-107	1.0		
2/7/98	2	5	0	75	103-109	1.0		
2/9/98	1	9 1/4	0	75	76-77	3.0		
2/9/98	2	9 1/4	0	75	76-77	3.0		
2/10/98	1	9	3	75	74-76	3.0		
2/10/98	2	9	3	75	75-76	3.0		
2/11/98	1	5	3	75	73-74	1.0		
2/11/98	2	5	3	75	73-74	1.0		
2/13/98	1	4 1/4	3	25	100-107	3.0		
2/13/98	2	4 1/4	3	25	103-105	3.0		
2/13/98	1	20	-	25	86-112	2.15	memory effect	
2/13/98	2	19 3/4	-	25	97-113	2.14	memory effect	
2/14/98	1	9	3	25	103-109	3.0		
2/14/98	2	9	3	25	106-107	3.0		
2/15/98	1	41	-	25	103-115	mix/3	memory effect	
2/15/98	2	41	-	25	104-108	mix/3	memory effect	
2/16/98	1	mem. effect test 2/15/98 to 2/16/98						memory effect
2/16/98	2						memory effect	
2/17/98	1	9 1/4	0	25	104-106	3.0		
2/17/98	2	9 1/4	0	25	102-109	3.0		
2/18/98	1	3 3/4	1	25	102-103	3.0		
2/18/98	2	3 3/4	1	25	104-107	3.0		
2/19/98	1	4 1/4	1	25	101-106	1.1		
2/19/98	2	4 1/4	1	25	101-109	1.0		
2/20/98	1	10 1/4	3	75	102-105	3.0		
2/19/98	2	23	0	75	101-112	3.0		
2/20/98	2	this test begun 2/19/98 ended on 2/20/98						
3/31/98	1	10	6	75	100-105	3.0		
3/31/98	2	10	0	75	101-110	3.0		
Note: All these tests used Fluids Lab. hose/tap water							systest3a.xls	

TABLE BI System Test Parameter Summary (cont.)							
Test date	Syst. No.	Test Time (hrs)	Number of Magnets	Added CaCO3 (mg/L)	Water Temp. ( F )	Pump Rate (gpm)	Comments
4/2/98	1	start	-	75	111-117	3.0	memory effect
4/2/98	2	start	-	75	113-115	3.0	memory effect
4/3/98	1	end	-	75	102	3.0	memory effect, 28 hours
4/3/98	2	end	-	75	107	3.0	memory effect, 28 hours
4/4/98	1	10	3	75	99-101	3.0	
4/4/98	2	10	0	75	102-104	3.0	
4/7/98	1	10	1	75	105-110	3.0	
4/7/98	2	10	3	75	104-110	3.0	
4/10/98	1	10	0	75	107-111	3.0	
4/10/98	2	10	6	75	107-111	3.0	
4/11/98	1	midpt	-	75	111	3.0	memory effect, 23.5 hours
4/11/98	2	midpt	-	75	107-111	3.0	memory effect, 23.5 hours
4/13/98	1	end	-	75	118	3.0	memory effect, 72 hours
4/13/98	2	end	-	75	109-116	3.0	memory effect, 72 hours
4/17/98	1	10 1/3	0	75	105-107	3.0	
4/17/98	2	10 1/3	1	75	105-108	3.0	
Note: All these tests used Fluids Lab. hose/tap water							systest3a.xls

TABLE B2 Water Chemistry - Hardness, Alkalinity and pH								sheet 1	
Test date	Syst. No.	No. of Magnets	Added CaCO3 (mg/L)	Sys. Test Temp. ( F )	Alkalinity (mg/L as CaCO3)	Calcium	Total	pH	Comments
						Hardness	Hardness		
11/21/97	1	6	filter*	104	25	19	19	-	after
11/21/97	2	0	filter*	103	25	19.7	20.3	-	after
12/11/97	1	0	filter*	104	35	26.2	26.7	-	after
12/11/97	2	6	filter*	104	30	26.1	26.6	-	after
12/23/97	1	0	filter*	104	35-40	31	-	8.3	start
12/23/97	2	-	filter*	-	35-40	29	-	-	start
1/24/98	1	0	75	104	150-155	29	160	8.8	end
1/24/98	2	6	75	105	165-170	114	184	9.1	end
1/27/98	1	6	75	103	140-150	82	137	8.8	start
1/27/98	2	0	75	100	160	100	157	9.1	start
1/27/98	1	6	75	103	115-120	77	160	8.8	end
1/27/98	2	0	75	100	135-140	116	144	8.8	end
1/29/98	1	6	75	104	115	<50	163	8.95	start
1/29/98	2	0	75	108	100-105	64	119	9	start
1/29/98	1	6	75	104	100-105	47	108	8.95	end
1/29/98	2	0	75	108	105	62	117	9	end
1/30/98	1	3	75	106	95	83	106	9.1	start
1/30/98	2	3	75	102	100	50	117	8.9	start
1/30/98	1	3	75	106	95	<=40	103	9	end
1/30/98	2	3	75	102	100	62	113-114	8.9	end
1/31/98	1	1	75	104	90	63	102	9.15	start
1/31/98	2	1	75	110	100	52	107	9.3	start
1/31/98	1	1	75	104	80	44	101	9.1	end
1/31/98	2	1	75	110	90-95	46	111	9.2	end
2/2/98	1	1	75	106	85	74	103-104	9.1	start
2/2/98	2	1	75	104	110	48	111	9.2	start
2/2/98	1	1	75	106	90-95	69	101	-	end
2/2/98	2	1	75	104	110	73	131	9.1	end
2/6/98	1	3	75	104	-	-	-	8.9	start
2/6/98	2	3	75	105	-	-	-	8.95	start
2/6/98	1	3	75	104	95	44	108	9.1	start
2/6/98	2	3	75	105	125	78	133	-	start
2/7/98	1	0	75	104	-	-	-	9.2	start
2/7/98	2	0	75	106	-	-	-	9.1	start
2/7/98	1	0	75	104	90	59	105	9	end
2/7/98	2	0	75	106	105	57-58	131	9	end
2/9/98	1	0	75	76	-	-	-	9	start
2/9/98	2	0	75	76	-	-	-	9	start
2/9/98	1	0	75	76	85-90	51	106	8.85	end
2/9/98	2	0	75	76	100-105	60-62	118-120	8.85	end
2/10/98	1	3	75	75	-	-	-	8.8	start
2/10/98	2	3	75	76	-	-	-	8.8	start
2/10/98	1	3	75	75	95	40-45	136	8.6	end
2/10/98	2	3	75	76	110	71	129	8.8	end

\*Note: Filter = ultrapure water from lab unit without added CaCO3

TABLE B2 Water Chemistry - Hardness, Alkalinity and pH (cont.)									sheet 2
Test date	Syst. No.	Number of Magnets	Added CaCO3 (mg/L)	Sys.test Temp. ( F )	Alkalinity (mg/L as CaCO3)	Calcium Hardness	Total Hardness	pH	Comments
2/11/98	1	3	75	74	-	-	-	8.6	start
2/11/98	2	3	75	74	-	-	-	8.75	start
2/11/98	1	3	75	74	90	<=35	107	8.55	end
2/11/98	2	3	75	74	110	71	126	8.7	end
2/13/98	1	3	25	104	-	-	-	8.5	start
2/13/98	2	3	25	104	-	-	-	8.6	start
2/13/98	1	3	25	104	160-165	116	170	8.7	start
2/13/98	2	3	25	104	160	117	176	8.55	start
2/14/98	taken from Fluids Lab hose				155	121-122	177-179	-	-
2/14/98	1	0	25	99	-	-	-	8.7	start
2/14/98	2	0	25	105	-	-	-	8.3	start
2/14/98	1	0	25	99	150	107-110	168-169	9.0	end
2/14/98	2	0	25	105	155	100-101	177	9.0	end
2/15/98	1	3	25	106	-	-	-	8.85	start
2/15/98	2	3	25	106	-	-	-	9.0	start
2/15/98	1	3	25	106	130	73-75	145	8.55	end
2/15/98	2	3	25	106	135	96-97	148	8.5	end
2/16/98	1	0	25	109	-	-	-	8.9	start
2/16/98	2	0	25	112	-	-	-	8.8	start
2/16/98	1	0	25	109	85	<=39	110	8.7	end
2/16/98	2	0	25	112	100	56-58	114	8.55	end
2/17/98	1	0	25	105	-	-	-	8.9	start
2/17/98	2	0	25	106	-	-	-	8.8	start
2/17/98	1	0	25	105	75	71-72	103	9.0	end
2/17/98	2	0	25	106	90	42-44	107	8.85	end
2/18/98	1	1	25	102	-	-	-	9.0	start
2/18/98	2	1	25	105	-	-	-	9.0	start
2/18/98	1	1	25	102	85	39	105	9.0	end
2/18/98	2	1	25	105	90	50	110	9.0	end
2/20/98	1	3	75	104	-	-	-	8.8	start
2/20/98	2	0	75	106	-	-	-	8.5	start
2/20/98	1	3	75	104	135	93	161	8.5	end
2/20/98	2	0	75	106	130-135	100-101	150-152	8.5	end
3/31/98	1	6	75	102	170	94-96	177-178	9.2	start
3/31/98	2	0	75	106	160	116	165-170	8.8	start
3/31/98	1	6	75	102	-	-	-	8.6	end
3/31/98	2	0	75	106	-	-	-	8.55	end
NOTES:									
Data ranges listed due to questionable titration endpoint in a number of instances.									
Average system tank water temperature is listed. For temperature range see									
System Test Summary table in appendix.									

TABLE B2 Water Chemistry - Hardness, Alkalinity and pH (cont.)								sheet 3	
Test date	Syst. No.	Number of Magnets	Added CaCO3 (mg/L)	Sys.test Temp. ( F )	Alkalinity (mg/L as CaCO3)	Calcium Hardness	Total Hardness	pH	Comments
4/4/98	1	3	75	100	90	32-40	108	8.9	start
4/4/98	2	0	75	103	95	58-59	114-115	8.6	start
4/4/98	1	3	75	100	-	-	-	8.9	end
4/4/98	2	0	75	103	-	-	-	8.6	end
4/7/98	1	1	75	108	90	39-49**	110	9.0	start
4/7/98	2	3	75	107	90-95	41	102	9.0	start
4/7/98	1	1	75	108	-	-	-	9.0	end
4/7/98	2	3	75	107	-	-	-	9.0	end
4/10/98	1	0	75	109	75	32	94	9.0	start
4/10/98	2	6	75	109	80	37	98	9.1	start
4/10/98	1	0	75	109	-	-	-	9.0	end
4/10/98	2	6	75	109	-	-	-	9.0	end
4/17/98	1	0	75	106	75-80	***	92	9.2	start
4/17/98	2	1	75	106	75-80	<50****	92	9.15	start
4/17/98	1	0	75	106	-	-	-	9.1	end
4/17/98	2	1	75	106	-	-	-	9.05	end
NOTES:									
***39 is certain minimum, 49 is questionable due to digital titrator problem									
****titrant cartridge emptied before color change was reached									
*****overshot color change significantly during titration									
pH reading occasionally continued to fluctuate, in which case the average value is listed									
6/6/98, chemistr3.xls,sht 1									

TABLE B3 Provo City's Drinking Water Analysis

1997

**WITH STATE OF UTAH AND EPA  
SAFE DRINKING WATER STANDARDS**

	PROVO WATER	STATE OF UTAH	EPA
<b>Inorganic Chemicals (ppm)</b>	<b>(AVERAGE)</b>	<b>STANDARD</b>	<b>STANDARD</b>
ANTIMONY	<0.003	0.006	0.006
ARSENIC	<0.005	0.05	0.05
BARIUM	0.052	2.0	2.0
BERYLLIUM	<0.001	0.004	0.004
CADMIUM	<0.001	0.005	0.005
CHROMIUM	<0.005	0.1	0.1
COPPER	0.119	1.0	1.3
CYANIDE	<0.05	0.2	0.2
FLUORIDE	0.139	4.0	4.0
LEAD	<0.004	0.015	0.015
MERCURY	<0.0002	0.002	0.002
NICKEL	<0.010	0.1	0.1
NITRATE (TOTAL)	0.37	10.0	10.0
SELENIUM	<0.002	0.05	0.05
SODIUM	9.4	NS	NS
SULFATE	38.5	250	1000
THALLIUM	<0.001	0.002	0.002
TOTAL DISSOLVED SOLIDS	241	500	500
Microbial (Coliform Bacteria)	No Violations	ABSENCE	ABSENCE
Radiologic Chemicals	No Violations		
Pesticide/PCB/SOC Contaminants (33)	No Violations		
Volatile Organic Contaminants (21)	No Violations		
Total Trihalomethanes (ppb)	3.9	100	100
Physical Characteristics			
ALKALINITY (ppm)	208	NS	NS
HARDNESS (ppm) Total <sup>(winter)</sup> (150-200)	* 210	NS	NS
pH	7.5-8.0	6.5-8.5	6.5-8.5
TURBIDITY (NTU)	<0.5	5.0	5.0
Abbreviations			
ppm = parts per million	NTU = Turbidity Units	NS = No Standard	
	ppb = parts per billion		

IRON (ppb) 10 - 23 (data from previous years)  
 MAGNESIUM (ppm) 13 - 33 (data from previous years)  
 ZINC (ppb) < 20 (detect limit)  
 Sr, Si no results

TABLE B4 Zeta Potential Results For System Tests													sheet 1
Test date	Sys. No.	# of Mag. nets	Average Specific Conductivity	Start, End, or Memory	Zeta Potent. ave. (mV)	Zeta Pot.-std. dev. (mV)	sample temp. (F)	Temp. correction factor	Zeta Potential	Comments			
1/27/98	1	6	298	End	-22.0	>5.84	73.4	0.99	-21.8	2 sets of 12 counts			
1/27/98	2	0	330	End	-22.4	>5.34	73.4	0.99	-22.2	2 sets of 11 counts			
1/29/98	1	6	266	End	-20.2	5.56	78.8	0.94	-19.0	42 counts			
1/29/98	2	0	274	End	-20.1	5.19	76.1	0.965	-19.4	45 counts			
1/30/98	1	3	250	End	-21.8	5.12	82	0.904	-19.7	rest are >= 48 counts			
1/30/98	2	3	271	End	-22.2	5.12	81	0.918	-20.4				
1/31/98	1	1	239	End	-20.7	5.31	76	0.966	-20.0				
1/31/98	2	1	252	End	-19.8	3.95	76	0.966	-19.1				
2/2/98	1	1	246	End	-22.7	5.34	78	0.948	-21.5				
2/2/98	2	1	294	End	-21.2	4.59	77.5	0.954	-20.2				
2/6/98	1	3	266	End	-22.3	5.59	87	0.864	-19.3				
2/6/98	2	3	320	End	-20.7	7.09	85	0.882	-18.3	35 counts			
2/7/98	1	0	245	End	-19.5	4.81	75	0.972	-19.0				
2/7/98	2	0	284	End	-20.4	4.81	75.5	0.968	-19.7				
2/9/98	1	0	248	End	-23.0	7.75	75.5	0.968	-22.3				
2/9/98	2	0	272	End	-23.1	11.43	75.5	0.968	-22.4				
2/10/98	1	3	253	End	-22.3	3.89	75.5	0.968	-21.6				
2/10/98	2	3	272	End	-20.0	6.66	75.5	0.968	-19.4				
2/11/98	1	3	256	End	-20.2	5.31	73	0.994	-20.1				
2/11/98	2	3	274	End	-20.3	4.72	73	0.994	-20.2				
2/13/98	1	3	368	End	-18.8	4	72	1.008	-19.0				
2/13/98	2	3	364	End	-18.5	8.06	71.5	1.012	-18.7				
2/14/98	1	0	361	End	-20.8	5.44	76	0.966	-20.1	memory effect			
2/14/98	2	0	364	End	-18.6	8.37	76	0.966	-18.0	memory effect			
2/14/98	1	3	317	End	-19.1	12.31	79.5	0.932	-17.8				
2/14/98	2	3	340	End	-18.1	15.37	78	0.948	-17.2				

TABLE B4 Zeta Potential Results For System Tests (cont.)													sheet 2
Test date	Sys. No.	# of Mag. neils	Average Specific Conductivity micromhos/cm	Start, End, or Memory Test		Zeta Potent. ave. (mV)	Zeta Pot.-std. dev. (mV)	sample temp. (F)	Temp. correction factor	Zeta Potential	Comments		
				Zeta Potent. ave. (mV)	Zeta Pot.-std. dev. (mV)								
2/16/98	1	0	252	End	End	-20.9	5.84	81	0.916	-19.1	memory effect		
2/16/98	2	0	262	End	End	-21.6	10.12	79.5	0.932	-20.1	memory effect		
2/17/98	1	0	240	End	End	-21.8	7.41	78	0.948	-20.7			
2/17/98	2	0	254	End	End	-22.7	15.43	77.5	0.954	-21.7			
2/18/98	1	1	242	End	End	-19.2	5.59	81	0.918	-17.6			
2/18/98	2	1	250	End	End	-19.0	10	78	0.948	-18.0			
2/19/98	1	1	238	End	End	-19.0	5.16	78	0.948	-18.0			
2/19/98	2	1	244	End	End	-23.1	4.91	77.5	0.954	-22.0			
2/20/98	1	3	328	End	End	-18.5	4.12	79	0.937	-17.3			
2/20/98	2	0	330	End	End	-23.2	>13.4	79	0.937	-21.7			
3/31/98	1	6	384	Start	Start	-18.2	4.62	79.5	0.932	-17.0	69 counts		
3/31/98	2	0	381	Start	Start	-21.2	8.06	78.5	0.943	-20.0			
4/1/98	1	6	334	End	End	-17.9	5.97	76	0.966	-17.3			
4/1/98	2	0	352	End	End	-21.2	9.3	76	0.966	-20.5			
4/1/98	1	6	326	Memory	Memory	-18.9	4.25	77.5	0.954	-18.0			
4/1/98	2	0	344	Memory	Memory	-23.8	7.66	77	0.958	-22.8			
4/2/98	1	6	282	Memory	Memory	-17.9	5.12	76	0.966	-17.3			
4/2/98	2	0	312	Memory	Memory	-18.8	14.4	76	0.966	-18.2			
4/3/98	1	6	267	Memory	Memory	-19.0	5.91	79.5	0.932	-17.7			
4/3/98	2	0	286	Memory	Memory	-18.8	5.87	79	0.987	-18.6			
4/4/98	1	3	250	Start	Start	-19.9	12.06	77	0.958	-19.1			
4/4/98	2	0	266	Start	Start	-20.3	4.28	78	0.948	-19.2			
4/4/98	1	3	244	End	End	-20.0	5.69	78.5	0.943	-18.9			
4/4/98	2	0	264	End	End	-18.6	5.84	78	0.948	-17.6			
4/7/98	1	1	240	Start	Start	-19.3	5.12	76.5	0.962	-18.6			
4/7/98	2	3	245	Start	Start	-20.1	3.39	77.5	0.954	-19.2			
4/7/98	1	1	241	End	End	-21.5	4.34	78.5	0.943	-20.3			
4/7/98	2	3	247	End	End	-22.3	3.81	79.5	0.932	-20.8	49 counts		

TABLE B4 Zeta Potential Results For System Tests (cont.)													sheet 3
Test date	Sys. No.	Mag. nets	Average Specific Conductivity micromhos/cm	Start, End, or Memory	Zeta Potent. ave.(mV)	Zeta Pot.-std. dev.(mV)	sample temp. (F)	Temp. correction factor	Zeta Potential	Comments			
4/10/98	1	0	233	Start	-19.1	4.47	77	0.958	-18.3				
4/10/98	2	6	238	Start	-19.7	4.22	77	0.958	-18.9				
4/10/98	1	0	238	End	-20.4	7.03	79	0.937	-19.1				
4/10/98	2	6	247	End	-22.8	14.87	80	0.927	-21.1				
4/11/98	1	0	233	Memory	-20.9	7.19	77	0.958	-20.0				
4/11/98	2	6	243	Memory	-19	5.81	78	0.948	-18.0				
4/13/98	1	0	228	Memory	-19.2	6.06	77	0.958	-18.4				
4/13/98	2	6	232	Memory	-20.4	3.83	77	0.958	-19.5				
4/17/98	1	0	232	Start	-21.9	6.06	78	0.948	-20.8				
4/17/98	2	1	241	Start	-19.2	6.19	79.5	0.932	-17.9				
4/17/98	1	0	232	End	-20.1	5.03	77.5	0.954	-19.2				
4/17/98	2	1	237	End	-16.8	3.83	78	0.948	-15.9				
NOTES:													
1) The 6x scale was used on the ocular (eyepiece) scale.													
2) Kfactor tests at 66-67													
3) Tracking time for good results should be > or = 2.5 sec													
4) Water source for all these tests was the hose in the fluids lab.													
5) Zeta potential corrected to 22.5 degree C													
6) Ct= temperature correction factor interpolated from Zeta-Meter manual.													
7) Spec. conductivity gradually decreasing with or w/o CaCO3 added, no consistent pattern after 4/1 - 4/3 tests													
8) Particle counts are 50 unless otherwise noted.													
9) No consistent trend for system 1 or 2 for memory effect													
											zetaipot5.xls		

TABLE B5 Zeta Meter Readings for Different Source Waters

Source water description	specific conductivity (micromhos/cm)	Voltage used (V)	sample counts	zeta potential (mV)	
				ave.	std. Dev.
calibration sample,11/4/97	228	300	12	-51.5	6.16
calibration sample,11/4/97	228	150	11	-44.5	3.53
calibration sample,12/8/97	221	150	12	-47.6	4.72
Filtered,200 mg/L CaCO3	13	300	11	-20.7	9.12
D.I., 200 mg/L CaCO3	12	200	9	-24.1	7.62
Reg.tap, 200mg/L CaCO3	360	200	11	-26.8	3.58
Distilled, 200mg/L CaCO3	13.5	300	10	-28.7	5.12
Distilled, 200mg/L CaCO3	13.5	200	6	-32.4	9.94
Filtered, 50 mg/L CaCO3	12.5	150	7	-30.9	7.81
D.I., 50 mg/L CaCO3	15	200	8	-29.3	15.2
Reg.tap, 50 mg/L CaCO3	333	200	12	-24.4	2.64
Distilled, 50 mg/L CaCO3	15.9	200	4	-32.6	7.5
Filtered,200 mg/L CaCO3	30.9	300	13	-20.9	5.34
D.I., 200 mg/L CaCO3	18.2	200	10	-26.3	5.72
Reg.tap, 200mg/L CaCO3	343	200	11	-25.7	5.22
Distilled, 200mg/L CaCO3	15.9	200	5	-48.5	13.37
Filtered, 50 mg/L CaCO3	28.6	150	12	-36.4	6.09
D.I., 50 mg/L CaCO3	20.3	200	11	-33.9	9.12
Reg.tap, 50 mg/L CaCO3	336	200	11	-32.3	3.84
Distilled, 50 mg/L CaCO3	17.5	200	4	-55.7	25.74
Filtered,50mg/L; Min-U-Sil	18	100	10	-72	7.5
D.I., 50 mg/L; Min-U-Sil	21	75	12	-90.3	5.53
Distilled,50mg/L;Min-U-Sil	20.1	75	16	-111	7.06

NOTES:  
 1. Zeta-Meter readings taken 1/9/98  
 2. The concentration of CaCO3 added to the water listed under "description" above represents a rough range of CaCO3 added to the samples. 50 represents a range of 50 - 80 mg/L, 200 represents a range of 200 - 250 mg/L of added CaCO3.

sourcwat.xls

TABLE B6 XRF Results For Filter Residues

Sample	Test date	Syst. No.	Number of Magnets	Added CaCO3 (mg/L)	Flow (gpm)	Test Time (hrs)	Fe (cps)	Zn (cps)	Sr (cps)	Cu (cps)	Pb (cps)	Mg (cps)
Batch 1 XRF Analysis Date 2/5/98												
1-1		chelometric std					280	ND	839	373	309	Tr
1-2	1/23/98	1	0	75	3	10	1010	13768	826	Tr	551	319
1-3	1/27/98	2	0	75	3	10.5	3645	13738	2056	654	654	805
1-4	1/27/98	1	6	75	3	10.5	595	2082	7336	397	Tr	Tr
1-5	1/29/98	2	0	75	3	4	970	2716	7953	Tr	388	685
1-6	1/29/98	1	6	75	3	4	494	1086	6515	Tr	Tr	Tr
1-7	1/30/98	2	3	75	3	4	749	1310	6550	374	Tr	446
1-8	1/30/98	1	3	75	3	4	387	678	5034	Tr	Tr	Tr
1-9	2/2/98	1	1	75	3	4	463	556	1668	Tr	Tr	Tr
1-10	2/2/98	2	1	75	3	4	911	1731	2824	364	Tr	328
Batch 2 XRF Analysis Date 3/4/98												
2-1		chelometric std					315	302	610	<300	ND	ND
2-2	2/20/98	1	3	75	3	10	613	4931	3766	<600	ND	150
2-3	2/20/98	2	0	75	3	23	1381	7954	5242	<700	Tr	242
2-4	2/17/98	1	0	25	3	9.25	341	1117	3530	<400	Tr	144
2-5	2/13/98	1	0	25	3	20	1738	3125	1489	Tr	Tr	190
2-6	2/10/98	1	3	75	3	9	456	744	1455	400-500	Tr	166
2-7	2/9/98	1	0	75	3	9	516	1021	2783	~500	ND	141
Notes: 1) ND=non-detect 2) Tr=trace (barely above background noise, generally 100-300 cps) 4) Batch 2 data for Cu was only noted roughly relative to Fe as Cu presence was mainly attributed to the XRF machine. 3) cps= counts per second xrfcomp.xls												

TABLE B7. Water Chemistry Calculations

Test Date	Syst. No.	Alkalinity (mg/L as CaCO3)	Calcium Hardness (mg/L as CaCO3)	Total Hardness	Test Sample Time	alkalinity to Ca hardness ratio	alkalinity to total hardness ratio	Calcium hardness start to end ratio	alkalinity start to end ratio	Calcium hardness start to end ratio	total hardness start to end ratio
1/23/98	1	38	30.5	NA	start	1.25	NA	NA			
1/23/98	2	38	29	NA	start	1.31	NA	NA			
1/23/98	1	152	98	160	end	1.55	0.95	0.61	0.25	0.31	N/A
1/23/98	2	168	114	184	end	1.47	0.91	0.82	0.23	0.25	N/A
1/27/98	1	145	82	137	start	1.77	1.06	0.60			
1/27/98	2	160	100	157	start	1.60	1.02	0.64			
1/27/98	1	118	77	160	end	1.53	0.74	0.48	1.23	1.06	0.86
1/27/98	2	138	116	144	end	1.19	0.96	0.81	1.16	0.86	1.09
1/29/98	1	115	48	163	start	2.40	0.71	0.29			
1/29/98	2	102	64	119	start	1.59	0.86	0.54			
1/29/98	1	102	47	108	end	2.17	0.94	0.44	1.13	1.02	1.51
1/29/98	2	105	62	117	end	1.69	0.90	0.53	0.97	1.03	1.02
1/30/98	1	95	83	106	start	1.14	0.90	0.78			
1/30/98	2	100	50	117	start	2.00	0.85	0.43			
1/30/98	1	95	39	103	end	2.44	0.92	0.38	1.00	2.13	1.03
1/30/98	2	100	62	114	end	1.61	0.88	0.54	1.00	0.81	1.03
1/31/98	1	90	63	102	start	1.43	0.88	0.62			
1/31/98	2	100	52	107	start	1.92	0.93	0.49			
1/31/98	1	80	44	101	end	1.82	0.79	0.44	1.13	1.43	1.01
1/31/98	2	92	46	111	end	2.00	0.83	0.41	1.09	1.13	0.96
2/2/98	1	85	74	104	start	1.15	0.82	0.71			
2/2/98	2	110	48	111	start	2.29	0.99	0.43			
2/2/98	1	92	69	101	end	1.33	0.91	0.68	0.92	1.07	1.03
2/2/98	2	110	73	131	end	1.51	0.84	0.56	1.00	0.66	0.85
2/6/98	1	95	44	108	start	2.16	0.88	0.41	NA	NA	NA
2/6/98	2	125	78	133	start	1.60	0.94	0.59	NA	NA	NA
2/7/98	1	90	59	105	end	1.53	0.86	0.56	NA	NA	NA
2/7/98	2	105	58	131	end	1.81	0.80	0.44	NA	NA	NA

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TABLE B7 Water Chemistry Calculations (cont.)

Test Date	Syst. No.	Alkalinity (mg/L as CaCO3)	Calcium Hardness (mg/L as CaCO3)	Total Hardness	Test Sample Time	alkalinity to Ca hardness ratio	alkalinity to total hardness ratio	Calcium hardness to total hard. ratio	alkalinity start to end ratio	Calcium hardness start to end ratio	total hardness start to end ratio
2/9/98	1	88	51	106	end	1.73	0.83	0.48	NA	NA	NA
2/9/98	2	102	61	119	end	1.67	0.86	0.51	NA	NA	NA
2/10/98	1	95	42	136	end	2.26	0.70	0.31	NA	NA	NA
2/10/98	2	110	71	129	end	1.55	0.85	0.55	NA	NA	NA
2/11/98	1	90	35	107	end	2.57	0.84	0.33	NA	NA	NA
2/11/98	2	110	71	126	end	1.55	0.87	0.56	NA	NA	NA
2/13/98	1	162	116	170	start	1.40	0.95	0.68	NA	NA	NA
2/13/98	2	160	117	176	start	1.37	0.91	0.66	NA	NA	NA
2/14/98	1	150	108	169	end	1.39	0.89	0.64	NA	NA	NA
2/14/98	2	155	100	177	end	1.55	0.88	0.56	NA	NA	NA
2/15/98	1	130	74	145	end	1.76	0.90	0.51	NA	NA	NA
2/15/98	2	135	96	148	end	1.41	0.91	0.65	NA	NA	NA
2/14/98	tap	155	122	178	room temp	1.27	0.87	0.69	NA	NA	NA
2/16/98	1	85	39	110	end	2.18	0.77	0.35	NA	NA	NA
2/16/98	2	100	57	114	end	1.75	0.88	0.50	NA	NA	NA
2/17/98	1	75	72	103	end	1.04	0.73	0.70	NA	NA	NA
2/17/98	2	90	43	107	end	2.09	0.84	0.40	NA	NA	NA
2/18/98	1	85	39	105	end	2.18	0.81	0.37	NA	NA	NA
2/18/98	2	90	50	110	end	1.80	0.82	0.45	NA	NA	NA
2/20/98	1	135	93	161	end	1.45	0.84	0.58	NA	NA	NA
2/20/98	2	132	100	151	end	1.32	0.87	0.66	NA	NA	NA
3/31/98	1	170	95	178	start	1.79	0.96	0.53	NA	NA	NA
3/31/98	2	160	116	168	start	1.38	0.95	0.69	NA	NA	NA
4/4/98	1	90	38	108	start	2.37	0.83	0.35	NA	NA	NA
4/4/98	2	95	58	114	start	1.64	0.83	0.51	NA	NA	NA
					average ratio =	1.69	0.87	0.53	0.92	0.98	1.04
					standard deviation =	0.37	0.07	0.12	0.33	0.49	0.18
					% std. deviation =	22.1%	8.4%	23.2%	36.0%	50.4%	17.6%

NOTE: NA = not applicable. These tests were not sampled at both the start and end of the test. chemist1.xls, sht 2

TABLE B8 Results of Flame Ionization Atomic Absorption Iron Analysis

Sample ID # *2	Mean Concn. raw data (ppb) *3	Std. Deviat. raw data (ppb)	Relative Std. Deviation raw data (%)	Sample Concent. Factor *4	Mean Concn. adjusted for conc. factor (ppb) *5
QC ERA 9975*1	432	47	10.9	-	-
A0	69	59	85.5	1	69
A1	103	55	53.8	3.7	27.8
A2	99	45	45.4	14.9	6.6
B0	13	37	285	1	13
B1	-3	43	NA *6	5.3	? *7
B2	150	49	32.7	35.2	4.3
C	10	46	460	5	2
D	16	60	375	7	2.3
E	-1	55	NA	8.7	?
E0	69	50	72.8	1	69
F0	44	48	109	1	44
F1	222	41	18.4	4.5	49.3
F2	225	47	20.8	11	20.5
G0	87	49	56.1	1	87
G1	-12	52	NA	5	?
G2	-14	38	NA	15.1	?
H0	78	56	71.2	1	78
U1	35	48	137	4.1	8.5
U2	94	51	54.4	14.3	6.6
QC ERA 9975*1	426	48	11.2	-	-

NOTES:

Analysis performed by Provo Water Resources Laboratory, run 2/26/98

\*1) External Quality Control Sample, known standard value= 418 ppb with performance acceptance limits = 342-492 ppb.

\*2) Sample ID is as follows:

A0-A2: Hose tap water, 2/13/98, no test system exposure

B0-B2: Hose tap water + 75 mg/L CaCO<sub>3</sub>, 2/25/98, no test system exposure

C: system 1, 1/27/98, tap water + 75mg/L CaCO<sub>3</sub> added, 6 magnets, 3 gpm, 10 1/2 hrs

D: system 1, 1/23/98, tap water + 75mg/L CaCO<sub>3</sub> added, 0 magnets, 3 gpm, 10 hrs

E-E0: system 2, 2/20/98, tap water + 75mg/L CaCO<sub>3</sub> added, 0 magnets, 3 gpm, 23 hrs

F0-F2: system 1, 2/20/98, tap water + 75mg/L CaCO<sub>3</sub>, 3 magnets, 3 gpm, 10 1/4 hrs

G0-G2: system 2, 1/27/98, tap water + 75 mg/L CaCO<sub>3</sub>, 0 magnets, 3 gpm, 10 1/2 hrs

H0: system 2, 1/23/98, tap water + 75mg/L CaCO<sub>3</sub> added, 6 magnets, 3 gpm, 10 hrs

U1-U2: syst.1, 1/27/98 or syst. 2, 2/20/98; bottles were mixed up

\*3) Mean Concentration is the laboratory measured value for samples as submitted

\*4) Sample concentration factor is the ratio of the original volume, before evaporation, to final volume after evaporation.

\*5) The mean concentration adjusted for the concentration factor is mean concentration (raw data) multiplied by the sample concentration factor. This should yield the Fe concentration in the sample prior to evaporation.

\*6) NA - relative standard deviation has no real significance for negative mean values.

\*7) A negative concentration value has no meaning for the aqueous samples.

8) Fe concentration only valid for sample concentration factors = 1

fiaafe.xls

**TABLE B9 Filter Residue Mass Recovered From Filters And Mass CaCO3 Added To Tank**

Test Date	System No.	Recovered Mass (mg)	CaCO3 added to tank-start of test (mg)
1/23/98	1	2842	4260
1/23/98	2	44	4260
1/27/98	1	2522	2899
1/27/98	2	1004	47
1/29/98	1	1489	2073
1/29/98	2	1970	1442
1/30/98	1	2133	1457
1/30/98	2	1079	1938
1/31/98	1	641	0
1/31/98	2	661	0
2/2/98	1	1808	2772
2/2/98	2	1887	1737
2/6/98	1	145	1794
2/6/98	2	42	1873
2/7/98	1	186	0
2/7/98	2	256	0
2/9/98	1	1138	330
2/9/98	2	321	296
2/10/98	1	897	1108
2/10/98	2	90	318
2/11/98	1	284	881
2/11/98	2	97	.
2/13/98	1	1158	1408
2/13/98	2	420	1420
2/14/98	1	317	1389
2/14/98	2	246	564
2/15/98	1	802	0
2/15/98	2	289	0
2/16/98	1	162	0
2/16/98	2	476	0
2/17/98	1	671	994
2/17/98	2	190	681
2/18/98	1	393	667
2/18/98	2	20	194
2/19/98	1	8.6	0
2/19/98	2	13	0
2/20/98	1	3231	4258
2/20/98	2	1264	4251
3/31/98	1	2347	4250-4270
3/31/98	2	837	4250-4270
4/4/98	1	1527	2306
4/4/98	2	366	836
4/7/98	1	1338	1525
4/7/98	2	986	367
4/10/98	1	996	1325
4/10/98	2	692	982
4/17/98	1	233	990
4/17/98	2	27	692

Notes: Residue masses don't include filter membranes. \*CaCO3 added-not recorded. residue.x

**APPENDIX C**

Particle Count and Size Distributions

TABLE C1 Particle Counter Data From System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from System Tests		labdatak.xls												Sheet 1
		1/23/98	17:22	1/23/98	17:24	1/24/98	1:43	1/23/1998	1:47	1/23/98	1:56	1/23/98	1:58	
Channel No.		test	sys #1	test	sys #2	test	sys #1	test	sys #1	test	sys #2	test	sys #2	
		stir off	stir off	stir off	stir off	run 1	stir off	run 2	run 2	stir on	stir on	stir on	stir on	
		Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	
		(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	
		Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	
1		2	464	2	914	2	460	2	467	2	2101	2	2121	
2		3	562	3	1032	4	193	4	197	4	694	4	711	
3		6	95	6	126	7	19.3	7	20.1	7	86	7	92	
4		10	41	10	60	12	3.7	12	4.8	12	46	12	47	
5		15	15.2	15	27	18	0.9	18	1.3	18	19.8	18	19.9	
6		20	5	20	10.2	25	0.3	25	0.2	25	17.9	25	15.7	
7		25	4.2	25	11.9	35	0	35	0.1	35	7.7	35	6.4	
8		35	2.6	35	5.5	50	0	50	0	50	1	50	0.8	
		1/23/98	1:49	1/23/98	1:50	1/23/98	1:54	1/24/98	1:55	1/24/98	1:59	1/24/98	2:00	
Channel No.		test	sys #1	test	sys #1	test	sys #1	test	sys #1	test	sys #1	test	sys #1	
		stir on	run 1	stir on	run 2	stir on	run 1	stir on	run 2	stir on	run 1	stir on	run 2	
		Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	Size	
		(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	
		Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	
1		2	564	2	583	2	224	2	233	2	255	2	239	
2		4	257	4	269	4	122	4	127	4	133	4	126	
3		7	39	7	46	7	14.3	7	14.8	7	13.5	7	11.8	
4		12	13.4	12	18.6	12	5.3	12	4	12	3.9	12	3	
5		18	5.6	18	5.7	18	1.8	18	1.1	18	0.9	18	0.7	
6		25	2.5	25	2.3	25	0.2	25	0.6	25	0.2	25	0.1	
7		35	0.9	35	1.7	35	0.1	35	0.1	35	0.1	35	0.1	
8		50	0.2	50	0.3	50	0	50	0	50	0	50	0	

TABLE C1

		labdatak.xls												Sheet 2							
		Hiac Royco Particle Counter (BYU) Data from System Tests																			
Channel No.	Size (microns)	22:07		1/29/98		22:12		1/29/98		22:15		22:18		1/29/98		22:21		1/29/98			
		flush w/ DI	Counts	test	sys #1	run 1	1/29/98	run 2	test	sys #1	flush w/ DI	run 1	sys #1	flush w/ DI	run 1	test	sys #2	run 1	test	sys #2	run 2
	Size	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts
1	2	114	2	1480	2	1473	2	37	2	538	2	560	2	538	2	538	2	560	2	560	
2	3	43.6	3	3475	3	3449	3	42	3	833	3	915	3	833	3	833	3	915	3	915	
3	6	1.9	6	1061	6	1091	6	4	6	146	6	189	6	146	6	146	6	189	6	189	
4	10	0.6	10	479	10	508	10	1.2	10	89	10	129	10	89	10	89	10	129	10	129	
5	15	0.7	15	175	15	199	15	0.6	15	45	15	71	15	45	15	45	15	71	15	71	
6	20	0.4	20	126	20	143	20	0.3	20	33	20	49	20	33	20	33	20	49	20	49	
7	30	0.2	30	85	30	79	30	0.2	30	15.2	30	23	30	15.2	30	15.2	30	23	30	23	
8	45	0.1	45	35	45	27	45	0	45	4.6	45	7.6	45	4.6	45	4.6	45	7.6	45	7.6	

Channel No.	Size (microns)	1/29/98		22:24		20:30		20:32		1/30/98		21:11		1/30/98		21:12		1/30/98		21:15					
		test	sys #2	run 3	1/29/98	run 3	flush w/ D	stir off	run 1	flush w/ DI	stir off	run 2	test	sys #1	stir on	run 1	test	sys #1	stir on	run 2	test	sys #1	stir on	run 3	
	Size	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts	(microns)	Counts
1	2	550	2	428	2	263	2	868	2	906	2	918	2	868	2	906	2	918	2	918					
2	3	930	3	556	3	386	3	1768	3	2043	3	2063	3	1768	3	2043	3	2063	3	2063					
3	6	202	6	83	6	40	6	506	6	640	6	636	6	506	6	640	6	636	6	636					
4	10	140	10	29	10	10.8	10	189	10	287	10	295	10	189	10	287	10	295	10	295					
5	15	71	15	7	15	3	15	62	15	100	15	96	15	62	15	100	15	96	15	96					
6	20	47	20	2	20	1	20	33	20	50	20	42	20	33	20	50	20	42	20	42					
7	30	21	30	0.2	30	0.3	30	12.7	30	15.7	30	10.8	30	12.7	30	15.7	30	10.8	30	10.8					
8	45	6.1	45	0.1	45	0	45	3.5	45	4.3	45	3.2	45	3.5	45	4.3	45	3.2	45	3.2					

TABLE C1

Hiac Royco Particle Counter (BYU) Data from System Tests		labdatak.xls		Sheet 3						
Channel No.	21:17	1/30/98	21:19	1/30/98	21:20	21:23	1/27/98	21:27	1/27/98	21:28
	flush w/ DI	test	sys #2	test	1/30/98	flush w/ DI	test	sys #1	test	1/30/98
	stir off	run 1	stir ?	sys #2	run 2	stir off	run 1	stir on	sys #1	run 2
	Size	run 1	Size	Size	Size	Size	Size	Size	Size	Size
	(microns)	Counts	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)
	2	229	2	222	2	257	2	587	2	1065
	3	326	3	322	3	338	3	1170	3	2195
	6	71	6	71	6	25	6	243	6	470
	10	45	10	47	10	5.7	10	91.1	10	158
15	20	15	19.4	15	1.2	15	37	15	61	
20	13.3	20	13.3	20	0.4	20	25	20	37	
30	5.8	30	6.3	30	0	30	12.8	30	17.6	
45	2.6	45	3.4	45	0	45	6.6	45	6.3	
1	21:30	1/27/98	21:32	1/30/98	21:34	21:37	1/30/98	21:38	1/30/98	21:41
test	test	sys #1	1/30/98	flush w/ DI	flush w/ DI	flush w/ DI	test	sys #2	test	1/30/98
sys #1	run 3	stir on	run 4	stir off	stir off	stir off	sys #2	stir on	sys #2	run 1
Size	run 3	Size	run 4	Size	Size	Size	Size	Size	Size	run 1
(microns)	Counts	(microns)	Counts	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	Counts
2	1199	2	1544	2	774	2	599	2	289	
3	2496	3	3211	3	2096	3	1448	3	445	
6	520	6	660	6	579	6	316	6	96	
10	164	10	207	10	157	10	67	10	62	
15	58	15	75	15	31	15	9.8	15	29	
20	35	20	53	20	6.2	20	2	20	20	
30	13.7	30	27	30	0.4	30	0.1	30	10.9	
45	5.7	45	13.4	45	0.1	45	0	45	5.4	

TABLE C1  
 Hiac Royco Particle Counter (BYU) Data from System Tests  
 3/18/98, labdatak.xls  
 Sheet 4

Channel No.	1/30/98 21:43		21:45		1/27/98 21:50		1/27/98 21:52	
	test	1/30/98 run 2	flush w/ DI run 1	1/30/98 run 1	test	1/30/98 run 1	test	1/30/98 run 2
	sys #2	sys #2	sys #2	sys #2	sys #2	sys #2	sys #2	sys #2
	stir on	stir on	stir on	stir on	stir on	stir on	stir on	stir on
	Size	Size	Size	Size	Size	Size	Size	Size
	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)	(microns)
	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts
1	2	262	2	770	2	268	2	350
2	3	392	3	2012	3	527	3	704
3	6	94	6	457	6	130	6	171
4	10	68	10	99	10	90	10	106
5	15	29	15	15.6	15	42	15	44
6	20	19.7	20	2.3	20	32	20	34
7	30	8.4	30	0.3	30	26	30	26
8	45	5	45	0.1	45	17.6	45	17.2

TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	3/31/98	3/31/98	3/31/98	3/31/98	3/31/98	3/31/98	3/31/98
Start or End Test:	-	-	-	-	-	-	-
No. of Magnets:	-	-	-	-	-	-	-
System #, Run #:	-	run 1	run 2	run 1	run 2	run 1	
Comment Field:	typical DI flush	7 µm part.-- size std.	7 µm part.-- size std.	DI Flush	DI Flush	20.5 µm part. size std.	
Particle Count Time:	16:45	16:59	17:01	17:06	17:08	17:11	
Stir :	on 3	on 3	on 3	off	off	on 3	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	108	387	426	219	214	33
2	6	11.5	63	56	19.6	16.7	6.4
3	9	6.08	25	22	13.2	11	5.04
4	12	2.88	13.70	11.4	4.32	4.32	2.16
5	15	1.12	9.52	7.96	2	1.64	3.6
6	20	0.6	3	3.36	0.36	0.24	0.4
7	30	0.08	1.04	0.88	0.08	0	0.16
8	45	0.04	0.2	0.16	0	0	0.04
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	3/31/98	3/31/98	3/31/98	3/31/98	3/31/98	3/31/98	3/31/98
Start or End Test:	-	-	-	start	start	-	-
No. of Magnets:	-	-	-	6	6	-	-
System #, Run #:	run 2	run 1	run 2	#1,#1	#1, #2	run 1	
Comment Field:	20.5 µm standard	29.9 µm size std.	29.9 µm standard			DI Flush	
Particle Count Time:	17:12	17:26	17:28	19:21	19:22	19:35	
Stir :	on 3	on 3	on 3	on 3	on 3	off	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	35.8	46	42	1141	1140	118
2	6	7.72	7.32	6.16	161	148	21
3	9	5.8	3.76	3.36	72	59	6.56
4	12	2.44	2.16	1.68	59	36	1.88
5	15	4.2	0.96	1.12	38	27	0.64
6	20	0.72	16.3	16.8	67	37	0.04
7	30	0.16	2.2	2.08	70	27	0.12
8	45	0	0.36	0.4	20.7	6.12	0.04
Ap1_labdata.xls, sht 1						Sheet 1	

Notes:

1) Particle size standards mixed from NBS traceable polymer microspheres in 200 ml of pure water (16 megaohm-cm) in sterilized glass bottles. Following amounts of microspheres added to water: 7 µm (4 drops), 20.5 µm (2 drops), 29.9 µm (2 drops)

TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	3/31/98	3/31/98	3/31/98	4/1/98	4/1/98	4/1/98	4/1/98
Start or End Test:	-	start	start	-	end	end	end
No. of Magnets:	-	0	0	-	6	6	6
System #, Run #:	run 2	#2, #1	#2, #2		#1, #1	#1, #2	
Comment Field:	DI Flush				DI Flush		
Particle Count Time:	19:36	19:38	19:40	11:19	11:23	11:24	11:24
Stir :	off	on 3	on 3	off	on 3	on 3	on 3
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	53	628	777	100	1503	1475
2	6	3.92	43	66	12.1	111	105
3	9	1.88	16.4	24	2.24	61	58
4	12	1.08	10.2	15.2	1.32	26	25.2
5	15	0.28	6.56	9.04	0.44	14.4	14.8
6	20	0.08	4.4	7.16	0.36	6.76	5.92
7	30	0	3.6	4.32	0.12	2.12	1.56
8	45	0	3.12	3.08	0.04	0.36	0.36
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/1/98	4/1/98	4/1/98	4/1/98	4/2/98	4/2/98	4/2/98
Start or End Test:	-	end	end	end	-	start	start
No. of Magnets:	-	0	0	0	-	6	6
System #, Run #:		#2, #1	#2, #2	#2, #3		#1, #1	#1, #1
Comment Field:	DI Flush				DI Flush	Memory Effect	Memory Effect
Particle Count Time:	11:28	11:30	11:31	11:32	12:14	12:16	12:16
Stir :	off	off	on 3	on 3	off	on 3	on 3
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	47	214	233	234	48	304
2	6	5.12	17.6	26	24	3.32	66
3	9	1.32	10.9	18.1	11.7	1.52	45
4	12	0.76	4.88	8.92	7.84	0.88	34
5	15	0.32	2.4	6.04	5.28	0.76	43
6	20	0.08	0.52	2.28	2.64	0.44	32
7	30	0	0.24	0.84	0.44	0.36	12.6
8	45	0	0.08	0.12	0.04	0	3.08
Ap1_labdatak.xls, sht 1						Sheet 2	

Notes:

- 2) stir indicates whether the magnetic stirrer was on or off and it's setting.
- 3) DI= deionized water from laboratory tap
- 4) Memory Effect= type of system test

TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/2/98	4/2/98	4/2/98	4/2/98	4/3/98	4/3/98	
Start or End Test:	start	-	start	start	-	end	
No. of Magnets:	6	-	0	0	-	6	
System #, Run #:	#1, #2	-	#2, #1	#2, #2	-	#1, #1	
Comment Field:	Memory	DI	Memory	Memory	DI	Memory	
	Effect	Flush	Effect	Effect	Flush	Effect	
Particle Count Time:	12:18	12:22	12:26	12:27	-	14:25	
Stir :	on 3	off	on 3	on 3	off	on 3	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	304	64	138	134	52.6	946
2	6	62	7.72	16.4	15.2	3.08	119
3	9	41	3.4	8.8	7.84	0.52	89.7
4	12	34	1.76	5	4.32	0.44	64.8
5	15	40	0.76	3.24	3.12	0.16	51.3
6	20	32	0.32	1.68	1.36	0	33.8
7	30	11.6	0	0.92	0.84	0	17
8	45	2.76	0	1.08	0.52	0	5.8
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/3/98	4/3/98	4/3/98	4/3/98	4/4/98	4/4/98	
Start or End Test:	end	-	end	end	-	end	
No. of Magnets:	6	-	0	0	-	-	
System #, Run #:	#1, #2	-	#2, #1	#2, #2	-	#1, #1	
Comment Field:	Memory	DI	Memory	Memory	DI	3	
	Effect	Flush	Effect	Effect	Flush		
Particle Count Time:	14:25	-	14:25	14:25	21:22	21:24	
Stir :	on 3	off	on 3	on 3	off	on 3	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	1000	53.4	1256	1261	54.9	643.5
2	6	130	4.96	87.4	88.8	17.8	84.2
3	9	94.1	1.2	57.8	53.4	7.24	39.0
4	12	66.7	0.52	33.9	34.5	2.2	23.4
5	15	52.7	0.4	17.8	18.7	0.52	16.6
6	20	34.7	0.12	8.36	5.84	0.40	9.96
7	30	15.9	0.08	2.48	1.56	0	6.28
8	45	5.4	0	0.88	0.48	0.12	2.0
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Notes:

- 5) Particle Count Time is the clock time from the counter printout in "hours: minutes."
- 6) Start or End Test usually refers to the start or end of system test.

TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/4/98	4/4/98	4/4/98	4/4/98	4/4/98	4/4/98	4/4/98
Start or End Test:	end	-	end	end	end	-	-
No. of Magnets:	3	-	0	0	0	-	-
System #, Run #:	#1, #2	-	#2, #1	#2, #2	#2, #3	run 1	run 1
Comment Field:		DI				DI	DI
		Flush				Flush	Flush
Particle Count Time:	21:26	21:28	21:29	21:31	21:32	12:05	12:05
Stir :	on 3	off	off	on 3	on 3	off	off
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	658	22.6	281	375	426	65.1
2	6	86.4	3.9	44.1	54.6	61.9	10.0
3	9	39.4	0.88	23.3	30.2	29.5	2.6
4	12	24.2	0.56	13.4	18.8	19.2	1.2
5	15	16.0	0.04	8.28	13.1	12.4	0.92
6	20	11.0	0	4.04	6.88	5.96	0.44
7	30	5.96	0	1.7	2.8	3.0	0.04
8	45	2.1	0	1.1	2.3	2.1	0
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/4/98	4/4/98	4/4/98	4/4/98	4/4/98	4/4/98	4/4/98
Start or End Test:	-	-	start	start	start	-	-
No. of Magnets:	-	-	3	3	3	-	-
System #, Run #:	run 2	run 3	#1, #1	#1, #2	#1, #3	run 1	run 1
Comment Field:	DI	DI				DI	DI
	Flush	Flush				Flush	Flush
Particle Count Time:	12:08	12:14	12:18	12:20	12:21	12:23	12:23
Stir :	off	off	on 3	on 3	on 3	off	off
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	57.1	45.6	636	745	829	46.8
2	6	7.12	4.92	82.0	94.7	99.2	5.12
3	9	2.4	1.2	54.9	71.5	70.6	1.8
4	12	0.48	0.6	55.1	105	86.1	0.88
5	15	0.2	0.3	39.0	45.0	45.6	0.64
6	20	0.1	0.1	47.8	76.8	73.0	0.1
7	30	0.0	0.1	52.4	119	98.2	0.04
8	45	0.1	0.1	34.7	125	74.1	0

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TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/4/98	4/4/98	4/7/98	4/7/98	4/7/98	4/7/98	4/7/98
Start or End Test:	start	start	-	-	start	start	
No. of Magnets:	0	0	-	-	1	1	
System #, Run #:	#2, #1	#2, #2	run 1	run 2	#1, #1	#1, #2	
Comment Field:			DI	DI			
			Flush	Flush			
Particle Count Time:	12:25	12:27	12:53	12:54	12:55	12:56	
Stir :	on 3	on 3	off	off	on 3	on 3	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	731	757	34.6	25.9	513	591
2	6	135	132	4.88	2.7	67.9	77.2
3	9	62.3	59.2	1.6	0.56	44.0	53.2
4	12	43.0	34.88	0.64	0.2	37.8	47.0
5	15	22.5	19.5	0.48	0	30.0	36.5
6	20	17.9	13.3	0.12	0.04	26.9	34.7
7	30	22.2	11.4	0.08	0	20.0	26.3
8	45	23.7	10.3	0.04	0	8.72	18.4
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/7/98	4/7/98	4/7/98	4/7/98	4/7/98	4/7/98	4/7/98
Start or End Test:	-	-	start	start	-	-	
No. of Magnets:	-	-	3	3	-	-	
System #, Run #:	run 1	run 2	#2, #1	#2, #2	run 1	run 2	
Comment Field:	DI	DI			DI	DI	
	Flush	Flush			Flush	Flush	
Particle Count Time:	12:58	12:59	13:05	13:07	22:00	22:02	
Stir :	off	off	on 3	on 3	off	off	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	57.8	50.56	6454	6655	70.3	28.4
2	6	5.96	4.20	2302	2543	20.2	2.6
3	9	2.0	1.4	1137	1376	11.6	0.76
4	12	1.6	1.0	688	890	2.6	0.60
5	15	0.96	0.6	492.5	693	0.60	0.2
6	20	0.2	0.04	215	359	0.1	0.08
7	30	0.04	0.04	78.0	151	0.1	0
8	45	0.04	0	34.7	80.2	0	0
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TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/7/98	4/7/98	4/7/98	4/7/98	4/7/98	4/7/98	4/7/98
Start or End Test:	end	end	-	-	-	-	end
No. of Magnets:	1	1	-	-	-	-	3
System #, Run #:	#1, #1	#1, #2	run 1	run 2	run 3		#2, #1
Comment Field:			DI	DI	DI		
			Flush	Flush	Flush		
Particle Count Time:	22:04	22:05	22:09	22:10	22:11		22:14
Stir :	on 3	on 3	off	off	off		off
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	396	393	103	89.6	96.2	2709
2	6	51.8	41.7	13.8	8.88	7.24	975
3	9	22.8	21.04	4.40	2.7	2.4	531
4	12	14.1	14.6	2.8	1.5	1.8	364
5	15	11.6	9.44	1.4	1.0	0.48	339
6	20	3.9	4.84	0.2	0.2	0.1	174
7	30	1.2	1.9	0	0.04	0	30.8
8	45	0.2	0.76	0	0	0	3.32
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/7/98	4/7/98	4/10/98	4/10/98	4/10/98	4/10/98	4/10/98
Start or End Test:	end	end	-	-	start	start	start
No. of Magnets:	3	3	-	-	0	0	0
System #, Run #:	#2, #2	#2, #3	run 1	run 2	#1, #1	#1, #1	#1, #2
Comment Field:			DI	DI			
			Flush	Flush			
Particle Count Time:	22:16	22:18	10:54	11:02	11:04		11:05
Stir :	on 3	on 3	off	off	on 3		on 3
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	2756	2799	33.7	8.80	774	728
2	6	999	1030	4.96	0.84	109	96.3
3	9	545	571	0.76	0.1	70.2	56.8
4	12	389	399	0.4	0.04	62.2	45.0
5	15	376	397	0.1	0.1	63.9	50.1
6	20	204	215	0.2	0.1	106	54.0
7	30	57.0	54.4	0.04	0	83.7	27.4
8	45	14.4	13.3	0.04	0	29.2	6.60
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TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/10/98	4/10/98	4/10/98	4/10/98	4/10/98	4/10/98	4/10/98
Start or End Test:	start	-	-	start	start	-	-
No. of Magnets:	0	-	-	6	6	-	-
System #, Run #:	#1, #3	run 1	run 2	#2, #1	#2, #2	run 1	-
Comment Field:		DI	DI			DI	
		Flush	Flush			Flush	
Particle Count Time:	11:07	11:08	11:10	11:11	11:12	20:15	
Stir :	on 3	off	off	on 3	on 3	off	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	750	12.4	11.2	1852	1903	22.4
2	6	97.9	2.2	1.2	635	653	6.64
3	9	56.1	1.0	0.68	334	335	2.9
4	12	48.2	0.64	0.3	226	233	1.0
5	15	48.9	0.56	0.3	152	164	0.84
6	20	54.2	0.72	0.4	115	134	0.52
7	30	25.9	0.40	0	101	107	0.2
8	45	7.44	0	0	49.0	50.6	0.04
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/10/98	4/10/98	4/10/98	4/10/98	4/10/98	4/10/98	4/10/98
Start or End Test:	-	-	end	end	end	-	-
No. of Magnets:	-	-	0	0	0	-	-
System #, Run #:	run 2	run 3	#1, #1	#1, #2	#1, #3	run 1	-
Comment Field:	fresh H2O	DI				DI	
	DI Flush	Flush				Flush	
Particle Count Time:	20:18	20:19	20:21	20:22	20:25	20:30	
Stir :	off	off	on 3	on 3	on 3	off	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	20.5	15.6	310	298	310	41.2
2	6	4.92	2.7	43.0	39.8	41.7	3.5
3	9	1.8	0.44	23.9	21.7	21.2	1.6
4	12	1.7	0.68	16.0	11.8	10.8	0.76
5	15	0.96	0.40	12.7	9.88	7.60	0.44
6	20	0.4	0.1	13.4	7.72	4.64	0.04
7	30	0.4	0	9.20	3.7	0.8	0
8	45	0	0.04	2.7	0.80	0.1	0.04
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TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/10/98	4/10/98	4/10/98	4/10/98	4/11/98	4/11/98	
Start or End Test:	-	end	end	end	-	-	
No. of Magnets:	-	6	6	6	-	-	
System #, Run #:	run 2	#2, #1	#2, #2	#2, #3	run 1	run 2	
Comment Field:	DI				DI	DI	
	Flush				Flush	Flush	
Particle Count Time:	20:31	20:33	20:35	20:37	19:55	19:56	
Stir :	off	off	on 3	on 3	off	off	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	20.2	108.2	126.2	136.6	23.24	15.8
2	6	1.6	20.2	26.2	29.6	5.76	2.6
3	9	0.52	11.3	16.5	17.7	1.72	1.1
4	12	0.40	7.00	12.2	13.24	0.80	0.80
5	15	0.4	5.96	8.64	10.8	0.72	1.0
6	20	0.1	2.6	7.48	8.36	0.3	0.64
7	30	0	1.2	5.52	6.12	0.1	0.04
8	45	0	0.3	2.0	2.3	0	0
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/11/98	4/11/98	4/11/98	4/11/98	4/11/98	4/11/98	
Start or End Test:	-	-	-	-	-	-	
No. of Magnets:	-	0	0	-	6	6	
System #, Run #:	run 3	#1, #1	#1, #2	run 1	#2, #1	#2, #2	
Comment Field:	DI	Memory	Memory	DI	Memory	Memory	
	Flush	Effect	Effect	Flush	Effect	Effect	
Particle Count Time:	20:09	20:11	20:13	20:15	20:17	20:18	
Stir :		on 3	on 3		on 3	on 3	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	8.32	287	393	6.28	159	169
2	6	2.6	33.6	44.4	1.8	21.9	25.7
3	9	1.2	13.1	13.8	0.92	10.4	13.7
4	12	0.9	7.56	7.68	0.44	7.64	9.24
5	15	1.0	6.04	5.60	0.2	5.96	7.08
6	20	0.2	3.6	3.7	0.2	3.2	3.20
7	30	0.0	1.3	1.0	0.04	1.3	1.44
8	45	0.0	0.4	0.2	0	0.2	0.76
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TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/13/98	4/13/98	4/13/98	4/13/98	4/13/98	4/13/98	4/13/98
Start or End Test:	-	-	-	-	-	-	-
No. of Magnets:	-	-	0	0	0	-	-
System #, Run #:	run 1	run 2	#1, #1	#1, #2	#1, #3	-	-
Comment Field:	DI Flush	DI Flush	Memory Effect	Memory Effect	Memory Effect	DI Flush	DI Flush
Particle Count Time:	8:28	8:29	8:33	8:34	8:35	8:38	8:38
Stir :	off	off	off	on 3	on 3	off	off
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	30.0	24.2	398	421	434	27.5
2	6	2.4	3.1	36.7	43.6	47.2	3.5
3	9	1.2	1.0	17.8	20.6	21.4	1.0
4	12	0.60	0.76	9.04	15.0	14.4	0.80
5	15	0.72	0.60	6.36	10.9	10.4	0.4
6	20	0.3	0	2.2	7.56	6.64	0.04
7	30	0.1	0.04	0.48	2.2	2.4	0
8	45	0.04	0	0.04	0.68	0.60	0
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/13/98	4/13/98	4/17/98	4/17/98	4/17/98	4/17/98	4/17/98
Start or End Test:	-	-	-	-	start	start	start
No. of Magnets:	6	6	-	-	0	0	0
System #, Run #:	#2, #1	#2, #2	run 1	run 2	#1, #1	#1, #2	#1, #2
Comment Field:	Memory Effect	Memory Effect	DI Flush	DI Flush			
Particle Count Time:	8:40	8:42	10:53	10:54	10:55	10:57	10:57
Stir :	on 3	on 3	off	off	on 3	on 3	on 3
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	588	604	33.2	13.3	337	448
2	6	47.7	50.5	2.32	1.68	48.2	72.6
3	9	18.6	18.8	0.56	0.36	24.4	38.8
4	12	11.5	11.0	0.36	0.16	16	27.8
5	15	7.12	7.48	0.4	0.08	12.7	21.5
6	20	5.24	4.84	0.32	0.08	8.52	17.6
7	30	3.8	2.0	0.12	0	4.2	12.5
8	45	0.76	0.52	0	0	3.36	11.3
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TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/17/98	4/17/98	4/17/98	4/17/98	4/17/98	4/17/98	4/17/98
Start or End Test:	-	start	start	-	-	-	end
No. of Magnets:	-	1	1	-	-	-	1
System #, Run #:	-	#2, #1	#2, #2	run 1	run 2		#1, #1
Comment Field:	DI			DI	DI		
	Flush			Flush	Flush		
Particle Count Time:	10:58	11:00	11:01	20:34	20:35		20:37
Stir :	off	on 3	on 3	off	off		on 3
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	16.4	254	256	21.2	8.20	244
2	6	3.00	39.2	42.0	7.04	0.36	33.9
3	9	0.92	16.6	16.7	2.56	0.24	13.5
4	12	0.60	9.56	10.5	0.68	0.20	8.00
5	15	0.44	6.00	6.80	0.12	0.08	4.60
6	20	0.08	2.88	2.68	0	0.04	3.08
7	30	0	1.44	0.80	0	0	1.16
8	45	0	0.32	0.36	0	0	1.16
Hiac Royco Particle Counter (BYU) Data from April System Tests							
System Test Date:	4/17/98	4/17/98	4/17/98	4/17/98	4/17/98	4/17/98	4/17/98
Start or End Test:	end	-	-	-	-	-	-
No. of Magnets:	0						
System #, Run #:	#1,#2	run 1	run 2	run 3	run 4	run 5	
Comment Field:		DI	DI	DI	DI	DI	DI
		Flush	Flush	Flush	Flush	Flush	Flush
Particle Count Time:	20:38	20:39	20:40	20:42	20:44		20:47
Stir :	on 3	off	off	off	off		off
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)					
1	3	284	43.7	33.0	50.3	41.2	5.28
2	6	41.6	6.40	3.24	7.04	4.52	1.40
3	9	15.2	4.80	4.24	3.08	2.16	0.36
4	12	8.84	3.20	3.80	1.72	2.28	0.32
5	15	5.92	1.28	4.60	0.96	1.00	0.12
6	20	3.04	0.16	11.8	0.24	0.12	0
7	30	1.48	0.04	0.28	0	0	0
8	45	0.84	0	0.04	0	0	0
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TABLE C2 Particle Counter Data From April System Tests With Tap Water

Hiac Royco Particle Counter (BYU) Data from April System Tests			
System Test Date:	4/17/98	4/17/98	
Start or End Test:	end	end	
No. of Magnets:	1	1	
System #, Run #:	#2, #1	#2, #2	
Comment Field:			
Particle Count Time:	20:48	20:50	
Stir :	on 3	on 3	
Channel No.	Threshold Bin Size	Particle Counts Units: (counts/1ml)	
1	3	404	398
2	6	52.0	53.4
3	9	20.0	20.2
4	12	10.1	9.52
5	15	7.68	7.16
6	20	3.04	3.36
7	30	0.92	0.68
8	45	0.12	0
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TABLE C3 SYSTEM TEST DATA AVERAGES: PARTICLE COUNTS

Code ->	A	B	C	D	I	J	K	L	M	N
Bin size (um)	Particle Counts: Units (counts/1 mL)									
3	1140	702	1489	227	737	744	651	361	552	6554
6	154	54.5	108	22.5	92	134	85.3	53.5	72.6	2422
9	65.5	20.2	59.5	13.6	65.7	60.8	39.2	27.7	48.6	1256
12	47.5	12.7	25.6	7.21	82.1	39.0	23.8	17.1	42.4	789
15	32.5	7.80	14.6	4.57	43.2	21.0	16.3	11.3	33.2	592
20	52.0	5.78	6.34	1.81	65.9	15.6	10.5	5.63	30.8	287
30	48.5	3.96	1.84	0.51	89.9	16.8	6.12	2.48	23.2	114
45	26.8	3.1	0.36	0.08	77.9	17.0	2.02	1.84	13.6	57.4
Code ->	O	P	Q	R	S	T	Y	Z	AA	BB
Bin size (um)	Particle Counts: Units (counts/1 mL)									
3	394	2755	751	1878	306	124	392	255	264	401
6	46.8	1001	101	644	41.5	25.3	60.4	40.6	37.8	52.7
9	21.9	549	61	334	22.3	15.2	31.6	16.6	14.4	20.1
12	14.4	384	51.8	230	12.9	10.8	21.9	10.00	8.42	9.81
15	10.5	371	54.3	158	10.1	8.47	17.1	6.40	5.26	7.42
20	4.36	198	71.4	124	8.59	6.16	13.1	2.78	3.06	3.20
30	1.52	47.4	45.7	104	4.57	4.29	8.35	1.12	1.32	0.80
45	0.48	10.3	14.4	49.8	1.20	1.55	7.33	0.34	1.00	0.06

LEGEND:

Letter Code	# of magnets	Test length(hrs)	Test date	syst. #	Description
A	6	10	31-Mar 1998	1	start test
B	0	10	31-Mar 1998	2	start test
C	6	10	1-Apr 1998	1	end test
D	0	10	1-Apr 1998	2	end test
I	3	10	4-Apr 1998	1	start test
J	0	10	4-Apr 1998	2	start test
K	3	10	4-Apr 1998	1	end test
L	0	10	4-Apr 1998	2	end test
M	1	10	7-Apr 1998	1	start test
N	3	10	7-Apr 1998	2	start test
O	1	10	7-Apr 1998	1	end test
P	3	10	7-Apr 1998	2	end test
Q	0	10	10-Apr 1998	1	start test
R	6	10	10-Apr 1998	2	start test
S	0	10	10-Apr 1998	1	end test
T	6	10	10-Apr 1998	2	end test
Y	0	10 1/3	17-Apr 1998	1	start test
Z	1	10 1/3	17-Apr 1998	2	start test
AA	0	10 1/3	17-Apr 1998	1	end test
BB	1	10 1/3	17-Apr 1998	2	end test

partcont,sht3,p16

TABLE C4 Enviromental Lab DI, Fluids Lab Tap Water Samples & Calibration Standards: Particle Counts					
Ave. of 52 DI, 4 Fluids Lab tap samples & 2 of ea. calib. std.					
Bin Size (um)	Differential Particle Counts per mL				
	D.I.	Tap	7 µm	20.5 µm	29.9 µm
3	57.42	205	406	34.4	44.0
6	6.49	16.8	59.5	7.06	6.74
9	2.66	5.87	23.5	5.42	3.56
12	1.28	3.2	12.6	2.30	1.92
15	0.73	2.42	8.74	3.90	1.04
20	0.25	1.05	3.18	0.56	16.6
30	0.08	0.26	0.96	0.16	2.14
45	0.02	0.15	0.18	0.02	0.38

TABLE C5 System Test Data Averages for Memory Effect: Particle Counts								
partcnt6,sht2,p.6								
Code -> Bin Size (um)	E	F	G	H	U	V	W	X
	Differential Particle Counts per mL							
3	304	136	973	1258	340	164	418	596
6	64.0	15.8	124.5	88.1	39.0	23.8	42.5	49.1
9	43.0	8.32	91.9	55.6	13.4	12.0	19.9	18.7
12	34.0	4.66	65.8	34.2	7.62	8.44	12.8	11.2
15	41.5	3.18	52.0	18.2	5.82	6.52	9.23	7.30
20	32.0	1.52	34.2	7.10	3.64	3.18	5.47	5.04
30	12.1	0.88	16.4	2.02	1.14	0.96	1.68	2.90
45	2.92	0.80	5.60	0.68	0.28	0.40	0.44	0.64

LEGEND:						
Letter Code	No. of magnets	Time (hrs)	Test Date		System No.	Description
			Start	End		
E	6	0	2-Apr	3-Apr	1	start test
F	0	0	2-Apr	3-Apr	2	start test
G	6	28	2-Apr	3-Apr	1	end test
H	0	28	2-Apr	3-Apr	2	end test
S	0	0	10-Apr	13-Apr	1	start test
T	6	0	10-Apr	13-Apr	2	start test
U	0	23 1/2	10-Apr	13-Apr	1	mid test
V	6	23 1/2	10-Apr	13-Apr	2	mid test
W	0	72	10-Apr	13-Apr	1	end test
X	6	72	10-Apr	13-Apr	2	end test

NOTE: Particle counts for "S" and "T" are found in Table C3.

**TABLE C6 COMPARISON OF DIFFERENT WATER SOURCE PARTICLE COUNTS**

NOTES BYU CE Enviro. Lab - Hiac Royco particle counter - Tests run 1/5/98

D.I. = deionized water from mid counter tap in main enviro. Lab

old tube = old, dirty tubing on lab water filtration unit, new tube = new, clean tube

filter = water from enviro. Lab filtration unit, stirrer at 50% = stirr knob set between 4 & 5

stored = water originally from old tube, lab filter unit, stored in plastic can for 4-8 weeks without addition of hydrogen peroxide

Chan = channel #, Diff. Count = differential particle counts per mL

Same sample, 3 runs from same bottle

Test A: D.I. Water, stirrer off

Chan	Size (um)	Run 1	Run 2	Run 3	Ave.1-3
		Diff. Count	Diff. Count	Diff. Count	Diff. Count
1	2.0	262	228	236	242
2	3.0	210	206	205	207
3	4.0	301	295	302	299
4	6.0	29.0	26.5	28.4	28.0
5	7.0	13.3	13.4	12.6	13.1
6	8.0	15.5	14.9	16.5	15.6
7	11.0	6.0	6.2	6.2	6.1
8	14.0	4.0	5.0	5.4	4.8

Same sample, 2 runs from same bottle

Test B: filter water, old tube, stirrer off

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	935	1689	1312
2	3.0	199	189	194
3	4.0	165	159	162
4	6.0	11.6	11.7	11.7
5	7.0	4.6	4.6	4.6
6	8.0	7.0	7.7	7.4
7	11.0	5.5	5.2	5.4
8	14.0	5.9	5.0	5.5

Same sample, 3 runs from same bottle

Test F: filter, stored water, old tube, stirr on 50%

Chan	Size (um)	Run 1	Run 2	Run 3	Ave.1-3
		Diff. Count	Diff. Count	Diff. Count	Diff. Count
1	2.0	443	490	282	405
2	3.0	131	152	143	142
3	4.0	91	106	108	102
4	6.0	5.2	6.4	7.5	6.4
5	7.0	3.2	3.4	4.1	3.6
6	8.0	6.0	6.1	6.7	6.3
7	11.0	5.2	4.2	5.4	4.9
8	14.0	3.6	3.3	3.4	3.4

Same sample, 2 runs from same bottle

Test C: filter water, old tube, stirrer on

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	743	910	827
2	3.0	54	69	62
3	4.0	57	69	63
4	6.0	4.3	4.5	4.4
5	7.0	1.5	2.1	1.8
6	8.0	2.2	2.5	2.4
7	11.0	1.0	0.9	1.0
8	14.0	0.9	0.7	0.8

Same sample, 2 runs from same bottle

Test D: filter water, new tube, stirrer off

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	388	875	632
2	3.0	22.2	24.8	23.5
3	4.0	29.2	33.6	31.4
4	6.0	1.4	2.6	2.0
5	7.0	1.2	0.9	1.1
6	8.0	2.5	1.9	2.2
7	11.0	2.0	1.7	1.9
8	14.0	1.4	1.8	1.6

Same sample, 2 runs from same bottle

Test E: filter water, new tube, stirrer on

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	258	242	250
2	3.0	29	31.8	30.5
3	4.0	28	30.7	29.4
4	6.0	1.9	2.6	2.3
5	7.0	1.1	1.0	1.1
6	8.0	1.7	1.6	1.7
7	11.0	0.6	0.6	0.6
8	14.0	0.9	0.9	0.9

FN = partcont.xls, sheet 1

**TABLE C6 COMPARISON OF DIFFERENT WATER SOURCE PARTICLE COUNTS**

**NOTES:** CE Enviro. Lab - Hiac Royco particle counter - Tests run 1/9/98  
 D.I. = deionized water from mid counter tap in main enviro. Lab  
 old tube = old, dirty tubing on lab water filtration unit, new tube = new, clean tube  
 filter = water from enviro. Lab filtration unit, stirrer at 50% = stir knob set between 4 & 5  
 stored = water originally from old tube, lab filter unit, stored in plastic can for 4-8 weeks  
 without addition of hydrogen peroxide  
 Chan = channel #, Diff. Count = differential particle counts per mL

Same sample, 2 runs from same bottle  
 Test A: D.I. Water, stirrer on 50%

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	1.0	1.0	1.0
2	4.0	15.6	20.9	18.2
3	7.0	4.8	6.1	5.4
4	11.0	3.5	4.4	4.0
5	17.0	0.8	0.8	0.8
6	25.0	0.3	0.0	0.2
7	35.0	0.3	0.0	0.1
8	60.0	0.1	0.0	0.1

Same sample, 2 runs from same bottle  
 Test B: filter water, old tube, stirrer on 50%

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	2.2	0.6	1.4
2	4.0	32.5	16.1	24.3
3	7.0	8.1	8.0	8.0
4	11.0	7.6	7.6	7.6
5	17.0	1.5	1.8	1.6
6	25.0	0.1	0.1	0.1
7	35.0	0.0	0.1	0.0
8	60.0	0.1	0.0	0.0

Same sample, 2 runs from same bottle  
 Test C: filtered water, new tube, stirrer on 50%

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	0.5	1.0	0.7
2	4.0	12.6	14.4	13.5
3	7.0	6.6	6.8	6.7
4	11.0	6.5	6.8	6.7
5	17.0	1.8	1.3	1.6
6	25.0	0.1	0.2	0.2
7	35.0	0.2	0.1	0.1
8	60.0	0.0	0.0	0.0

Same sample, 2 runs from same bottle  
 Test D: filter water, no tube, stirrer on 50%

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	3.4	4.0	3.7
2	4.0	34.2	36.4	35.3
3	7.0	10.9	11.4	11.2
4	11.0	12.4	14.2	13.3
5	17.0	3.0	2.8	2.9
6	25.0	0.5	0.4	0.5
7	35.0	0.2	0.2	0.2
8	60.0	0.0	0.0	0.0

Same sample, 2 runs from same bottle  
 Test E: stored filter water, old tube, stirrer on 50%

Chan	Size (um)	Run 1	Run 2	Ave.1-2
		Diff. Count	Diff. Count	Diff. Count
1	2.0	18.9	5.0	11.9
2	4.0	78.0	47.2	62.6
3	7.0	20.6	20.6	20.6
4	11.0	25.7	25.6	25.6
5	17.0	6.1	5.2	5.6
6	25.0	1.1	0.8	0.9
7	35.0	0.4	0.3	0.4
8	60.0	0.0	0.0	0.0

FN = partcont.xls, sheet 2

**APPENDIX D**

XRD Peak Area Table

XRD Plots

TABLE D1 XRD Peak Areas (cpm)

2-Theta-->	29.49	39.43	43.18	47.53	26.24	45.9	27.25	33.18	sum c	sum a	calcite ratio	corrected calcite %	date	Syst. No.	No. Mags
File	c1	c2	c3	c4	a1	a2	a3	a4	c	a					
kicalwd23.ni	15120	1986	1730	2615	0	369	0	0	21451	369	0.98	99	-	-	-
ca80ar20.ni	7806	1232	1279	1457	796	910	506	1720	11774	3932	0.75	80	-	-	-
ca60ar40.ni	5432	935	959	1163	1414	1561	1005	720	8489	4720	0.64	60	-	-	-
ca40ar60.ni	3329	499	572	723	1821	2463	979	701	5123	5964	0.46	40	-	-	-
ca20ar80.ni	1643	172	336	1691	1840	2389	915	667	3842	5811	0.40	20	-	-	-
kira03b2.ni	0	0	0	0	2661	3975	1640	1068	0	9344	0.00	0	-	-	-
klaast.ni	8430	1562	1259	1805	124	758	430	278	13056	1590	0.89	90	1/27	1	6
klbbst.ni	6563	1568	1481	2021	95	0	105	0	11633	200	0.98	98	1/27	2	0
klccst.ni	6200	1481	1294	1546	81	545	432	250	10521	1308	0.89	90	1/29	2	0
kladdst.ni	10331	1247	1177	1802	140	590	197	0	14557	927	0.94	95	1/30	1	3
kleest.ni	7977	1238	1435	1783	200	0	550	250	12433	1000	0.93	94	1/29	1	6
kiffst.ni	365	596	555	678	46	173	168	0	2194	387	0.85	86	1/30	2	3
klggst.ni	11257	1909	1549	2461	0	0	0	0	17176	0	1.00	100	1/23	1	0
klhhst.ni	11717	1434	1534	2047	0	0	0	0	16732	0	1.00	100	2/2	2	1
klijst.ni	9969	1198	1465	1975	901	231	144	0	14607	1276	0.92	93	2/9	1	0
klkkst.ni	10435	1613	1439	2295	0	0	0	0	15782	0	1.00	100	2/13	1	0
killst.ni	10777	1806	1574	1715	198	0	148	0	15872	346	0.98	98	2/10	1	3
klimmst.ni	10338	1642	1455	1666	195	0	0	0	15101	195	0.99	99	2/2	1	1
kloost.ni	8501	1447	1162	1257	179	391	363	177	12367	1110	0.92	93	2/20	2	0
klppst1.ni	7517	1462	1453	1656	25	346	124	1100	12088	1595	0.88	89	2/17	1	0
klqqst1.ni	7402	833	1000	1152	74	993	415	1570	10387	3052	0.77	79	1/31	1	1
klqqst2.ni	7265	1035	1260	1291	129	959	427	1295	10851	2810	0.79	81	1/31	1	1
klrrs12.ni	5105	699	501	774	764	1143	514	441	7079	2862	0.71	71	1/31	2	1
File Name	File Description														
kicalwd23.ni	calcite prepared by Wray and Daniel method. Nearly 100% calcite														
ca80ar20.ni	calcite 80% prepared by weight, aragonite 20% by weight														
ca60ar40.ni	calcite 60% prepared by weight, aragonite 40% by weight														
ca40ar60.ni	calcite 40% prepared by weight, aragonite 60% by weight														
ca20ar80.ni	calcite 20% prepared by weight, aragonite 80% by weight														
kira03b2.ni	calcite used in previous 4 samples are from batch 2, Wray & Daniel method. Aragonite used from Rao Method														
	Aragonite prepared by Rao method, batch 2														

xrdpeak2.xls

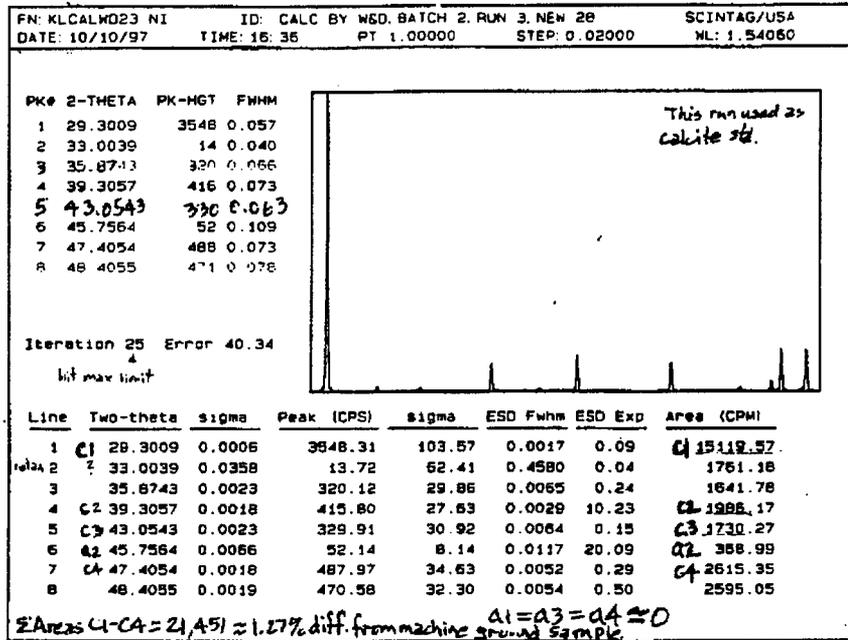


Figure D1 Curve fit of XRD pattern with peak areas: calibration powder, calcite: Wray/Daniel method

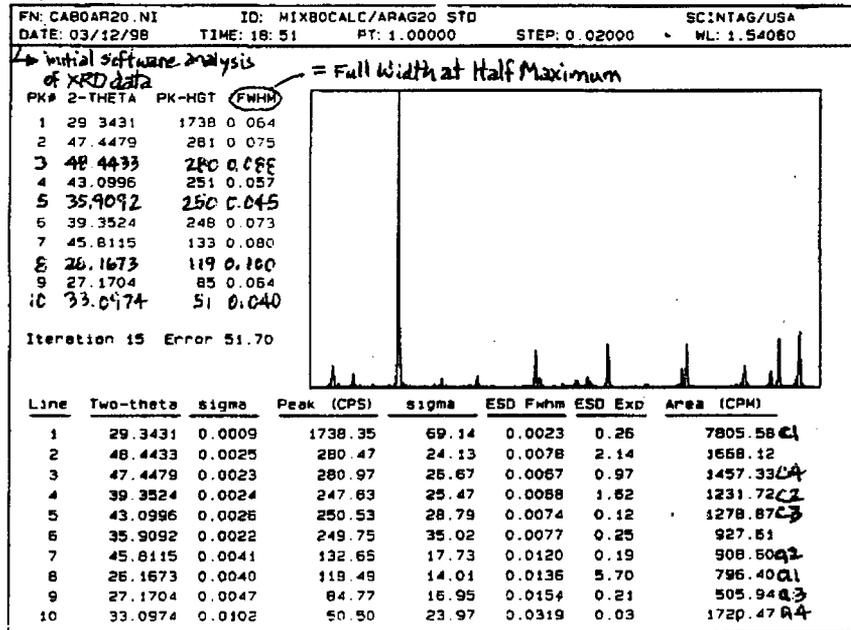


Figure D2 Curve fit of XRD pattern with peak areas: calibration powder, 80% calcite, 20% aragonite

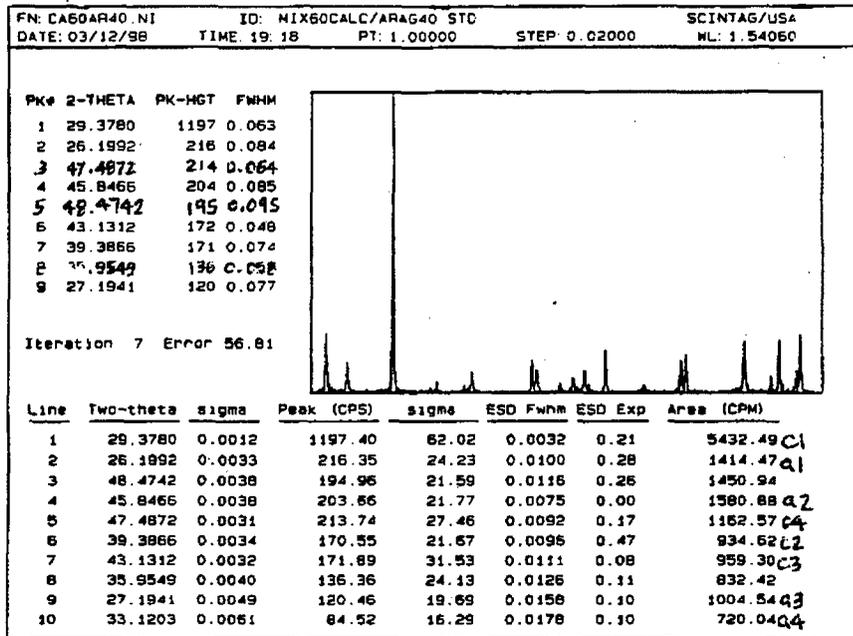


Figure D3 Curve fit of XRD pattern with peak areas: calibration powder, 60% calcite, 40% aragonite

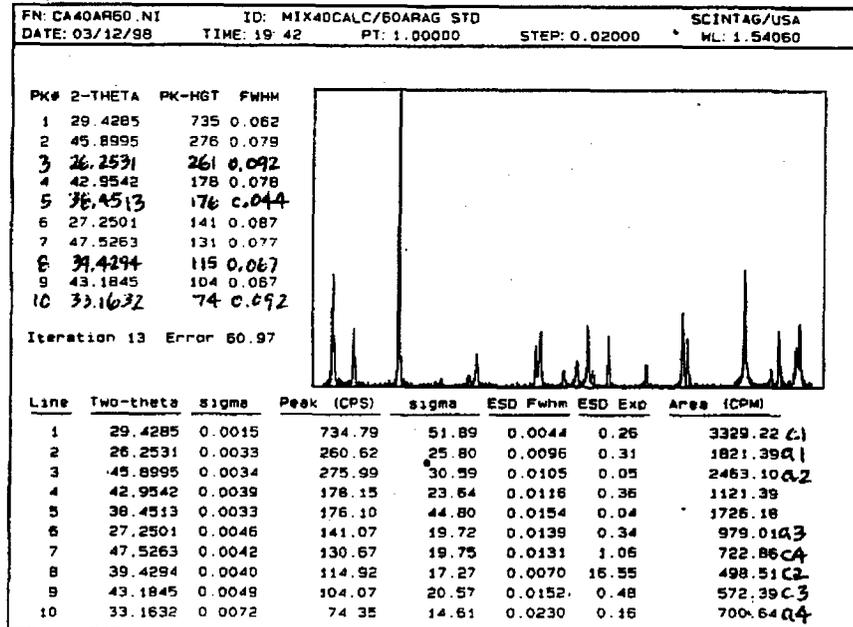


Figure D4 Curve fit of XRD pattern with peak areas: calibration powder, 40% calcite, 60% aragonite

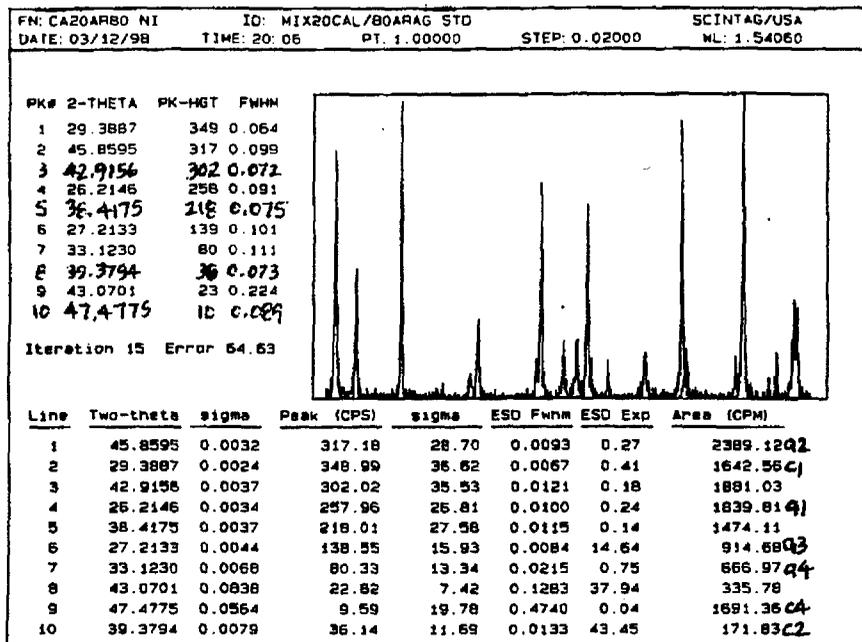


Figure D5 Curve fit of XRD pattern with peak areas: calibration powder, 20% calcite, 80% aragonite

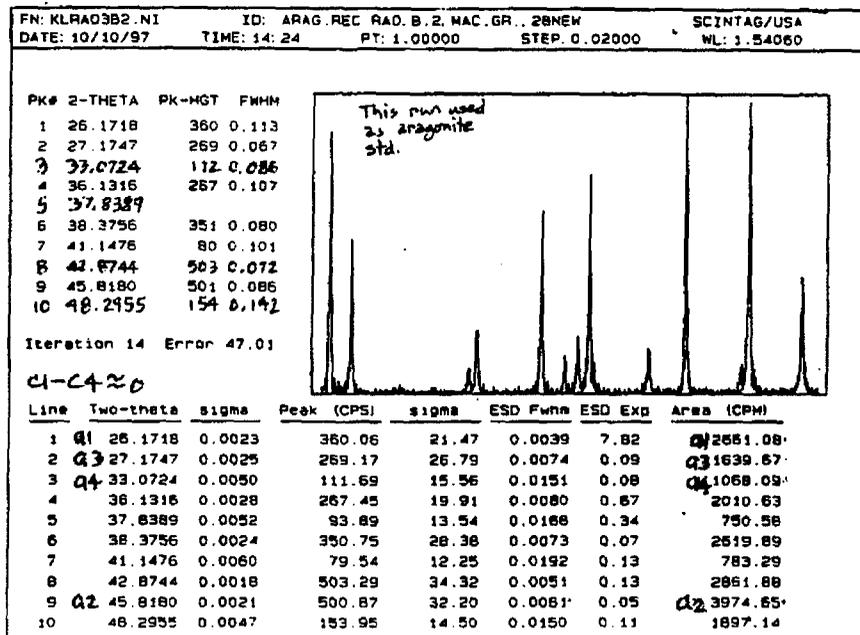


Figure D6 Curve fit of XRD pattern with peak areas: calibration powder, aragonite by Rao's method

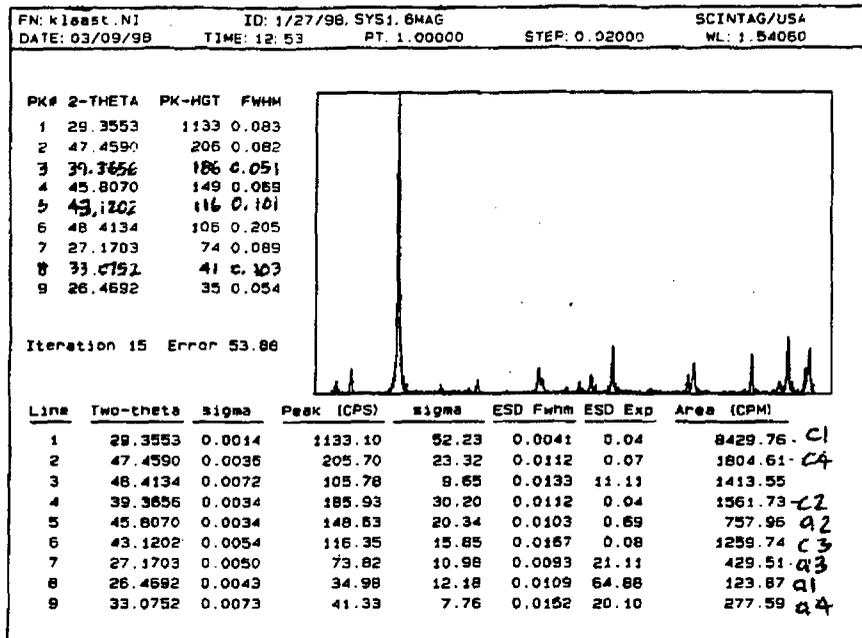


Figure D7 Profile curve fit of XRD pattern with peak areas: system 1 test date 1/27/98, 6 magnets

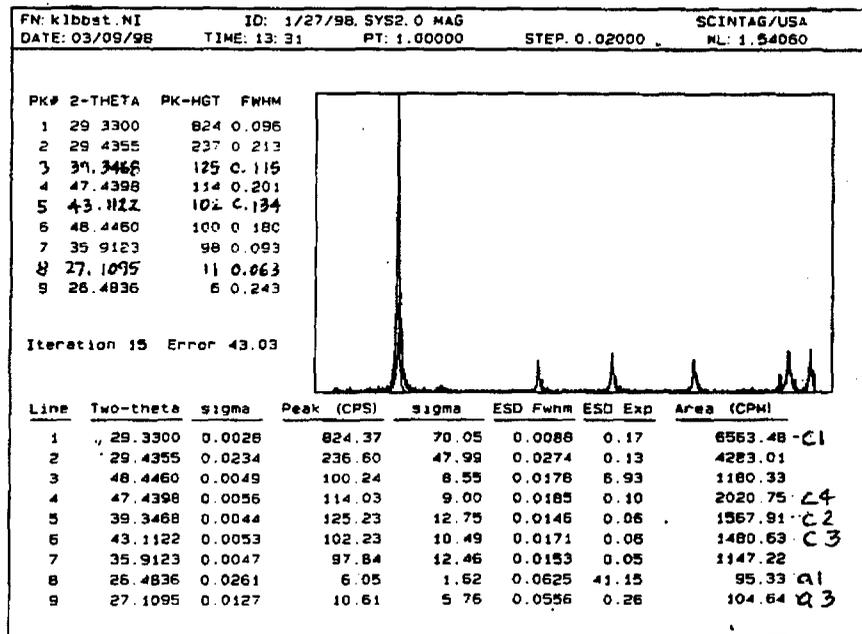


Figure D8 Profile curve fit of XRD pattern with peak areas: system 2 test date 1/27/98, 0 magnets

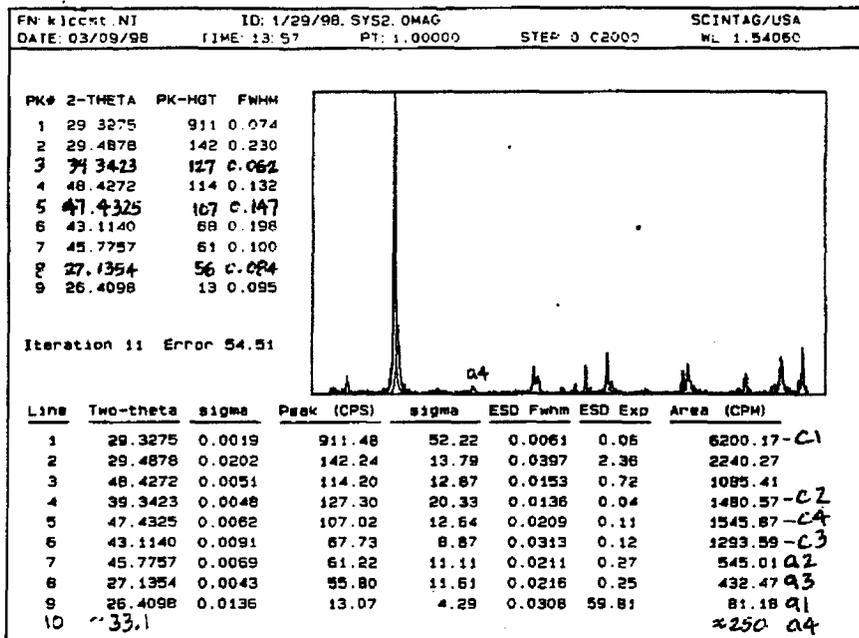


Figure D9 Profile curve fit of XRD pattern with peak areas: system 2 test date 1/29/98, 0 magnets

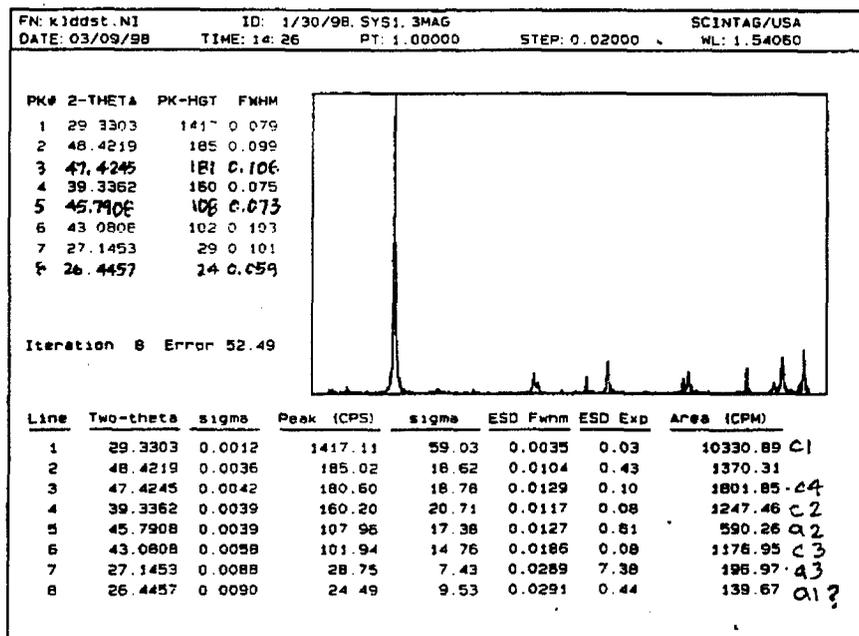


Figure D10 Profile curve fit of XRD pattern with peak areas: system 1 test date 1/30/98, 3 magnets

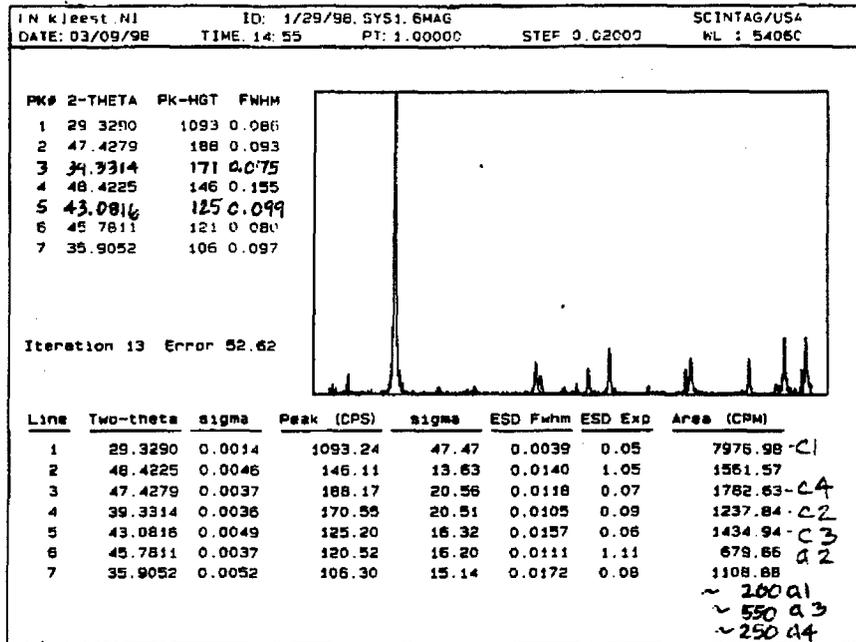


Figure D11 Profile curve fit of XRD pattern with peak areas: system 1 test date 1/29/98, 6 magnets

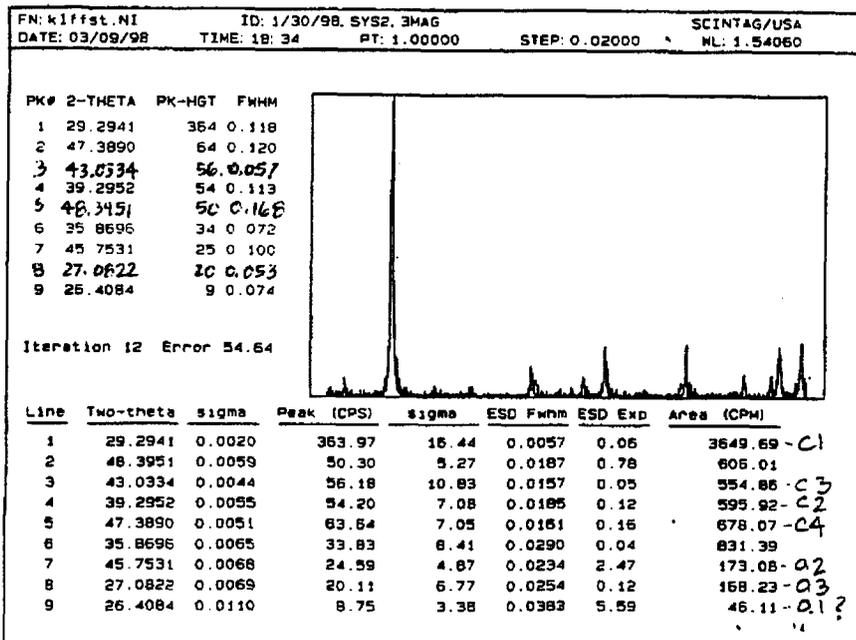


Figure D12 Profile curve fit of XRD pattern with peak areas: system 2 test date 1/30/98, 3 magnets

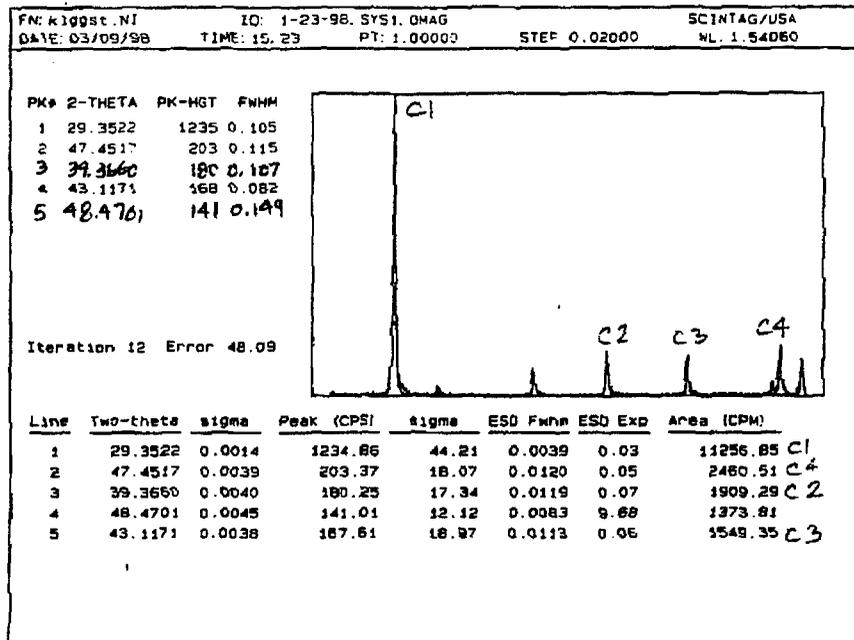


Figure D13 Profile curve fit of XRD pattern with peak areas: system 1 test date 1/23/98, 0 magnets

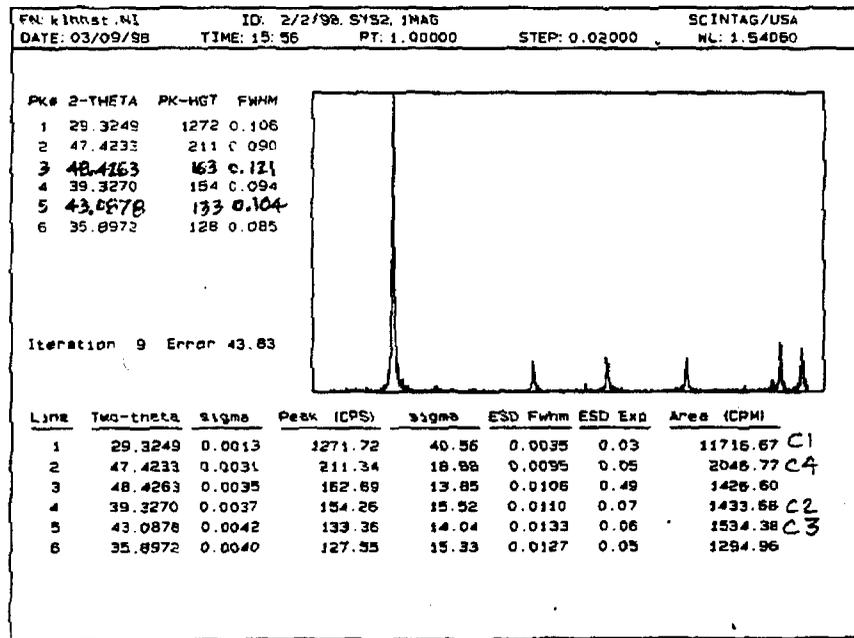


Figure D14 Profile curve fit of XRD pattern with peak areas: system 2 test date 2/2/98, 1 magnet

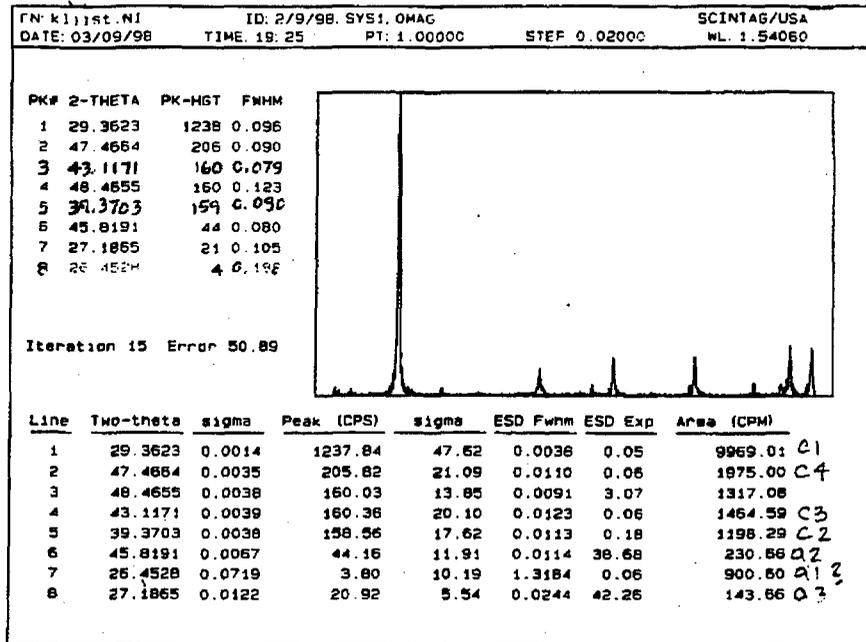


Figure D15 Profile curve fit of XRD pattern with peak areas: system 1 test date 2/9/98, 0 magnets

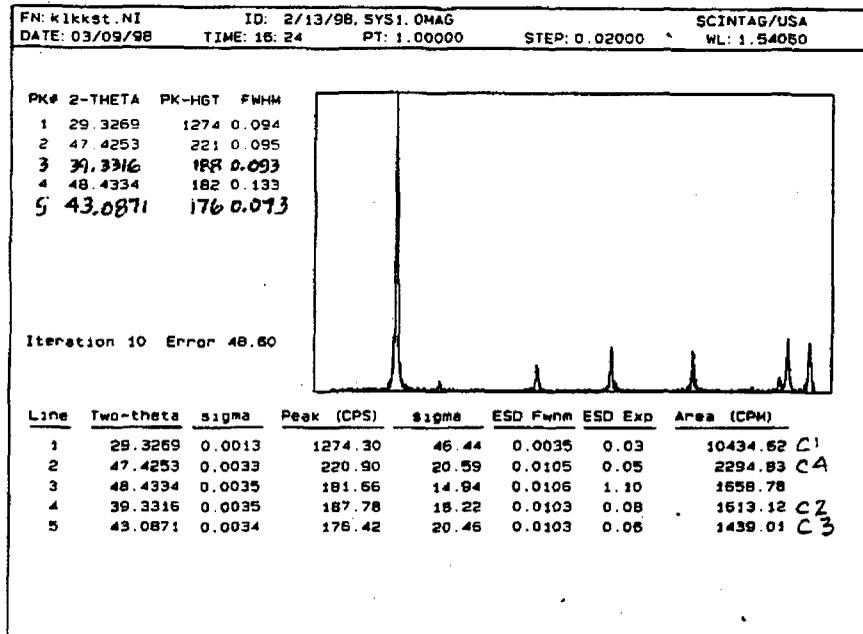


Figure D16 Profile curve fit of XRD pattern with peak areas: system 1 test date 2/13/98, 0 magnets

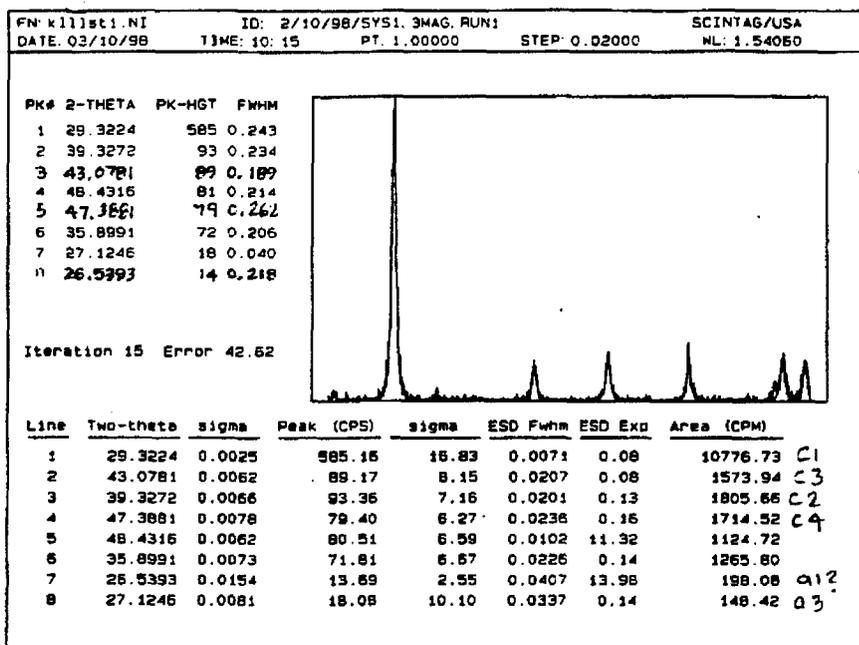


Figure D17 Profile curve fit of XRD pattern with peak areas: system 1 test date 2/10/98, 3 magnets

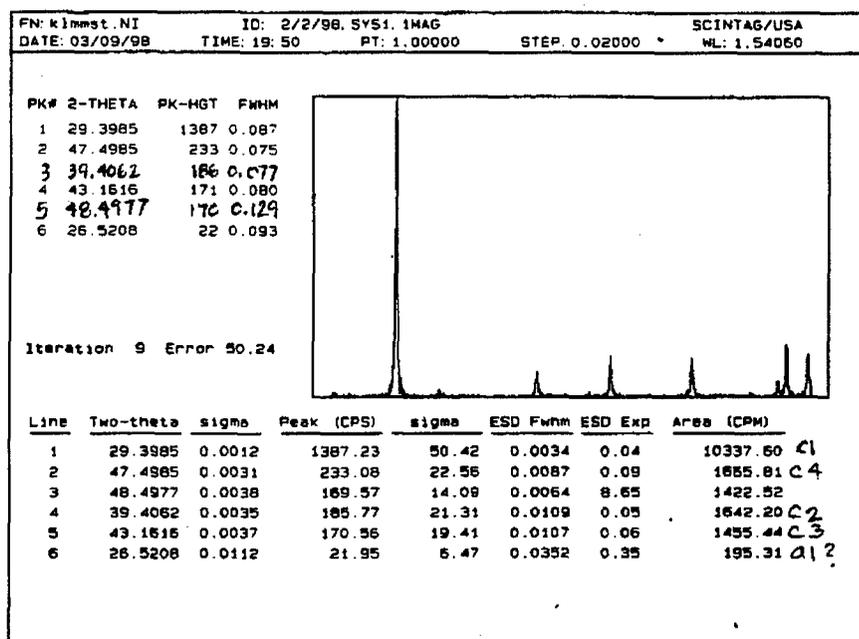


Figure D18 Profile curve fit of XRD pattern with peak areas: system 1 test date 2/2/98, 1 magnet

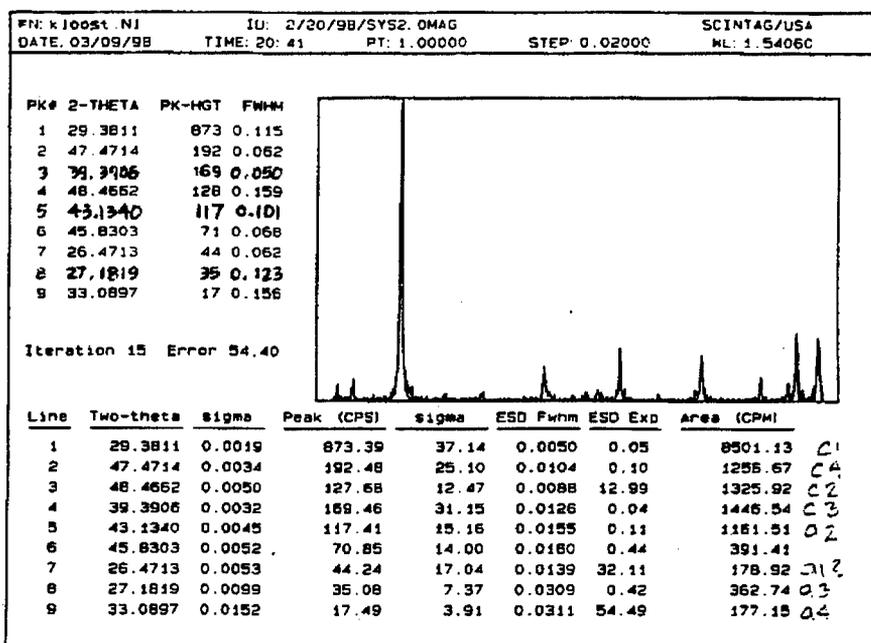


Figure D19 Profile curve fit of XRD pattern with peak areas: system 2 test date 2/20/98, 0 magnets

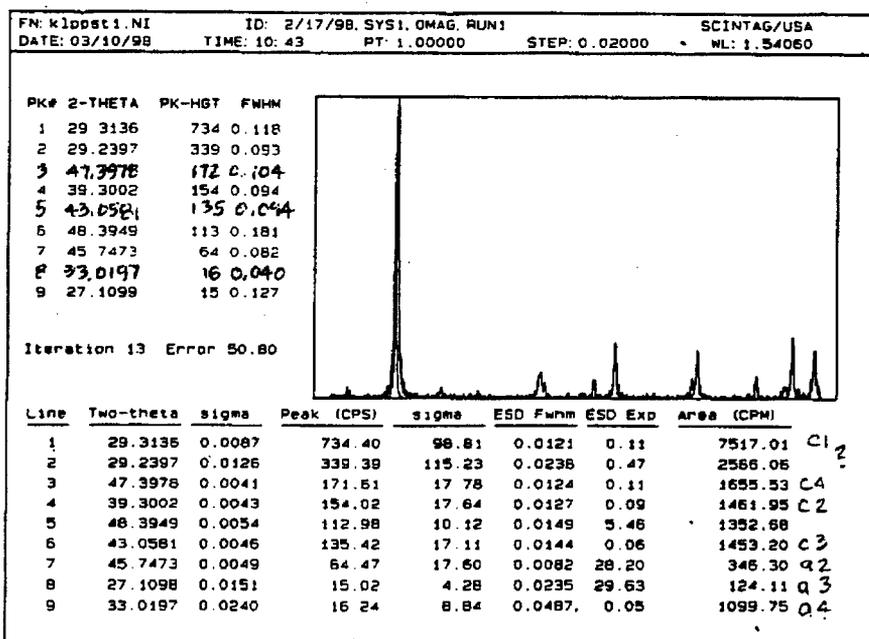


Figure D20 Profile curve fit of XRD pattern with peak areas: system 1 test date 2/17/98, 0 magnets

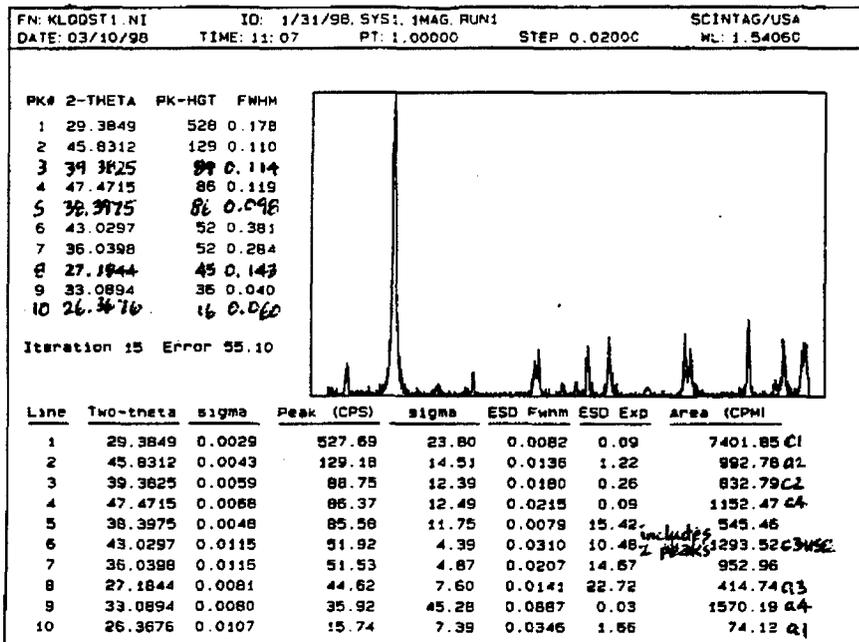


Figure D21 Profile curve fit of XRD pattern with peak areas: system 1 test date 1/31/98, 1 magnet, about 0.7 gr. powder in sample holder without glass disk

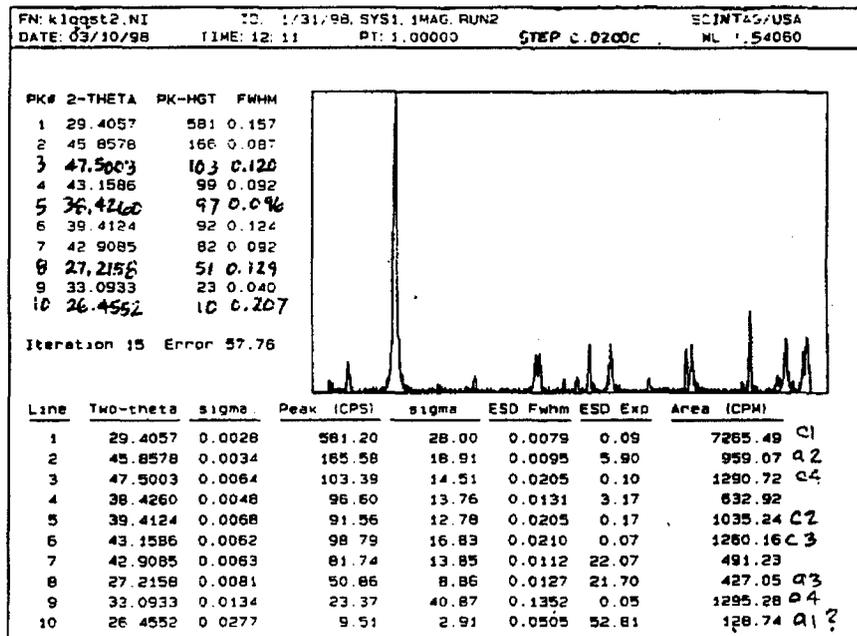


Figure D22 Profile curve fit of XRD pattern with peak areas: system 1 test date 1/31/98, 1 magnet, about 0.3 gr. powder in sample holder with glass disk

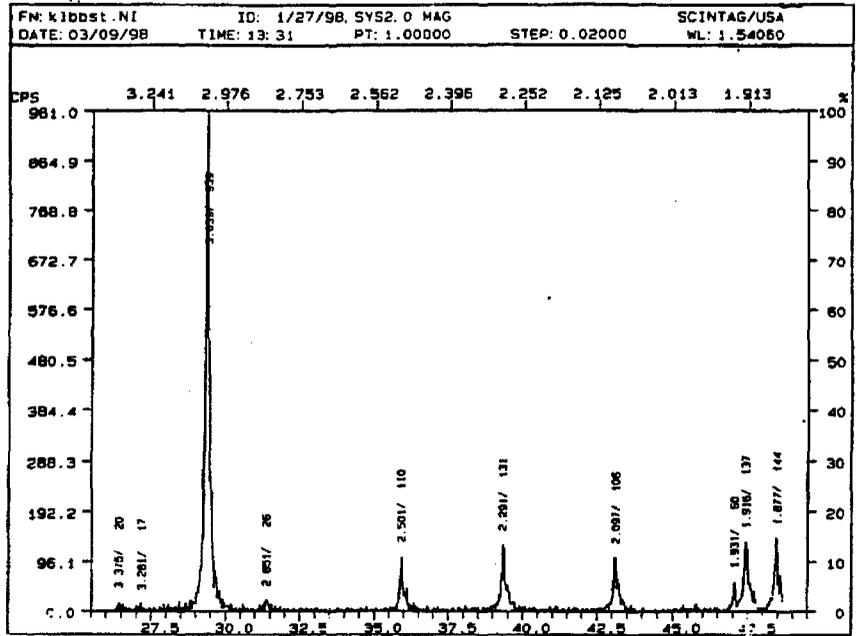


Figure D23 XRD pattern shows peak heights, planar "D" spacing: system 2 tested 1/27/98, 0 magnets

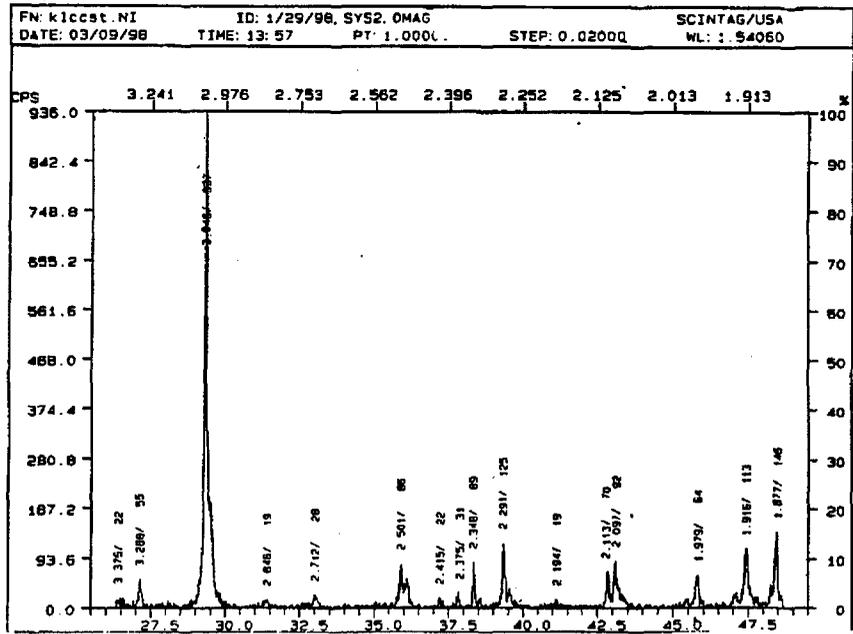


Figure D24 XRD pattern shows peak heights, planar "D" spacing: system 2 tested 1/29/98, 0 magnets

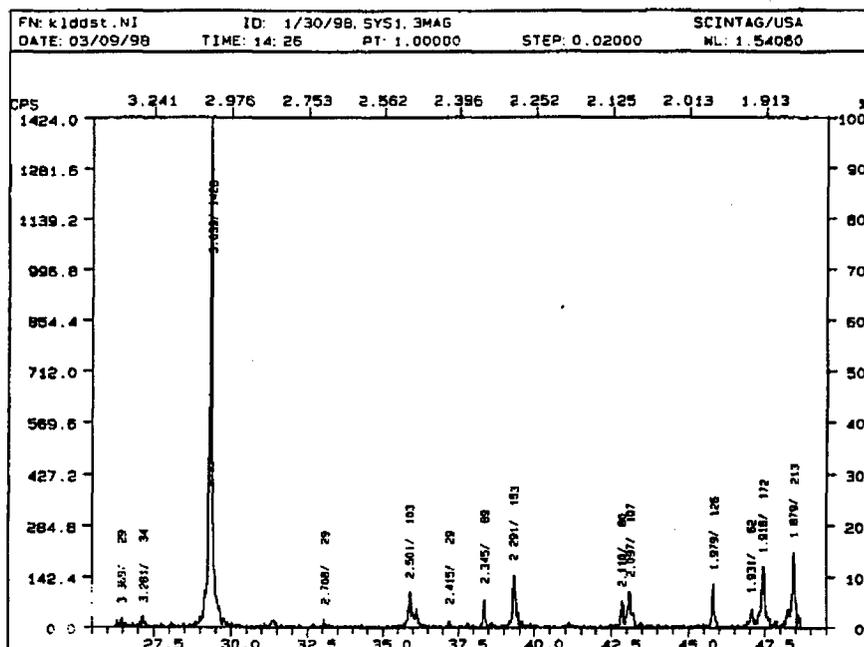


Figure D25 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 1/30/98, 3 magnets

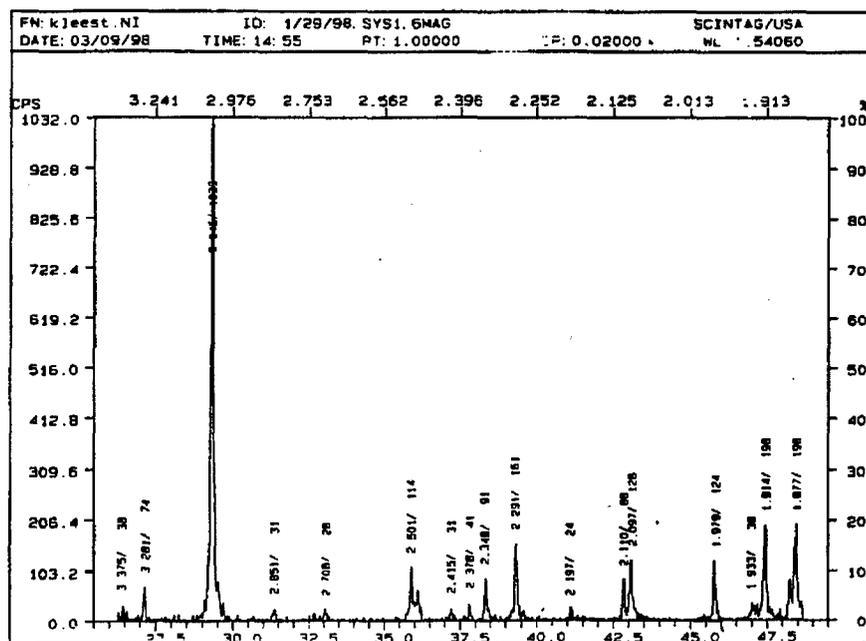


Figure D26 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 1/29/98, 6 magnets

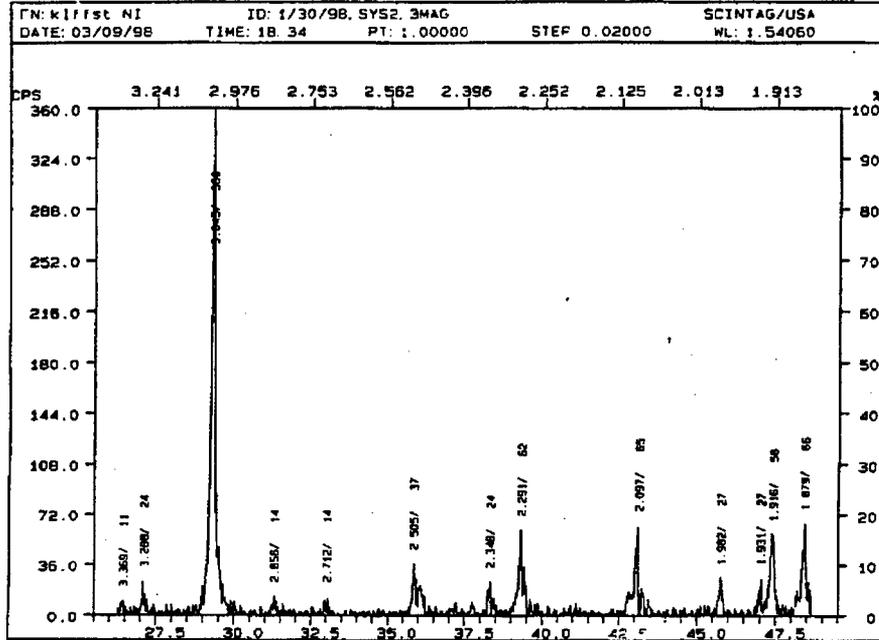


Figure D27 XRD pattern shows peak heights, planar "D" spacing: system 2 tested 1/30/98, 3 magnets

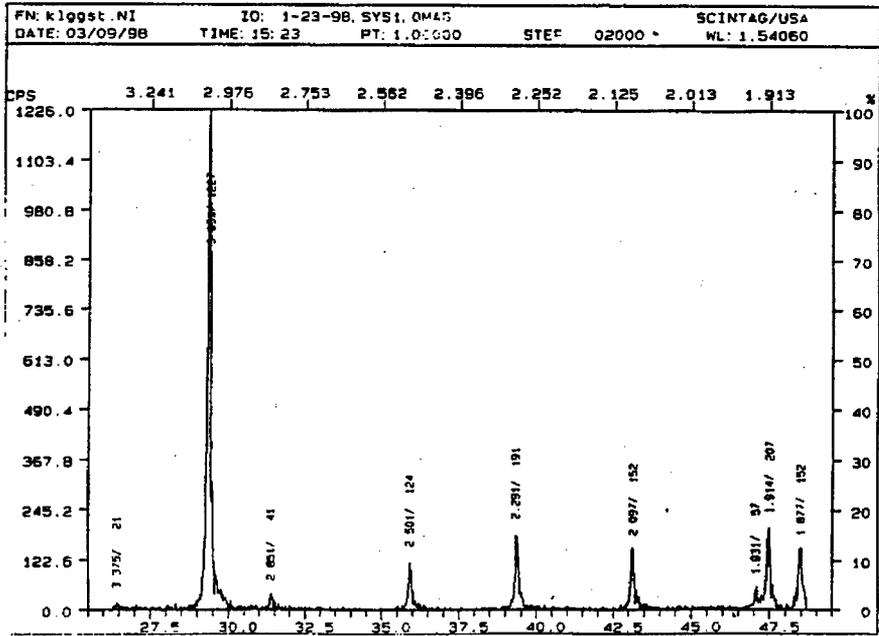


Figure D28 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 1/23/98, 0 magnets

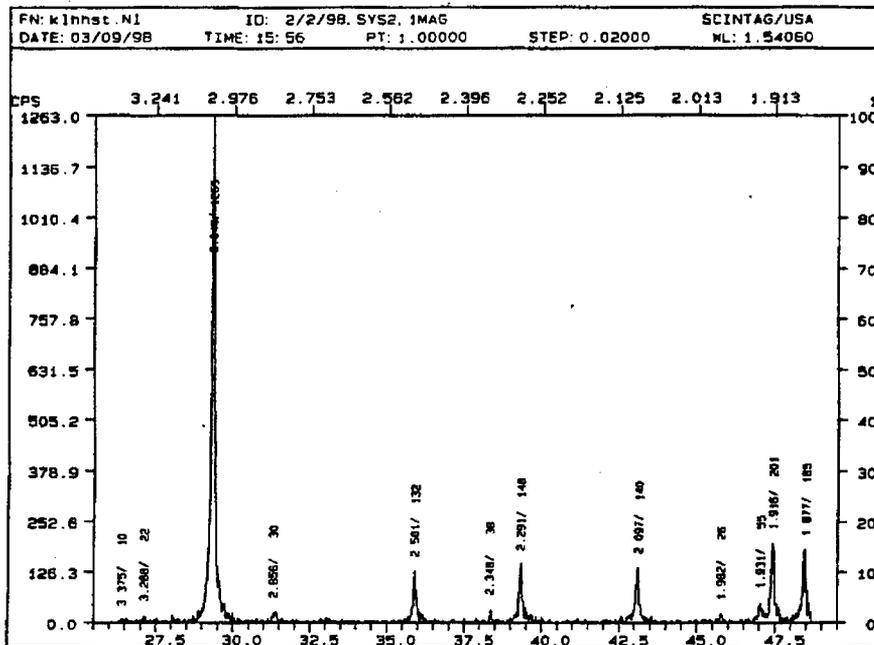


Figure D29 XRD pattern shows peak heights, planar "D" spacing: system 2 tested 2/2/98, 1 magnet

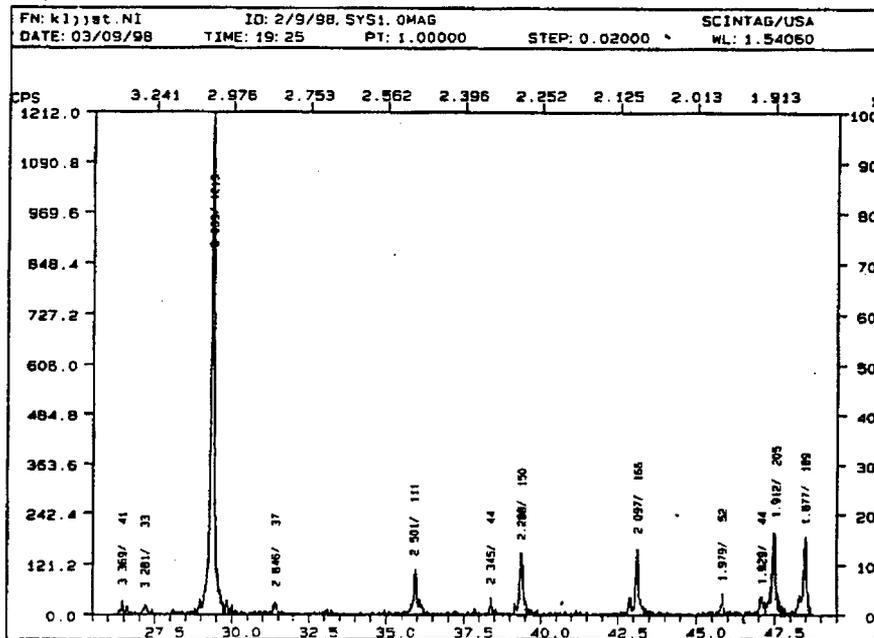


Figure D30 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 2/9/98, 0 magnets

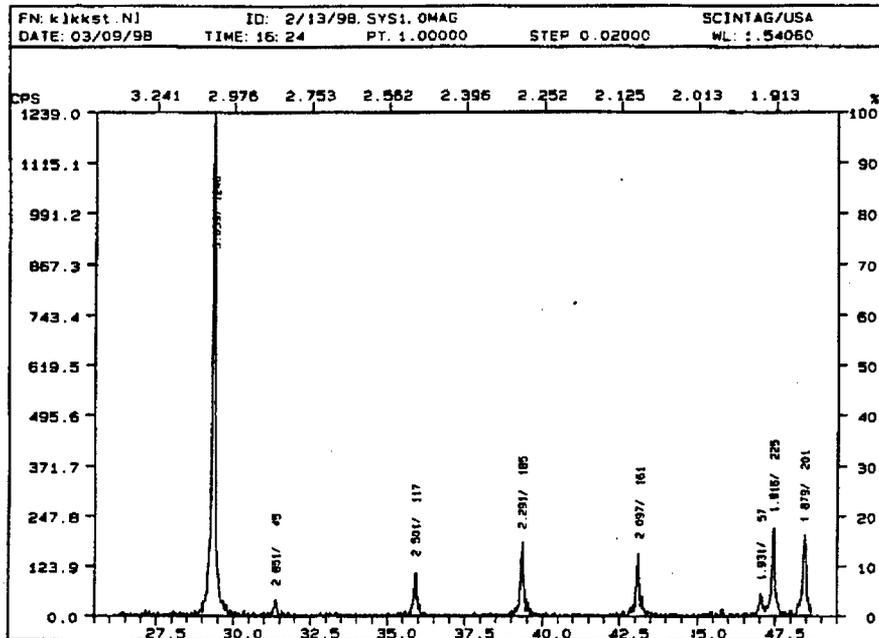


Figure D31 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 2/13/98, 0 magnets

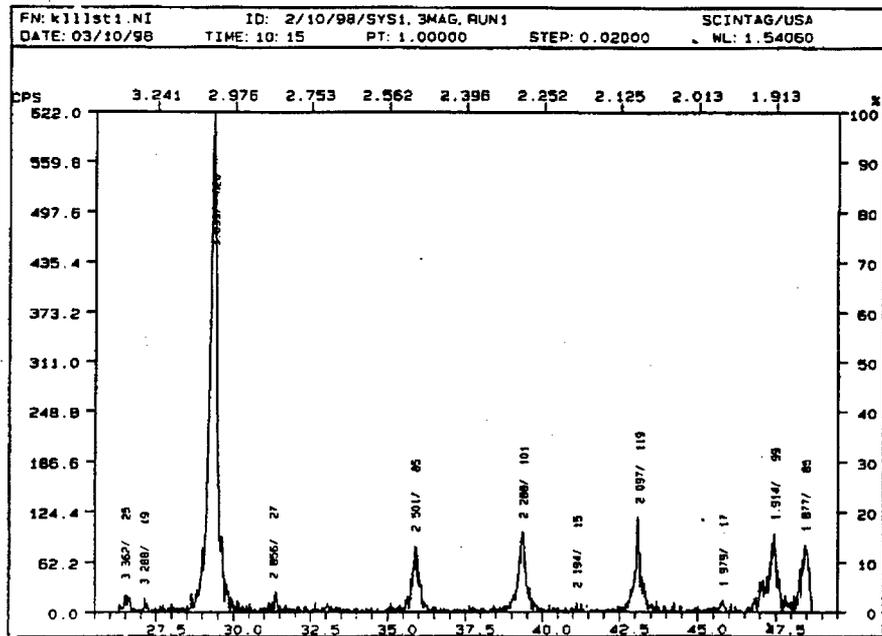


Figure D32 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 2/10/98, 3 magnets

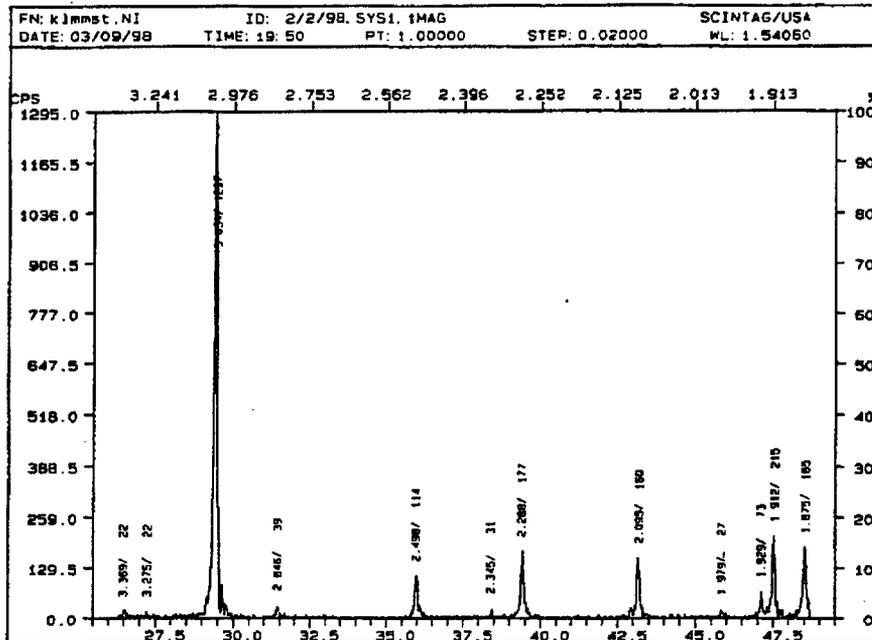


Figure D33 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 2/2/98, 1 magnet

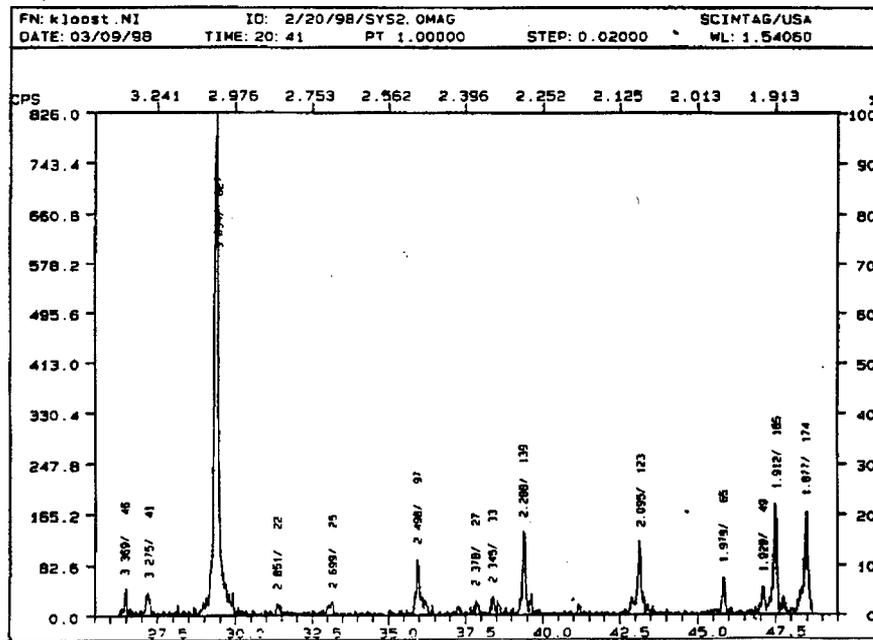


Figure D34 XRD pattern shows peak heights, planar "D" spacing: system 2 tested 2/20/98, 0 magnets

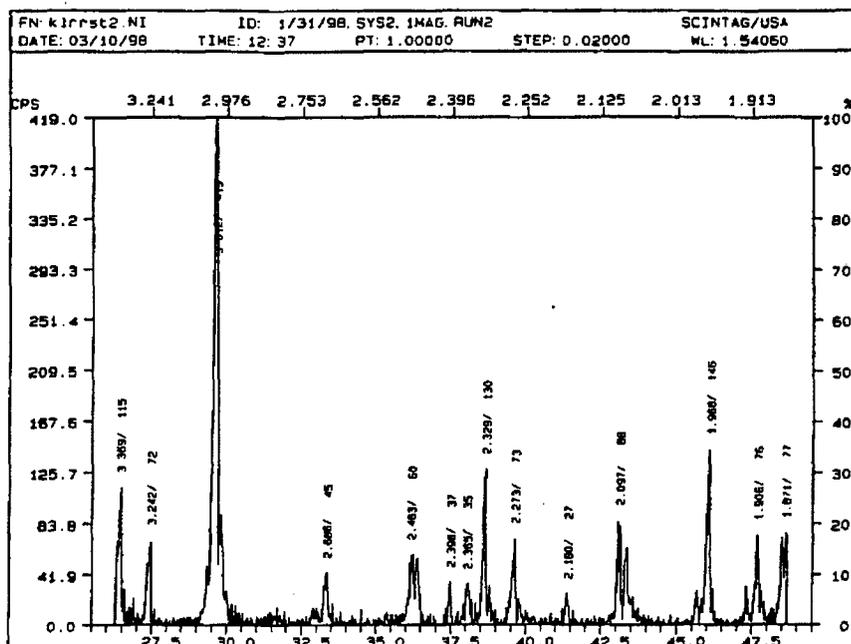


Figure D35 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 2/17/98, 0 magnets about 0.3 gr. powder in sample holder with glass disk

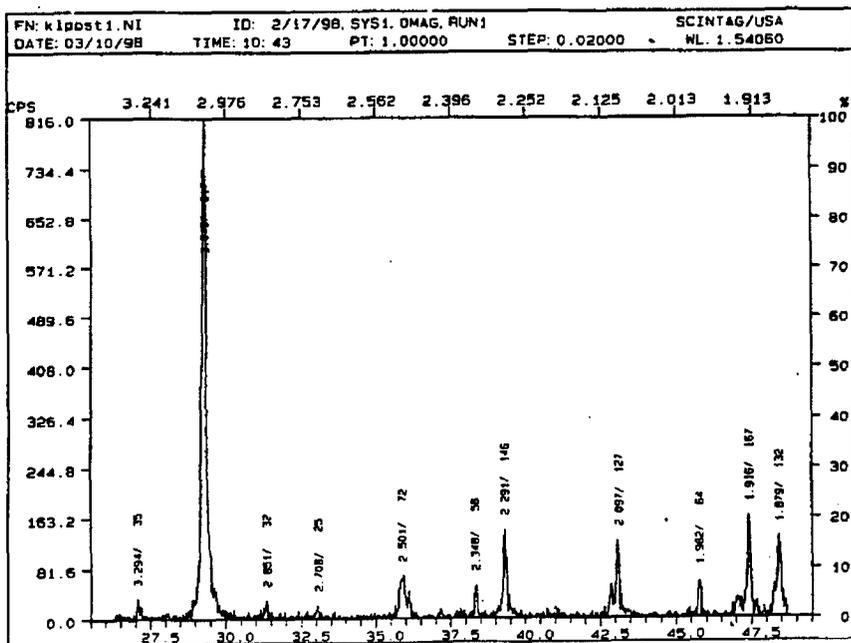


Figure D36 XRD pattern shows peak heights, planar "D" spacing: system 2 tested 1/31/98, 1 magnet

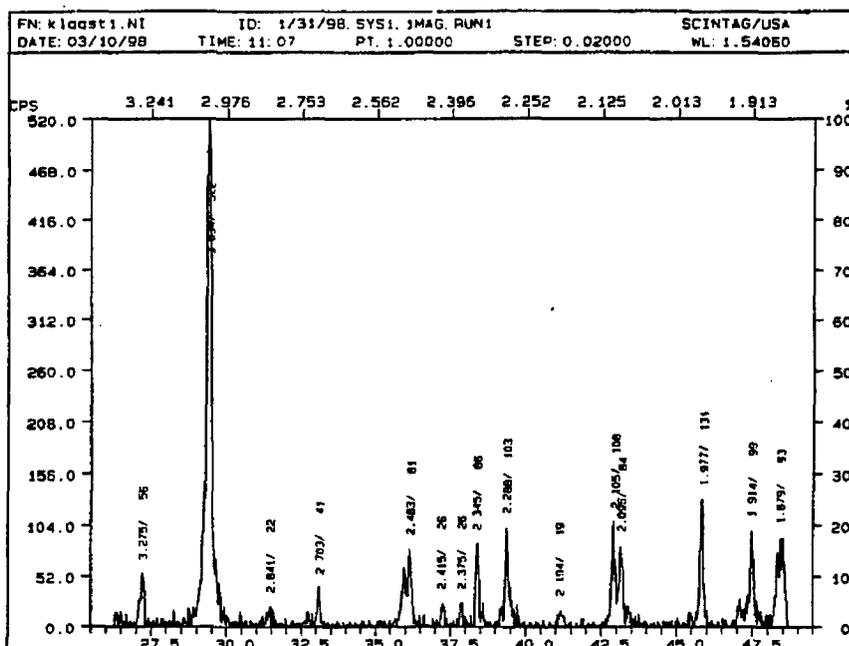


Figure D37 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 1/31/98, 1 magnet, about 0.7 gr. powder in sample holder without glass disk

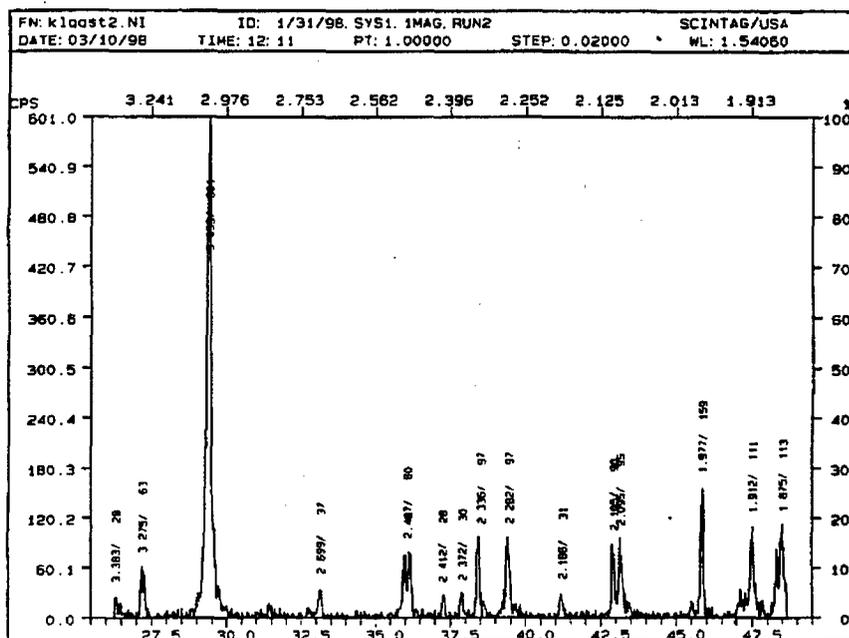


Figure D38 XRD pattern shows peak heights, planar "D" spacing: system 1 tested 1/31/98, 1 magnet, about 0.3 gr. powder in sample holder with glass disk