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DEPARTMENT OF THE AIR FORCE

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Wright-Patterson Air Force Base, Ohio

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AFIT/GEM/DEM/91S-12

A COMPARATIVE ANALYSIS OF THREE WATER TREATMENT PROGRAMS FOR COOLING TOWER SYSTEMS

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AFIT/GEM/DEM/91S-12

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A COMPARATIVE ANALYSIS OF THREE WATER TREATMENT PROGRAMS FOR COOLING TOWER SYSTEMS

THESIS

Presented to the Faculty of the School of Systems and
Logistics of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Engineering Management

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September 1991

Acknowledgements

This research project took a lot of effort by many people. I would like to thank all those who helped me make this a meaningful project. First, I would like to thank my thesis committee, Capt Tracy Willcoxon (advisor), Capt David Funk, and Dr. Panos Kokoropoulos for their hard work and diligent help throughout this entire process.

Thanks goes to those people in the field who kept the cooling towers operational and helped me understand the process. At WPAFB, I offer my thanks to Sgt. John Sheen at Bldg 271 and Larry Raugh at Bldg 676 for monitoring the systems so closely. At Newark AFB, I would to thank Greg Foltz for all the extra things he did to complete this experiment.

Special thanks goes to Kevin McLaughlin, WPAFB, Kevin Adams, Newark AFB, and Jeff Eldridge, Crown Engineering for helping me put this study together and then understanding what I had when it was over.

And a special note of thanks to my wife Kelly for her support throughout this whole ordeal.

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Abstract

This study investigated the cost and effectiveness of three cooling tower water treatment programs. The programs studied were an acid program developed at WPAFB, a commercial solubilizer program manufactured by Lombardi, Inc, and a crystal modifier program developed by Dias, Inc. The experiment ran for 60 days at which time cost and effectiveness data were collected. Cost comparison was evaluated on the basis of tower performance in MBtu. The costs considered in this experiment were water costs , sewer costs, and chemical costs. All costs were recorded and totalled, then divided by the tower's performance. The effectiveness of each treatment method was evaluated on its ability to control scale, inhibit corrosion, and prevent microorganism growth. The results showed the acid and crystal modifier programs cost the same at $.30 per MBtu, while the solubilizer method was almost double the cost at $.54 per MBtu. The crystal modifier was the most effective program based on the three factors measured. All the programs allowed excessive corrosion of one metal (steel or copper), and the crystal modifier allowed unacceptable scale growth on the tower's drift eliminators.

A COMPARATIVE ANALYSIS OF THREE WATER TREATMENT PROGRAMS FOR COOLING TOWER SYSTEMS

I. Introduction

The purpose of water treatment in cooling tower systems is to eliminate or reduce scale buildup, prevent fouling, control corrosion, and stop microbiological growth (Drew, 1983:43). Scale, a hard mineral deposit, when it builds up in the pipes and equipment reduces the heat-transfer capabilities of the heat exchanger and also reduces the water flow in the system - resulting in an inefficient system. Another major problem in cooling towers is corrosion. Corrosion actually destroys the metal in the system causing leaks and damaging pumps and associated equipment. Corrosion problems left unchecked can lead to very expensive repairs. Uncontrolled microbiological growth in the system can cause fouling (obstruction of water flow and heat transfer), human health problems, and increase corrosion rates of metal surfaces. Legionnaire's disease is a prime example of a serious health problem associated with cooling towers (AFP 91-41,1988:21).

A good treatment program aimed at controlling the problems mentioned previously can improve cooling tower performance and reduce system downtime. Any downtime is critical, especially for a cooling tower supporting air conditioning systems for hospitals or mission-essential computer hardware. These programs are site specific and dependent on water chemistry, tower characteristics, and environmental limitations (Irving-Monshaw, 1989:60). Therefore, it is essential that systems' operators and engineers in the Air Force implement effective and economical cooling tower water treatment programs. The purpose of this research effort was to evaluate the effectiveness and the costs of operating three different water treatment programs at Wright-Patterson AFB (WPAFB) and Newark AFB.

It is important that Air Force personnel responsible for operating and maintaining cooling towers have a good working knowledge of the different treatments available. With this information they can manage an effective treatment program. The Air Force has multi-million dollar facilities that rely heavily on the air conditioning provided by cooling tower systems. Air Force Logistics Command (AFLC) alone has 319 cooling towers valued at over $19 million. Table 1 on the following page lists the location and costs of AFLC towers.

Definition of Terms

Terms commonly used in cooling tower water treatment.

Acid: A substance that dissolves in water with a formation of hydrogen ions (AFP 91-41, 1988:69).

TABLE 1

TOWERS AT AFLC BASES

BASE	NO. OF TOWERS	VALUE(million)
Wright Patterson	40	Not Avail.
Hill	57	$2.8
McClellan	103	$0.9
Tinker	28	$2.2
Kelly	31	$0.9
Robins	59	$11.0
Newark	1	$1.0

Alkalinity: A measure of water's capacity to absorb hydrogen ions without significant pH change (i.e., to neutralize acids) (Clark and others, 1977:415).

Anion: A negatively charged ion resulting from dissociation of salts, acids, or alkalies in aqueous solution (Nalco, 1979:G-1).

Anode: The electrode (part of the metal surface) that supplies electrons to an external circuit (Van Vlack, 1980:524).

Blowdown: Removal of water from an evaporating water system to maintain a solids balance within specified limits of concentration of those solids (Nalco, 1979:G-2).

Cation: A positively charged ion resulting from dissociation of molecules in solution (Nalco, 1979:G-2).

Cathode: The electrode that receives electrons from an external circuit (Van Vlack, 1980:526).

Conductivity: The reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specified temperature.

Electrical conductivity is expressed in micromhos (mmhos). This is used as a measure of total dissolved solids (AFP 91-41, 1988:69).

Corrosion: The destruction of a substance; usually a metal, or its properties because of a reaction with its surroundings (AFP 91-41, 1988:70).

Cycles of Concentration: Ratio of makeup water quantity to the blowdown quantity (AFP 91-41, 1988:70).

Dispersant: A chemical which causes particulates in a water system to remain in suspension (Nalco, 1979:G-3).

Foulants: Deposition of materials normally in suspension. This includes such things as silt, air scrubbed dust, microbiological residuals, reaction products from treatment, and corrosion products (AFP 91-41, 1988:70).

Hardness: A characteristic of water, chiefly due to the existence of carbonate and sulfate salts of calcium, iron, and magnesium (AFP 91-41, 1988:70).

Ion: An atom or radical in solution carrying an integral electrical charge either positive or negative (Nalco, 1979:G-5).

Makeup water: Water supplied to replace the loss in a system by leaks, evaporation, wind drifts, bleedoff, blowdown, or withdrawal (AFP 91-41, 1988:71).

Oxidation: A chemical reaction in which an element or ion is increased in positive valence, losing electrons to an oxidizing agent (Nalco, 1979:G-6).

pH: The hydrogen-ion activity (i.e., intensity of the acid or alkaline condition of a solution) (Clark and others, 977:414). pH is measured from 1 to 10, 1 being the extreme acid condition and 10 being the extreme alkaline condition.

Precipitate: An insoluble reaction product; in an aqueous chemical reaction, usually a crystalline compound that grows in size to become settleable (Nalco, 1979:G-6).

Scale: The precipitate that forms on surfaces in contact with water as the result of a physical or chemical change (Nalco, 1979:G-7).

Sludge: A water-formed deposit that will settle and may include all suspended solids carried by water (AFP 91-41, 1988:71).

Solubility: The amount of a substance that will dissolve in a given amount of another substance (Webster's, 1979:1099).

Cooling Tower Operation Defined

Cooling tower systems used in this study are the open recirculating type. Figure 1 shows a simplified single cell cooling tower. It is a simplified single line drawing that shows how the water circulates through the important parts of the system. The system is considered open because

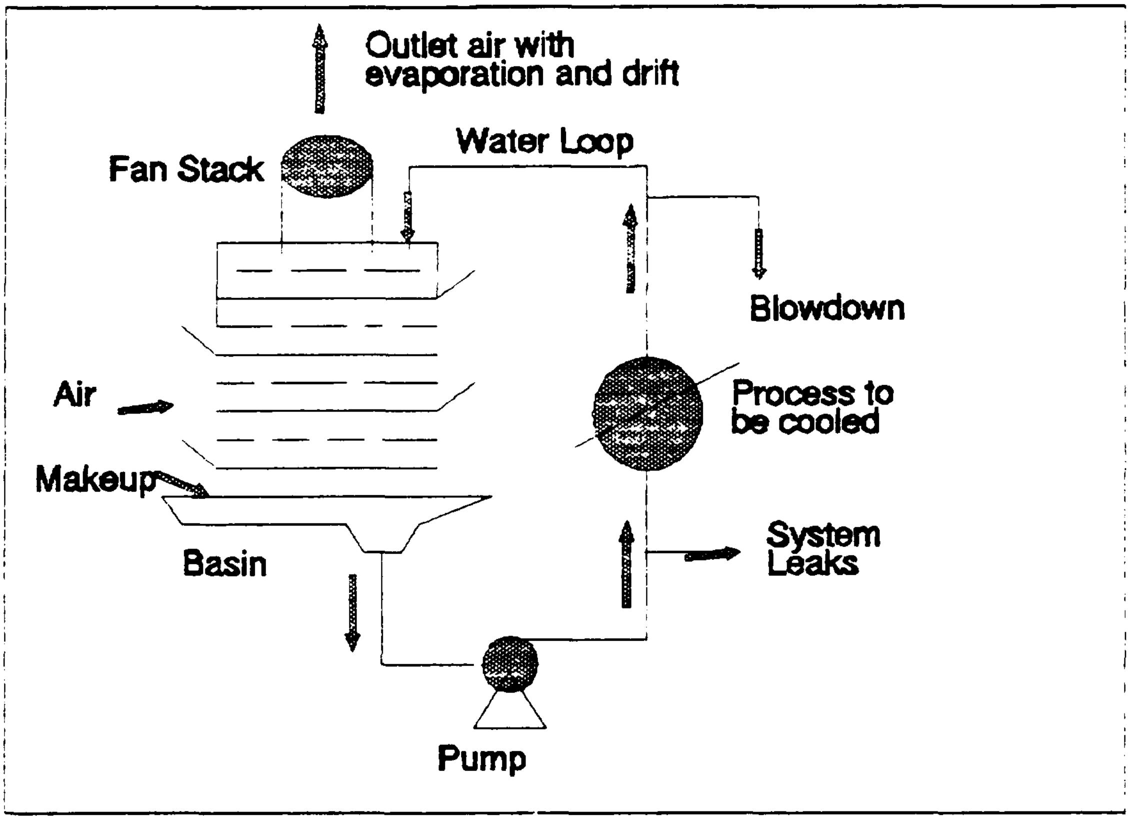

Figure 1. Cooling Tower Operation (AFP 91-41, 1987:15)

the water is pumped to the top of the tower and allowed to fall freely through the air in the tower. Recirculating means the same water is recycled through the system multiple times.

A once-through system (the water goes through the system once and then it is discharged from the system - sometimes a cooling tower is not even used) operates under the same principles using similar equipment as the open recirculating system but is not very efficient unless there is a cheap and plentiful water source for makeup water (AFP 91-41:13). The cooling tower system consists of the tower, the heat-transfer units (condensers), and the water distribution lines. Throughout this study, cooling tower and cooling tower system will be used interchangeably.

The cooling tower removes heat from the water by allowing a portion of the heated water to evaporate as it falls through the tower. The evaporation process releases heat to the atmosphere and lowers the temperature of the remaining water. The heat rejected is measured in British thermal units (Btu). A Btu is the amount of heat required to increase the temperature of a pound of water one degree Fahrenheit (McCoy, 1983:4).

The remaining cooled water falls to the bottom of the tower and is pumped back into the system and reused. The number of times the water is reused or recycled through the system is called cycles of concentration (COC). Obviously in locations where water is scarce or expensive, a treatment program that allows high COCs will reduce water usage. Lower water consumption not only saves water costs, but also reduces blowdown and its treatment costs. In addition, less treatment chemicals are necessary since the system requires less makeup water.

A good example of cost savings due to increased COCs comes from a trip report on a visit to Hill AFB, Utah by the Air Force Logistics Command's Corrosion Engineer. Hill AFB's 57 towers operated at about 1.1 COC and the annual cost of the water used was $350,000. Yearly water savings were calculated for higher COCs, and in this case range from $137,100 if COCs are raised to 1.65 and $153,900 if 3 COCs are maintained (Willcoxon:1990). In Figure 2 the makeup water requirements are plotted against the cycles of concentration for temperature drops of 30, 20, and 10 degrees fahrenheit across the cooling tower. The graph clearly illustrates the dramatic water savings that can be attained by increasing cycles by one or two.

When cycles of concentration are increased though, another problem arises. This problem is high concentrations of unwanted substances. As a percentage of the water is allowed to evaporate in the cooling tower, the impurities in the remaining water such as calcium, silica, sulfate, and phosphate do not evaporate but become more and more concentrated with each cycle. As the water in the

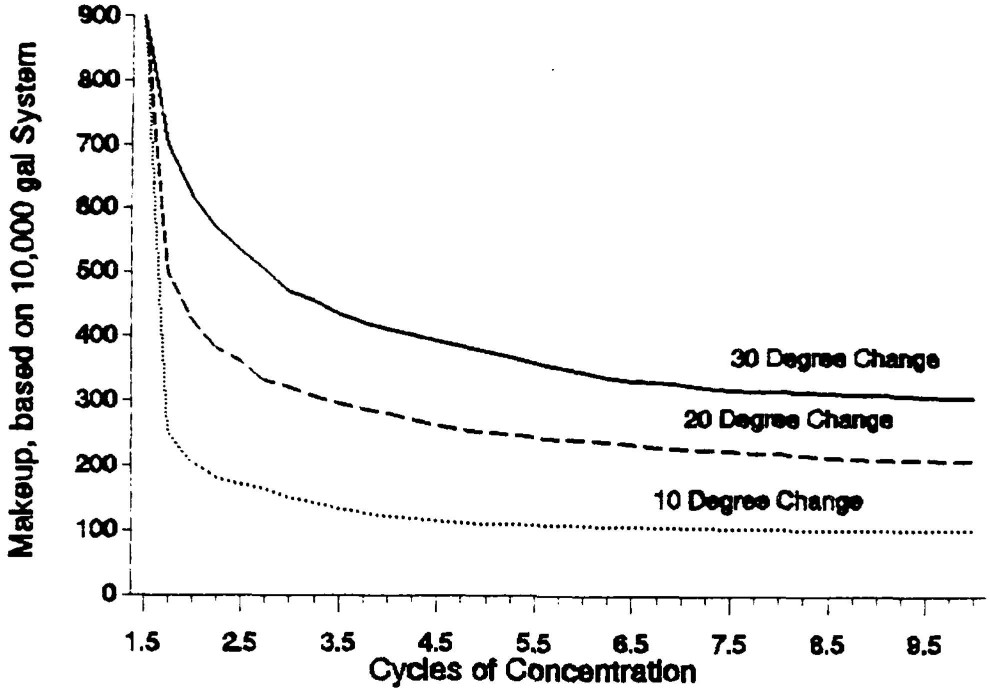

Figure 2. Effect of *COCs on* Makeup (Drew, 1983:123)

system continues to become more concentrated in these impurities, they begin to precipitate, fall out of the water, and form deposits on surfaces (these surfaces can be the interior of pipes, pumps or any other surface in the system). Therefore the water treatment program must keep these impurities in solution or not allow them to build up on the pipes and equipment. Another point to remember is that the increased concentrations of impurities can lead to very quick scale formation if the treatment fails (Strauss and Puckorius, 1984:5). Close monitoring of the system is therefore essential.

Until recently one of the most popular water treatment methods was the sulfuric acid program. This program is still indorsed by Air Force Regulation 91-40. System operators use sulfuric acid to lower the pH and alkalinity of the water thereby increasing the solubility of the scale forming minerals. The more soluble the minerals are the less likely they are to precipitate out of the water and form scale.

Acids require special handling though, and COCs are limited using an acid program. Also, acids can cause severe and rapid corrosion if system control is lost even for a short time. These are just a few reasons why the water treatment industry developed newer methods for controlling scale in cooling tower systems.

Air Force Policy

Air Force Regulation 91-40 states, all industrial water systems (including cooling tower systems) shall be treated and tested using generic chemicals (1987:1). Additionally, three approved treatment programs are listed in Air Force Pamphlet 91-41 (1988). Chapter 3 of the pamphlet is devoted entirely to cooling towers and their water treatment.

AFP 91-41 addresses three ways of controlling scale. (1) This first method explains the use of acid in preventing calcium phosphate and calcium carbonate scale. (2) This second method discusses adding 1-

hydroxyethylidene-1, 1-diphosphonic acid (HEDP) to the water to help prevent other calcium salts from forming scale. (3) The final method is adjusting COC to prevent high concentrations of silica and calcium salts. Table 3-1 of AFP 91-41 lists seven biocides used to control microbiological growth (21). For fouling control, AFP 91-41 suggests using a dispersant like polyacrylate acid. Also five corrosion inhibitors have been approved for controlling corrosion. Attachment four to AFP 91-41(C1) lists these chemicals with their federal specification and national stock number (AFP 91-41, 1988). These chemicals and biocides are listed in Appendix A.

Problem

Base Civil Engineers (BCE) and mechanical superintendents are faced with the difficult task of determining the best water treatment method for their cooling tower systems given their specific water conditions. Additionally, the quantity and cost of the makeup water are factors as well as the materials used in the cooling system.

To further complicate matters, the chemical industry continually develops new chemical blends and techniques for water treatment. The BCE and mechanical superintendent must develop generic programs in an area where technological improvements are fast paced. Many bases encouraged by these new technological advancements have contracted with chemical proprietors to develop "package" treatment programs. The proprietors supply the chemicals and monitor the system periodically.

McClellan AFB conducted a study from September 1988 to January 1989 to choose a company to provide their cooling tower water treatment chemicals. They had frequent condenser failures due to inconsistencies with the existing chemicals, and lack of in-house manpower. Three companies were given cooling towers for 120 days to maintain with their proprietary chemicals. After the test period, McClellan chose the company that provided the most effective treatment at the lowest cost (Jackson-Gistelli, 1991).

Investigative Questions

The purpose of this research is to evaluate and quantify data on the effectiveness of three different water treatment programs. The outcome of this study will provide a better understanding of the advancements in cooling tower treatments and help the BCE evaluate and select treatments best suited for his or her cooling towers. This experimental research evaluates three different cooling water treatment methods, to determine which one is the most cost effective. The three different treatment methods analyzed were an acid program, a solubilizer program (Organosperse-1311), and a crystal modifier program (DIAS-

AID). The following questions were developed to provide a measure for the effectiveness of the programs:

1. What are the benefits of using a crystal modifier or solubilizer program in lieu of an acid program?
2. Are there cost advantages to any of the programs?
3. Are the operational and maintenance requirements different among the different methods?
4. Is one of the methods more effective against the problems of scale buildup and corrosion?

Hypothesis

Both the crystal modifier and solubilizer programs will prove to be less expensive and more effective than the acid program.

Scope

This research was limited to only three different water treatment programs. There are other programs available, but they are not within the scope of this research effort. Time and proximity of the towers limited the number of towers that could be used in this experiment. These three treatment programs will give a good cross-section of methods currently used in industry and available for Air Force implementation.

II. Literature Review

Introduction

Chapter one introduced the fact there are many methods for treating water in a cooling tower system. This chapter describes how some of these treatment methods work and their effectiveness. The emphasis of this literature review is focused on scale, corrosion, and microbiological control.

This chapter begins with a brief history of cooling water treatment, listing a few of the advancements made since 1930. Next, the types of scale and how they are formed is covered. Following the description of scale is a review of the literature on newer chemical treatment methods available for scale prevention. The acid treatment method is presented first since it is the baseline method for this research. Also, the two treatment methods, solubilizers and crystal modifiers, under examination in this experiment are discussed. After the scale section, the next topic is corrosion and the chemicals used to control it. Microbiological problems and control methods are the final separate chemical treatments addressed. Following the review of chemical treatments, two methods of total treatment are reviewed. These two methods are ozone and magnetic treatment. The technology for ozone treatment is not new but its application to cooling towers is. The final part of this chapter is devoted to a short history on the evolution of cooling tower water treatment methods used at Wright-Patterson AFB, OH.

According to the Betz Handbook of Industrial Water Conditioning, the earliest treatment of cooling tower water began in the 1930's. Acid addition and pH adjustment to control the buildup of calcium carbonate were the extent of treatment at that time. A major development that is still used today was the development of the Langelier Saturation Index (LSI). Cooling tower operators could use the LSI to determine whether scale would form in their system. In the 1940's a new index, the Stability Index, was developed to quantitatively determine the amount of scale that would form in a given system. Instead of simply knowing scale would form, now the severity of the scaling could be determined. Also during this decade considerable research was done in the area of controlling scale deposition. In the 1960's great breakthroughs came in the area of corrosion control. The use of polyphosphates in cooling systems was studied along with the recovery and reuse of chromates. In the 70's the environmental movement started and pressured the cooling tower water treatment industry into reducing the use of chromate and zinc treatment methods. Researchers began looking to polymers and organic phosphates to keep systems clear of fouling. Another big step in the 70's was the improvement of system monitoring devices (1980 :Chap 1).

Before reviewing the methods of water treatment, it is important to have an understanding of scale and scale formation. The next section describes the more common types of scale and some treatment methods.

Scale

Water in many geographical areas contains calcium and magnesium salts that can precipitate out of the water under certain conditions. This precipitate can form hard deposits on surfaces including the inside surfaces of pipes. These deposits are called scale. When scale builds up on a heat transfer surface it acts as an insulator and can drastically reduce the amount of heat transferred between the medium on each side of the surface. Because a cooling system is designed to transfer heat in this way (water in the tube absorbs heat from water inside the system by conduction through the pipe), it is critical that the pipes be as clean as possible. A coating of scale as thin as 0.1 inch on the inside of a tube wall may diminish heat transfer by 40% (Nalco, 1979:38-3). Also scale restricts the flow in the tube by reducing the inside diameter of the pipe. Both reduced heat transfer and pipe diameter lessen the system's efficiency.

There are many kinds of scale but the most common forms are calcium carbonate, calcium sulfate, calcium and magnesium silicates and calcium phosphate. Of this group, calcium carbonate is the most common scale and is found in nearly all cooling towers (Drew, 1983:73). Calcium carbonate is formed when calcium bicarbonate breaks down due to a temperature or pH increase. The resulting products from this breakdown are carbon dioxide and calcium carbonate. Eq (1) shows the calcium bicarbonate breaking down to form these two products and water.

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

The calcium carbonate then precipitates out (arrow pointing down) of the water forming scale. The carbonate forms as scale more rapidly than bicarbonate because of carbonate's lower solubility point. Figure 3 shows that as temperature increases the solubility of calcium carbonate decreases. In simple terms this means calcium carbonate scale will form more rapidly at higher temperatures.

Scale Indices

Some waters do not have a tendency to form scale. In these cases it would be unnecessary and a waste of money to include a scale inhibitor in such water treatment programs. Therefore, it is important to have reliable information on the scaling behavior of a given makeup water (Muller-Steinhagen and Branch, 1988:1005). Normally scale

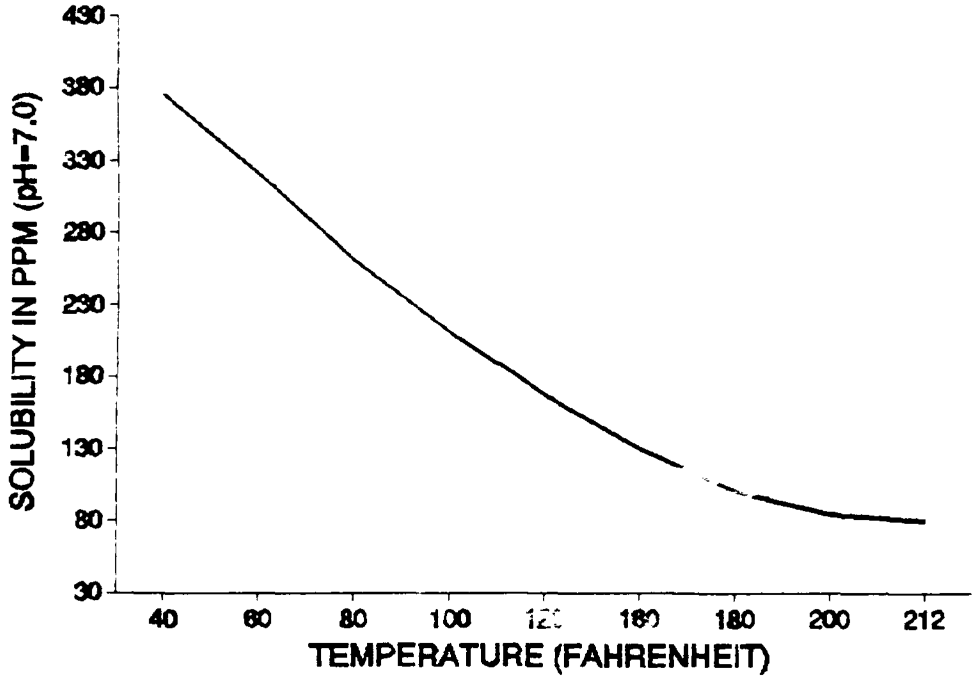

Figure 3. Solubility of Calcium Bicarbonate (CTI, 1990:19)

formation is calculated using one or more scaling indices. The indices use the makeup of the solution to determine if the solution has the potential for scaling or corrosion (Muller-Steinhagen and Branch, 1988:1005).

One of these indices, the Langelier Saturation Index (LSI) indicates whether there is a tendency for scale formation or corrosion. This index is simply the pH of the sample water minus the computed saturation pH as shown by Eq (2).

$$Langelier\ Index = pH - pH_s \qquad (2)$$

The saturation pH is the pH at which water with a given calcium content and alkalinity is in equilibrium with calcium carbonate (Betz, 1980:177). Nomographs have been prepared to make calculating the saturation pH quicker and easier. The results of the LSI indicates the following: If the value is greater than 0 the water tends to scale. A value less than 0 indicates a tendency to corrode (Mueller-Steinhagen and Branch, 1988:1005). At 0 the water is at equilibrium and neither scales or corrodes.

The LSI indicates a tendency to scale or corrode, but does not indicate the severity of the problem. Ryzner devised a new index called the Ryzner Saturation Index, which provides a quantitative measure of scale formation (Muller-Steinhagen and Branch, 1988:1005). Ryzner's Index is calculated by subtracting the water's pH from two times the saturation pH. Eq (3) shows how it is calculated.

$$\text{Ryznar Stability Index} = 2pH_s - pH \tag{3}$$

Muller-Steinhagen and Branch did a study comparing the different indices and suggest that the RSI always be checked with a saturation index for accurate results (1007). Table 2 lists the RSI values and their associated water tendencies.

A newer index called the Puckorius (or Predictable) Scaling Index (PSI) has been developed to reportedly improve on the other indices (Power, 1983:80). The PSI is similar to the RSI except the measured pH is replaced with what is called the equilibrium pH. This equilibrium pH takes into account the total alkalinity of the water being evaluated. Alkalinity can not be buffered as easily as pH, therefore alkalinity is a much better indicator than pH (Power, 1983:80). Paul Puckorius reports that using his PSI index leads to reduced acid requirements, allows higher COCs, increases water savings, and improves system protection (1983:81).

TABLE 2

RYZNER STABILITY INDEX

RSI	TENDENCY OF WATER
4.0 - 5.0	heavy scale
5.0 - 6.0	light scale
6.0 - 7.0	little scale or corrosion
7.0 - 7.5	corrosion significant
7.5 - 9.0	heavy corrosion
9.0 and higher	corrosion intolerable

(Drew, 1983:284)

Scale Control

Acid Treatment.

Acid treatment is one of the oldest methods for controlling scale in cooling towers (Drew, 1983:76). WPAFB developed an acid treatment program in 1983 that is still used at a couple of towers. This method is inexpensive and works well if sufficient manpower is available to monitor it closely. One of the big drawbacks of acid treatment is the fact that operators have to handle sulfuric acid. Also, if the system accidently overfeeds acid, the acid can eat through the pipes quickly and cause extensive damage to the tower.

Sulfuric acid is the most commonly used acid since it is readily available and inexpensive. The acid works by neutralizing the alkalinity in the system, thus inhibiting the formation of calcium carbonate with its low solubility. Instead, the calcium bicarbonate in the water reacts with the acid to form calcium sulfate. The calcium sulfate is over a hundred times more soluble than calcium carbonate. The following Eq (4) shows the chemical reaction that takes place using acid treatment.

$$Ca(HCO_3)_2 + H_2SO_4 \rightarrow CaSO_4 + 2CO_2 \uparrow + 2H_2O \qquad (4)$$

Therefore, water treated with acid can be recycled through the system until the much higher calcium sulfate solubility limit is reached. This method works well if monitored closely to insure the pH is held within specified limits. One shortfall of acid treatment is its ineffectiveness in controlling silica scale. If a system is prone to silica scale the concentration of silica must be kept below its solubility level to alleviate scaling problems (Strauss and Puckorius, 1984:4). AFP 91-41 gives the solubility of silica as 150 ppm (18). In determining the maximum allowable COCs for a system, divide 150 by the silica concentration in the makeup.

Solubilizers. Three of the most commonly used solubilizing chemicals are polyacrylates, organo-phosphorus compounds, and phosphonates (Strauss and Puckorius, 1984:5). Solubilizing or threshold treatment chemicals when added to the water allow it to remain stable when supersaturated with the scale-causing minerals. Supersaturated is defined as the concentration level of the mineral in the water beyond the saturation point for that mineral. At this point instead of precipitating out of the solution and forming scale, the minerals stay in solution in the water. The treatment agents actually hinder the scale crystal's growth. The way this treatment actually works is still not well understood (CTI, 1990:35).

An added advantage of some solubilizers is they control more than scale formation. Some of these solubilizers work well as corrosion inhibitors and dispersants. Due to the variance of all cooling towers it is difficult to determine a treatment dosage. Therefore, treatments are determined by experimenting with different dosage levels.

Polyacrylates are cheap and work well controlling both calcium carbonate and sulfate scale. They also can be modified to work as a calcium phosphate scale inhibitor. Polyacrylates inhibit scale growth at high temperatures and also at high and low pH levels. These chemicals do have disadvantages though. For one, too high a dosage can cause the polyacrylate to precipitate out of the solution and form a scale itself. Another disadvantage is the chemical's ineffectiveness in controlling calcium carbonate scale at a PSI of 4.5 or greater (Strauss and Puckorius, 1984:5). Finally these chemicals have a tendency to react with biocides and this results in a reduction of their effectiveness as inhibitors.

A second class of solubilizers is the organo-phosphorus compounds. These solubilizers work against calcium salts at very high pHs and when scaling tendencies are very severe. In cooling water systems two kinds of organo-phosphorus compounds are used, they are phosphonates and phosphate esters. Of the two groups of compounds, phosphate esters are not very effective so the phosphonates are the more frequently used scale inhibitors (Strauss and Puckorius, 1984:5).

AMP (amino-methylene phosphonic acid) and HEDP (1-hydroxy-ethylidine-1, 1-diphosphonic acid) are the two phosphonates most often used in recirculating cooling tower systems to control calcium carbonate scale (Strauss and Puckorius, 1984:5). A problem with AMP is that it is broken down by chlorine, rendering it useless against scale. Furthermore, when destroyed by chlorine, the AMP produces orthophosphate which can react with calcium hardness to form scale or with corrosion products to form deposits. HEDP is different from AMP in that most chlorine levels found in cooling tower systems do not affect the HEDP. Both the HEDP and AMP will corrode steel and copper alloys though.

Iron in the water presents a problem to both of these phosphonates. The iron lowers the HEDP and AMP's ability to control scale. This degradation process can lead to the formation of iron phosphate sludge and scale. Even with these restrictions, HEDP is the most frequently used scale controlling chemical in large cooling tower systems (Strauss and Puckorius, 1984:5). HEDP is very effective against calcium carbonate, calcium sulfate and fairly effective against calcium phosphonate.

Crystal Modifiers. Crystal modifiers allow the scale to form but distort the crystalline structure of the scale. The scale that forms when these crystal modifiers are present has the consistency of a sludge that will not adhere to pipes. One of the major advantages of crystal modifiers over solubilizers is their ability to permit high cycles of concentration in the system. They also work at higher temperatures and are more cost effective (Strauss and Puckorius, 1984:6).

Polymaleic acids and sulfonated polystyrenes are two of the better crystal modifiers. They work best against calcium carbonate, but also work well with calcium sulfate and calcium phosphate. These modifiers will not break down in chlorine like other treatments, but like polyacrylates they may react with some biocides reducing the modifier's effectiveness. Crystal modifiers form a sludge material which must be handled. Other chemicals can be added to the water to keep the sludge fluidized in the system or it can be allowed to settle out in an easily accessible place like the cooling tower basin.

Corrosion

Corrosion put in simple terms is the tendency of a processed metal to return to its natural state. It is very important to control corrosion because it can lead to equipment failure and allow deposits which potentially reduce the heat transfer capacity of the system. There are four steps in the corrosion process. Oxidation, the first step, involves the loss of electrons from the anodic part of the metal. The next step, reduction, is the gain of electrons at the cathode. The third step is the electron path. This is the flow of the electrons through the conductor from the anode to the cathode. The final step is the completion of the circuit flow of electrons with an electrolyte (CTI, 1990:13). All these steps are required for corrosion to attack the metal. All metals have anodic and cathodic areas due to microstructure differences in the metal. Therefore, an electron path and electrolyte are the only things necessary for corrosion to occur. If any one of these four components is missing, the corrosion process can not occur.

To protect carbon steel and other steel alloys in the cooling water system requires corrosion inhibitors. Inhibitors interfere with the chemical reaction that takes place when a metal corrodes. Corrosion inhibitors can either be anodic or cathodic depending on which part of the metal it protects. If it impedes the reaction at the anode it is considered an anodic inhibitor and similarly a cathodic inhibitor restricts reaction at the cathode. The two chemical equations that follow are the reactions that are controlled by the two classes of inhibitors. Eq (5) is the anodic reaction and is controlled by inhibitors such as chromates and nitrites which are discussed later (Moriarty, 1990:47). This reaction shows that the iron (Fe) is dissolving in solution.

$$Fe \rightarrow Fe^{2+} + 2e^{-} \qquad (5)$$

Cathodic inhibitors such as zinc and polyphosphates restrict this next chemical equation Eq (6) from happening by forming an insoluble nonconductive precipitate on the cathodic parts of the metal. This reaction shows the receiving end of the electrons from Eq (5) forming hydroxide.

$$O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \qquad (6)$$

Both Eq (5) and (6) must occur before the precursor to rust can occur which is shown in the next equation Eq (7) as ferrous hydroxide (right side of reaction) (Hey and Hollingshad, 1988:33).

$$Fe^{++} + 2OH^{-} \rightarrow Fe(OH)_2 \tag{7}$$

Of the two types of inhibitors, the cathodic type is safer. If any part of the anode inhibitor protected metal is exposed, current will flow and severe pitting will occur. Cathode protection reduces the flow, thus reducing the metal loss at the anode - no severe pitting (Puckorius:C-4). There are some inhibitors called mixed inhibitors which actually control corrosion at both the anode and the cathode. A common practice in implementing a corrosion control program is to use both a cathodic and anodic inhibitor together (CTI, 1990:27).

Corrosion Inhibitors

Chromates are very effective corrosion inhibitors, but the EPA banned their use due to their toxicity (Federal Register, 1990:40 CFR Part 749). Chromates had been the standard for the industry for the last few decades (Kaufman, 1990:13). Treatment consisted of controlling the water at a corrosive level, (ex. using acid to keep the pH between 6 and 7) thus eliminating scale and adding chromate to control corrosion. Compared to non-chromate programs this treatment method was easy to administer and control was not critical. Following the actions of the EPA, the Air Force amended AFP 91-41 on 25 November 1988 deleting all chromate treatment programs (Wilson, 1990).

A commonly used corrosion inhibitor, polyphosphate, protects carbon steel. It works by forming a calcium or metal polyphosphate film on the cathodic surfaces of the steel. Because of this it is important that the water have considerable amounts of calcium or a metal like zinc present. Polyphosphate is one of those chemicals that serves a dual purpose. Not only does it inhibit corrosion but it also inhibits calcium carbonate scale and works well against corrosion in a pH range of 6.5 to 8.5. One problem associated with polyphosphate is it breaks down into orthophosphate as soon as it dissolves in water. Therefore, a calcium phosphate scale inhibitor is almost always used with polyphosphates to prevent this scale from forming (CTI, 1990:28).

Another corrosion inhibitor, orthophosphate can be added directly to the water or formed from polyphosphates as described in the previous paragraph. Orthophosphate provides anodic corrosion protection by forming a film on the anodic parts of the steel. To form this film the orthophosphate uses dissolved oxygen found in solution.

Zinc by itself is not a very good corrosion inhibitor. However, when it is combined with other inhibitors, the combination of the two can provide good protection. Zinc is a cathodic protector, forming a thin film on the cathode area of the steel. Zinc alone has a very limited pH range, near neutral, in which it is effective. If the pH moves above 7.5 the zinc begins to precipitate out and form deposits on surfaces. Another problem with this inhibitor is many states have discharge restrictions on zinc (CTI, 1990:29). Zinc is normally combined with orthophosphate for corrosion inhibition, then organic phosphates and blends of polymeric dispersants are added for scale control (Kaufman, 1990:14).

All-organic programs are the more expensive programs for corrosion control. These programs generally operate in a pH range from 8.8 to 9. Since the pH range is high, no acid or pH control is required. Organic filming molecules are used for corrosion inhibition. Light industry has adopted these programs strongly because it eliminates the need for handling acids. Organic programs' biggest drawbacks are their low temperature tolerances (Kaufman, 1990:14).

Due to the environmental constraints on other corrosion inhibitors, primarily chromates, applications using molybdate are receiving a closer look (Fivizzani, 1991:6). Molybdate and chromate anions are very similar, but molybdate has substantially lower toxicity. Although the similarity does not extend to corrosion inhibition characteristics though. And therefore molybdate should not be considered a substitute for chromate. Instead, molybdate may interact synergistically with other inhibitors. Therefore, they are used with inhibitors such as organic phosphate, orthophosphate, zinc or a combination of the four (Kaufman, 1990:14).

Nitrites have also proven to synergize well with other inhibitors providing good corrosion control (Al-Borno and others, 1989:990). Al-Borno, Islam, and Haleem conducted a study to determine the synergistic affects of nitrite with inorganic phosphates (1989). They determined that a combination of low levels of nitrite and inorganic phosphates provided a more cost effective and better corrosion inhibitor than each individual component could by itself.

Microorganisms

The three microorganisms of concern in a cooling tower system are bacteria, algae, and fungi. Bacteria in this discussion are free swimming organisms that secrete a sticky substance. The bacteria themselves are not a big concern, but their secretions are. Dirt and other debris in the water are stuck together with this glue-like substance, forming slimy masses which interfere with heat transfer. Algae is a green slime that grows in the water on sunlit areas of the tower. Also, it can be a brown slime on the unexposed interior of the tower. Algae can slough off the tower and interfere with water flow in the piping system. More importantly it coats the slats inside the tower reducing the tower's heat transfer capability. Algae and bacteria both enter the system by attachment to wind-blown dust. The cooling tower itself is exposed to the outside environment. When the water trickles down the inside surface of the tower during normal operations it picks these dust particles out of the air and brings them into the water system. The final microorganisms of concern, fungi, become a problem only if the cooling tower is made of wood. The fungi will attack the wood and cause it to rot (McCoy, 1983:82). Table 3 lists some typical microorganisms and the problems they cause.

The best way to control microorganisms in cooling tower water is by using biocides. Biocides are normally considered either oxidizing or non-oxidizing depending on how they destroy the microorganisms. Chlorine, bromine, and chlorine dioxide are commonly used oxidizing biocides (CTI, 1990:40). They are considered oxidizing agents because they accept electrons from other chemical compounds (Betz, 1980:187).

Oxidizing Biocides. Chlorine is a cost-effective oxidizing biocide which controls bacteria, algae, and fungi. Chlorine reacts with water breaking down into hydrochloric and hypochlorous acid. The hypochlorous acid does the actual killing of microorganisms. As the pH rises in a system the hypochlorous acid breaks down further to a

TABLE 3

MICROORGANISMS AND ASSOCIATED PROBLEMS

TYPE OF ORGANISM	TYPE OF PROBLEM
A. Bacteria	
1. Slime forming	Form dense, sticky slime with subsequent fouling. Water flows can be impeded and promotion of other organism growth occurs.
2. Spore forming	Become inert when their environment becomes hostile to them. However, growth recurs whenever the environment becomes suitable again. Difficult to control if complete kill is required. However, most processes are not affected by sporeformers when the organism is in the spore form.
3. Iron Depositing	Cause the oxidation and subsequent deposition of insoluble iron from soluble iron.
4. Nitrifying	Generate nitric acid from ammonia contamination. Can cause severe corrosion.
5. Sulfate reducing	Generate sulfides from sulfates and can cause serious localized corrosion.
6. Anaerobic corrosive	Create corrosive localized environments by secreting corrosive wastes. They are always found underneath other deposits in oxygen deficient locations.
B. Fungi, Yeasts & mold	Cause the degradation of wood in contact with the water system. Cause spots on paper products.
C. Algae	Grow in sunlit areas in dense fibrous mats. Can cause plugging of distribution holes on cooling tower decks or dense growths on reservoirs and evaporation ponds.

(Nalco, 1979:22-2)

less effective biocide - hypochlorite ion. This is not a concern for systems that have continuous chlorine feeds (long contact time), but slug feed systems have shorter contact periods and should be monitored closely. Slug feed means the chemical is fed into the system at one time usually into the tower basin. Contact time is important for the chlorine to kill microorganisms effectively. Chlorine is a very good biocide, but it does have drawbacks.

Chlorine can be destroyed by other chemicals in the water or it can destroy other water treatment chemicals. In either case a part of the total treatment program is lost. Chlorine can actually attack and destroy wood in the cooling tower structure. Chlorine also increases the corrositivity of the water. If certain trace organics are in the water, chlorine can react with them forming trihalometnanes, which are EPA regulated carcinogens. Another consideration when using chlorine gas is it is very dangerous (CTI, 1990:39).

Two other oxidizing biocides are bromine and chlorine dioxide. Bromine's advantage over chlorine is its ability to work at higher pH levels. Bromine does not form trihalomethanes as readily as chlorine, and it is also less corrosive. But Bromine is not as strong an oxidizing agent as chlorine. Chlorine dioxide's properties are similar to bromine's. Chlorine dioxide is quite expensive and more volatile than chlorine or bromine. Therefore it can be quickly air-stripped from the water in a tower (CTI, 1990:40).

Non-oxidizing Biocides. Table 4, on the next page, provides a list of common non-oxidizing biocides.

A common practice with microorganism treatments is to use two different biocides, alternating their use. This lessens the possibility that a microorganism might develop an immunity to one biocide.

A couple of considerations must be addressed when deciding which biocide to use. The pH of the water and other treatment chemicals may affect the killing capability of the biocide. Also the biocide can deter the affects of other treatment chemicals. Many states regulate the discharge of biocides into public water sources. Therefore, before using any biocides the EPA should be contacted to ensure no restrictions apply to the chemicals contained in the selected biocides (CTI, 1990:41).

Ozonation

Ozonation is presented here by itself because it can be used as a single chemical treatment for controlling scale, corrosion, and microorganism growth. Since it can be used alone in some applications, it can eliminate the need for chemicals. Ozonation has received special attention by some operators for this reason (Henley, 1991:14). Ozone works because of its strong oxidizing

TABLE 4

COMMON NON-OXIDIZING BIOCIDES

Active	Application	pH Range	Comment
Carbamates	Bacteria Fungi	> 7.0	Corrosive to copper
Cocdiamine	Bacteria	6 - 9.0	Cationic Charge
Dibromonitrilopro- rapidly pionamide	Bacteria	6 - 8.5	Quick kill, hydrolyzes at high pH
Isothiazolones	Broad spectrum	6 - 9.5	Half-life 3-14 days, dangerous to handle
Methylene-(bis)thiocyanate	Bacteria	6 - 7.5	Rapidly decompose at pH > 7.5
Quaternary ammonium salts	Broad spectrum	7 - 9.5	Frequently foams, cationic charge, dispersive
Tributyl tin oxide	Fungi Algae	7 - 9.5	Adsorbs on and protects cooling tower lumber, synergistic with quats
Glutaraldehyde	Broad	7 - 9.5	Partially inactivated by amines

(CTI, 1990:41)

effects. It is the second strongest oxidizer know (Echols and Mayne, 1990a:36). Ozone is a form of oxygen with three oxygen molecules instead of two as shown in the following equation, Eq (8).

$$3O_2 + High\ Voltage \rightarrow 2O_3 \qquad (8)$$

It is formed by passing dry air or oxygen through a high-voltage field (Echols and Mayne, 1990b:163). Ozone is not a new development. Europeans have used ozone for years to purify drinking water and it has recently been used to purify water for the city of Los Angeles (Pryor and Bukay, 1990:26).

Ozone is very unstable and must be generated at the site of the cooling tower. Two to three grams of ozone per hour are required for every 100 tons of cooling capacity to insure adequate treatment. The best results occur when ozone is introduced to the system via a side loop. The cycles of concentration a tower operates at using ozone increases up to a level of 10 - 60 cycles (Echols and Mayne, 1990:38).

At these high COCs, the scale forming minerals calcium, magnesium and silica begin to precipitate out of solution. The sludges these minerals form can easily be removed periodically from the tower basin. The precipitates do not form new scale, and existing scale falls off because the ozone destroys organic material necessary for scale to adhere to the pipe walls (Echols and Mayne, 1990:37).

Ozone prevents corrosion of metal surfaces by producing a protective film on the metal. Also, ozone reduces corrosion by killing microorganisms that aid corrosion, thus reducing corrosion in another way. Echols and Mayne cite a study by Edward Banks done in 1987 that showed ozone reduced corrosion rates by 50 percent (1990:38). Ozone is also a good biocide. It kills the microorganisms by penetrating the cell wall and through complex reactions, denaturing the microbes (Echols and Mayne, 1990:37).

Although ozonation has not been readily accepted by industry, Pryor and Bukay in an article on the history of ozonation in cooling towers suggest that this is because earlier uses of ozonation failed due to misapplication of the technology (1990:26). These failures sent a message to industry that this treatment was not effective.

In 1980 NASA conducted some of the earliest studies on ozonation of cooling tower water. These studies documented the success of three towers that were treated solely using ozonation technology. Because of NASA's success many others tried ozone treatment during the 1980's. In 1987 Pryor and Bukay surveyed many ozonation users to determine how successful the method was. Their results indicated if the user applied the technology correctly, used good equipment, and monitored and maintained the system, large scale application of ozonation could be successful (Pryor and Bukay, 1990:31).

One hundred and thirty successful applications of ozonation are in place today. One of the examples Pryor and Bukay cite is a hospital that reduced water usage by 1.5 million gallon per year, significantly reduced the corrosion rate in a gas production facility, and saved over a million dollars in reduced energy charges all attributable to ozonation.

Pryor and Bukay elaborate on why they think the unsuccessful systems failed. The first area they address is inadequate design. Cooling tower ozonation is a very precise process and strict design specifications must be met. In many of the cases the authors found inadequate ozone supply to the system and in some instances the temperature was maintained too high to effectively utilize ozonation All these parameters must be met in the initial design of the system. Another problem the authors discovered was contamination by other chemicals - ozone works best by itself. Other chemicals can actually destroy the ozone. Another reason ozonation did not work was due to equipment failure and not the process. Lastly, Pryor and Bukay found systems not working correctly because of improper monitoring and maintenance by the operators. Monitoring the system closely is critical for ozonation because of the close tolerances that must be maintained to insure the treatment works effectively.

Magnetic Fields

The use of magnetic fields like ozonation can be a stand-alone cooling tower water treatment method. Magnetic fields can eliminate the need for adding chemicals to the water. This is cost effective considering the chemical costs and new environmental restrictions imposed on the use of some chemicals. Air Force personnel are prohibited by AFR 91-40 from using non-chemical treatment methods such as electricity, magnetism, or radiation. Although magnetism can not be used in Air Force cooling towers, success in some applications warrants a short discussion on this topic.

Magnetic field treatment works by simply passing the water flow through a magnetic field. It is not known for sure how a magnetic field inhibits scale and corrosion. Otakar Sohnel and John Mullin list six proposed explanations (1988:357).

1) The scaling solids nucleate preferentially in the bulk solution as a result of, for example increased hydrodynamic cavitation and deaeration, the enhancement of calcium bicarbonate decomposition and the formation ferric hydroxide (rust) particles, all caused by a magnetic field.

2) The nucleation of scaling solids in the bulk solution is enhanced by an electric field generated when water passes through a magnetic field.

3) During their passage through a magnetic device, ferromagnetic particles present in an aqueous feedstock, form a fluidized zone that adsorbs dissolved salts and gases in excess of equilibrium and thus reduces scaling.

4) Highly charged nucleating particles, "crystallites", are affected by a magnetic field and this interaction can influence the crystal size, morphology and even the crystalline structure of the deposited phase.

5) The diffusion rates of ions towards growing crystals are changed by a magnetic field.

6) Magnetically promoted corrosion increases the Fe(III) concentration in the aqueous liquid and this inhibits the nucleation and/or growth of crystalline scale.

Sohnel and Mullin are not convinced (from present studies) a magnetic field has any significant impact on scale formation. They suggest more research must be conducted on magnetic water treatment methods (1988:358).

Magnetic Field. The magnetic field can be set up in several ways. The oldest method employs large electromagnets around the flow. The electromagnets are large and require a significant amount of voltage to operate, and are maintenance intensive (Raisen, 1984:4). Another method, electrostatic charge, requires electrodes be placed directly into the flow. This method is also maintenance intensive and dangerous due to the high voltages in the water. The power must be monitored constantly, and the electrodes must always be scale free or they will not work. A third method uses bar magnets mounted directly in the water flow. This method requires no power source and requires little to no maintenance.

III. Methodology

Introduction

The objective of this experimental study was to determine the cost and analyze the effectiveness of three different methods for treating cooling tower water. As mentioned in chapter two, acid treatment, controlling cycles of concentration, and a phosphonate program are the only treatment programs specifically addressed in Air Force Pamphlet 91-41 (1988:25). The water treatment industry has developed more cost effective and less hazardous methods for treating cooling tower water. This research examined the effectiveness and costs of two newer methods, a crystal modifier treatment (Dias Aid Cooling Water Treatment System "Plus") and a solubilizer treatment containing HEDP (Organosperse-1311), in comparison to the acid treatment program used at WPAFB.

First, the methodology of the experiment is discussed followed by the specifics of each tower. Second, the water sources (makeup water) for each tower are chemically analyzed. Then each of the three treatment methods are discussed in detail. Next, the actual measurement techniques are discussed. The last section is devoted to how the data was analyzed.

General Method

This experiment involved three open-recirculating cooling towers and three different water treatment methods. The water in each tower was treated using one of the three methods: acid, crystal modifier, or solubilizer. The experiment was conducted 16 April 1991 to 14 June 1991 with chemical costs and operational data collected.

The Cooling Towers

Tower one, on the acid treatment program, is located in Area B, facility 20676 at Wright-Patterson Air Force Base (WPAFB), Ohio (referred to as tower 676). This tower supports four centrifugal chillers which supply chilled water to a system providing both comfort and computer system air conditioning. Tower two, on the crystal modifier program, is also on WPAFB located in Area A, facility 10271 (reference tower 271). Tower 271 also provides comfort cooling and computer system air conditioning support, but uses only three centrifugal chillers. Tower three is located 20 miles east of Columbus, Ohio at Newark AFB, building 4, and uses a solubilizer program (reference Newark tower). The tower at Newark was the nearest Air Force tower to WPAFB that used an orthophosphonate solubilizer program. The Newark tower provides cooling primarily for laboratory clean rooms and supports eight chillers. Table 5 lists some of the important specifications of each tower.

TABLE 5

TOWER SPECIFICATIONS

Parameter	Tower 676	Tower 271	Newark Tower
Capacity (Tons)	470	1050	3200
Flow (gpm)	1413	3150	11,200
Draft	induced counterflow	induced crossflow	induced counterflow
Fill Material	PVC slats	PVC slats	PVC slats
Cells	2	2	4

Makeup Water Analysis

A careful analysis of the water supply (the water used for makeup in the system) is essential so the correct water treatment method is used to produce acceptable water quality for its intended use (CTI, 1990:2). Groundwater is pumped from an aquifer below WPAFB and used for makeup in towers one and two. This water, like most groundwater, is very hard due to its high mineral content (Betz, 1980:11). Other than chlorination for the purpose of disinfection, the water is not treated before it is used in the towers. This is generally true, but recent findings documenting contamination of WPAFB groundwater by trichloroethylene (TCE) and other chemicals has changed the treatment methods. Base environmental personnel placed air strippers in the water system to eliminate volatile organic compounds

(VOCs) associated with this groundwater contamination. These strippers tend to intensify the water's tendency to form scale in the towers.

The water used for makeup at the Newark, AFB tower also comes from a groundwater source. Base personnel pump the water from the ground through base wells. Before the water is used in the cooling system, it is pre-softened using a zeolite bed. The water is also filtered through potassium permanganese to eliminate excess iron in the water. The water chemistries are quite similar as shown in the water analyses, Table 6, except for the concentrations of calcium hardness.

TABLE 6

WATER ANALYSES

Parameter	WPAFB	Newark AFB
pH	7.8	7.4
M-Alkalinity (ppm CaCO3)	310	326
Conductivity (micro-mhos)	655	659
Calcium Hardness (ppm)	235	150
RSI *	5.8	6.6
Production Cost +	$0.756 kgal	$1.94 kgal
Discharge Cost +	$0.9244 kgal	$0.56 kgal

+ costs are per 1000 gallons of water (kgal)
* RSI determined using nomograph on pg. 4-14 (Nalco, 1979)

Treatment Methods

Tower 676 was treated with the same acid treatment program as all towers on WPAFB have been treated from 1986 to 1990. The WPAFB acid treatment program uses sulfuric acid to control scale buildup. The acid is pumped directly into the water line just before it goes into the condenser. An electronic pH meter measures the cooling water's pH and automatically cycles the acid pump, adding acid to the water and keeping the pH constant. The following control parameters were used to insure the treatment was being administered correctly. The desired pH control range is 7.0 to 7.5. Conductivity should be 2.7 to 2.9 times the makeup mmhos. Calcium hardness must be less than 800 ppm, and the COC level should be between 2.7 and 2.9 (Eldridge, 1989). Appendix B lists the procedures on how each of the above parameters were calculated. Acid cost is $14.15 per 15 gallons.

In addition to the sulfuric acid, Table 7 lists the composition of corrosion inhibitor 3005 used as part of the complete treatment program. Corrosion inhibitor Hydrodynamics 3005 is a liquid that comes in 15 gallon drums and like the acid is pumped directly into the water line. The amount of Hydrodynamics 3005 in the water is controlled by a conductivity meter and timer. The cost of Hydrodynamics 3005 is $139.00 per 15 gallons.

TABLE 7

PHOSPHATE BASED CORROSION INHIBITOR FORMULA
HYDRODYNAMICS 3005

INGREDIENT	PERCENT BY WEIGHT
Zeolite softened water	30.5%
Phosphoric acid (75% active)	5.5%
Tetrapotassium pyrophosphate (100% active)	7.0%
Caustic potash liquid (45% active)	29.0%
Sherwin Williams Cobratec TT-50S Tolyltriazole (50% active) or equivalent	6.0%
Monsanto Dequest 2010 (60% active) or equivalent	4.0%
Rohm and Haas Acrysol QR1086 39.5% active) or equivalent	18.0%

Two biocides were used to control the growth of microorganisms. The trade names for the two biocides are Premier Nos. 143 and 146 Microbicide. Their respective costs are $163.59 per 5 gallons, and $360.00 per 5 gallons. From the Material Safety Data Sheet (MSDS) the active ingredient for the 143 is methylene bisthiocyanate at 10%. 146 is composed of n-alkyl (50% C 14; 40% C 12; 10% C 16) diethyl benzyl ammonium chloride at 12.5% and bis (tri-n-butyltin) oxide at 2.25%. The biocides were used on a re-occurring basis. A set amount of biocides was simply poured into the tower sump every Friday. Premier 143's and 146's dosages were approximately 0.1 gal/week and 0.25 gal/week, respectively. The biocides were used alternatingly to reduce any chances of the microorganisms developing a tolerance to the biocide.

Tower 271 used a proprietary product developed by DIAS, Inc. This product, a single treatment program, is DIAS-AID Cooling Water Treatment System "Plus". This product will be referred to as DIAS-AID. Due to the proprietary nature of the product, DIAS does not want the chemical makeup of this product published. According to the manufacturer though, this is a crystal modifier treatment. The DIAS-AID program allows the scale to form as a sludge, but does not permit hard deposits to form in the system. This treatment program contains no corrosion inhibitor and instead of a biocide it contains a biostat. A biostat in contrast to a biocide does not kill microorganisms that already exist, but rather prevents the microorganisms from growing initially (Betz, 1980:185). The DIAS product cost $705.00 per 15 gallons.

The DIAS-AID was pumped into the condenser water line entering the chiller. The chemical was pumped into the water at a constant rate which was set by an electronic timer. According to the manufacturer's recommendation the COCs were maintained between eight and ten cycles by blowdown. A conductivity meter in the system activated the blowdown valve when the conductivity reached too high a level.

The Newark tower operates with a solubilizer program using a commercial HEDP phosphonate program called Organosperse-1311 (Lombardi). Organosperse-1311 is an all-organic cooling water treatment inhibitor supplied by Lombardi Water Management, Inc. located in Columbus, Ohio. In contrast to the crystal modifier program, the phosphonate program increases the solubility of the calcium. This keeps the calcium hardness in solution even at high concentrations. Like the DIAS-AID, Organosperse-1311 is also a proprietary product so the actual chemical constituents are known only by the manufacturer. This treatment product does not contain a biocide. Organosperse-1311 contains both a scale and corrosion inhibitor, but the biocide must be added separately. The cost of Organosperse-1311 is $656.00 per 55 gallons.

Organosperse-1311 was fed into the system at a constant rate according to the amount of makeup water added to the system. The amount of Organosperse-1311 added was determined by conducting a phosphonate test. The phosphonate test was measured in drops and according to the manufacturer's literature the control range was three to six drops. Appendix B lists the procedure on how the drop test was performed. A manual adjustment was made to the pump to ensure the correct amount of Organosperse-1311 was administered into the system. COC was controlled automatically by blowdown and electronically activated by a conductivity meter. COCs were maintained at the suppliers recommended level of three. The manufacturer's recommended maximum pH of nine was also controlled by blowdown.

Two biocides were used, HTH twice a week and Algaecide 100 (also supplied by Lombardi) were added once a week. The active ingredient in the algaecide is polyoxyethylene (dimethyliminio) ethylene-(dimethyliminio) ethylene dichloride at 10%. The biocides were poured into the tower sump regularly at the following rates: algaecide - 2 quarts per application (as recommended by the supplier); HTH - 5 pounds per application. Both biocides cost $1.00 per pound of chemical. Therefore, the Algaecide 100 useage was converted to pounds using its density of 8.36 lbs/gal (Lombardi).

Measures

Data were collected from a number of areas in the cooling tower systems. The three primary measurements were the amounts of chemicals used, the water consumed in makeup, and the temperature difference between the supply and return of the chilled water. Daily water meter readings for makeup water requirements were recorded at all the towers. Some of this water was blowndown and had to be disposed of. All water from cooling towers must go to a water treatment facility, therefore it was important to know the cost of that treatment. None of the three towers had discharge water meters, therefore the blowdown was determined by calculating an estimated evaporation for each tower. This evaporation was divided by the COC minus one to obtain the blowdown. The two equations used to determine blowdown came from McCoy (1983:10). Eq (7) was initially used to determine an evaporation rate for each system. The R values are listed in Table 8 for each chiller along with gpm values which are used to calculate Btu in Eq (9).

$$E = R * \frac{\Delta t}{1000} \qquad (7)$$

where

E = evaporation (gpm)
R = recirculation rate (gpm)
t = the temperature difference between supply and return water (degrees Fahrenheit)

After the evaporation rate for each day was computed, the values were averaged over the duration of the experiment. Using the evaporation rate calculated above and an average COC, the average blowdown rate was computed using Eq (8). This number was multiplied by 60 days in the experiment, 60 minutes per hour, and 24 hours per day to obtain a total blowdown for the system. The calculated blowdowns are higher than actual blowdowns because the temperature readings were taken during a warmer time of day. All the towers were treated the same, so no adjustments were necessary.

$$B = \frac{E}{C - 1} \tag{8}$$

where

E = average value from Eq (7), evaporation

C = cycles of concentration (average value)

B = blowdown (gpm)

TABLE 8

CHILLER FLOW RATES

CHILLER NUMBER	R-VALUE	GPM
Bldg 676		
Chiller 1	471	350
Chiller 2	471	350
Chiller 3	471	350
Chiller 4	1050	840
Bldg 271		
Chiller 1	1050	840
Chiller 2	1050	840
Chiller 3	1050	840
Newark		
Chiller 1	1200	960
Chiller 2	1200	960
Chiller 3	1725	1380
Chiller 4	1200	960
Chiller 5	1200	960
Chiller 6	1200	960
Chiller 7	600	480
Chiller 8	1200	960

The amount of chemicals added to the water in each system was carefully monitored and recorded on daily log sheets for each tower. Both water consumption and chemical usage were accounted for during the entire 60 days of the experiment. In contrast, the temperature readings for Btu calculations were only recorded on working days during the experiment. No readings were taken on weekends and holidays.

Btu Computation. Each duty day at 1500 hrs, the operating chillers' water supply and return temperatures were recorded. These temperatures were used to calculate the cooling performance in millions of Btu (MBtu) for each tower. Appendix E lists the calculated values. Eq (9) was the formula used to calculate hourly Btu. Upon completion of the experiment the MBtu for each tower was summed and an average daily MBtu was computed. The average MBtu was multiplied by the number of days (60) in the experiment to get a total Btu for each tower. The total MBtu was used as a means to compare the three towers. With building load and outside air temperature changes, it was expected that the Btu would change throughout the day. Therefore, to enhance the validity of the experiment all temperature readings were taken at the same time each day. Eq (9) from McCoy was used to determine the heat rejected by each tower in Btu per hour (1983:4).

$$\mathit{Heat\ duty, Btu/h} = 500 * \mathit{GPM} * \Delta t \qquad (9)$$

where

gpm = value from Table 8, (column 3)

t = same temperatures used in Eq (7)

This became one of the cost comparison bases for the different towers.

Corrosion Coupons. Mild steel and copper corrosion coupons were installed in each system to measure their respective corrosion rates. The coupons were placed in racks that allow system water to flow over them. Steel and copper coupons were used since the tower systems were predominately constructed of these two metals. The theory being, what happens to the corrosion coupons also happens to the system metals. Therefore it is important to locate the coupons in a location that duplicates the system's flow and temperature characteristics. The ideal time for the coupons to stay in the system is from 30 to 90 days. The results from this test are not definitive, but give a general idea as to what is happening in the system. If bad results are obtained further investigation is necessary.

Microbiological Growth. Microbiological growth was measured by two methods. The first was by a visual inspection that was performed periodically. Observations were recorded on a checklist taken from the Guidelines for Evaluation of Cooling Water Treatment Effectiveness (1981:18). These checklists are located in Appendix C. Also a paddle tester manufactured by Hach Company out of Ames, Iowa, was used to determine total bacteria/yeast and mold growth (Appendix D). The paddle test was administered three times during the experiment to each tower. Each time the paddle was compared to the manufacturer's chart and the number of bacteria and fungi colonies was recorded. Up to 500,000 colonies of bacteria per milliliter (ml) constitutes a clean system. Above 1,000,000 colonies/ml indicates treatment is required (McCoy, 1983:113).

Analysis

Costs. The first question to be answered was how much does it cost to use each of the treatment methods. The scope of this research was limited to water and chemical costs only. Power consumption could not be measured due to unavailability of equipment. Labor costs were nearly impossible to obtain for each of these towers, therefore they were unavailable for this analysis. Another important factor tied to manpower is the time required to clean the system condensers and cooling tower if poor treatment occurs. This can be a substantial cost, but cannot be determined until the system is actually opened and cleaned - normally during downtime in the heating season.

The chemical cost for each treatment method was obtained by simply multiplying the total amount of chemicals consumed by their costs. Since both water sources, WPAFB and Newark, were unmetered government wells, the cost of makeup water had to be estimated. The sanitary costs were calculated using the actual local treatment facility's cost. The blowdown (water sent to the facility for treatment) was calculated in all three towers using Eqs (7 and 8).

At the conclusion of the experiment, all the costs for each tower were totalled and divided by the total Btus calculated for each tower over the span of the experiment. Another comparison was made by simply dividing the total cost by the rated tons of the tower. Table 5 contains the ton ratings for this calculation. Another calculation of interest was the cost of chemicals per thousand gallons of makeup water.

The outside air average temperature for each recording day was also recorded for comparison with the daily Btu calculations (Appendix H). This comparison could give some indication if the building load was fairly steady and the load varied with the outside air temperature.

Effectiveness. Cost was not the only factor analyzed in this research. The effectiveness of each treatment method was also assessed. The effectiveness of a treatment method is its ability to keep the system operating at optimum capacity. One of the best ways to evaluate the effectiveness of a treatment program is to physically open each system and look for signs of deposition and corrosion. Due the critical nature of these cooling systems, shutdown was prohibited during this experiment. Therefore, other methods were used to measure effectiveness. The tower was visually inspected periodically for scale and microbiological growth. To get some idea of what was going on inside the system, the condenser pressures were monitored each day for any changes. Any increase in pressure could indicate a buildup of scale inside the pipes. These pressure readings are recorded in Appendix G.

The corrosion coupon's laboratory analyses were reviewed for any significant differences among the three towers. Table 9 gives the acceptable corrosion rates used in the experiment.

TABLE 9

Qualitative Classification of Corrosion Rates

	Corrosion Rates (mpy)	
Description	Carbon Steel	Copper Alloy
Negligible	< 1-2	< 0.1
Mild	2-5	0.15-0.2
Moderate	5-10	0.2-0.35
Severe	> 10	0.5-1

*mpy-mils per year (McCoy, 1983:37)

A mil is a thousandth of an inch. Each of the three coupons were converted to mils per year (mpy) using the following equation Eq (10) (CTI,1981:8).

$$mpy = \frac{365 days/yr * 1000 mils/in * 0.061 in^3/cc}{metal\ density(g/cc) * area(in^2)} * \frac{Initial\ Weight(g) - Final\ Weight(g)}{Days\ Exposed} \qquad (10)$$

Where the metal densities were 7.87 grams per cubic centimeter (g/cc) for mild steel and 8.89 g/cc for copper. The weights are the actual weights before and after the coupon is placed in the system. The number of days is the time the coupon spent in the system. The area is the surface area of the coupon in square inches.

Chapter four discusses and analyzes the results of the actual experiment including some of the problems encountered.

IV. Findings and Analysis

Introduction

This chapter contains the data collected during the sixty day period of the experiment. Water and chemical consumptions were logged for the entire period. Control data values and the temperatures used for MBtu calculations were taken on forty three duty days during the experiment.

This chapter begins by giving an overview of the actual experiment, including problems encountered. The next section is devoted to an analysis of each system's control parameters. Following the discussion on controls, the cost data is presented for each tower. The final section contains the results of the effectiveness parameters (scale, corrosion, and microorganism control) covered in chapter three.

The Experiment

Throughout the data collection phase of the experiment all three towers functioned properly and provided adequate cooling to each of their respective facilities. One point of interest is the fact that the operator's primary job should be ensuring the system was always running properly. But, in some instances monitoring the system and keeping it exactly within control limits was often overlooked due to more important operational requirements.

Temperature readings for the three towers were acquired differently in each case. Tower 676 had thermometers mounted directly in the water line that measured to the nearest degree fahrenheit, temperatures were interpolated to the nearest half of a degree. The chillers at building 271 were on computers and had digital readouts. The computer registered temperatures to the nearest tenth of a degree. The Newark tower also registered temperatures to the nearest tenth of a degree. allowing for the same accuracy as tower 271. The Newark data was collected on a system monitoring computer and at the end of the test period, a report listing the required data was produced.

The biggest problem encountered during the experiment was a malfunctioning acid pump at tower 676. The pump malfunctioned in mid May and was not replaced for approximately 15 days. After the pump was repaired it took a week to balance the system.

The drift eliminators on tower 271 began to scale heavily during the experiment, so the COCs were raised in an attempt to fix the problem. This adjustment, another deviation during the experiment, made to the system was required to keep the tower operational. This adjustment affected the experiment by reducing the makeup water requirement. Little change was noted on the scale formation after the COCs were increased.

Only two of the systems had corrosion coupon racks installed. Tower 271 did not have a rack so the coupons were placed near the recirculating pumps in the tower basin. Additionally, the coupons could not be placed in the systems for the same time period. Newark had their coupons in for 95 days, tower 676 for 78 days, and tower 271 for 31 days. This was not a problem since the weight calculations, Eq (9), convert the metal loss to a per year basis for each tower.

Control Parameters

The key to an effective and efficient treatment program is to carefully monitor the cooling tower system. As stated in chapter three each treatment program had control limits that should have been monitored and used to adjust the system. This section presents an analysis of the data collected on each tower. Presentation of the data begins with tower 676 (acid treatment).

Tower 676. Tower 676 was not well monitored, due to the acid pump problem. The pump could not inject enough acid into the system to keep the water's pH within limits. Figure 4 shows the pH plot for tower 676. The graph shows good control until early June when the pump was changed. The severe drop in pH is due to the adjustment phase after installing a new pump.

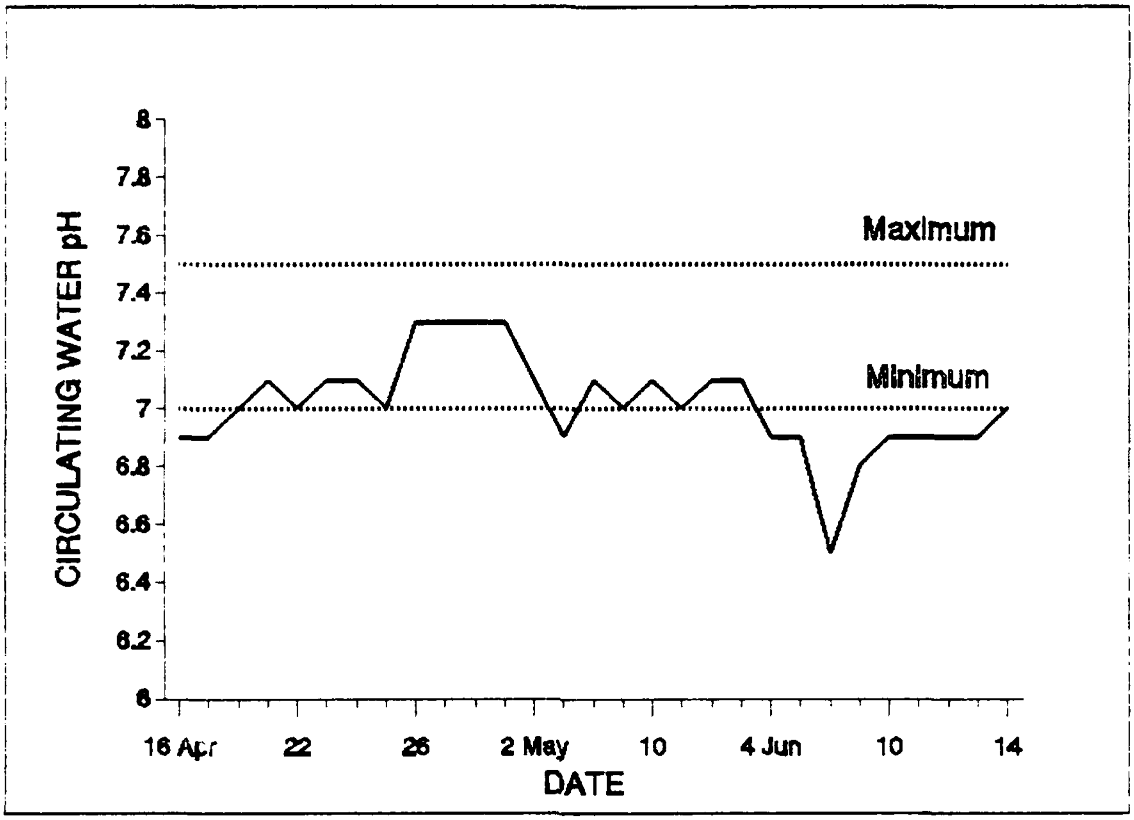

Figure 4. Tower 676 pH

Figure 5 shows the levels of calcium hardness in the circulating water. The hardness was not closely monitored as is indicated by only six recorded measurements taken during the experiment. Calcium hardness should be monitored at least once a week. This parameter is controlled by blowdown and the maximum concentration should be 800 parts per million (ppm). The upper limit was exceeded on 22 April after the system was heavily dosed with acid to lower the pH quickly. This could cause the high concentration of calcium hardness in the system. The rise on June 10 is the result of losing control over the weekend.

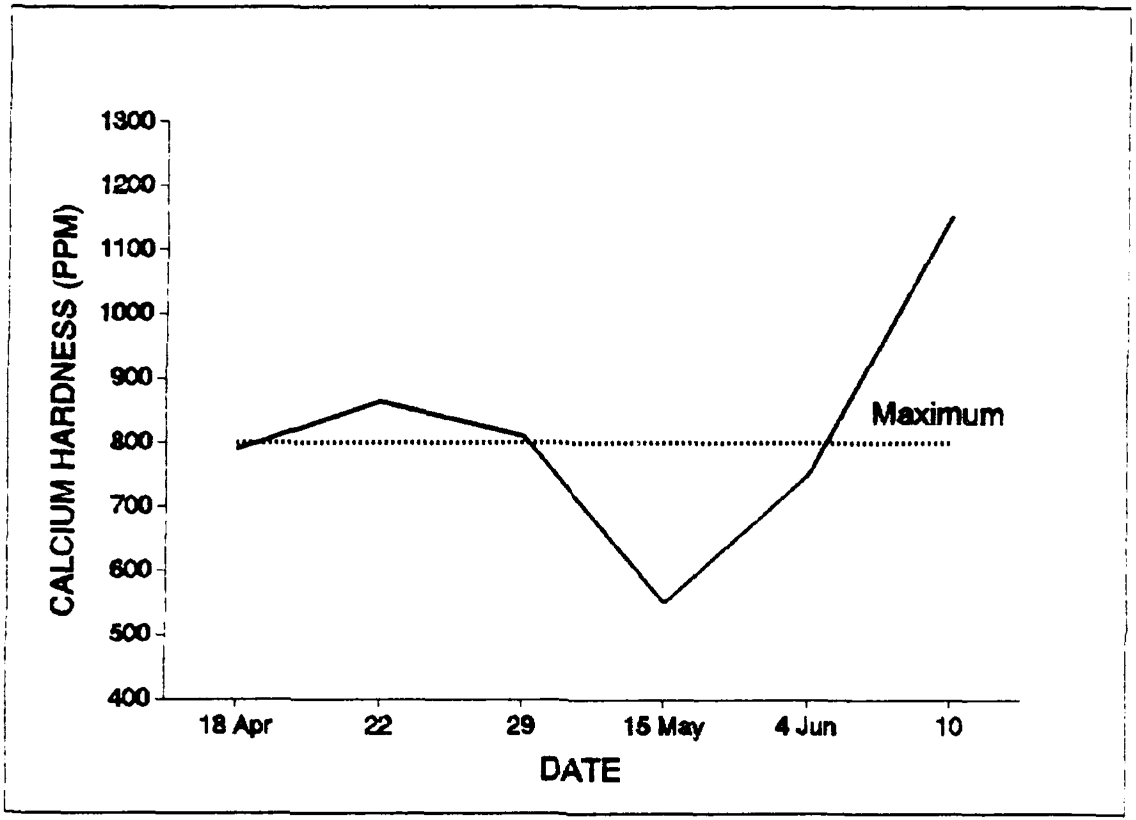

Figure 5. Tower 676 Calcium Hardness

M-Alkalinity reacts with the calcium hardness in the system to form scale. A little alkalinity is necessary to buffer the acid, which is why there is a minimum. The M-Alkalinity is controlled by the acid feed and blowdown. Figure 6 shows, for the days recorded, the alkalinity was controlled fairly well.

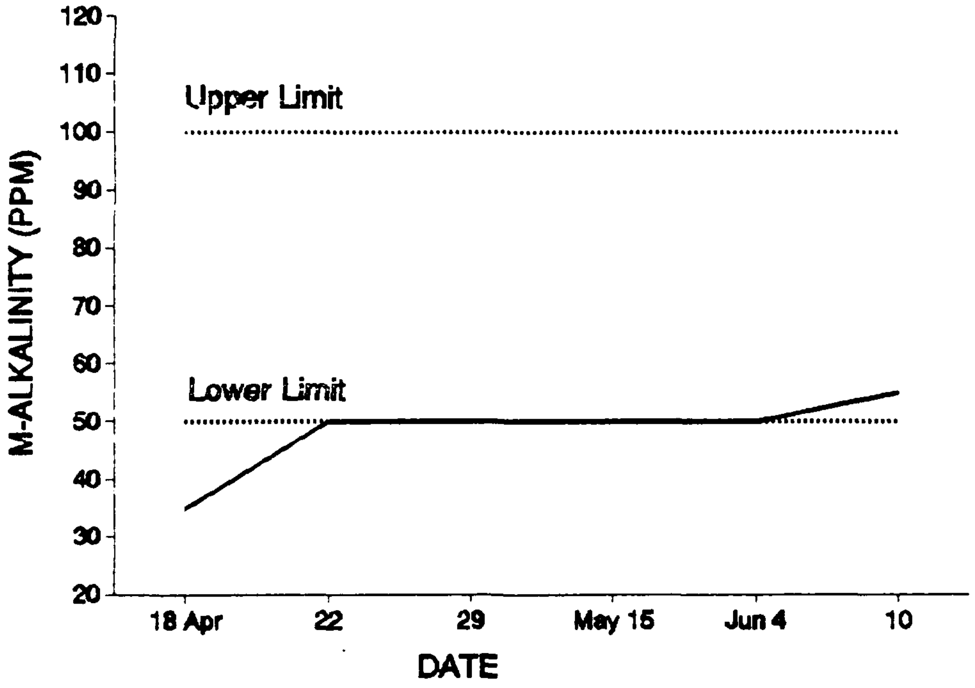

Figure 6. Tower 676 M-Alkalinity

The next plot, Figure 7, is an indication of the amount of scale and corrosion inhibitor (3001) in the system. Phosphonate (an ingredient in 3001) is easy to test for, therefore the concentration of phosphonate is checked to ensure proper amounts of 3001 are in the water. Adjustments are made to the feed pump if the values of phosphonate are too high or low. Again the plot shows good control of the corrosion and scale inhibitor.

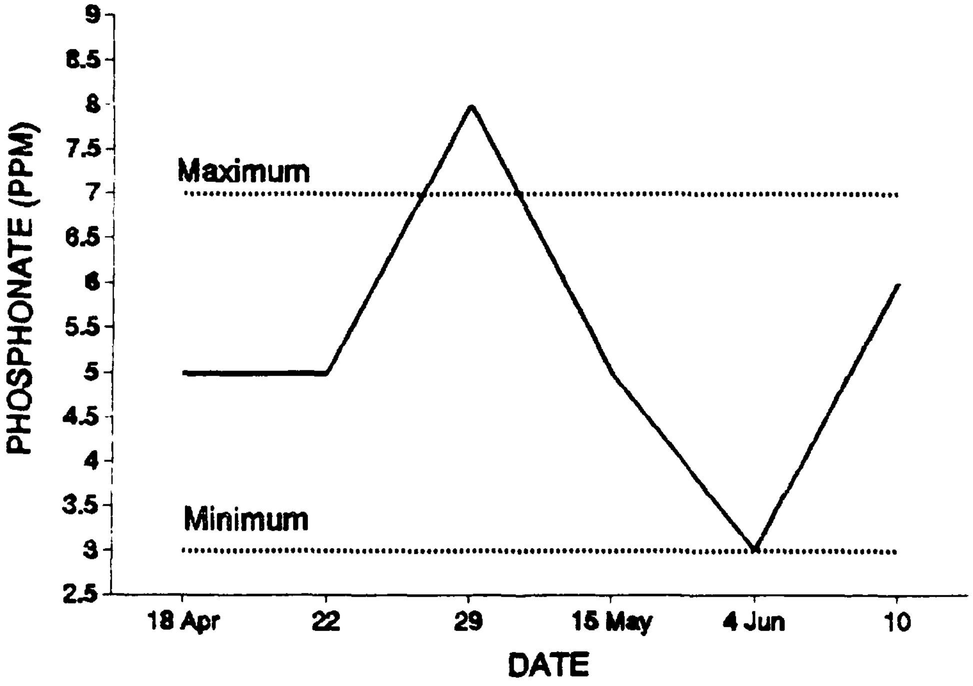

Figure 7. Tower 676 Phosphonate

The final control on tower 676 was the cycles of concentration. This parameter was controlled by blowdown. As Figure 8 shows there seemed to be problems with the calibration of the controls. The high spike again was probably linked to the control problem over the weekend. This control insures that concentrations of scale forming solids do not exceed the upper limits allowing calcium carbonate to precipitate out of solution forming scale. On the other hand, it also ensures that the water cycles more than once to save water and chemical costs.

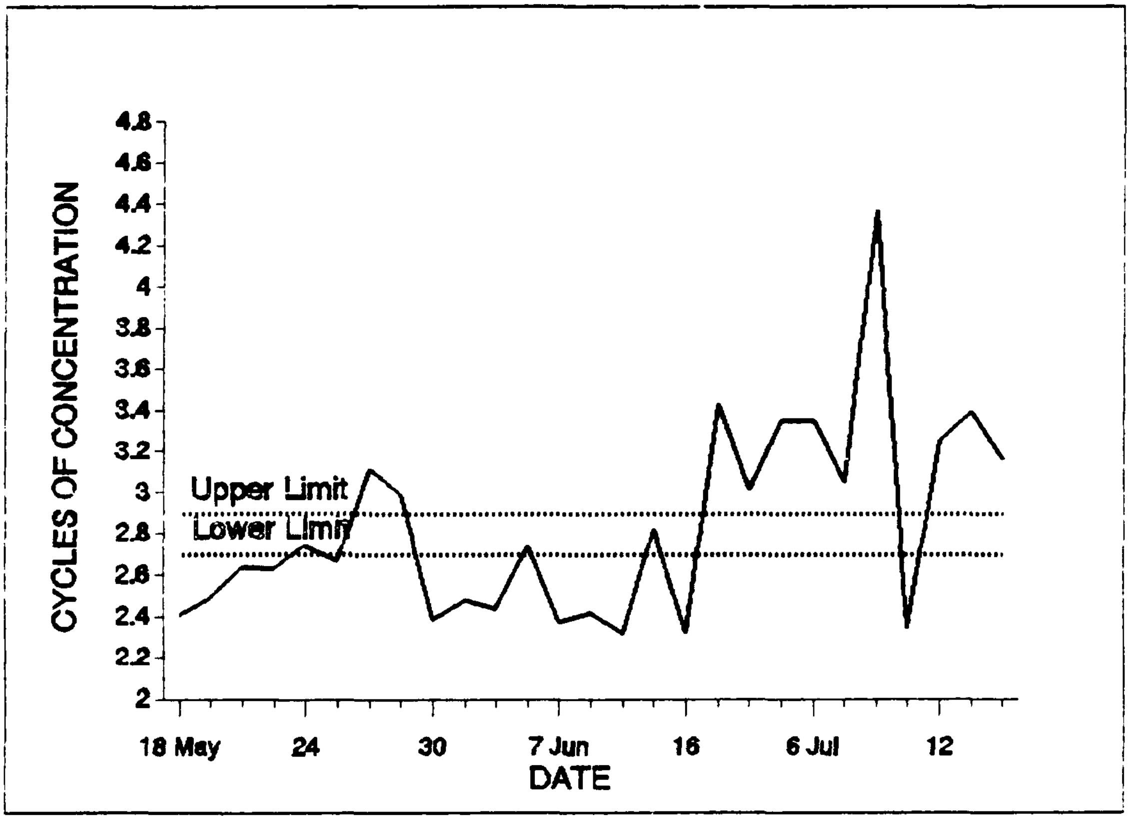

Figure 8. Tower 676 Cycles of Concentration

Tower 271. In the case of tower 271 only one parameter was monitored per the manufacturer's recommendation. Their guidance was to control the cycles of concentration between 8 and 10 cycles. Figure 9 shows that the controls were met until the middle of May. This was when the operators attempted to reduce scale an the tower's drift eliminators by increasing the cycles and thereby increase the concentration of DIAs-AID in the solution.

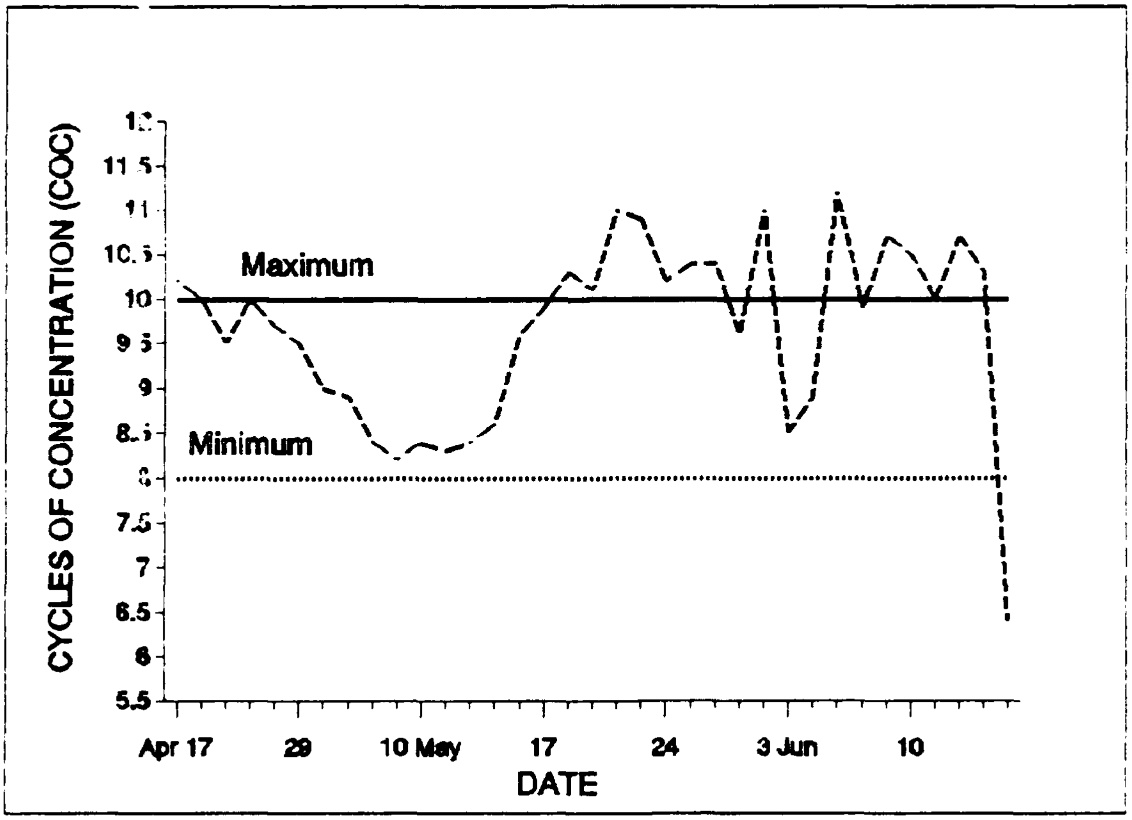

Figure 9. Tower 271 Cycles of Concentration

Newark Tower. The tower at Newark was controlled in much the same matter as tower 676. Therefore, the parameters monitored at Newark serve the same control function. Figure 10 indicates the Newark tower was kept very close to the recommended pH of 9.0. Even though there are three spikes, their magnitudes were less than 0.2.

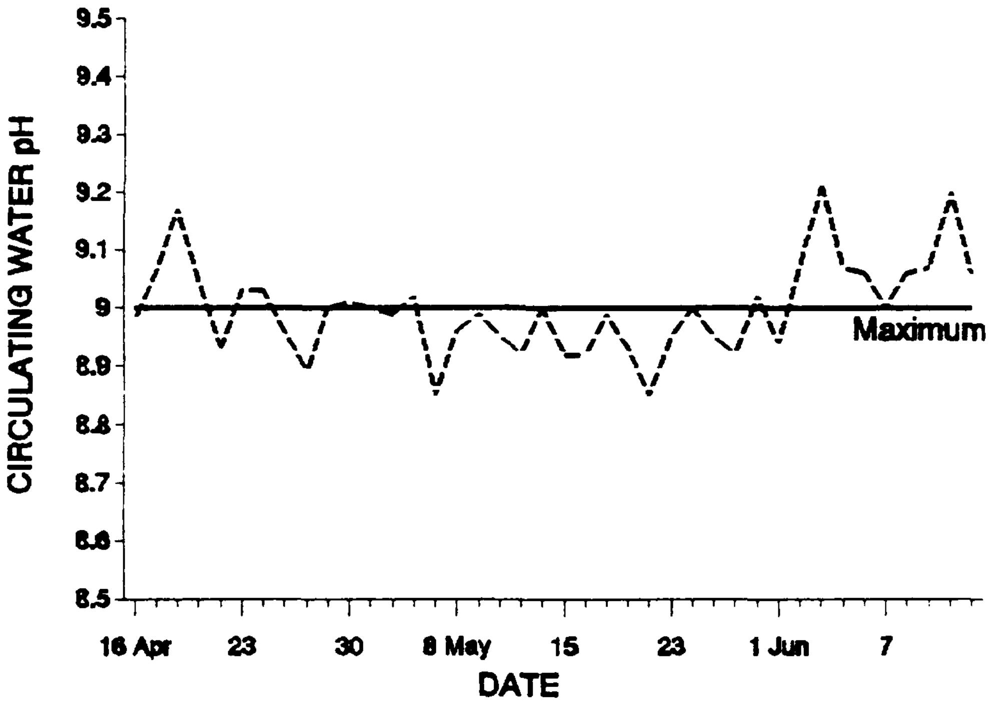

Figure 10. Newark Tower pH

The next plot, Figure 11, indicates the COCs were maintained right at the maximum which is optimum. This means the system was minimizing water consumption and chemical useage.

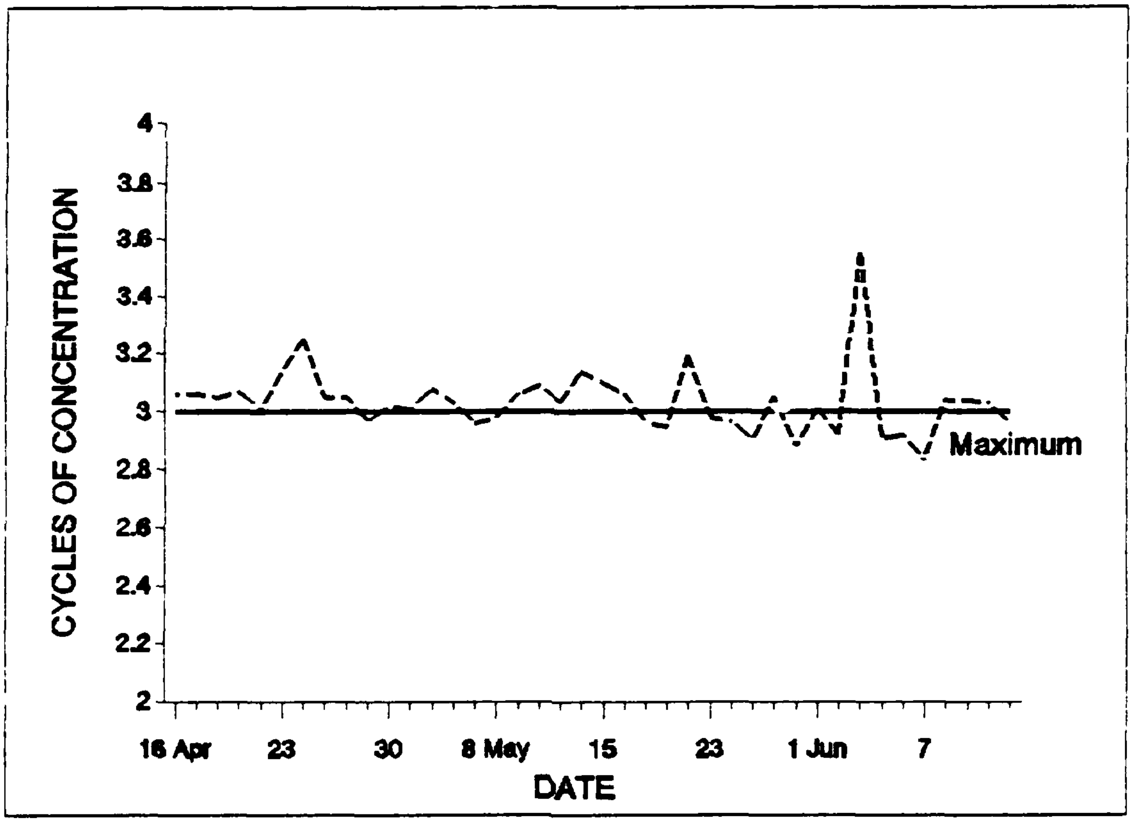

Figure 11. Newark Tower Cycles of Concentration

Conductivity is the amount of solids in solution. This parameter is directly tied to COCs, therefore it should be similar to the COC plot as was illustrated in Figure 12. The control problem mentioned earlier also affects the conductivity as shown by the spike in early June.

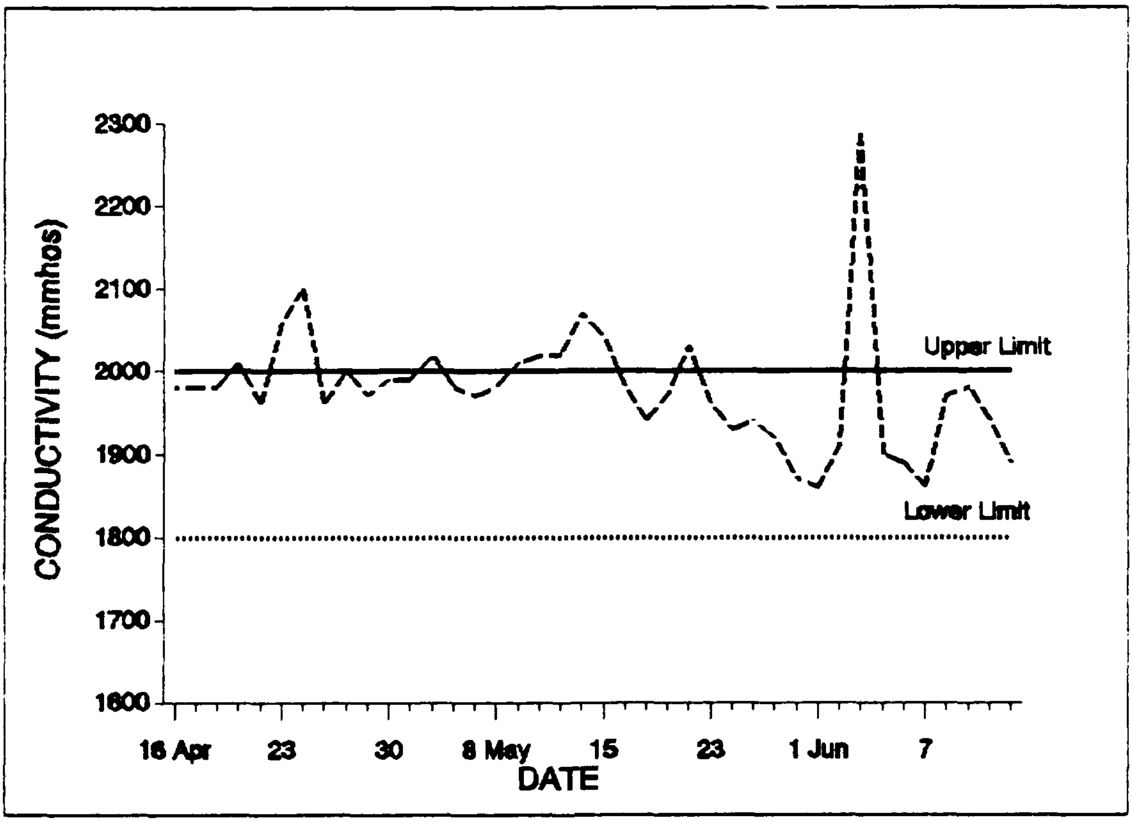

Figure 12. Newark Tower Conductivity

The final plot, Figure 13, like tower 676 was a phosphonate test to ensure the right amount of scale and corrosion inhibitor was in the circulating water. There were a few values above the limit which means too much chemical was in the system. For the most part the control was good, but recommend calibrating the controller to maintain the upper limit.

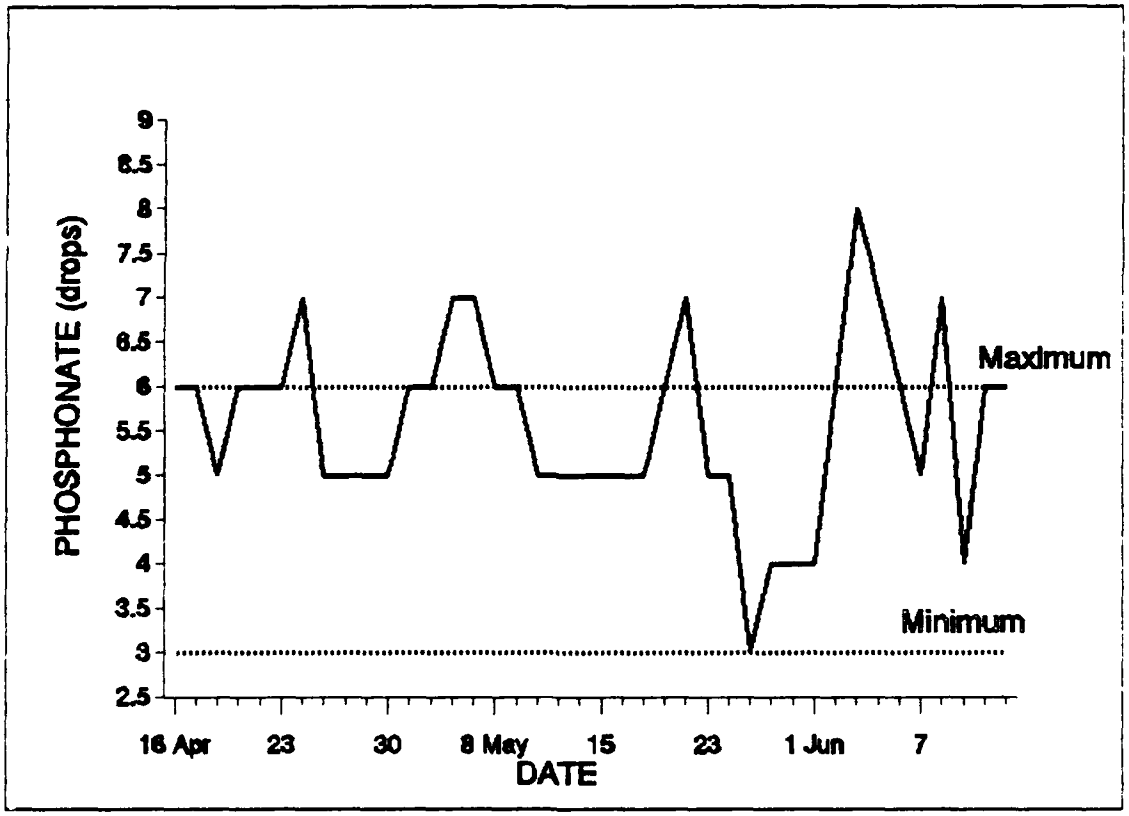

Figure 13. Newark Tower Phosphonate

Cost Comparison

The following three tables, Tables 10, 11, and 12, list the actual water and chemical consumptions and costs for each tower. The MBtu for each tower was also included for comparison purposes. Figure 19 in appendix E provides a plot of the daily performance for each tower. The bottom line in each table is the total cost divided by the performance of each tower in total MBtu.

Two other cost comparisons were calculated and presented. One is simply the total cost divided by the design tons (Table 5 providess design tonnage for each tower). This figure is not as significant since more than just performance is involved in this calculation. This involves total system design, including the extra capacity kept in reserve for emergencies (to meet peak design load days). The other cost comparison (cost/kgal) is very important because it provides a cost per thousand gallons of makeup water. Therefore, if an operator or engineer knows the size or volume of water a cooling tower requires, they could estimate chemical costs for that system.

A couple of aspects concerning the MBtu factor used in this experiment should be noted. First, the temperatures used to calculate each tower's performance (in MBtu) were taken at a the same time each day (1500 hrs). These temperatures fluctuated according to the heat load applied by each air conditioning system. Throughout each day the outside air temperatures and facility cooling needs shifted up and down due to changing heat loads. Since the temperature readings were taken in the afternoon, the load on the tower was nearly maximized each day. No hourly compensations were made for this fluctuation, therefore the MBtu numbers in this experiment exceed actual tower ratings. The significance of this methodology is that comparisons of performance can only be made between these three towers and not extrapolated to other studies.

The tables of results are presented next with a discussion following the last table.

TABLE 10

WATER AND CHEMICAL CONSUMPTION
AND COSTS (TOWER 676)

ITEM	CONSUMPTION	COST
WATER	884,300 gal	$668.53
SEWER	772,440 gal	$714.04
ACID	117.50 gal	$110.84
3001	89.00 gal	$824.73
BIOCIDE 143	2.24 gal	$73.36
BIOCIDE 146	0.94 gal	$67.50
TOTAL COST		$2459.01
CHEM COST/KGAL		$1.22
COST/TON		$5.23
MBTU AND COST/MBTU	8243.33	$0.30

TABLE 11

WATER AND CHEMICAL CONSUMPTION AND COSTS (TOWER 271)

ITEM	CONSUMPTION	COST
WATER	898,800 gal	$679.49
SEWER	139,759 gal	$129.19
DIAS-AID	77.24 gal	$3630.28
TOTAL COST		$4438.97
CHEM COST/KGAL		$4.04
COST/TON		$4.23
MBTU AND COST/MBTU	8215.43	$0.54

TABLE 12

WATER AND CHEMICAL CONSUMPTION AND COSTS (NEWARK TOWER)

ITEM	CONSUMPTION	COST
WATER	5,251,970 gal	$10,188.82
SEWER	1,406,996 gal	$787.92
1311	70.8 gal	$844.45
100	28.5 qts	$59.57
HTH	135 lbs	$135.00
TOTAL COST		$12,015.76
CHEM COST/KGAL		$0.22
COST/TON		$3.75
MBTU AND COST/MBTU	19,041.35	$0.63

By simply looking at the cost/MBtu the acid treatment (tower 676) is the cheapest treatment program followed by DIAS-AID (tower 271) with Organsperse-1311 (Newark tower) being the most expensive program per MBtu. Figure 14 illustrates in graphical form these results.

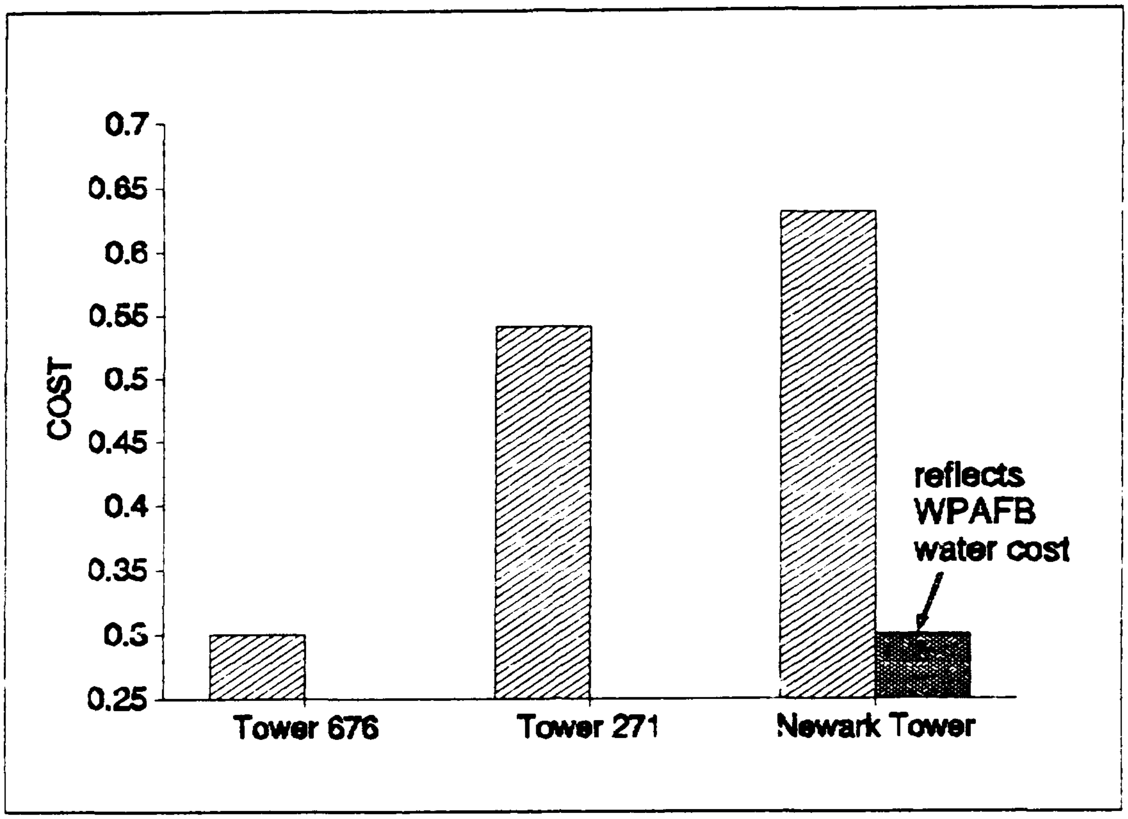

Figure 14. Costs Per MBtu

Acid vs DIAS-AID. The first thing worth mentioning is the fact that both towers 676 and 271 provided nearly equal amounts of cooling. Also, both systems consumed approximately equal amounts of water. The similar water consumption was not expected, since tower 271 was operating at over 8 cycles of concentration and tower 676 was operating at approximately 2.8 cycles. Logic would indicate greater COCs require less makeup water per MBtu of heat ejected from the system. But as shown in Figure 2, once COCs reach 3.5 to 4.0, any further increases will not significantly reduce makeup requirements. The lower cost for sanitary discharge was anticipated since more water was evaporated from the system since it was cycled more times through the tower (8 COCs vs 2.8 COCs).

The results of the cost per MBtu show a large cost increase, almost double, using the DIAS-AID compared to the acid program. Since the water costs are nearly the same, the big cost difference is the chemical costs. The chemical cost per thousand gallons of water tells the story ($1.22 vs $4.04). The cost of chemicals is over three times higher for DIAS-AID than the acid program. To balance the costs in chemicals between these two towers, tower 271 would have had to consume less than a third of the water it actually used.

Acid vs Organosperse-1311. The large cost differential between the Newark treatment and acid treatment is misleading. The unit cost for makeup water is dramatically different between Newark, AFB and WPAFB, $.0019 and $.00076 respectively. If Newark's water cost was the same as WPAFB's. Newark's cost for water would drop from $10,188 to $3970. This translates to $0.30 per MBtu, equal to the acid program cost, instead of $0.63. This would make the Organosperse-1311 solubilizer very competitive with the acid treatment method. This is not to say these treatments are totally interchangeable though. Since the water chemistries are different at both locations, the application might require some modifications. Newark's makeup water is pre-softened, which means the scaling tendency has been reduced. If the cost of softening the water could be assessed, it should be added to the cost.

The comparison that is significant is the chemical cost per thousand gallons of makeup. The Organosperse-1311 cost $0.22 per thousand gallons, considerably less than any of the other programs. This cost is a sixth of the acid cost and five percent the cost of the DIAS-AID product.

Treatment Effectiveness

Scale Control. As discussed earlier, one of the best ways to determine if a treatment program is effective against scale buildup is to open the system and look at it after a period of operation. In this experiment, time restrictions and mission requirements precluded shutting down the systems and opening them for a visual inspection. Therefore visual tower checks were made periodically for scale and the condenser pressures were monitored daily for abnormal changes.

The visual inspections were recorded on cooling tower condition checklists located in Appendix C. Both tower 676 and the Newark tower did not show any indications of scale formation in the towers during the experiment. Tower 271 showed substantial scale formation on the drift eliminators. The scale closed over half of the openings between the eliminators. The tower operators increased the

COCs in an attempt to fix the problem. By the end of the experiment no reduced scale buildup was noted.

One of the first indications of scale buildup in the heat exchanger could be a significant increase in condenser pressure. Figures 15, 16, and 17 show the recorded daily condenser pressure readings. Of the two chillers at tower 676 that operated most of the time only one had a pressure gauge, thus only one plot Figure 15. Tower 271 had two of the three chillers operational all the time. If a chiller was off, the pressure is recorded at the last value. The Newark tower had eight chillers that were randomly operated. Therefore, the three most frequently run chillers' pressures were plotted. If scale buildup occurred, the assumption was made that scale would increase pressure in frequently run chillers.

The condenser plot for tower 676, Figure 15 does not show any significant increase. This indicates there is probably little or no scale buildup occurring in this chiller. Verification can only occur when the system is opened for inspection or energy consumption data are collected.

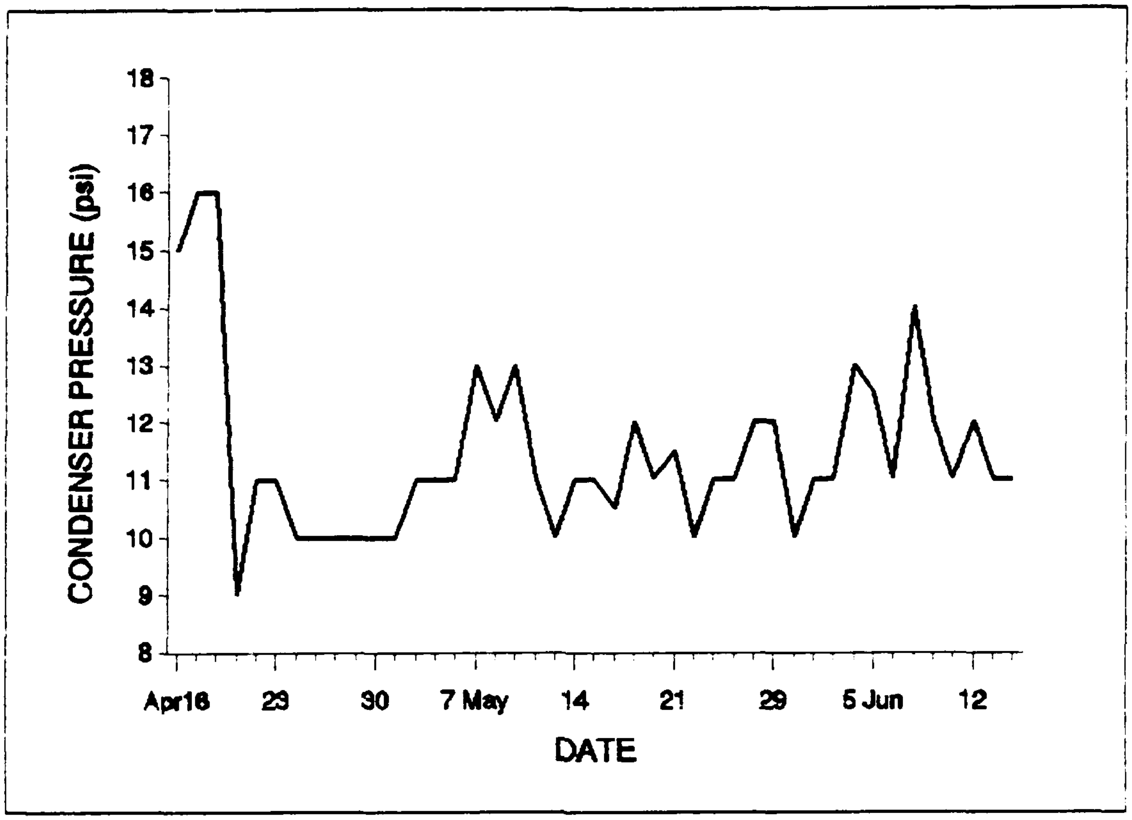

Figure 15. Tower 676 Condenser Pressure

The next graph, Figure 16, does show a steady increase, but nothing significant. If this plot is compared to the mean outside air temperatures, it looks like the dips and rises correspond to the temperature changes, Figure 21, Appendix H. The increase in condenser pressure could merely be a function of outside air temperature rather than scale buildup.

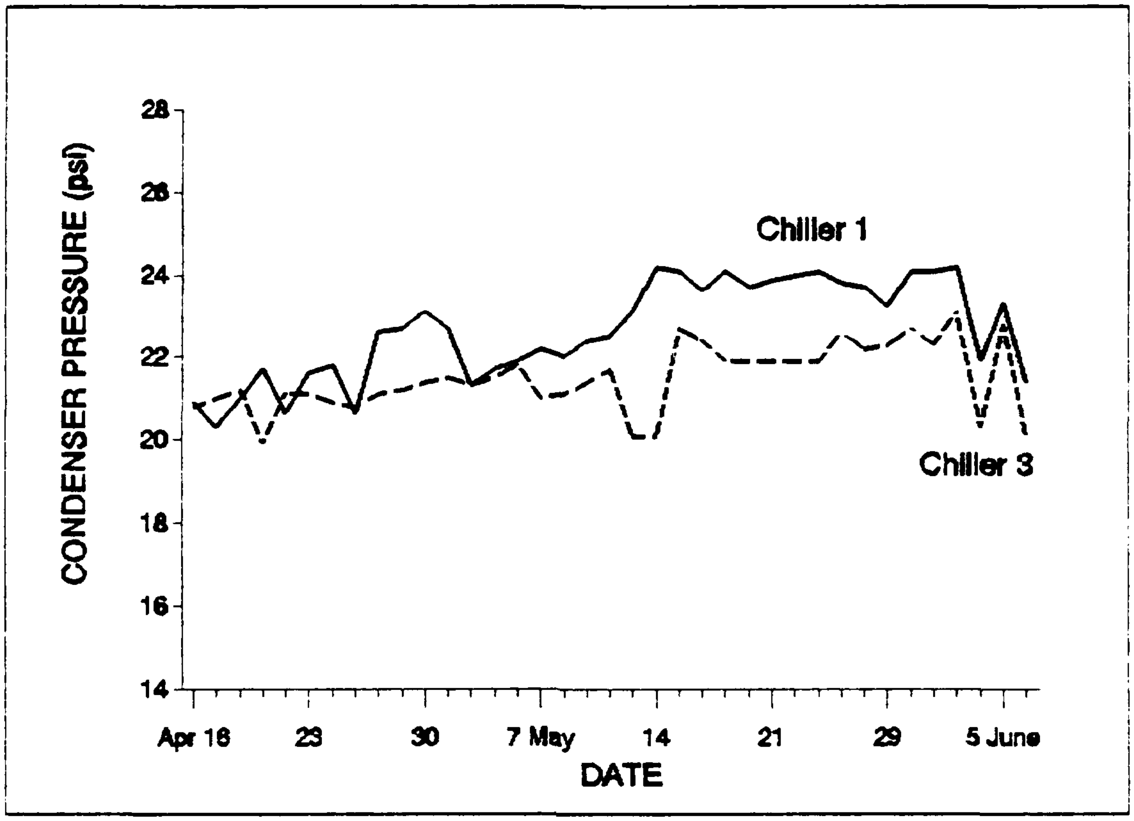

Figure 16. Tower 271 Condenser Pressure

A similar analysis could be made of Figure 17, Newark tower condenser plot, as was made with tower 271. The graph shows a slight increase, but it could also correlate with outside air temperatures.

As stated previously, the best scale control comparison of the three treatment programs should be based on visual inspections. Tower 676 and the Newark tower appeared to control scale satisfactorily. Tower 271 was plagued with a heavy scale buildup on the drift eliminators. This scale restricted air flow through the tower essentially reducing the effectiveness of the tower.

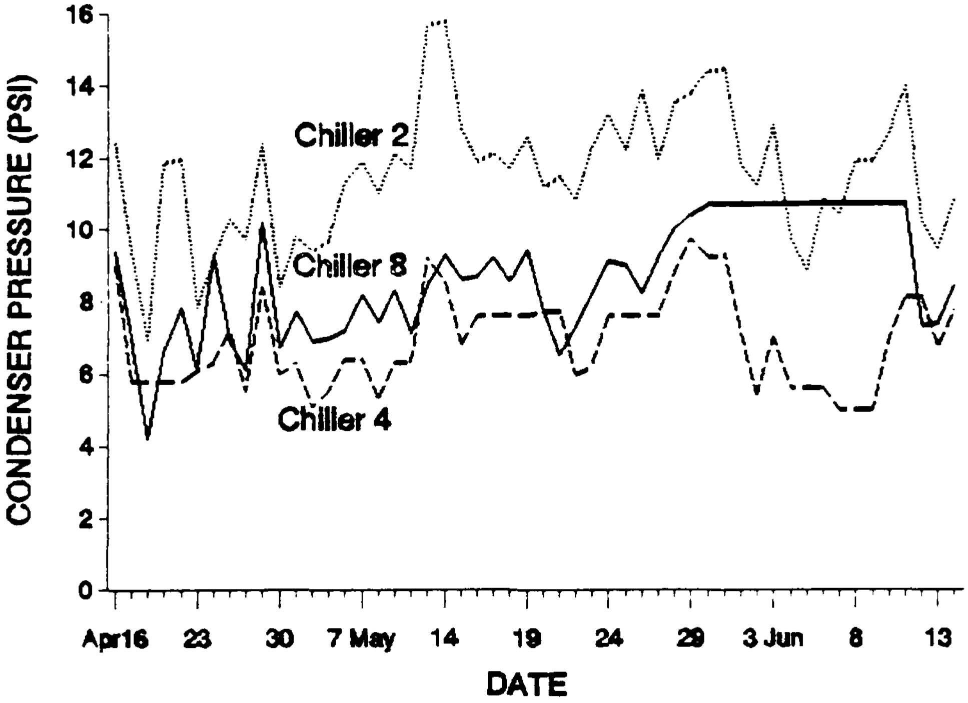

Figure 17. Newark Tower Condenser Pressure

Corrosion Control

Due to the proprietary nature of the DIAS-AID and Organosperse-1311 it was impossible to tell what type of corrosion inhibitors were used. Both of the treatments included the scale and corrosion inhibitors as part of the chemical mix . The corrosion inhibitors used with the acid program are listed in Table 7.

The corrosion coupons for towers 676 and 271 were analyzed by Crown Engineering of Dayton, Ohio. Newark's coupons were analyzed by Lombardi Water Management, Inc. of Columbus, Ohio. The results are tabulated in Table 13.

TABLE 13

CORROSION COUPON RESULTS

TOWER	METAL TYPE	DAYS EXPOSED	CORROSION RATE (MPY)
676	steel	78	7.73
676	copper	78	0.08
271	steel	31	2.30
271	copper	31	0.59
Newark	steel	95	0.50
Newark	copper	95	0.90

Comparing the results in Table 13 with established criteria (Table 9), all three programs exceeded acceptable standards either for steel or copper. Steel corrosion in tower 676 is classified moderate. Whereas, copper corrosion in both towers 271 and Newark was severe. All three situations where the corrosion rates exceeded acceptable rates should be further examined. No one program was significantly better than any of the others.

Microorganism Control

The evaluation of microorganism growth was evaluated both by visual inspections and the paddle test as outlined in chapter 3. The same inspection forms were used for checking scale (Appendix C) and to note any microorganism growth. Both tower 271 and the Newark tower remained relatively clean of visual growths during the experiment. A substantial amount of green slime was noted on the tower basin surface of tower 676. This surface was well over two thirds covered with growth, therefore classified as dirty.

The second part of the test involved the paddle test. Each tower was evaluated three times, at approximately two week intervals, for bacteria and fungus growth. No fungus growth was detected in any of the towers throughout the experiment. Figure 18 provides the bacteria count in bacteria colonies per milliliter (ml) for each day the tower was tested. The numbers on the y axis of the graph indicate the power of ten. Therefore, six on the graph equates to one million colonies.

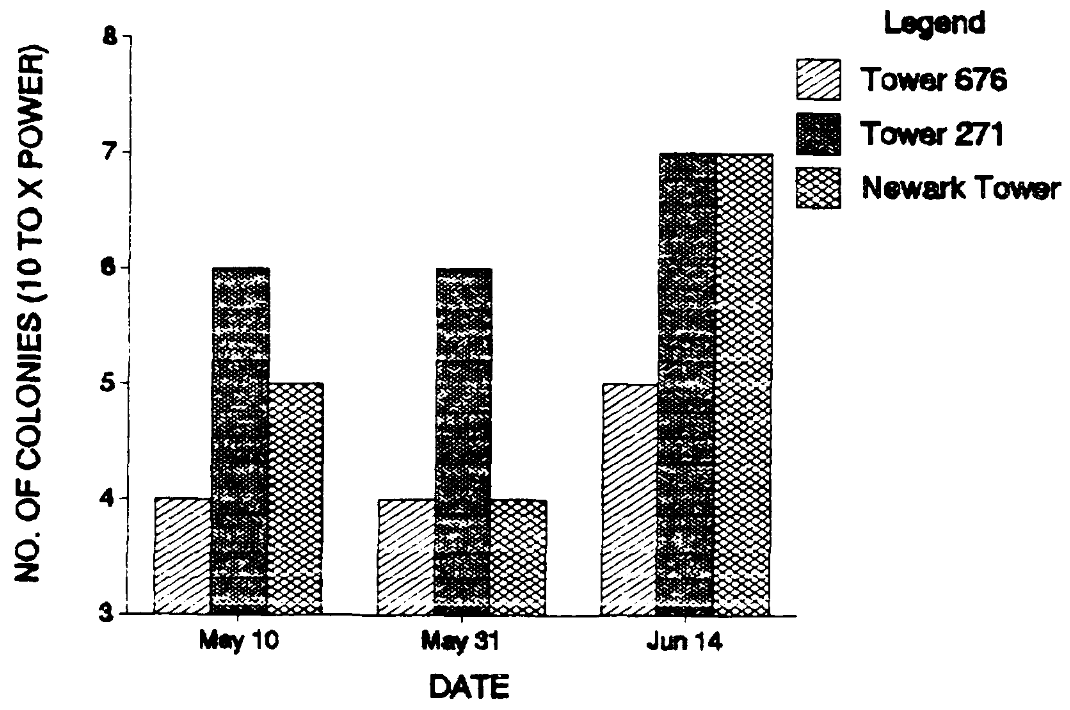

Figure 18. Bacteria Count

With the criteria that a clean system has a count less than 500,000 bacteria per ml, tower 676 incorporated the most effective treatment. The Newark tower's treatment kept the system clean until the last test. The chemical supplier for Newark's treatment commented that the timing of the test and the chemical application could cause the test results obtained on June 14. Tower 271 continually exceeded the clean criteria. The chemical treatment on tower 271 used a biostat instead of a biocide. A biocide is necessary to kill the bacteria, but the biostat should have kept the bacteria in check to some degree.

Further testing is required to test the actual effectiveness of the biostat in the DIAS-AID. The high bacteria counts could be the result of an improperly administered biocide program rather than the DIAS-AID product.

V. Conclusions and Recommendations

Research Overview

This experimental research project was undertaken to evaluate three different methods of water treatment in cooling tower systems. Efficiency, cost comparison, and effectiveness of each program were analyzed. The three methods evaluated were an acid treatment at tower 676, a crystal modifier treatment (DIAS-AID) at tower 271, and a solubilizer treatment (Organosperse-1311) at the Newark tower. Chemical and makeup water costs, tower performance in MBtu, and control data were all recorded during a 60 day time frame. These data were used to compute cost comparisons between the three systems.

The effectiveness of the three treatment programs was measured in three areas - scale control, corrosion inhibition, and microorganism growth containment. Scale control was evaluated by visual inspections and tracking condenser pressures for abnormal increases. Corrosion coupons were used in all three systems to determine how well the corrosion inhibitors worked. Two methods were used to check microorganism in each system. Periodic visual inspections were used to detect visible growths and a paddle test was used to check bacteria and fungus growth.

Conclusion

The findings in this study showed that the tower using DIAS-AID, tower 271, cost significantly more per MBtu of heat rejected by the tower than either the acid system, tower 676, or the Organosperse-1311 used in the Newark tower (unless using WPAFB water cost). Also, from visual inspections the DIAS-AID product did not perform as well in controlling scale as the other two systems. Recording and tracking condenser pressures was inconclusive in showing any trends which could indicate scale formation on the heat exchanger. The corrosion data does not single any specific program as best. In fact, each program satisfactorily protects one type metal from corrosion, but does not protect the other metal. The treatment program at tower 676 provided the best bacteria control while the DIAS-AID treatment had consistently high bacteria counts indicated by the paddle test. Table 14 summarizes the information obtained from this experiment.

Actual conditions inside the system can not be visually checked until the systems can be turned off and further investigation is required before making a final recommendation. Also, maintenance and some operational costs could not be included in this study. But, based on the results obtained, recommend an acid or solubilizer program dependent on your water and tower conditions.

TABLE 14

EXPERIMENT DATA SUMMARY

Parameter	Tower 676 Acid	Tower 271 Crystal Modifier	Newark Tower Solubilizer
Cost/MBtu	$0.30	$0.54	$0.63 ($.30)
Cost/Ton	$5.23	$4.23	$4.04
Chem$/kgal	$1.22	$4.04	$0.22
Scale Control	good	poor	good
Steel Corr.	moderate	mild	negligible
Copper Corr.	negligible	severe	severe
Microorg	clean	dirty	clean

Significance

Both 271 and Newark towers are on test programs with the DIAS-AID and Organosperse-1311, respectively. The information from this research allows a comparison of costs and effectiveness with an established program (acid) which has worked well in the past. Perhaps more importantly this information provides the initial data required to continue on with a longitudinal study on the three water treatment methods. In all the areas analyzed in this study, the Newark tower's program provided good water treatment. The DIAS-AID product overall did not perform as well as either the acid or Organosperse-1311 programs.

The next step is to review the subjective factors that were observed. The Newark tower is the only tower on base and is monitored very closely. The towers at WPAFB are two of 40 operational towers. Granted the WPAFB towers were smaller than the Newark tower, but they too require close monitoring. The 2750th Civil Engineering Squadron is not manned to have dedicated people assigned to each tower. Instead, individuals are assigned a number of towers to monitor, operate, and repair. If one system develops a problem, the technician must neglect the other towers while repairing the malfunctioning tower. In addition, the technician works as a refrigeration specialist when mission requirements dictate, thus ignoring tower operations completely.

Two good characteristics of the DIAS-AID program are low monitoring requirements and few equipment needs. The only control required for maintaining the cycles of concentration is a conductivity controller which pumps the chemical into the water. Also, it is a single product application. The acid system requires two meters and two pumps to operate, not to mention all the required monitoring of chemical tests to maintain system balance. Both the lower monitoring and reduced equipment requirements are appealing to an organization with limited manpower. Another benefit of DIAS-AID is it will not destroy a tower in an overfeed situation like acid. Many of the operators at WPAFB have acid burns on their skin from handling sulfuric acid in the past. The DIAS-AID is virtually harmless and can be handled directly by operators and repair personnel.

Like DIAS-AID, Organosperse-1311 does not use a strong acid. Thus operators and maintenance personnel at Newark, AFB do not worry about the hazards of working with acid. The Newark program did a good job of controlling scale, inhibiting corrosion, and restricting microorganism growth. It also cost about the same as the acid program using WPAFB water costs and not including the pre-softening cost.

Recommendations

- This study attempted to compare water and chemical operating costs in three different size towers by their performances. Additional studies involving towers of the same size could better help operators make decisions on what chemicals to use.
- When the systems are turned off for maintenance during the heating season, document all levels of scale and corrosion and compare results with previous observations to make necessary adjustments to ensure effective protection.
- A direct comparison of the DIAS-AID with acid on the same tower would be beneficial. Using the data from this study, convert tower 676 to DIAS-AID and run the exact same experiment.
- Close monitoring of any system can improve both the treatment programs efficiency and effectiveness. Programs like the DIAS-AID require careful monitoring to ensure enough chemical is in the system. Operating at eight and greater cycles of concentration can lead to disaster if the

chemical runs out. The system would be so concentrated with calcium it would scale quickly and possibly shut down the system.

- This study only looked at two costs (chemical and water) involved in operating a cooling tower. Other studies should look at energy costs that are a function of how well a treatment program works. Another cost that must be studied is the labor costs involved in maintaining each treatment method.

- With ever changing environmental standards, evaluate each of the three treatments methods to determine if they will meet future EPA standards.

- Air Force regulations specifically restrict use of non-chemical treatments for cooling towers. With improvements in magnetic treatments, the Air Force should allow limited testing using this technology.

- Also, Air Force regulations require generic water treatment programs. Most Air Force bases do not have the technical expertise to develop a generic program. Therefore, would have to contract with a chemical company to develop a program. Once the program is developed then the base would have to mix the chemicals themselves. This would require additional manpower that is simply unavailable. It would probably be more cost effective to use a treatment program already developed. This would provide another area for further study and evaluation.

Appendix A: List of Approved Chemicals

BIOCIDE, active ingredient, Methylenebis(thiocynate), 10 percent in water solution. None. Use: Cooling towers treated with acid and pH less than 7.5. Federal specification: MIL-A-46153.

BIOCIDE, active ingredient 20 percent 2,2-Dibromo-3-nitrilopropionmide, 80 percent inert ingredients. Use: Cooling towers treated with acid and pH less than 7.5. Federal specification: None.

BIOCIDE, active ingredients 20 percent n-Alkydimethylbenzylammonium chloride and 3 to 4 percent Bis(tri-n-butyltin)oxide, pH greater than 10.5. Use: Cooling towers with pH greater than 7.5. Federal specification: None.

BIOCIDE,active ingredients 20 percent n-Alkyldimethybenzylammonium chloride and 3 to 4 percent Bis(tri-n-butyltin)oxide, pH greater than 10.5. Use: Cooling towers with pH greater than 7.5. Federal Specification: None.

BIOCIDE, active ingredient 60 percent Poly [oxyethylene(dimethyliminio)ethylene-(dimethyliminio)ethylene dichloride]. Use: Cooling towers with pH greater than 7.5. Federal specification: None.

BIOCIDE, active ingredient 96 to 98 percent 1-Bromo-3-chloro- 5,5-dimethylhydantion, granular. Use: Remote cooling towers with any pH. Federal Specification: None.

BIOCIDE, active ingredients 60 percent consisting of 14 to 15 percent Disodium cyanodithioimidocarbonate and 20 to 21 percent Potassium n-methyldithiocarbamate. Use: Cooling towers with pH greater than 7.5. Federal Specification: None.

CALCIUM HYPOCHLORITE, granular, 65 percent chlorine by weight. Use: Algae control in cooling towers and disinfectant in treatment for Legionnaire's disease. Federal Specification:: O-C-114.

DIPHOSPHONIC ACID (HEDP) 1-hydroxyethylidenel, 1-diphosphonic acid, active ingredient 58 to 62 percent, specific gravity 1.45 at 20 degrees C, pH of 1 percent solution less than 2.0. Use: Inhibitor to prevent formation of calcium and magnesium scale in cooling water applications. Federal Specification: None.

POLYPHOSPHATE GLASS, SLOWLY SOLUBLE, Minimum P2O5 content 67 percent, Solubility: 10 to 20 percent per month. Use:

Treatment of cooling water in smaller cooling towers. Federal Specifications: None.

SODIUM HEXAMETAPHOSPHATE, type II, 66.5 percent P_2O_5, glassy form, beads or plates. Use: A cathodic corrosion inhibitor in cooling towers and to remove hardness in boiler water. Federal Specification: O-S-635, Type II.

TETRASODIUM PYROPHOSPHATE, anhydrous, granular, 53 percent P_2O_5 minimum. Use: Corrosion inhibitor in cooling towers and to remove hardness in boiler water. Federal Specification: None.

TETRASODIUM PYROPHOSPHATE, decahydrate, 31 percent P_2O_5 minimum. Use: Corrosion inhibitor in cooling towers and to remove hardness in boiler water. Federal Specification: None.

POLYACRYLIC ACID, low molecular weight, water white to light amber color, total solids 45 to 65±2 percent, approximate molecular weight 1000 to 4000, specific gravity 1.1 to 1.3 at 25 degrees C, viscosity 200-1000 cps at 25 degrees C. Use: Dispersant in cooling tower to prevent fouling by nonliving matter. Federal Specification: None.

SODIUM HYPOCHLORITE SOLUTION, clear, light yellow liquid containing not less than 10 percent available chlorine by volume. Use: Disinfectant and treatment of Legionnaires' disease in cooling towers. Federal Specification: O-S-602.

SODIUM SILICATE,relatively low alkalinity, 41 degree Baume, approximately 28.8 percent SiO_2, 6 to 7 percent Na_2O, not more than 0.5 percent suspended matter. Use: Cathodic corrosion inhibitor in cooling towers. Federal Specification: O-S-605.

SULFURIC ACID, technical, class A, grade 2, 93 percent sulfuric acid concentration. 66 degrees Baume. Use: Regenerate ion exchange resins, adjust pH in cooling towers. Federal Specification: O-S-809.

TOLYLTRIAZOLE (TT), active ingredient 50 percent tolyltriazole. Use: Corrosion inhibitor for copper alloys in cooling water systems. Federal Specification: None.

ZINC SULFATE, monohydrate, white, free flowing powder, soluble in water. Use: Cathodic corrosion inhibitor in cooling towers. Federal Specification: None.

Appendix B: Water Treatment Tests

TOTAL (M) ALKALINITY
TEST PROCEDURES

APPARATUS:
Burette 10 ml, Automatic (for N/50 Sulfuric Acid)(item 1001)
Graduated Cylinder, 50 ml, Plastic (item 1004)
Bottle, w/Dropper (for Mixed Indicator) 2 oz (item 1005)
Casserole, Porcelain, Heavy Duty, 200 ml Capacity (item 1003)
Stirring Rod, Plastic (item 1006)

REAGENTS:
Standard Sulfuric Acid Solution, N/50 (item 2001)
Mixed Indicator Solution (item 2036)

METHOD:
1. Measure the amount of water to be tested in the graduated cylinder. The amount should be based on the expected results of the test according to the following:

M Alkalinity Expected, as CaCO3	Sample Size	Factor
Less than 100 ppm	50 ml	20
More than 100 ppm	20 ml	50

2. Pour into the casserole.

3. Add 10 drops of Mixed Indicator Solution to the casserole and stir.

4. If the water changes to a light pink color, free mineral acid is present. There is no mixed indicator alkalinity, and the "M" reading is reported as "zero "

5. If the water changes to a green or blue color, "M" alkalinity is present and the test should be continued.

6. Squeeze the rubber bulb to force the Standard Sulfuric Acid Solution to fill the burette just above the zero mark; then allow the excess to drain back automatically into the bottle.

5. While stirring the water constantly, add Standard Sulfuric Acid Solution slowly from the burette to the casserole until the green or blue color changes to light pink. This is the end point. Read the burette to the nearest 0.1 ml.

RESULTS:
The M alkalinity (ppm as $CaCO_3$) is calculated as follows:

M alkalinity (ppm as $CaCO_3$) = (ml acid) * (factor)

NOTES:
1. If the end point color is difficult to see, repeat the entire test using 15 drops of Mixed Indicator Solution.
2. Just before the end point is reached, the green or blue color fades to alight blue color and then becomes a light pink. The end point is the first appearance of a permanent pink color.

CONDUCTIVITY
TEST PROCEDURES

APPARATUS:
1. Conductivity Meter, Complete (item 1014 or item 1034) (Authorized by TA 404-This item is available through normal supply channels. It is not furnished by the check-analysis laboratory.)

2. In general, there are two types of conductivity meters. One has an electrode that is put into a cell containing the water to be tested, The other has a small cup mounted on the meter into which the water to be tested is poured. Either type of meter may be automatically temperature compensated, or the meter may require a temperature correction. The meter may indicate TDS or conductivity as micromhos, but either measurement represents the same characteristic of the water sample. Where the meter is designed to give either measurement, it is important to always use the same measurement to avoid an error.
Cylinder, Ungraduated, Footed Base, about 5 inches high x 1 1/2-inch diameter (item 1016)

REAGENTS:
Phenolphthalein Indicator, 1 percent (item 2040)
Gallic Acid Powder (item 2063)

METHOD:
It is necessary to follow the instructions furnished with the conductivity meter that is being used. The general procedure should be similar to the following steps:
1. The quantity of water sample should be as specified for the meter.
2. Add 3 drops of Phenolphthalein Indicator. If the sample turns red, add Gallic Acid Powder until the red color disappears. If the water does not turn red when the Phenolphthalein Indicator is added, continue the test.

3. Follow the instructions for the meter to measure the conductivity, using the appropriate method (that is, with or without the acid addition).

RESULTS:

Depending upon the type of meter used, the results are read as either conductivity in micromhos or TDS in ppm. The relationship between these measurements when these procedures are used is as follows:

TDS, ppm = 0.66 * Conductivity, micromhos
Conductivity, micromhos = 1.5 * TDS, ppm.

NOTES:

1. Periodically, the meter should be calibrated against a standard solution.
2. Two standard potassium chloride solutions are available from the check-analysis laboratory:
    a. Item 2095--500 micromhos
    b. Item 2096==7000 micromhos

TOTAL PHOSPHATE
TEST PROCEDURES

APPARATUS

Comparator Slide Base, Taylor No. 9190, or equal (item 1017)
High Phosphate Comparator, Range 5 to 100 ppm, Taylor No. 9119, or equal (item 1028)
Phosphate Mixing Tube Graduated at 5, 15, and 17.5 ml with Rubber Stopper, Taylor No. 4021, or equal (items 1029 and 1030)
Test Tube, 5 ml (two required), Taylor No. 4023, or equal
Wash Bottle for Molybdate Reagent
Funnel, Plastic
Filter Paper, Whatman No. 5, 12.5 cm. dia, or equal
Test Tube Cleaning Brush
Measuring Cup, Plastic 0.1 gm Capacity
Beaker, Plastic 150 ml Capacity
Erlenmeyer Flask, 250 ml, Glass
Hot Plate, 120 V, 60 Hz
Graduated Cylinder, 50 ml, Plastic

REAGENTS

Sulfuric Acid Solution, 4 N - CAUTION STRONG ACID.
Sodium Hydroxide Solution, 4 N - CAUTION STRONG CAUSTIC.
Phosphate Indicator Powder
Molybdate Reagent Solution - CAUTION STRONG ACID.
Distilled Water

PREPARATION FOR WATER SAMPLE TO BE TESTED:

It is imperative that the water sample to be tested be free from suspended matter. Mere traces will cause serious errors. Filter the water into the beaker and through the same filter paper as many times as required to produce a clear sample.

METHOD

1. Measure 25 ml of the filtered water sample in the 50 ml graduate cylinder.

2. Pour into the Erlenmeyer flask.

3. Measure 5 ml of 4 N Sulfuric Acid (reversion acid) in the 10 ml cylinder and slowly pour into the Erlenmeyer flask.

4. Heat the flask just to boiling (electric hot plate) and then turn the heat down so that the water simmers for 15 to 20 minutes. The heating should be done gently so that not more than half of the mixture evaporates. A clean funnel placed in the mouth of the flask will reduce evaporation. In no case should the rate of heating cause white fumes to be given off. If this happens, discard the sample and start the test over.

5. Cool the mixture to room temperature.

6. Add 5 ml of 4 N Sodium Hydroxide (reversion neutralizer).

7. Pour the contents of the flask into graduated cylinder.

8. Add distilled water to the graduated cylinder to fill to the 25 ml mark, then mix the contents of the graduate.

9. Fill the phosphate mixing tube to the 5 ml (bottom) mark with the prepared water sample from the graduated cylinder.

10. Fill to the 15 ml (middle) mark with Molybdate Reagent Solution.

11. Add 2 LEVEL measuring dipperfuls of the Phosphate Indicator Powder to the phosphate mixing tube.

12. Insert the rubber stopper and mix. If a blue color does not develop in 3 minutes, there are no phosphates present; the total PO4 reading is reported as "zero" and the test is discontinued. If phosphates are present, a blue color will develop and the test is continued.

13. Place the phosphate mixing tube in the middle hole of the comparator.

14. Fill two 5 ml test tubes with filtered water samples and place the test tubes in the holes on either side of matched by one of the color standards of the slide.

RESULTS
The phosphate, in ppm PO4, is the number appearing on the slide as indicated by the arrow on the base. If the phosphate exceeds 80 ppm, discard the test. Repeat the test, using 2.5 ml of the filtered water sample (instead of 5 ml); dilute to the (bottom) with distilled or condensate water and repeat the test starting with step 10. Multiply reading by 2 to obtain PO4 in ppm.

PHOSPHONATE TEST PROCEDURE (TAYLOR DROP TEST)

1. To filter the water sample, use a 0.22 micron membrane filter in a filter holder/syringe assembly. Fill the sample tube to the 35 ml mark with filtered sample.

2. Add 1 drop of R-0697 Thiosulfate N/10 and swirl to mix. Wait 30-60 seconds.

3. Add 10 drops of R-0805 Fluoride Masking Agent and swirl to mix.

4. Add one level dipper of R-0802P Xylenol Orange Indicator Powder and swirl to mix.

5. The pH of the sample must be adjusted between 2.5 and 3.0. Add R-0686 Sulfuric Acid N drop by droop, mixing after each drop. Use pH test strips to determine pH. When the pH is between 2.5 and 3.0 the sample will be lemon yellow in color.

6. Add R-0803 Titrating Solution one drop at a time, swirling after each drop until a permanent pink/violet end point appears. Keep count of the number of drops. Always hold the bottle in a vertical position.

7. Perform a blank on the raw makeup water which does not contain phosphonate by following steps 1-6. Record the number of drops.

8. Subtract the number of drops of R-0803 Titrating Solution obtained in the blank from the number of drops obtained in the sample titration (step 6).

TESTING REAGENTS

Thiosulfate N/10 - Code #R-0697
Fluoride Masking Agent - Code #R-0805
Xylenol Orange Indicator Powder - Code #R-0802P
Sulfuric Acid N - Code #R-0686
pH Test Paper - Code #9315
25 MM Filter - Millipore GSWP02500

Appendix C: Cooling Tower Condition Checklist

Tower #676

Cell # N/A

Operating

Date 10 May

	Clean	Fair	Dirty
Distribution Deck		X	
Distribution Nozzles		X	
Fill Material		X	
Structural Members		X	
Air Louvers	(N/A)		
Drift Eliminators		X	
Basin		X	
Pump Screens	(N/A)		

Operating

Date 14 June

	Clean	Fair	Dirty
Distribution Deck		X	
Distribution Nozzles		X	
Fill Material		X	
Structural Members		X	
Air Louvers	(N/A)		
Drift Eliminators		X	
Basin			X
Pump Screens	(N/A)		

	OK	Repair
Chemical Feed Pump	X	
Water Level Control	X	

Bleed	N/A	gpm
Tower Inlet Temperature	N/A	C
Tower Outlet Temperature	N/A	C
Circulation Rate	N/A	gpm
Wet Bulb Temperature	N/A	C

CLEAN: All surfaces clearly visible - no slimy feel.

FAIR: Some visible biological growth easily removed with finger tips. At least 2/3 of the surfaces free of visible growth, but may feel slimy.

DIRTY: More than 2/3 of the observable surfaces are covered with biological growth or deposits. Other surfaces are slimy. The deposits are hard to remove with finger tips.

Tower # 271 Cell # N/A

Operating Date 10 May

	Clean	Fair	Dirty
Distribution Deck		X	
Distribution Nozzles		X	
Fill Material	X		
Structural Members	X		
Air Louvers		X	
Drift Eliminators			X
Basin	X	X	
Pump Screens	(N/A)		

Operating Date 14 June

	Clean	Fair	Dirty
Distribution Deck		X	
Distribution Nozzles		X	
Fill Material	X		
Structural Members	X		
Air Louvers		X	
Drift Eliminators			X
Basin	X		
Pump Screens	(N/A)		

	OK	Repair
Chemical Feed Pump	X	
Water Level Control	X	

Bleed	N/A	gpm
Tower Inlet Temperature	N/A	C
Tower Outlet Temperature	N/A	C
Circulation Rate	N/A	gpm
Wet Bulb Temperature	N/A	C

CLEAN: All surfaces clearly visible - no slimy feel.

FAIR: Some visible biological growth easily removed with finger tips. At least 2/3 of the surfaces free of visible growth, but may feel slimy.

DIRTY: More than 2/3 of the observable surfaces are covered with biological growth or deposits. Other surfaces are slimy. The deposits are hard to remove with finger tips.

Tower # Newark

Cell # 3

Operating

Date 17 May

		Clean	Fair	Dirty
Distribution Deck		X		
Distribution Nozzles		X		
Fill Material		X		
Structural Members		X		
Air Louvers		X		
Drift Eliminators	(N/A)			
Basin	(N/A)			
Pump Screens	(N/A)			

Operating

Cell # 2

		Clean	Fair	Dirty
Distribution Deck		X		
Distribution Nozzles		X		
Fill Material		X		
Structural Members		X		
Air Louvers		X		
Drift Eliminators	(N/A)			
Basin	(N/A)			
Pump Screens	(N/A)			

	OK	Repair
Chemical Feed Pump	X	
Water Level Control	X	

Bleed	N/A	gpm
Tower Inlet Temperature	N/A	C
Tower Outlet Temperature	N/A	C
Circulation Rate	N/A	gpm
Wet Bulb Temperature	N/A	C

CLEAN: All surfaces clearly visible - no slimy feel.

FAIR: Some visible biological growth easily removed with finger tips. At least 2/3 of the surfaces free of visible growth, but may feel slimy.

DIRTY: More than 2/3 of the observable surfaces are covered with biological growth or deposits. Other surfaces are slimy. The deposits are hard to remove with finger tips.

Tower # Newark

Cell # 1

Operating

Date 17 May

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

Operating

Cell # 4

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

	OK	Repair
Chemical Feed Pump	X	
Water Level Control	X	

Bleed	N/A	gpm
Tower Inlet Temperature	N/A	C
Tower Outlet Temperature	N/A	C
Circulation Rate	N/A	gpm
Wet Bulb Temperature	N/A	C

CLEAN: All surfaces clearly visible - no slimy feel.

FAIR: Some visible biological growth easily removed with finger tips. At least 2/3 of the surfaces free of visible growth, but may feel slimy.

DIRTY: More than 2/3 of the observable surfaces are covered with biological growth or deposits. Other surfaces are slimy. The deposits are hard to remove with finger tips.

Tower # Newark   Cell # 1

Operating   Date 1 June

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

Operating   Cell # 2

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

	OK	Repair
Chemical Feed Pump	X	
Water Level Control	X	

Bleed N/A gpm
Tower Inlet Temperature N/A C
Tower Outlet Temperature N/A C
Circulation Rate N/A gpm
Wet Bulb Temperature N/A C

CLEAN: All surfaces clearly visible - no slimy feel.

FAIR: Some visible biological growth easily removed with finger tips. At least 2/3 of the surfaces free of visible growth, but may feel slimy.

DIRTY: More than 2/3 of the observable surfaces are covered with biological growth or deposits. Other surfaces are slimy. The deposits are hard to remove with finger tips.

Tower # Newark

Cell # 3

Operating

Date 1 June

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

Operating

Cell # 4

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

	OK	Repair
Chemical Feed Pump	X	
Water Level Control	X	

Bleed	N/A	gpm
Tower Inlet Temperature	N/A	C
Tower Outlet Temperature	N/A	C
Circulation Rate	N/A	gpm
Wet Bulb Temperature	N/A	C

CLEAN: All surfaces clearly visible - no slimy feel.

FAIR: Some visible biological growth easily removed with finger tips. At least 2/3 of the surfaces free of visible growth, but may feel slimy.

DIRTY: More than 2/3 of the observable surfaces are covered with biological growth or deposits. Other surfaces are slimy. The deposits are hard to remove with finger tips.

Tower # Newark

Cell # 1

Operating

Date 12 June

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

Operating

Cell # 2

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

	OK	Repair
Chemical Feed Pump	X	
Water Level Control	X	

Bleed	N/A	gpm
Tower Inlet Temperature	N/A	C
Tower Outlet Temperature	N/A	C
Circulation Rate	N/A	gpm
Wet Bulb Temperature	N/A	C

CLEAN: All surfaces clearly visible - no slimy feel.

FAIR: Some visible biological growth easily removed with finger tips. At least 2/3 of the surfaces free of visible growth, but may feel slimy.

DIRTY: More than 2/3 of the observable surfaces are covered with biological growth or deposits. Other surfaces are slimy. The deposits are hard to remove with finger tips.

Tower # Newark

Cell # 3

Operating

Date 12 June

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

Operating

Cell # 4

	Clean	Fair	Dirty
Distribution Deck	X		
Distribution Nozzles	X		
Fill Material	X		
Structural Members	X		
Air Louvers	X		
Drift Eliminators	(N/A)		
Basin	(N/A)		
Pump Screens	(N/A)		

	OK	Repair
Chemical Feed Pump	X	
Water Level Control	X	

Bleed N/A gpm
Tower Inlet Temperature N/A C
Tower Outlet Temperature N/A C
Circulation Rate N/A gpm
Wet Bulb Temperature N/A C

CLEAN: All surfaces clearly visible - no slimy feel.

FAIR: Some visible biological growth easily removed with finger tips. At least 2/3 of the surfaces free of visible growth, but may feel slimy.

DIRTY: More than 2/3 of the observable surfaces are covered with biological growth or deposits. Other surfaces are slimy. The deposits are hard to remove with finger tips.

Appendix D: Bacteria-Fungus Indicator

A simple reliable test for semi quantification of bacteria, yeast and mold.

DIRECTION

1. Remove paddle from the container.
2. Dip the paddle into the fluid tank or fluid sample so that the surface of the media are completely covered.
3. Drain excess fluid from the sides of the paddle.
4. Return paddle to container. Tighten cap.
5. Fill in necessary information on the label provided.
6. Incubate unit in an upright position at 27 - 30 degrees C (82 -86 degrees F) for 48 hours.
7. Compare the number of colonies found on the paddle with the colony density chart to determine actual cell quantity in fluid tested.
8. If no colonies detected after 48 hours, incubate paddle for another 48 hours and read results again.

INTERPRETATION

Malt Extract Agar (Brown Side): Supports only the growth of yeast and mold. Bacterial growth is inhibited due to low pH. Mold grow as fuzzy colonies while yeast colonies are smooth and round.

STORAGE

Can be stored at room temperature. DO NOT FREEZE.

EXPIRY DATE

Seven months from the date of production (Testers used expire 12 Sept 1991).

FORMULATION

T.G.E.A.		Malt Extract Agar	
Ingredients	Gram per liter	Ingredients	Gram per liter
Beef Extract	3.00	Malt Extract	30.00
Tryptone	5.00	Mycological Peptone	5.00
Dextrose	1.00	Agar	15.00
Agar	15.00		

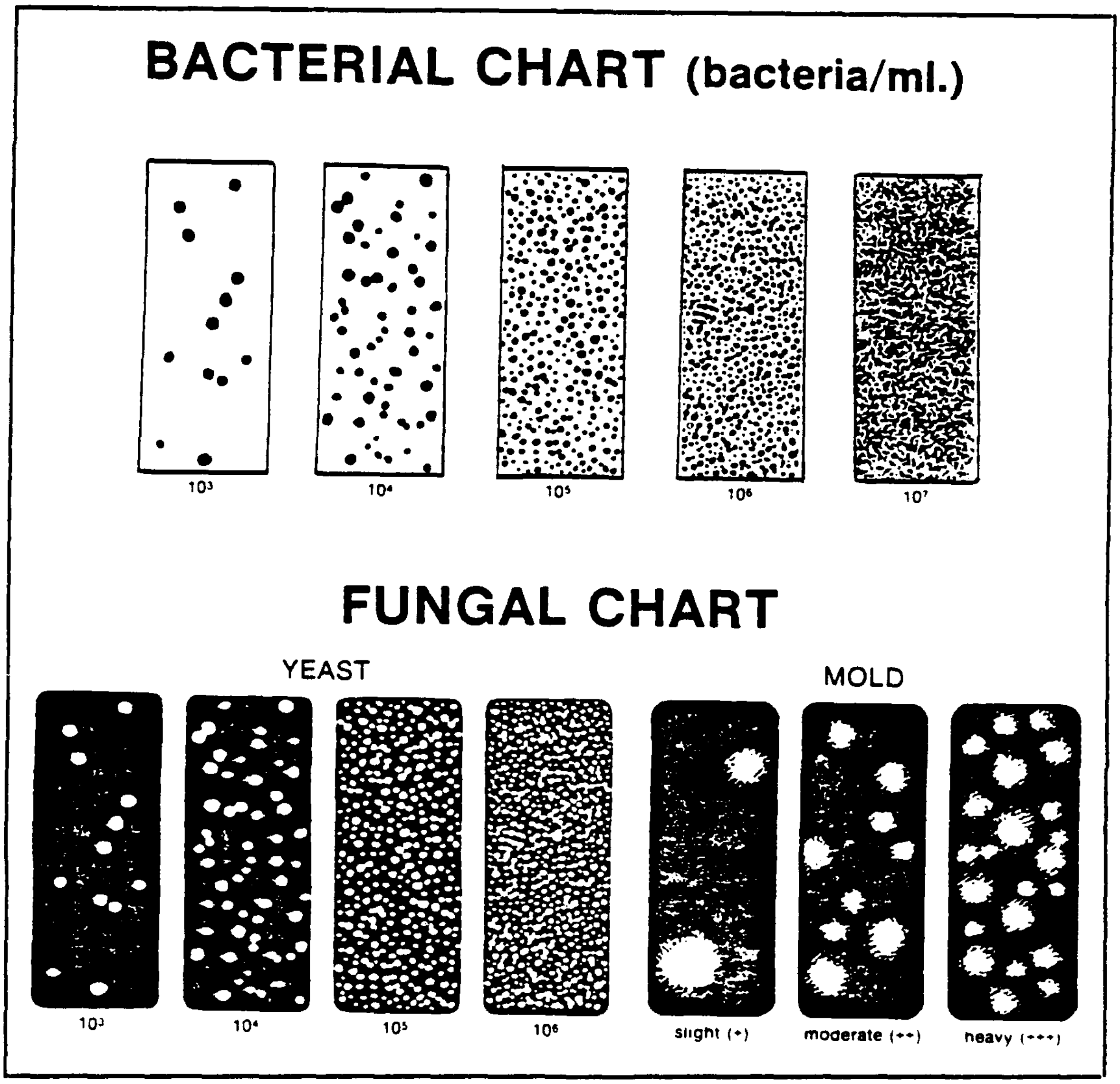

Figure 19. Density Comparison Chart

Appendix E: Temperature, MBtu, and Evaporation Data

Tower 676

Date	Chiller 1		Chiller 2		Chiller 3		Chiller 4			
Apr	Sup	Ret	Sup	Ret	Sup	Ret	Sup	Ret	MBtu	Evap
16	44	54	44	52	44	56	0	0	126.0	14.13
17	44	54	44	52	44	56	0	0	126.0	14.13
18	44	52	44	50	44	56	0	0	109.2	12.25
19	44	52	0	0	0	0	44	54	134.4	14.27
22	44	52	0	0	0	0	44	52	114.2	12.17
23	44	54	0	0	0	0	44	53	132.7	14.16
24	43	50	0	0	0	0	44	53	120.1	12.75
25	44	51	0	0	0	0	44	54	130.2	13.80
26	43	51	0	0	0	0	44	54	134.4	14.27
29	43	51	0	0	0	0	44	54	134.4	14.27
30	43	50	0	0	0	0	44	54	130.2	13.80
May										
1	43	51	0	0	0	0	44	54	134.4	14.27
2	43	51	0	0	0	0	43	54	144.5	15.32
3	43	51	0	0	0	0	43	53	134.4	14.27
6	43	51	0	0	0	0	44	53	124.3	13.22
7	43	51	0	0	0	0	43	54	144.48	15.32
8	43	50	0	0	0	0	43	54	140.28	14.85
9	43	50	0	0	0	0	43	54	140.3	14.85
10	43	50	0	0	0	0	44	54	130.2	13.80
13	43	51	0	0	0	0	44	55	144.5	15.32
14	43	51	0	0	0	0	44	55	144.5	15.32
15	43	51	0	0	0	0	44	55	144.5	15.32
16	43	51	0	0	0	0	44	55	144.5	15.32
17	43	51	0	0	0	0	44	55	144.5	15.32
20	43	51	0	0	0	0	44	55	144.5	15.32
21	43	51	0	0	0	0	44	55	144.5	15.32
22	43	51	0	0	0	0	44	55	144.5	15.32
23	43	51	0	0	0	0	44	55	144.5	15.32
24	43	51	0	0	0	0	44	55	144.5	15.32
28	43	51	0	0	0	0	44	55	144.5	15.32
29	43	51	0	0	0	0	44	55	144.5	15.32
30	43	52	0	0	0	0	45	56	148.7	15.80
31	43	52	0	0	0	0	45	56	148.7	15.80
Jun										
3	43	51	0	0	0	0	44	55	144.5	15.32
4	43	50	0	0	0	0	44	54	130.2	13.80
5	43	50	0	0	0	0	44	54	130.2	13.80
6	43	51	0	0	0	0	44	54	134.4	14.27
7	43	50	0	0	0	0	44	54	130.2	13.80
10	43	51	0	0	0	0	44	55	144.5	15.32
11	43	51	0	0	0	0	44	55	144.5	15.32
12	43	51	0	0	0	0	44	55	144.5	15.32
13	43	51	0	0	0	0	44	55	144.5	15.32
14	43	51	0	0	0	0	44	55	144.5	15.32

Tower 271

Date	Chiller 1		Chiller 2		Chiller 3			
Apr	Sup	Ret	Sup	Ret	Sup	Ret	MBtu	Evap
16	44	49	44	50	0	0	110.9	11.55
17	44	49	44	50	0	0	100.8	10.5
18	44	50	43.6	49.5	0	0	120.0	12.5
19	44	49	44	50	0	0	110.9	11.55
22	43.8	49.5	43.7	48.8	0	0	108.9	11.34
23	43.7	49.2	44.1	48.9	0	0	103.8	10.82
24	44.1	49.1	43.8	49.1	0	0	103.8	10.82
25	43.7	49.2	44.1	49.8	0	0	112.9	11.76
26	44.2	49.9	44.1	50.1	0	0	117.9	12.29
29	43.8	49.8	44.1	50.4	0	0	124.0	12.92
30	44.2	50.5	43.7	50.1	0	0	128.0	13.33
May								
1	44.1	49.6	44	49.8	0	0	113.9	11.87
2	44.5	50.8	43.9	50.4	0	0	129.0	13.44
3	43.7	49.6	44.1	50.1	0	0	120.0	12.50
6	43.8	50.1	44.1	49.6	0	0	118.9	12.39
7	44.1	50.4	44.2	51.5	0	0	133.1	13.86
8	43.7	50.1	43.6	50.1	0	0	130.0	13.55
9	43.7	49.8	44.1	50.4	0	0	125.0	13.02
10	44.1	50.8	44.4	51.1	0	0	135.1	14.07
13	44.2	51.4	44.1	51.6	0	0	148.2	15.44
14	44.5	52.2	44.1	51.6	0	0	153.2	15.96
15	44.7	52.2	44	51.8	0	0	154.2	16.07
16	43.9	51.5	44.5	52.5	0	0	157.2	16.38
17	44.1	51.6	43.4	51.1	0	0	153.2	15.96
20	44.1	51.1	0	0	44.7	52.2	146.2	15.22
21	43.9	50.6	0	0	44.1	50.8	135.1	14.07
22	43.6	51.6	0	0	43.6	51.2	157.2	16.38
23	44.6	52.9	0	0	44.2	52.6	168.3	17.53
24	44.1	52.2	44.6	22.6	0	0	168.3	17.53
28	43.7	51.5	43.6	51.6	0	0	159.3	16.59
29	43.5	50.8	43.7	51.6	0	0	153.2	15.96
30	43.9	51.8	43.9	51.9	0	0	160.3	16.69
31	43.5	51.6	43.6	51.6	0	0	162.3	16.91
Jun								
3	43.8	51.2	43.9	51.8	0	0	154.2	16.07
4	43.9	50.9	43.6	50.8	0	0	143.1	14.91
5	44.1	50.4	44.1	50.5	0	0	128.0	13.33
6	43.7	50.5	43.8	50.9	0	0	140.1	14.60
7	43.8	50.4	44.1	50.8	0	0	134.1	13.97
10	43.7	50.8	43.9	50.8	0	0	141.1	14.70
11	44.1	52.1	43.7	51.8	0	0	162.3	16.91
12	44	51.5	43.9	51.5	0	0	152.2	15.86
13	43.9	50.9	43.7	51.7	0	0	151.2	15.75
14	43.5	51.1	43.7	51.8	0	0	158.3	16.49

Tower Newark

Date	Chiller 3		Chiller 1		Chiller 2		Chiller 4		
Apr	Sup	Ret	Sup	Ret	Sup	Ret	Sup	Ret	MBtu
16	41.6	46.8	0	0	40.1	46.6	40.6	47.3	387.9
17	41	45.8	39.7	46.4	39.9	46	40	46.8	342.1
18	41.2	46.6	40.4	47	39.8	46.2	0	0	292.2
19	41.5	46.1	40.1	46.9	41.1	46.6	0	0	283.5
22	41.9	47.3	0	0	41.4	47.3	0	0	216.7
23	41	46	0	0	40.2	46.1	40.9	46.9	275.2
24	41.2	46.7	0	0	40.8	46.8	40.9	47.5	255.8
25	41.7	46.8	0	0	40.7	46.9	40.9	47.6	266.5
26	40.7	45.8	40	46.3	40.2	45.9	41	46.3	314.9
29	41.4	46.5	39.9	47	40.8	46.5	40.7	47.2	342.5
30	41.1	46.3	0	0	41.2	46.4	40.5	46.9	273.3
May									
1	41.2	46.5	0	0	41.2	46.6	40.7	47.2	283.6
2	40.9	46.3	0	0	40.8	46.3	40.9	46.6	282.4
3	0	0	0	0	41	47.5	41.5	48.5	300.7
6	0	0	40.5	47.1	40.7	46.6	40.5	47.3	254.6
7	0	0	41	47.7	41.1	47.1	41.7	47.9	253.4
8	0	0	41	47.3	40.9	46.8	41.2	47.6	273.6
9	42.5	46.2	40	46.9	40.2	46	40.5	47	398.8
10	0	0	40.5	47.2	40.5	46.5	41	47.3	347.9
13	0	0	40.2	46.9	40.2	46.2	40.3	46.9	375.6
14	0	0	41.1	47.5	41.4	47.5	41	48.3	379.0
15	0	0	41	47.6	41.2	47.3	41.3	48.1	361.7
16	0	0	41.1	47.9	41.4	47.7	41.5	48.4	376.7
17	0	0	40.9	48	41.3	47.6	41.7	47.9	331.8
20	0	0	39.7	46.8	41	45.9	40.5	47.1	313.3
21	0	0	40	46.9	41.4	46.6	40.9	47.2	318.0
22	0	0	40.5	47.7	41.6	46.7	41.5	47.3	316.8
23	0	0	40.8	47.7	41.7	47.1	41.2	47.9	324.9
24	0	0	40.2	47.2	41.1	46.2	41.1	47.2	345.0
28	0	0	40.9	47.1	41.3	46.5	41.1	47.8	333.5
29	0	0	39.5	46.2	40.4	45.8	40.2	46.8	404.9
30	0	0	40	46.8	41.6	46.3	41.3	46.9	364.0
31	0	0	40.2	47	41.8	46.4	41	47.2	335.2
Jun									
3	0	0	40.7	47.3	0	0	41.4	47.9	342.7
4	0	0	0	0	0	0	41	47.6	288.6
5	42.5	48.1	0	0	0	0	0	0	264.4
6	0	0	40.5	47.1	0	0	0	0	273.6
7	0	0	40.1	47	0	0	41.7	46.8	318.0
10	0	0	40.6	47.2	0	0	41.1	47.1	330.6
11	0	0	40	46.7	0	0	41.3	47	351.9
12	0	0	40.4	46.7	41	46.4	0	0	312.2
13	0	0	40.7	47	41.5	46.7	40.8	47.6	332.9
14	0	0	0	0	41.9	46.6	40.9	47.5	305.3

Date	Chiller 5		Chiller 6		Chiller 7		Chiller 8		
Apr	Sup	Ret	Sup	Ret	Sup	Ret	Sup	Ret	Evap
16	40.1	47.3	0	0	0	0	50	55.8	40.41
17	0	0	0	0	0	0	48.2	51.4	35.64
18	0	0	0	0	42.8	47	48.9	51.4	30.44
19	0	0	0	0	43.2	47.2	48.6	52.3	29.54
22	0	0	0	0	43.1	48.4	49.8	52.3	22.57
23	0	0	0	0	42.2	46.8	48.1	50.6	28.66
24	0	0	0	0	0	0	49.3	51	26.65
25	0	0	0	0	0	0	49.3	52.2	27.76
26	0	0	0	0	0	0	48.3	51	32.80
29	0	0	0	0	0	0	48.8	51.9	35.68
30	0	0	0	0	42.5	46.8	49	51.5	28.47
May									
1	0	0	0	0	42.1	47.1	48.9	51.5	29.54
2	0	0	0	0	41.7	47	48.5	51.4	29.42
3	38.9	48.5	0	0	0	0	49.8	52.8	31.32
6	0	0	0	0	0	0	48.9	51.7	26.52
7	0	0	0	0	0	0	49.3	52.4	26.4
8	0	0	0	0	42.7	47	49.1	52.1	28.5
9	40.1	47	0	0	0	0	48.3	51.5	41.54
10	39	47.2	0	0	0	0	48.9	51.9	36.24
13	38.7	46.9	0	0	43.5	47.1	48.7	52	39.12
14	38.7	48.2	0	0	0	0	50	53.2	39.48
15	39.2	48	0	0	0	0	49.5	52.6	37.68
16	38.8	48.4	0	0	0	0	49.8	52.9	39.24
17	0	0	40.6	47.1	0	0	50	52.7	34.56
20	0	0	39.9	45.7	0	0	48.5	51.3	32.64
21	0	0	39.7	46	0	0	48.6	51.5	33.12
22	0	0	40.1	46.7	0	0	49.3	52.1	33
23	0	0	40.4	46.8	0	0	49.7	52.5	33.84
24	0	0	39.7	46.3	42.5	47.2	48.7	51.5	35.94
28	0	0	40.2	46.3	43	47.5	49.3	51.8	34.74
29	41.1	46.8	39.9	45.4	42.5	46.6	47.8	51	42.18
30	40.6	46.8	40.4	46.3	0	0	48.9	51.3	37.92
31	0	0	40	46.6	42.8	47.2	49.1	51.8	34.92
Jun									
3	41	47.4	41.1	46.4	42.8	47.5	49.3	51.9	35.7
4	40.3	47.8	40.7	46.3	42.4	47.5	49.1	51.9	30.06
5	42.3	49	42.1	47.8	0	0	50.7	53.2	27.54
6	40.5	47.3	41	46.2	42.8	47.3	48.8	51.7	28.5
7	39.8	46.7	40.6	46.1	0	0	48.4	51.6	33.12
10	39.6	47	40.4	45.9	0	0	48.6	51.8	34.44
11	39.6	46.5	40	45.6	42.4	46.5	47.9	51.5	36.66
12	39.8	47.3	40.7	45.9	0	0	48.6	51.3	32.52
13	39.6	47.6	0	0	0	0	49.1	51.7	34.68
14	40.1	47.2	40.9	46.3	0	0	49.1	51.8	31.8

Appendix F: Control Parameters Data

Newark Tower

Date	pH	COC	Phosphonate	Conductivity
Apr				
16	8.98	3.06	6	1980
17	9.06	3.06	6	1980
18	9.17	3.05	5	1980
19	9.05	3.07	6	2010
22	8.93	3.01	6	1960
23	9.03	3.14	6	2060
24	9.03	3.25	7	2100
25	8.96	3.05	5	1960
26	8.89	3.05	5	2000
29	9.00	2.97	5	1970
30	9.01	3.02	5	1990
May				
1	9.00	3.01	6	1990
2	8.99	3.08	6	2020
3	9.02	3.03	7	1980
7	8.85	2.96	7	1970
8	8.96	2.98	6	1980
9	8.99	3.06	6	2010
10	8.95	3.09	5	2020
13	8.92	3.03	5	2020
14	9.00	3.14	5	2070
15	8.92	3.10	5	2040
16	8.92	3.06	5	1980
17	8.99	2.96	5	1940
20	8.93	2.95	6	1970
22	8.85	3.19	7	2030
23	8.95	2.98	5	1960
24	9.00	2.97	5	1930
28	8.95	2.90	3	1940
30	8.92	3.05	4	1920
31	9.02	2.88	4	1870
Jun				
1	8.94	3.01	4	1860
3	9.07	2.92	6	1910
4	9.21	3.56	8	2290
5	9.07	2.91	7	1900
6	9.06	2.92	6	1890
7	9.00	2.83	5	1860
10	9.06	3.04	7	1970
11	9.07	3.04	4	1980
13	9.20	3.03	6	1940
14	9.06	2.96	6	1890

Tower 271

Date	COC	Date	COC	Date	COC
Apr					
17	10.2	19	10.0	22	9.5
24	10.0	26	9.7	30	9.5
May					
1	9.0	3	8.9	6	8.4
7	8.2	8	8.3	9	8.4
10	8.4	13	8.2	14	8.3
15	8.6	16	9.6	17	9.9
20	10.3	21	10.1	22	11.0
23	10.8	24	10.2	28	10.3
29	10.3	30	9.5	31	11.0
Jun					
3	8.5	4	8.8	5	11.1
6	9.9	7	10.7	10	10.5
11	9.9	12	10.7	13	10.2
14	6.4				

Tower 676

Date	COC	pH	Phosphonate	Ca Hardness	M-Alk
Apr					
16		6.9			
17		6.9			
18	2.4	7.0	5	790	35
19	2.5	7.1			
22	3.8	7.0	5	865	50
23	2.6	7.1			
24	2.5	7.1			
25	2.6	7.0			
26	3.1	7.3			
29	3.5	7.3	8	810	50
30	2.3	7.3			
May					
1	2.4	7.3			
2	2.4	7.1			
6	2.7	6.9			
7	2.3	7.1			
8	2.4	7.0			
10	2.3	7.1			
15	2.2	7.0	5	550	50
16	2.3	7.1			
17	2.7	7.1			
Jun					
4	2.9	6.9	3	750	50
5	3.1	6.9			
6	3.1	6.5			
7	2.8	6.8			
10	4.3	6.9	6	1150	55
11	2.3	6.9			
12	3.2	6.9			
13	3.2	6.9			
14	3.0	7.0			

Appendix G: Chiller Condenser Pressures Data (psi)

	676	271		Newark		
Date	#1	#1	#3	#2	#4	#8
Apr						
16	15			9.4	9	12.5
17	16	20.8	20.9	7	5.8	9.4
18	16	21	20.3	4.2	off	6.9
19	9	19.9	21.7	6.6	off	11.9
22	11			7.8	off	12
23	11	21.1	21.6	6.1	6.1	7.8
24	10	20.9	21.8	7.3	6.3	9.2
25	10	20.8	20.6	6.9	7.2	10.3
26	10	21.1	22.6	6.1	5.5	9.7
29	10	21.2	22.7	10.2	8.4	12.4
30	10	21.4	23.1	6.7	6	8.4
May						
1	10	21.5	22.7	7.7	6.3	9.8
2	11	21.3	21.3	6.9	5.1	9.4
3	11	21.5	21.7	7	5.5	9.7
6	11	21.8	21.9	7.2	6.4	11.3
7	13	21	22.2	8.2	6.4	11.9
8	12	21.1	22	7.4	5.3	11
9	13	21.4	22.4	8.3	6.3	12.1
10	11	21.7	22.5	7.1	6.3	11.7
13	10	20.1	23.1	8.4	9.2	15.7
14	11		24.2	9.3	8.5	15.8
15	11	22.7	24.1	8.6	6.8	12.8
16	10.5	22.4	23.6	8.7	7.6	11.9
17	12	21.9	24.1	9.2	7.6	12.1
20	11	23.6	23.7	7.7	7.7	11.2
21	11.5	24.1	23.9	6.5	7.7	11.5
22	10	23.3	24	7.3	6	10.8
23	11	23.4	24.1	8.2	6.2	12.3
24	11	22.6	23.8	9.1	7.6	13.2
28	12	22.2	23.7	10	8.8	13.5
29	12	22.3	23.2	10.4	9.7	13.8
30	10	22.7	24.1	10.7	9.2	14.4
31	11	22.3	24.1	10.7	9.3	14.5
Jun						
3	11	23.1	24.2	off	7	12.9
4	13	20.3	21.9	off	5.6	9.7
5	12.5	22.8	23.3	off	off	8.8
6	11	20.1	21.4	off	off	10.8
7	14	22.8	23.6	off	5	10.4
10	12	22.1	23.1	off	off	12.7
11	11	22.3	24.1	off	8.1	14
12	12	23	24.4	7.3	off	10.2
13	11	22.4	24.2	7.4	6.7	9.4
14	11	22.4	23.2	8.4	7.7	10.8

Appendix H: MBtu and Mean Air Temperature

Date	WPAFB Temp	Newark Temp	676 MBtu	271 MBtu	Newark MBtu
Apr 16	61	63	126	110.88	387.936
Apr 17	58	69	126	100.8	342.144
Apr 18	52	54	109.2	119.952	292.176
Apr 19	53	55	134.4	110.88	283.536
Apr 22	49	50	114.24	108.864	216.72
Apr 23	50	51	32.72	103.824	275.184
Apr 24	51	50	120.12	103.824	255.816
Apr 25	50	52	130.2	112.896	266.472
Apr 26	64	66	134.4	117.936	314.856
Apr 29	71	74	134.4	123.984	342.504
Apr 30	66	66	130.2	128.016	273.312
May 1	59	61	134.4	113.904	283.608
May 2	56	59	144.48	129.024	282.384
May 3	57	57	134.4	119.952	300.672
May 6	52	58	124.32	118.944	254.592
May 7	58	58	144.48	133.056	253.44
May 8	62	62	140.28	130.032	273.6
May 9	65	66	140.28	124.992	398.808
May 10	69	69	130.2	135.072	347.904
May 13	74	75	144.48	148.176	375.552
May 14	77	79	144.48	153.216	379.008
May 15	74	77	144.48	154.224	361.728
May 16	74	77	144.48	157.248	376.704
May 17	75	77	144.48	153.216	331.776
May 20	68	68	144.48	146.16	313.344
May 21	69	71	144.48	135.072	317.952
May 22	74	75	144.48	157.248	316.8
May 23	71	77	144.48	168.336	324.864
May 24	77	80	144.48	168.336	345.024
May 28	77	79	144.48	159.264	333.504
May 29	78	81	144.48	153.216	404.928
May 30	80	81	148.68	160.272	364.032
May 31	77	79	148.68	162.288	335.232
June 3	75	76	144.48	154.224	342.72
June 4	65	67	130.2	143.136	288.576
June 5	63	65	130.2	128.016	264.384
June 6	64	67	134.4	140.112	273.6
June 7	66	67	130.2	134.064	317.952
June 10	71	72	144.48	141.12	330.624
June 11	75	76	144.48	162.288	351.936
June 12	76	76	144.48	152.208	312.192
June 13	73	74	144.48	151.2	332.928
June 14	76	75	144.48	158.256	305.28

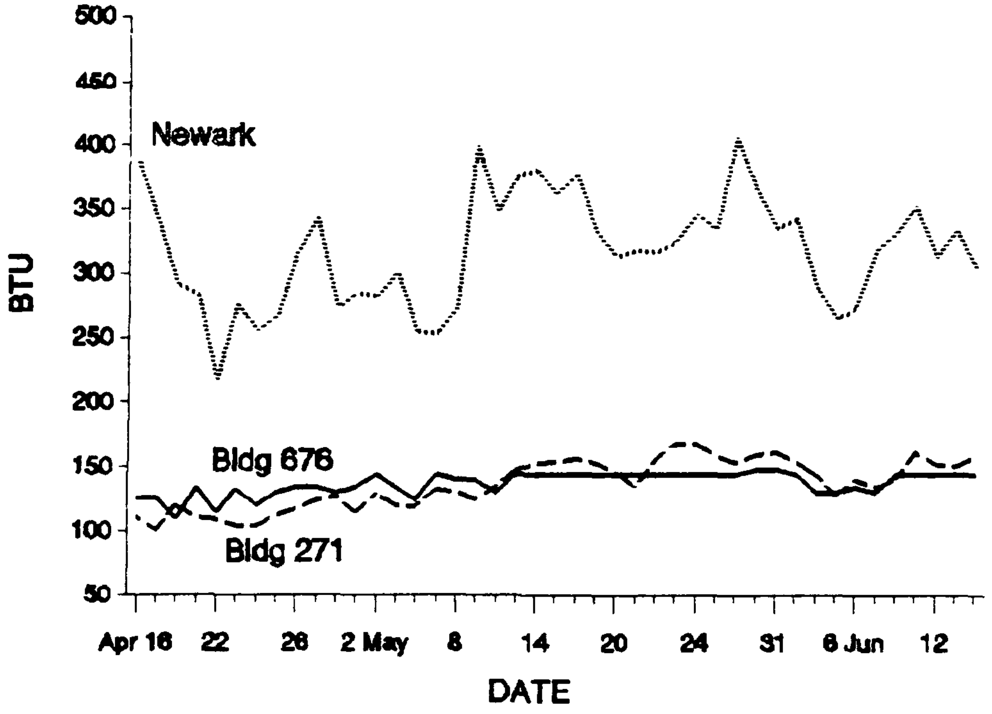

Figure 20. MBtu Plot for All Towers

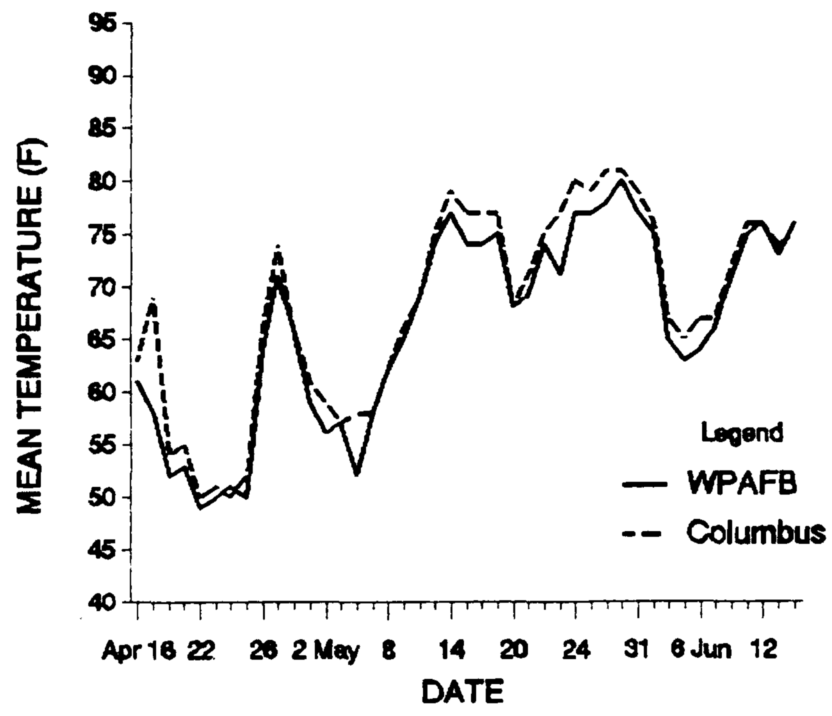

Figure 21. Mean Outside Air Temperatures

Bibliography

Betz. Handbook of Industrial Water Conditioning(Eighth Edition). Engineering and Technical Staff, Betz Laboratories Inc, Trevose PA, 1980.

Clark, John W. and others. Water Supply and Pollution Control(Third Edition). New York: Harper and Row, Publishers, 1977.

Cooling Tower Institute(CTI). Guidelines For Evaluation Of Cooling Water Treatment Effectiveness. CTI Bulletin No. WTP - 130. Houston, October 1981.

Cooling Tower Institute(CTI). Water Chemistry and Treatments. Cooling Tower Manual. Houston, July 1990.

Department of the Air Force. Industrial Water Treatment. AFR 91-40. Washington: HQ USAF, 18 September 1987.

Department of the Air Force. Industrial Water Treatment Procedures. AFP 91-41(C1). Washington: HQ USAF, 25 November 1988.

DIAS. DIAS Incorporated, Kalamazoo MI, undated.

Drew. Principles of Industrial Water Treatment(Sixth Edition). Technical Staff, Drew Chemical Corporation, Boonton NJ, 1983.

Echols, Joseph T. and Mayne, Sherman T. "Cooling-Water Cleanup By Ozone," Chemical Engineering, 97: 163-167 (May 1990a).

-----. "Cooling Tower Management Using Ozone Instead of Multichemicals," ASHRAE Journal, 32: 34-38 (June 1990b).

Eldridge, Jeff, Staff Chemist. Cooling Tower System Circulating Water Quality Control Limits. Correspondence to DEMMA. 2750 CES/DEM, Wright-Patterson AFB OH, 8 April 1990.

Federal Register(FR). Prohibition of Hexavalent Chromium Chemical in Comfort Cooling Towers; Final Rule. 40 CFR Part 749. Washington: EPA, 3 January 1990.

Henley, Mike. "Ozone Makes Cooling Tower Inroads, But Controversy Continues Over Its Efficacy," Industrial Water Treatment, 23: 14-18 (March/April 1991).

Hey, Gary W. and Hollingshad, William R. "Corrosion Control In Cooling Tower Systems," ASHRAE Journal, 30: 33-36 (August 1988).

Irving-Monshaw, Susan. "Non-Chromate Vie For a Cooling Water Niche," Chemical Engineering, 96: 59-66 (September 1989).

Jackson-Gistelli, Richard M. "Cooling Tower Treatment Study." 2852 Civil Engineering Squadron, McClellan AFB CA, 1989.

Lombardi Water Management. Product Data. Lombardi Water Management Incorporated, Columbus OH, May 1989.

McCoy, James W. The Chemical Treatment of Cooling Water(Second Edition). New York: Chemical Publishing Company, 1983.

Muller-Steinhagen, H. M. and Branch, C. A. "Comparison of Indices for the Scaling and Corrosion Tendency of Water," The Canadian Journal of Chemical Engineering, 66: 1005-1007 (December 1988).

Nalco. The NALCO Water Handbook. Technical Staff, Nalco Chemical Company. New York: McGraw-Hill Book Company, 1979.

Pryor, Alan and Bukay, Michael. "Historical Perspective of Cooling Tower Ozonation," Industrial Water Treatment, 23: 26-32 (October 1990).

Puckorius, Paul. "Get a Better Reading on Scaling Tendency of Cooling Water," Power, 127: 79-81 (September 1983).

Raisen, Elliot. "The Control of Scale and Corrosion In Water Systems Using Magnetic Fields," Paper Number 117 given at Corrosion 84. New Orleans LA, April 1984.

Sohnel, Otakar and Mullin, John. "Some Comments On The Influence Of A Magnetic Field On Crystalline Scale Formation," Chemistry and Industry, 11: 356-358 (June 1988).

Strauss, Sheldon D. and Puckorius, Paul R. "Cooling-water treatment for control of scaling, fouling, corrosion," Power, 128: 1-24 (June 1984).

Van Vlack, Lawrence H. Elements of Materials Science and Engineering(Fourth Edition). Reading MA: Addison-Wesley Publishing Company, 1980.

Webster's. New Collegiate Dictionary. Springfield Massachusetts: G. and C. Merriam Company, 1979.

Willcoxon, Tracy L, Command Corrosion Engineer. Hill AFB Trip Report. HQ AFLC, Wright-Patterson AFB OH, 1 June 1990.

Wilson, Ed E., Deputy Director, Operations and Maintenance. Use of Chromates in Industrial Water Systems. Letter to all HQ DEMs. HQ AFESC, Tyndall AFB FL, 2 April 1990.

Vita

Captain Jeffry W. Shea was born on 22 March 1956 in Iowa City, Iowa. He graduated from Lincoln High School in Sioux Falls, South Dakota in 1974 and enlisted in the Marine Corps for four years. Upon discharge he attended South Dakota State University, graduating with a Bachelor of Science in Civil Engineering in 1982. After completion of Officer Training School, he was assigned to Hill AFB, Utah. His jobs included programmer, designer, and construction manager on numerous projects. In 1987 he transferred to a remote assignment at Shemya AFB, Alaska as the Chief of Operations for the Civil Engineering Division. He was responsible for maintenance and repair of all facilities, and operation of the utilities. He was then reassigned to the 2854 Civil Engineering Squadron at Tinker AFB, Oklahoma as the Chief of Simplified Acquisition of Base Engineer's Requirements (SABER). There he was in charge of a multi-million dollar contract for facility minor construction and repair until entering the School of Systems and Logistics, Air Force Institute of Technology, in May 1990.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1991

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
A COMPARATIVE ANALYSIS OF THREE WATER TREATMENT PROGRAMS FOR COOLING TOWER SYSTEMS

5. FUNDING NUMBERS

6. AUTHOR(S)
Jeffry W. Shea, Capt, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology, WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GEM/DEM/91S-12

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This study investigated the cost and effectiveness of three cooling tower water treatment programs. The programs studied were an acid program developed at WPAFB, a commercial solubilizer program manufactured by Lombardi, Inc, and a crystal modifier program developed by Dias, Inc. The experiment ran for 60 days at which time,cost and effectiveness data were collected. Cost comparison was evaluated on the basis of tower performance in MBtu. The costs considered in this experiment were water costs, sewer costs, and chemical costs. All costs were recorded and totalled, then divided by the tower's performance. The effectiveness of each treatment method was evaluated on its ability to control scale, inhibit corrosion, and prevent microorganism growth. The results showed the acid and crystal modifier programs cost the same at $.30 per MBtu, while the solubilizer method was almost double the cost at $.54 per MBtu. The crystal modifier was the most effective program based on the three factors measured. All the programs allowed excessive corrosion of one metal (steel or copper), and the crystal modifier allowed unacceptable scale growth on the tower's drift eliminators.

14. SUBJECT TERMS
Cooling Tower, Water Treatment, Feed Water, Chemicals, Corrosion

15. NUMBER OF PAGES
132

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

AFIT Control Number AFIT/GEM/DEM91S-12

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