REAL TIME CONTROL OF SCALE INHIBITOR FEED RATE

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ABSTRACT

A process computer-controlled feed system is automatically adjusting scale inhibitor feedrates to a utility once-through cooling system. Inhibitor dosages are calculated by the computer as a function of water chemistry and operating parameters. Dosage changes are implemented every thirty seconds. Daily water chemistry variations, operating experiences, the equipment, programming safeguards, and results are discussed.

Calcium carbonate scale on utility surface condenser tubes increases the operating back pressure and fuel consumption of power generation units. Even thin deposits can also cause power generation capability loss. And scale can drastically reduce the useful life of condenser tubes when underdeposit corrosion occurs. Nineteen TU Electric stations currently use lake water for condenser cooling on a once-through basis. A high potential for calcium carbonate scale develops in most of the lakes when they serve as a combination cooling water source and heat sink for central station power generation units. These lakes concentrate with time. An increased driving force for calcium carbonate scale formation accompanies this concentration. Condenser cooling systems are treated with calcium carbonate scale inhibitors to prevent, or limit, deposit related problems of increased fuel consumption, potential capability loss, and decreased capital equipment life.

Optimization of scale inhibitor dosages has been an economic priority due to the high cooling water flows involved, and the predominance of lake water cooled condensers in the TU Electric system. Typical flows vary from under 100,000 to over 300,000 gallons per minute for a single fossil fueled power generation unit. Cooling water flows can exceed 1 million gallons per minute in nuclear plant once-through cooling systems. Dosage optimization reduces chemical usage and costs significantly due to the high volumes of water treated. Treatment optimization also can prevent underfeed of scale inhibitors when conditions change unexpectedly.

This report describes the development of, and operating experience with, a process computer directed feed system for on-line, real time modulation of calcium carbonate scale inhibitor treatment levels. OptiMiser^{sm}, as the system is known, directly adjusts feedrates to three once-through condenser cooling systems at the TU Electric Mountain Creek station. Operators enter laboratory determined values of slowly changing variables into the process computer manually on a weekly basis. On-line sensors directly input parameters observed to vary significantly in a twenty four hour period. These rapidly changing variables include cooling water pH and the cooling water outlet temperature for each of the three units treated. This report discusses daily and long term variations of these parameters as well as their impact upon scale inhibitor treatment levels.

PREVIOUS METHODS FOR DOSAGE OPTIMIZATION

It has long been recognized that the minimum effective dosage for scale inhibitors varies with the driving force for scale formation. As a result, operators varied dosages seasonally in the early days of utility once-through cooling system treatment. Utilities fed higher levels of scale inhibitors in the hotter summer months than in the cooler winter months. The dosages followed seasonal increases in the driving force for calcium carbonate scale formation and growth. The Langelier Saturation index, for example, increases with temperature and is typically higher during the summer than the winter. Studies conducted at TU Electric plants in the late 1970's and early 1980's led to the development of mathematical models which define the minimum effective dosage for calcium carbonate scale inhibitors[1,2]. These models recommend dosages as a function of the parameters of calcium carbonate driving force, temperature and time.

A major step in the optimization of scale inhibitor treatment costs occurred when water treatment service companies and utility personnel initiated routine dosage adjustment on a monthly, and sometimes weekly basis, using models of this type. They calculated dosages using the correlations established for minimum effective treatment level. Critical inputs to the calculations included calcite saturation level, cooling water outlet or tube wall temperature, and residence time in the condenser. Water treatment personnel typically based dosages upon the "worst case" scenario anticipated between service calls. They based this "worst case" dosage upon the highest pH, and the highest temperatures expected between chemical feed rate adjustments. Treatment chemicals were fed at a constant rate based upon the dosage recommended by the model. Managers recognized that their use of "worst case" treatment dosages led to higher treatment rates and costs than required. Undertreatment, and loss of scale control, was also a possibility should actual conditions become harsher than the anticipated "worst case" scenario between dosage adjustments.

Actual conditions can easily become harsher than the anticipated "worst case" when a pump is taken out of service. Power generation units use from two to six cooling water circulation pumps to supply a once-through cooling system. Removing a pump from service increases cooling water temperature, residence time in the condenser, and therefore dosage. In stations using manual pump adjustment, feed rates are not always changed when cooling water circulation pumps are taken in and out of service.

In recent years, the decreased cost of personal computers and increased familiarity of personnel with them, allowed for onsite installation of dosage modulation software. Onsite access to computerized treatment recommendations improves a plant's ability to react to changes in water chemistry.

Dosage modulation software was installed on an IBM Personal Computer at the TU Electric Mountain Creek station in June of 1987. Plant laboratory personnel familiarized themselves with dosage modulation by using the software as a system simulator. They developed an almost intuitive feel for the impact of water chemistry and operating parameter changes upon dosage. Manual adjustments were made on a weekly basis as a result of plant involvement with the software, and an increased understanding by the personnel concerning the impact of change upon dosage rates. They used an anticipated "worst case" scenario for dosage calculations.

At the time, water chemistry changes during a twenty-four hour period were believed to be minimal. Temperatures were known to change up to 19 degrees Fahrenheit in a twenty-four hour period. The units are swing loaded based upon system demand. Outlet cooling water temperature varies directly with unit load. A study was initiated to see if further benefits could be derived from on-line dosage optimization. Critical parameters were monitored and their impact upon dosages calculated. The objective of the evaluation was to determine if any water chemistry and operating parameters changed sufficiently in a twenty-four hour period to justify real time monitoring and dosage modulation.

THE IMPACT OF CHEMISTRY AND OPERATING PARAMETERS UPON TREATMENT RATES

The parameters relevant to the calcium carbonate scale inhibitor dosage modulation model were evaluated based upon their impact upon treatment rate. The objective of the evaluation was to determine which variables should be continuously monitored and input to the computer dosage modulation model, and which variables could be manually input on a daily to weekly basis without detrimental effects. The impact of water chemistry and operating parameter changes was evaluated in terms of the dosage modulation model being used for manual adjustment. The model used was derived from empirical correlations.

The correlations for the minimum effective dosage rates resulted from dosage optimization studies on utility surface condensers conducted in the late 70's and early 80's. Dosages were first optimized on side stream deposition monitors[2]. The deposition monitors operated under heat transfer and flow regime conditions modelled after the station surface condensers. The dosage optimization studies were conducted in three phases.

In the first phase, the deposition monitors were run under the test conditions in the absence of treatment. The time required for fouling to occur was recorded. This time was used as the minimum period between dosage changes in the next phase of the test.

In the second phase, treatment levels were initiated at a level known to control scale. Dosages to the deposition monitor cooling water were decreased until control, as indicated by a significant increase in fouling factor, was lost. The minimum effective dosage was considered to be the lowest dosage to successfully inhibit scale formation.

In phase 3, the minimum effective dosage was applied to the utility condenser cooling systems. During the dosage minimization studies, fouling factors were calculated for both the deposition monitors and the utility surface condensers on an hourly basis. Results of the dosage minimization studies were collated in a computer data base. Standard statistical methods were used to develop a model for predicting the minimum effective dosage[1]. A strong correlation was observed between the minimum effective dosage and calcite saturation level (sidebar 1). A correlation to temperature beyond that inherent in the effect of temperature on saturation level was also observed. An Arrhenius relationship (sidebar 2) provided an excellent model for fitting the non-saturation level related temperature effects to the data base.

This temperature function describes the effect of temperature upon reaction rate. A third major contributing variable to the model is time in the heated state. It is hypothesized that the empirically derived model describes the impact of common scale inhibitors upon the induction or contact time required for crystal formation or growth. Induction time varies inversely with driving force (sidebar 3)[3]. Gill et al. studied the impact of scale inhibitors and driving force upon induction time[4]. They observed an increasing induction time with increasing inhibitor concentrations.

Correlations were developed initially for common scale inhibitors (e.g., the phosphonates AMP and HEDP, and low molecular weight polyacrylic acid). Operating experience allowed further refinement of the correlations. The development of the correlations has been previously described. The correlations provide the dosage rate for an inhibitor or blend, which is sufficient to extend the induction time or contact time required for scale growth, until the cooling water has passed through the condenser. Table 1 summarizes the parameters which affect the dosage rate correlations. A typical impact upon dosages is indicated. The correlations were used to evaluate the impact of changing lake chemistry and changes in unit operating parameters upon scale inhibitor treatment rate.

Sidebar 1: CALCITE SATURATION LEVEL

$$\text{Saturation Level} = \frac{(Ca)(CO3)}{Ksp}$$

Where: (Ca) is the calcium activity
(CO3) is the carbonate activity
Ksp is the solubility product for calcite at the cooling water temperature evaluated.

Sidebar 2: ARRHENIUS RELATIONSHIP

$$\text{Temperature Effect Upon Reaction Rate} = A\, e^{-Ea/RT}$$

Where: A is a factor defining frequency of collision
Ea is Activation Energy for a reaction
R is the Gas Constant
T is absolute temperature.

Sidebar 3: INDUCTION TIME

$$t = \text{Lambda}\ (DF)^{1-P}$$

Where: Lambda is a temperature dependent constant.
DF is a driving force for scale formation such as calcite saturation level.
P is related to the number of molecules in a critical cluster. P is characteristic of the type of scalant.

Preliminary monitoring of the cooling lake chemistry at the TU Electric Mountain Creek station revealed the following:

1) Water chemistry parameters such as calcium level, alkalinity, and TDS did not change significantly during the 24 hour periods studied. No significant rainfall occurred during the preliminary evaluation.

2) A pH variation of up to 0.7 units was observed in a single 24 hour period. pH variations of over 1 unit were observed in a seven day period.

3) Temperature variations were typically 10 degrees F in a 24 hour period. Variations of up to 19 degrees F were observed.

TABLE 1 PRINCIPAL PARAMETERS AFFECTING DOSAGE

PARAMETER	AFFECT	IMPACT
Calcium	Calcite saturation level increases proportionally to calcium increases.	Dosage increases almost proportionally to increases in calcium level.
Alkalinity	Calcite saturation level	Dosage increases almost proportionally to increases in carbonate alkalinity.
pH	Calcite saturation level	Dosage increases almost an order of magnitude for an increase of 1 pH unit.
TDS	Calcite saturation level by affecting activity coefficients.	In most cases, the impact upon dosage is marginal.
Temperature	1) Calcite saturation . level 2) Rate of reaction.	Calcite saturation level increases 25 to 40% for a 10 deg F increase at cooling water temperatures. Dosage doubles for every 20 to 30 deg F increase due to rate of reaction.
Time	The inhibitor level required to extend time until water is through system.	Inhibitor dependent

The outlet cooling water temperature variations observed were primarily due to swing loading of the three units. A typical twenty-four hour temperature profile for Mountain Creek unit 8 is plotted in Figure 1. Figure 2 graphically depicts the impact of changes in temperature upon dosage rate for Unit # 8 at the Mountain Creek station. The "worst case " dosage for the twenty-four hour period is also indicated as a point of reference.

A typical twenty-four hour pH variation for the cooling lake is plotted in Figure 3. The impact of these pH changes upon dosage are portrayed in Figure 4. Figure 5 portrays the combined impact of pH and temperature upon the driving force for calcium carbonate scale formation, as estimated by the Langelier Saturation Index. The combined impact of pH and temperature variation upon dosage is depicted in Figure 6. Figure 7 compares the typical dosage reductions attainable with various forms of real time modulation versus the "worst case" condition.

Outlet cooling water temperature and pH were the input parameters selected for on-line monitoring based upon the twenty-four hour water chemistry and operating parameter profiles.

Figure 1 24 HOUR TEMPERATURE PROFILE

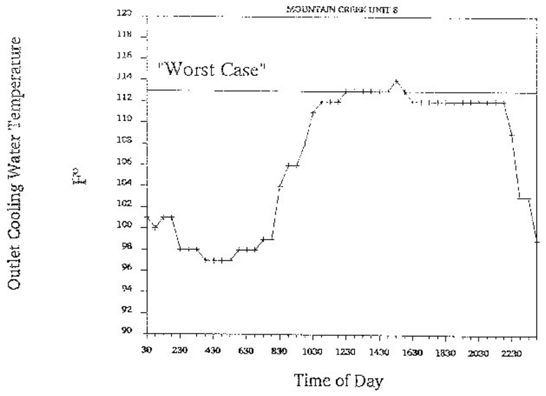


Fig 4

Figure 2 24 Hour Dosage Profile

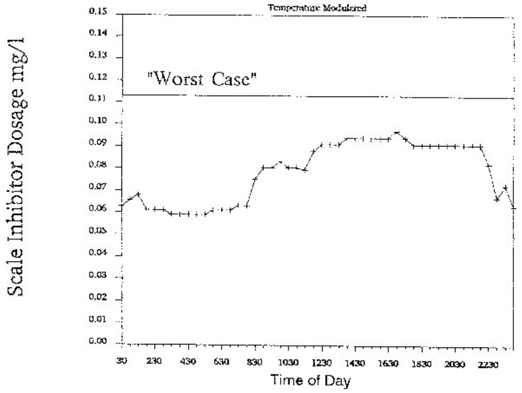


FIG 2

Figure 3 24 HOUR pH PROFILE

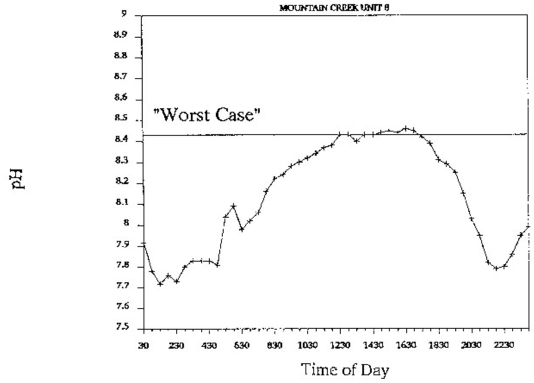


Figure 4 24 Hour Dosage Profile

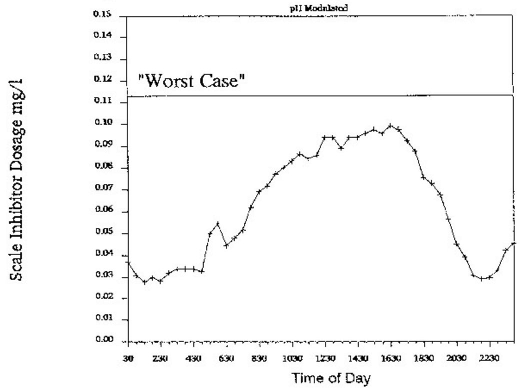


Figure 5 24 HOUR SATURATION INDEX PROFILE

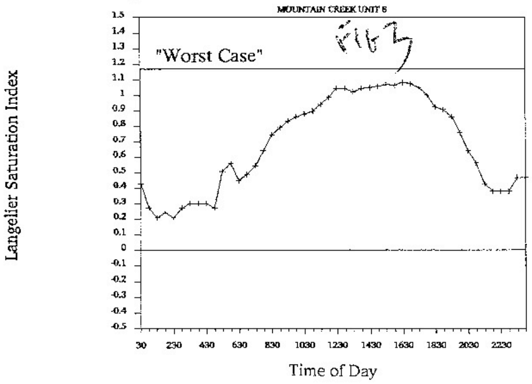


Figure 6 24 Hour Dosage Profile

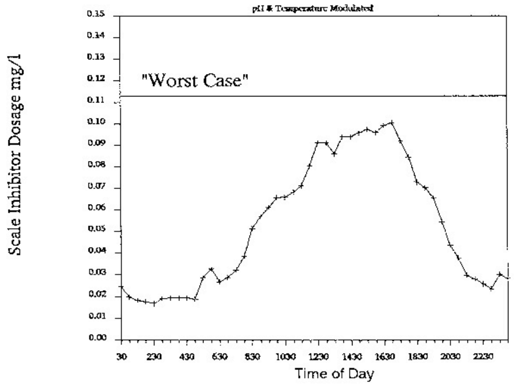
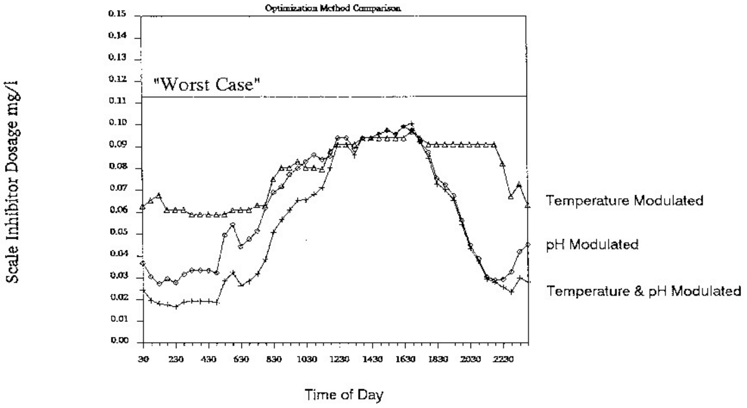


Figure 7 24 Hour Dosage Profile



THE EQUIPMENT

The hardware used in the OptiMiser^{sm} on-line control system was selected for dependability and the ability to operate under extremes of temperature. A process computer was specified to handle the dosage modulation calculations and for interfacing with the instrumentation and chemical feed pumps.

The unit installed at the TU Mountain Creek station consists of the following components:

1) The controller containing the central processing unit, power supplies, input-output boards, an input key pad and a fluorescent output display.

2) Thermocouples for each of the three (3) units. They are installed in the condenser outlets. A pH probe is located on a sidestream pumped from the intake bay.

3) The pumping system consisting of seven (7) electronically controlled, constant speed, variable stroke pumps. One feed pump was installed for every cooling water circulation pump.

4) A printer.

5) A shed to house the pumps, controller, and printer.

6) A scale inhibitor bulk storage tank.

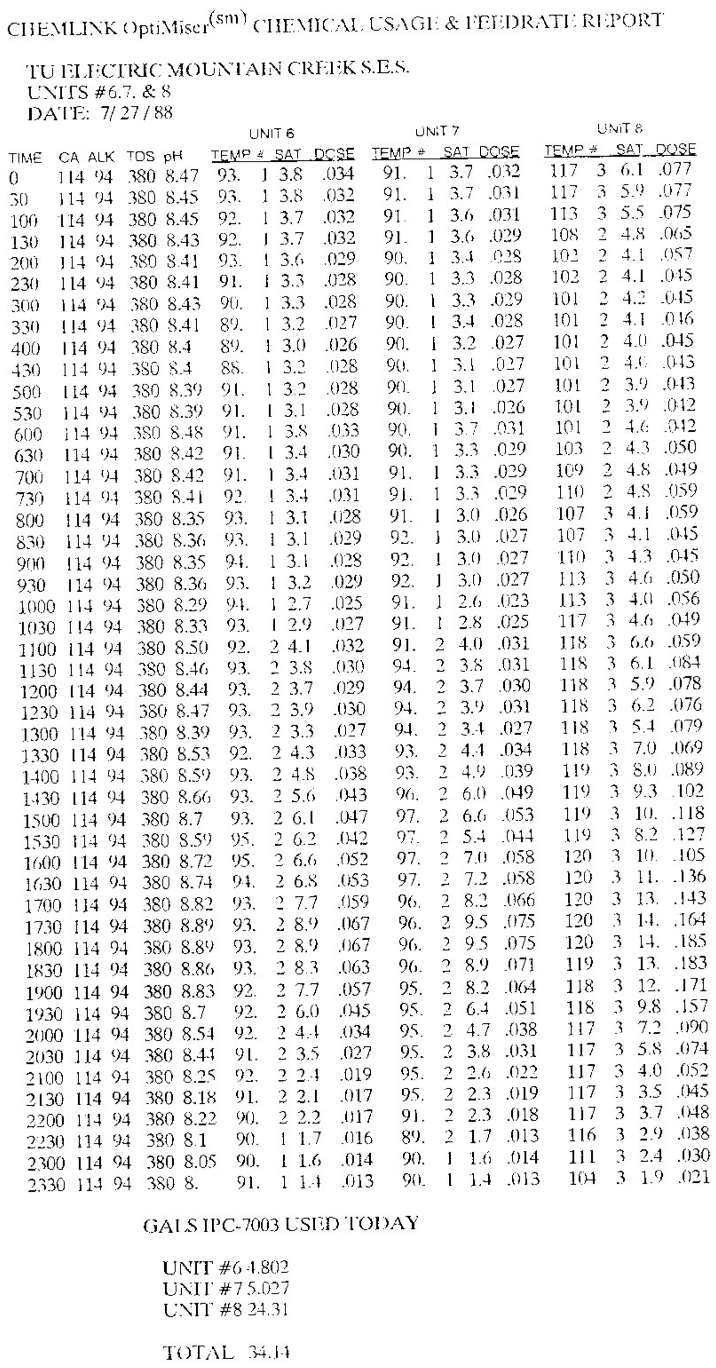
The system is presented in Pictures 1 through 4 in the appendix.

The controller is mounted in a NEMA 12 cabinet. Two processing units are included in the system. One processor handles interfacing with the power generation units. Hard contacts interlock the cooling water circulation pumps with the interface processor. This unit determines the number of pumps which are in service for each unit, turns on the appropriate chemical feed pumps, and provides the central processing unit with the residence time of cooling water in each condenser. The interface processor is programmed in ladder logic.

The central processing unit uses an enhanced basic interpreter for input-output operations and calculations. It scans the thermocouple, pH, and operating parameter inputs every thirty seconds and adjusts the feed pumps independently for each power generation unit cooling system. Input parameters and calculated variables can be accessed via the fluorescent display output device and keypad. Common indices, such as the Langelier Saturation Index and calcite saturation level, for example, are updated every thirty seconds. Feed rates, in ppm product in the water, and as % pump stroke can be accessed. An override for manually adjusting % stroke is included to make pump calibration as easy as possible. The feed rate from each pump in milliliters per minute is also available through the key pad and display as a further aid to pump calibration.

A summary of input parameters, calculated values, and feed rates for each unit is output to the printer every thirty minutes. The computer also maintains a running summary of daily chemical consumption for each unit as an inventory aid. Figure 8 is a typical daily printout from the OptiMiser^{sm} system.

FIGURE 8: EXAMPLE OptiMiser^{sm} PRINTOUT



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CHEMLINK OptiMiser(sm) CHEMICAL USAGE & FEEDRATE REPORT

  TU ELECTRIC MOUNTAIN CREEK S.E.S.
  UNITS #6.7. & 8
  DATE: 7/27/88
                              UNIT 6              UNIT 7              UNIT 8
TIME  CA  ALK TDS pH     TEMP # SAT DOSE     TEMP # SAT DOSE     TEMP # SAT DOSE
0     114 94  380 8.47   93.  1 3.8 .034     91.  1 3.7 .032     117  3 6.1 .077
30    114 94  380 8.45   93.  1 3.8 .032     91.  1 3.7 .031     117  3 5.9 .077
100   114 94  380 8.45   92.  1 3.7 .032     91.  1 3.6 .031     113  3 5.5 .075
130   114 94  380 8.43   92.  1 3.7 .032     91.  1 3.6 .029     108  2 4.8 .065
200   114 94  380 8.41   93.  1 3.6 .029     90.  1 3.4 .028     102  2 4.1 .057
230   114 94  380 8.41   91.  1 3.3 .028     90.  1 3.3 .028     102  2 4.1 .045
300   114 94  380 8.43   90.  1 3.3 .028     90.  1 3.3 .029     101  2 4.2 .045
330   114 94  380 8.41   89.  1 3.2 .027     90.  1 3.4 .028     101  2 4.1 .046
400   114 94  380 8.4    89.  1 3.0 .026     90.  1 3.2 .027     101  2 4.0 .045
430   114 94  380 8.4    88.  1 3.2 .028     90.  1 3.1 .027     101  2 4.0 .043
500   114 94  380 8.39   91.  1 3.2 .028     90.  1 3.1 .027     101  2 3.9 .043
530   114 94  380 8.39   91.  1 3.1 .028     90.  1 3.1 .026     101  2 3.9 .042
600   114 94  380 8.48   91.  1 3.8 .033     90.  1 3.7 .031     101  2 4.6 .042
630   114 94  380 8.42   91.  1 3.4 .030     90.  1 3.3 .029     103  2 4.3 .050
700   114 94  380 8.42   91.  1 3.4 .031     91.  1 3.3 .029     109  2 4.8 .049
730   114 94  380 8.41   92.  1 3.4 .031     91.  1 3.3 .029     110  2 4.8 .059
800   114 94  380 8.35   93.  1 3.1 .028     91.  1 3.0 .026     107  3 4.1 .059
830   114 94  380 8.36   93.  1 3.1 .029     92.  1 3.0 .027     107  3 4.1 .045
900   114 94  380 8.35   94.  1 3.1 .028     92.  1 3.0 .027     110  3 4.3 .045
930   114 94  380 8.36   93.  1 3.2 .029     92.  1 3.0 .027     113  3 4.6 .050
1000  114 94  380 8.29   94.  1 2.7 .025     91.  1 2.6 .023     113  3 4.0 .056
1030  114 94  380 8.33   93.  1 2.9 .027     91.  1 2.8 .025     117  3 4.6 .049
1100  114 94  380 8.50   92.  2 4.1 .032     91.  2 4.0 .031     118  3 6.6 .059
1130  114 94  380 8.46   93.  2 3.8 .030     94.  2 3.8 .031     118  3 6.1 .084
1200  114 94  380 8.44   93.  2 3.7 .029     94.  2 3.7 .030     118  3 5.9 .078
1230  114 94  380 8.47   93.  2 3.9 .030     94.  2 3.9 .031     118  3 6.2 .076
1300  114 94  380 8.39   93.  2 3.3 .027     94.  2 3.4 .027     118  3 5.4 .079
1330  114 94  380 8.53   92.  2 4.3 .033     93.  2 4.4 .034     118  3 7.0 .069
1400  114 94  380 8.59   93.  2 4.8 .038     93.  2 4.9 .039     119  3 8.0 .089
1430  114 94  380 8.66   93.  2 5.6 .043     96.  2 6.0 .049     119  3 9.3 .102
1500  114 94  380 8.7    93.  2 6.1 .047     97.  2 6.6 .053     119  3 10. .118
1530  114 94  380 8.59   95.  2 6.2 .042     97.  2 5.4 .044     119  3 8.2 .127
1600  114 94  380 8.72   95.  2 6.6 .052     97.  2 7.0 .058     120  3 10. .105
1630  114 94  380 8.74   94.  2 6.8 .053     97.  2 7.2 .058     120  3 11. .136
1700  114 94  380 8.82   93.  2 7.7 .059     96.  2 8.2 .066     120  3 13. .143
1730  114 94  380 8.89   93.  2 8.9 .067     96.  2 9.5 .075     120  3 14. .164
1800  114 94  380 8.89   93.  2 8.9 .067     96.  2 9.5 .075     120  3 14. .185
1830  114 94  380 8.86   93.  2 8.3 .063     96.  2 8.9 .071     119  3 13. .183
1900  114 94  380 8.83   92.  2 7.7 .057     95.  2 8.2 .064     118  3 12. .171
1930  114 94  380 8.7    92.  2 6.0 .045     95.  2 6.4 .051     118  3 9.8 .157
2000  114 94  380 8.54   92.  2 4.4 .034     95.  2 4.7 .038     117  3 7.2 .090
2030  114 94  380 8.44   91.  2 3.5 .027     95.  2 3.8 .031     117  3 5.8 .074
2100  114 94  380 8.25   92.  2 2.4 .019     95.  2 2.6 .022     117  3 4.0 .052
2130  114 94  380 8.18   91.  2 2.1 .017     95.  2 2.3 .019     117  3 3.5 .045
2200  114 94  380 8.22   90.  2 2.2 .017     91.  2 2.3 .018     117  3 3.7 .048
2230  114 94  380 8.1    90.  1 1.7 .016     89.  2 1.7 .013     116  3 2.9 .038
2300  114 94  380 8.05   90.  1 1.6 .014     90.  1 1.6 .014     111  3 2.4 .030
2330  114 94  380 8.     91.  1 1.4 .013     90.  1 1.4 .013     104  3 1.9 .021

               GALS IPC-7003 USED TODAY

                 UNIT #6 4.802
                 UNIT #7 5.027
                 UNIT #8 24.31

                 TOTAL  34.14
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THE PROGRAMS

Two programs interact to control the scale inhibitor feed rates to the condenser cooling systems. One program handles interfacing with the condenser cooling systems, while the second program performs the actual input-output operations, input data verification, and feed rate calculations.

The first processor is interlocked with the cooling water circulation pumps for each unit. It determines how many cooling water pumps are in service for each unit. Chemical feed pumps are activated or deactivated by this processor based upon this information. If a cooling water circulation pump is in service, the related inhibitor feed pump is activated. This safety feature ensures that chemical is not wasted by feed to a stagnant pump suction.

The interlock with the cooling water circulation pumps is also used to determine the flow rate for each condenser cooling system and the residence time for the cooling water in each condenser. These values are made available to the second processor for use in dosage and feed rate calculations. Manual override switches are available in the event of failure of the circulation pump - process computer interlock.

Thermocouple and pH inputs are also processed by this program. All outputs from the first processor are made available to the dosage calculation processor via commonly accessed storage registers.

TABLE 2 INPUT DATA & METHOD

PARAMETER	FREQUENCY	VALIDATION	BACKUPS & DEFAULTS
Temperature	On-line continuous	Range Tests	User input default Hard programmed default
pH continuous	On-line	Range Tests	User input default Hard programmed default
Calcium	Manual via keypad	Range Tests	Hard programmed default
Alkalinity	Manual via keypad	Range Tests	Hard programmed default
Total Dissolved Solids	Manual via keypad	Range Tests	Hard programmed default

As outlined in Table 2, temperature and pH are input directly to the controller from thermocouples and a pH probe. Two levels of default values are incorporated into the system to prevent system failure, or erroneous dosages, due to invalid inputs. pH and temperatures are tested for range by the program. If the values are in range (e.g., pH 7.0 to 9.0; or temperature 45 to 120 degrees Fahrenheit), the input values are used. If the values are out of range due to probe or thermocouple failure, the computer checks the register containing user input default values. The user default value is substituted for the erroneous value if it satisfies the range check conditions. If the user defined default value fails the range checks, the default value which is written into the program is used. This two-tiered level of default values was selected to ensure that chemical feed was not lost due to temperature or pH measurement failure. Station personnel are alerted to the use of a default value for pH or temperature in the summary printouts. An asterisk is printed to the left of any value for which a default value was substituted during a thirty minute reporting period. The asterisk will appear for any period during which a default was used, whether the default value was substituted for 30 seconds or for the entire 30 minute period.

Slowly changing variables are input to the common storage registers via a keypad on the front of the controller. Range checks are run on these variables to ensure that operator input error does not lead to under or overdosing of scale inhibitors.

The dosage calculation program runs on the basic processor. It scans the inputs in the common storage registers every 30 seconds, and calculates a new dosage rate for each unit. The dosage calculation program flows as follows:

1) Storage registers are scanned for input data. Range checks are run on the data. Default values are substituted if an input is found to be out of range.

2) Common indices are calculated for each unit, and output to storage registers for access via the keypad and output display. Calculated indices include calcite saturation level, Langelier Saturation Index, and the Ryznar Stability Index.

3) A dosage is calculated for each unit under real time control. The dosage rates calculated are based upon the calcite saturation level at each condenser outlet, the residence time of the cooling water in each condenser, and the outlet cooling water temperature for each condenser.

4) Dosages are converted to feed rates based upon the cooling water flow for each system. These feed rates are further converted to a pump stroke output to each feed pump in service.

5) Chemical usage is tallied on line during each 30 second loop. Daily chemical usage for each unit under control is summarized based upon these feed rate adjustments at thirty second intervals.

Calculated values output to the common storage register are updated during every thirty second loop. They can be accessed via the keypad and fluorescent display.

Error trapping routines within the program prevent the system from going down due to programming or input data errors. In the event of a power failure, a backup battery maintains the program, internal clock, and data registers. The program reboots when power is restored. The feed pumps will continue to pump at the last feed rate received prior to signal loss. Every effort was made to ensure that chemical feed would not be lost in the event of input failure or temporary power outages.

OPERATING EXPERIENCE

The OptiMiser^{sm} process computer-directed feed system was installed at the TU Electric Mountain Creek Station in the spring of 1988. The Mountain Creek Station includes three power generation units: Units 6, 7, and 8. Units 6 and 7 are rated at 115 and 125 megawatts, respectively. Unit 8 is a 550 megawatt unit. A small lake supplies cooling water for the condenser cooling systems on a once-through basis. Calcium carbonate deposits form on the condenser tubes of all three units if the cooling water is untreated. A typical lake water analysis is outlined in Table 3.

Table 3 Typical Lake Water Analysis

Calcium	102 - 183	as CaCO3
Total Alkalinity	94 - 127	as CaCO3
Total Dissolved Solids	308 - 407	mg/l
Iron	.1 - 0.8	as mg/l Fe
Manganese	0.05	as mg/l Mn
pH	7.2 - 9.0	Units

Prior to the installation of the process computer controlled feed system, cooling water grab samples were analyzed on a weekly basis. Samples were collected at about the same time of day. The pH analyzed was used to calculate the dosage for the week. The highest expected outlet cooling water temperature for the week was used in the calculations. These two parameters, in combination with the calcium, alkalinity, and total dissolved solids measurements, were used to establish a "worst case" dosage for the week. Chemical feed pumps were adjusted manually to apply the "worst case" dosage. Temperature was believed to be the only input parameter for the dosage calculations which changed significantly during the week between between analysis and manual chemical feed pump adjustments.

This paper summarizes experience with the system during 53 operating days. Data collected by the process computer is categorized and presented in terms of input data variations noted, and the impact of these variations upon treatment rate and chemical usage. Chemical usage for feed rates by the manual adjustment "worst case" method are compared to those achieved using the automated computer-controlled feed system.

Cooling Water Outlet Temperature

Daily minimum and maximum outlet cooling water temperatures for the 53 days of operating data are presented in Figures 9 through 11. the data was derived from the process computer printouts from the time period reported. Typically, the outlet cooling water temperature ranged from 15 to 20 degrees Fahrenheit each day. This variation would be expected based upon the swing loading of the unit. With the old manual adjustment system, treatment rates were based upon the highest anticipated outlet temperature. This resulted in overfeed of treatment chemicals any time the water temperature was less than this maximum, such as during low unit loads.

Figure 9 Test Period Temperature Profile

TU Electric Mountain Creek Unit 6

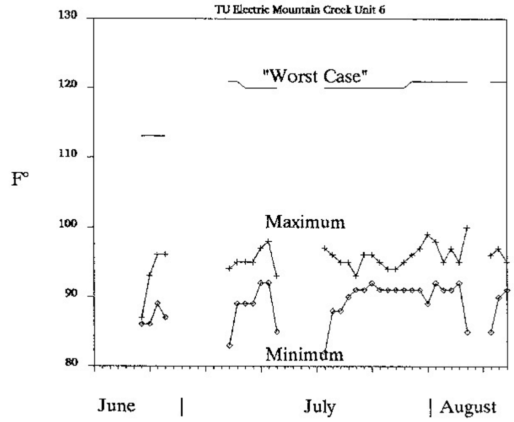
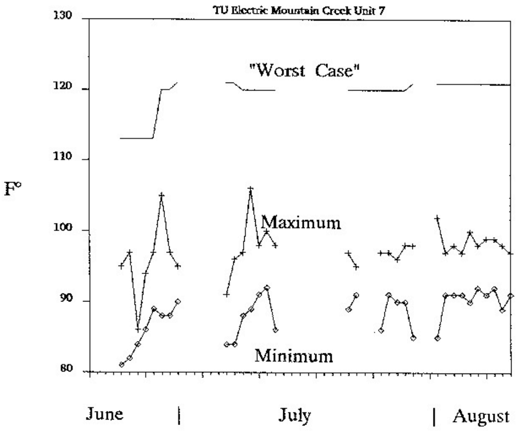


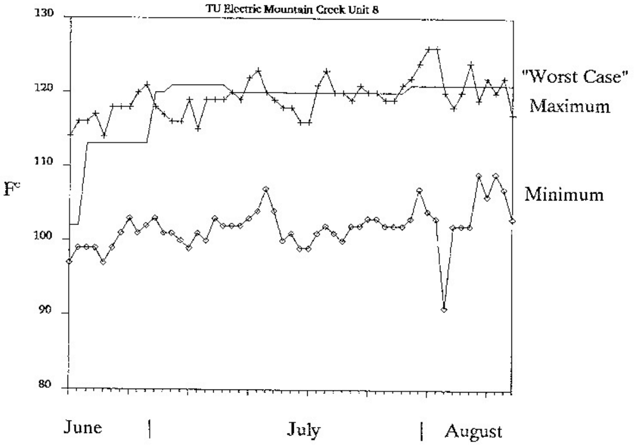
Figure 10 Test Period Temperature Profile

TU Electric Mountain Creek Unit 7



Lake Water pH

Figure 11 Test Period Temperature Profile

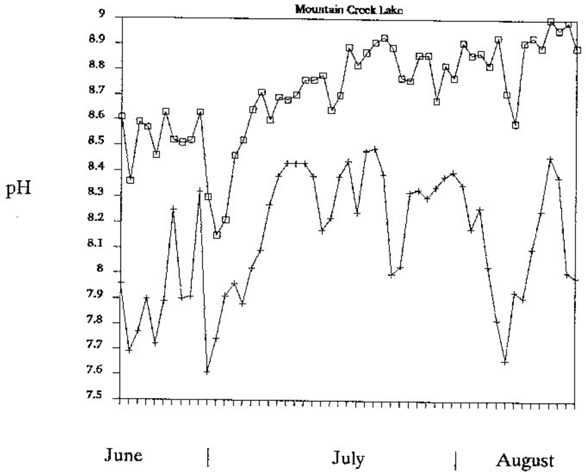


Daily minimum and maximum pH values for the period reported are shown in Figure 12. The wide diurnal pH ranges observed were surprising. The validity of measured values was carefully scrutinized to assure that the daily pH fluctuations observed were real and not a measurement anomaly. Variations ranged from a low of 0.3 pH unit to a high of 1.1 units during a twenty-four hour period. These pH readings were periodically verified with a laboratory pH meter. Other checks were run on the pH data to both to verify that the pH swings encountered were real, and to identify the source of the pH variations.

A laboratory study was conducted to determine the impact of temperature change upon the pH of Mountain Creek lake water. Temperature effects were evaluated to determine if the fluctuations could be explained by the impact of temperature upon dissociation constants for water and carbonic acid species. Dissociation constants affecting pH are temperature dependent. In a carbonate buffered system, variations in K1, K2, and Kw with temperature are known to depress pH as temperature increases^5. Lake water was tested to determine solution temperature effects. A maximum change of 0.01 pH unit per degree centigrade was observed. The pH variations observed in a 24 hour period exceeded that expected based upon the impact of temperature change upon dissociation constants. No direct relationship between temperature and pH were observed in comparing unit operating data to lake water chemistry. An alternate explanation was sought based upon this study.

Biological activity is the accepted explanation for the pH swings observed. Mountain Creek Lake is shallow with an average depth of 15 feet. This makes it readily influenced by changes in carbon dioxide due to photosynthesis by algae and aquatic plants. During hot, sunny days, photosynthesis consumes large quantities of carbon dioxide. The change in carbonate alkalinity species present is shifted towards carbonate from bicarbonate by the carbon dioxide removal, thereby increasing pH. At night, respiration releases carbon dioxide into the water and reduces the pH by shifting the CO_3/HCO_3 equilibrium towards the bicarbonate form^6. The photosynthesis hypothesis also explains why only minor pH fluctuations occur on overcast days.

Figure 12 Test Period pH Profile



A pH recorder was installed at three other TU Electric stations with lake cooling to determine if Mountain Creek was an isolated case. Similar pH swings were observed in the other cooling lakes monitored.

Under the old manual system for dosage adjustment, a grab sample pH reading was used to determine the dosage and feed rate for a week. The grab samples were usually taken around the same time of day. This precluded the recognition of the large pH swings observed when real time pH monitoring was implemented. After discovering the pH swings, it became apparent that the old method of manually controlling treatment levels was inadequate.

Residence Time

Under the old manual method, chemical feed rates were based upon the maximum circulating cooling water flow condition. The total chemical feed was divided equally amongst three chemical injection pumps. Each circulating pump had a dedicated chemical injection pump. Whenever a circulation pump was removed from service, chemical feed was reduced by one-third on Unit 8. In reality, cooling water flow rate does not decrease by one-third through the centrifugal pumps. More importantly, the velocity through the condenser tubes drops significantly. Residence time increases as the velocity decreases. The process computer corrects the dosage rate for increases in residence time as pumps are taken out of service. Treatment feed rates are calculated based upon the cooling water flow expected with 1, 2 or 3 pumps in service, rather than on the assumption that each pump contributes one-third of the total cooling water flow.

Chemical Consumption

The driving force for calcium carbonate scale varied substantially during the test period. Variations for the test period are plotted in Figures 13 through 15 for Units 6, 7 and 8 respectively. Daily minimum and maximum values for the Langelier Saturation Index are included in the plots as an indication of the wide variation encountered on even a daily basis.

Figure 13 Langelier Saturation Index Profile

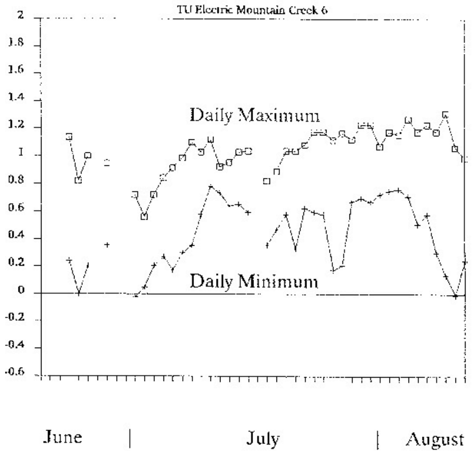


Figure 14 Langelier Saturation Index Profile

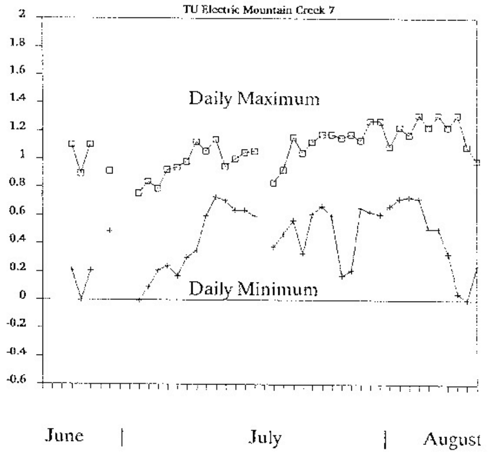
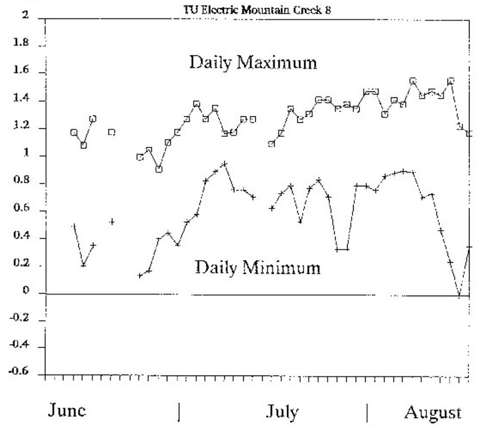


Figure 15 Langelier Saturation Index Profile



Figures 16 through 18 plot chemical consumption during the test period for Units 6, 7, and 8 respectively. The figures compare chemical consumption during the 53 day test period using the OptiMiser^{sm} automated feed system to that which would have occurred using the manual method of control and "worst case" dosage calculations.

As expected, computer-modulated feed rates are substantially lower than those based upon the "worst case" scenario a majority of the time. An unexpected observation was that the manual adjustment, "worst case" method would have occasionally resulted in chemical underfeed. This resulted from actual outlet temperatures higher than anticipated for the "worst case" and higher actual pH values than anticipated based upon a daily grab sample. The computer-directed feed system reacted to these changes and prevented what would have been scale inhibitor underfeed using the old system for scale inhibitor feed.

A quantitative comparison of OptiMiser^{sm} process computer-directed feed system chemical usage with the manual adjustment "worst case" method revealed the following. For the 53 day test period reported, the computer-controlled system reduced chemical consumption by an average of 21 % on Unit 8, in comparison to the old manual system of weekly adjustment. Typical ranges encountered on Unit 8 varied from a 75 % reduction to a 131 % increase during the test period.

Figure 16 Chemical Consumption Profile

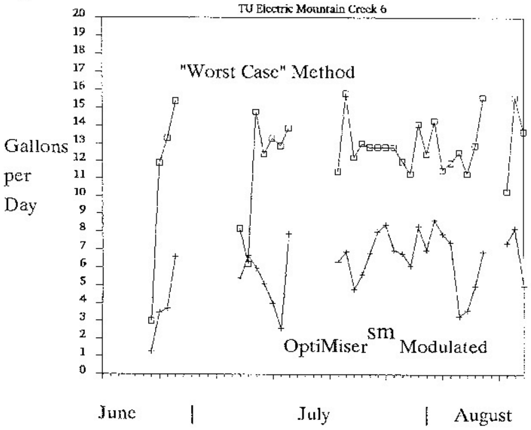
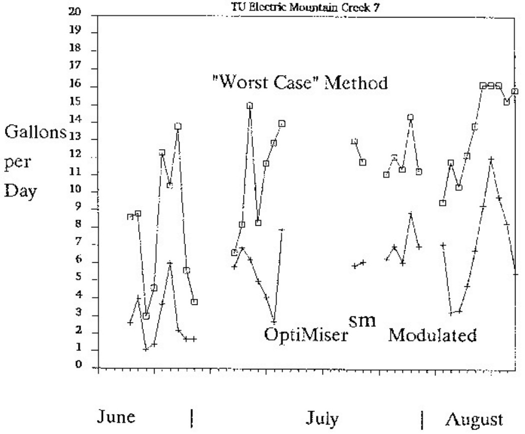


Figure 17 Chemical Consumption Profile



A 51% average decrease in chemical usage was achieved on Units 6 and 7 by the process computer-directed feed system during the same time period. Table 4 summarizes the savings realized during the test period for the three units.

Figure 18 Chemical Consumption Profile

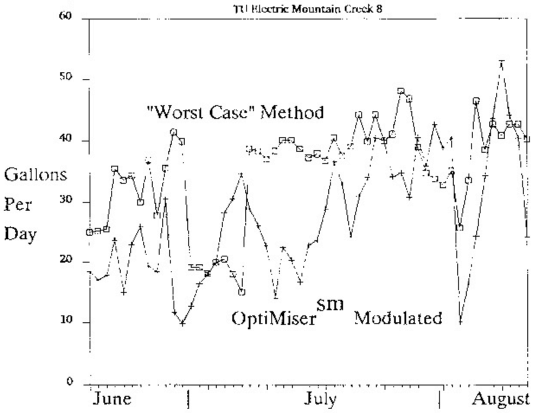


TABLE 4 Chemical Consumption Comparison

	Days	OptiMiser^{sm}	"Worst Case"	Savings
Unit	On-line	Gallons	Gallons	Gallons
6	34	198	408	210
7	33	181	370	190
8	53	1,446	1,855	409
Total		1,824	2,633	809

Note: All figures rounded to the nearest gallon.

It is anticipated that the computer-directed feed system will pay for itself in less than a year based upon test period data for all three units, and six months of previous operating data for Unit 8.

SUMMARY

The OptiMiser^{sm} computer-directed feed system has proven to be a state-of-the-art feed system for modulating scale inhibitor feed to once-through cooling water. During a test period in the hot Texas summer, all associated equipment performed reliably. Continuous adjustment of feed rates to actual conditions led to a reduction in chemical consumption of 21 % on Mountain Creek Unit #8. A 51% chemical usage reduction was realized on Units #6 and 7 during the same time period. The assurance that the computer would adjust feed rates when operating conditions exceeded the maximum anticipated values for pH and temperature proved as important as the cost savings realized. Automation prevented inhibitor underfeed and potentially scaled heat transfer surfaces.

1 Ferguson, R.J., "A Kinetic Model for Calcium Carbonate Deposition", Materials Performance, November, 1984.

2 Ferguson, B.W. and R.J. Ferguson, "Sidestream Evaluation of Fouling Factors in a Utility Surface Condenser", Corrosion '80.

3 Gill, J.S., "Evaluation of Mineral Scales Formation and Their Inhibition",IWC-80-22.

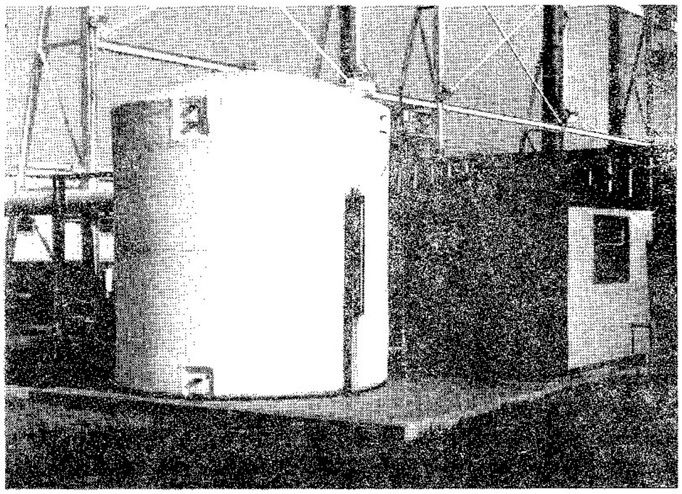
4 Gill, J.S.,C.D. Anderson, and R.G. Varsanik, "Mechanism of Scale Inhibition by Phosphonates",IWC-83-4.

5 Langelier, W.F., "Effect of Temperature on the pH of Natural Waters", J.A.W.W.A., 38, 179, (1946).

6 Stumm, W., and J.J. Morgan, "Aquatic Chemistry", John Wiley and Sons, pp 193-195, p 562, (1981).

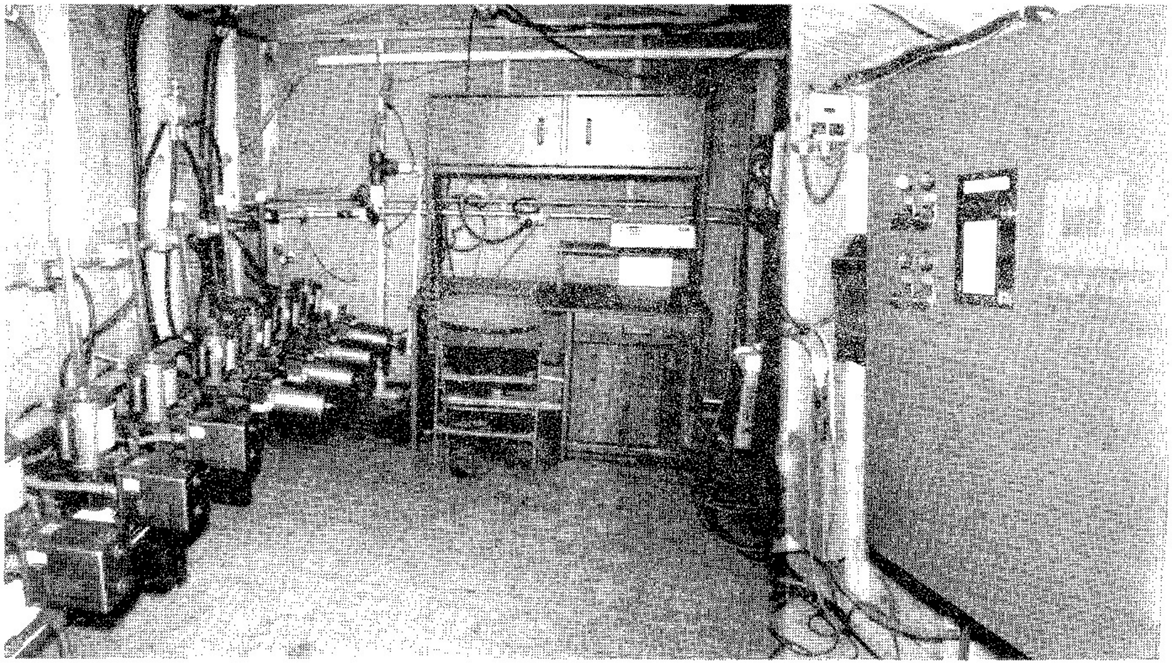
APPENDIX

PICTURES 1 &2



UPPER RIGHT: Bulk storage tank and the equipment shed housing the OptiMiser^{sm} system and feed pumps.

LOWER: Inside view of the equipment shed. The OptiMiser^{sm} process computer is on the right. A work station and printer is located at the rear of the shed. Chemical feed pumps are on the left.



PICTURES 3 & 4

UPPER RIGHT: Process computer input keypad and fluorescent display.

LOWER: Interior view of process computer.