AN ECONOMIC STUDY OF THE PRESENT
FEEDWATER TREATMENT SYSTEM
AT THE V. P. I. POWER PLANT

by

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I. INTRODUCTION

The problem of corrosion has consistently been a very troublesome one in the V.P.I. Power Plant and on the campus. The cost of maintaining the main condensate return lines and a small percentage of plant heating in leaks, heating failures and the like that were attributable to corrosion, cost the Institute five thousand to six thousand dollars annually over a period of five to ten years.

In light of increasing manhours of maintenance, this problem demanded careful consideration. A complete demineralized water treatment system, necessitated by the 100 per cent utilization of the New River water, was adopted in January, 1958.

With the installation of this demineralization system, it was deemed advisable to make a complete study on the V.P.I. Power Plant with regards to feedwater treatment and condensate corrosion problems. Three persons(1) were engaged in setting up a joint effort to carry out the experiments and obtain necessary data. Each person, however, investigated a specific topic independently, and the author of this paper dealt mainly on the costs of the present water treatment system at the V.P.I. Power Plant.

The difficult factor was that there was no universally accepted method for determining the cost of treated water for power plant usage, simply because each system presented its own intricate problem and required individual attention.

The purpose of this thesis was to study the cost, whatever incurred, of the present water treatment system at the V.P.I. Power Plant and to investigate whether these costs were justified and sufficient, in the course of producing quality feedwater and minimizing return condensate corrosion.

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(1) B. Bugar on "Return Condensate Corrosion Problems of the V.P.I. Power Plant".
F. Cheng on "An Analytical Study of the Feedwater Treatment System at the V.P.I. Power Plant".

II. REVIEW OF LITERATURE

There are many power plant design books written and all of these discuss, to some extent, the topic on power plant cost estimations and calculations. The most comprehensive work, in the writer's opinion, is Professor O. A. Leutweiler of the University of Illinois in his "Notes on the Design of Steam Power Plants", published in 1931 and was revised in 1950. Professor Leutweiler discusses at length all the terms entering into the problem of determining the cost of power. Although he does not devote too much space to the subject of feedwater treatment, like other authors on steam power plant design, nevertheless, he does present information technical as well as economical, such as the detailed calculations and explanations on all the factors that should be included in fixed charges and operating expenses.

In 1952, Mr. M. E. Brines, Assistant Superintendent of Power of the Dow Chemical Company, presented a paper on "Demineralization Plant Operational Experience" before the Symposium on Ion Exchangers. The paragraph on costs in this paper merits special attention. Raw water and regenerant costs of demineralization of the Mildland Plant, Michigan, of the Dow Chemical Company, are published based on thousand gallons of raw water demineralized of the typical month of November, 1951. The cost is expressed as 17.60 cents per thousand gallons of raw water treated and is accompanied by the typical water analysis. It is understandable that the cost of treated water of Mildland Plant bears no direct comparative value to that of the V.P.I. Power Plant. However, the procedure in finding the various costs for the demineralized water is applicable in this thesis. It should be noted that capital investment, overhead and labor are not included in the cost and out of the 17.60 cents only 6.9 cents are charged to regenerants.

Since 1929 when the V.P.I. Power Plant was built, there have been relatively few investigations conducted with regards to the plant economical considerations, particularly feedwater treatment costs. In 1935, J. B. Cunningham, J. D. Geddie and F. Q. Saunders wrote a thesis on "A Cost Study for the Virginia Polytechnic Institute Power Plant for the Year 1934". They determined the cost for rendering heating and power services by the V.P.I. Power Plant. The actual costs of these services, the variation of these costs for the different months of the year, and a method by which these costs can be predicted were also determined.

In 1938, R. C. Blackman and P. C. Lutz wrote a thesis on "AStudy of Cost Distribution for Services Rendered at the V.P.I. Power Plant for the Year 1937-1938". Their purpose was to determine only the average annual cost of services rendered and to put them into such form as to be useful in billing various departments of the school. In addition, the unit cost of softened water was determined as following:

Softened Water Distribution:

Boiler Feed Make-up	9,538,870	Gallons
Domestic Water	14,822,555	
Cooling Pond Make-up	5,924,706	
Laundry	2,365,959	
Total:	32,652,000	Gallons

Interest Plus Depreciation Charges:	565.77	Dollars
Operating Expenses:	2448.47	Dollars
Cost of Hard Water:		
32,652,000 Gallons (total)		
3,913,705 Gallons (regeneration)		
36,505,705 Gallons	6399.00	Dollars
	9413.24	Dollars

The Unit Cost Per Thousand Gallons Water Softened:

$9,413.24 / 32652 --- $ 0.28829

In 1940, A. E. Bock, G. J. Porter and W. B. Freeman made an estimate of service charges for the year 1940-1941, based on plant records for the corresponding period. In their thesis, titled "A Study Covering Services with Estimated Operating Costs of the V.P.I. Heating and Power Plant for the Fiscal Year 1940-1941", they determined the cost for future period based on past data and calculated addition. No attempt was made to separate the cost of treating and supplying the feedwater to the power plant from other costs. The salts and chemicals used were included in the general expenditures, while the power for pumping was considered in the general electrical charges.

Of these theses written on the services costs of the V.P.I. Power Plant, only Blackman and Lutze attempted, at least figuratively, to calculate the cost of water treatment aside from other expenses. It is understood, however, that all the previous investigators were not interested in the subject of water treatment and therefore, did not give much consideration to that matter. Perhaps it was because the topic of water treatment occupied much less importance than it does today.

With the ever increasing pressures and temperatures in modern steam generator design, with the additional chemicals being introduced in the science of water treatment, and with the call for less and less impurities and carry-over in water and steam, feedwater treatment can no longer be ignored, and the cost of treated water should not be absorbed in the general expenditures.

This thesis differs from all the previous ones in the following respects:

1. It considers the feedwater treatment as independent a subject as possible.
2. It is actually a time study.
3. It analyzes the operational economy of the whole feedwater treating system, based on experimental data.

The present demineralized system of the V.P.I. Power Plant and the functions of the chemicals used for internal treatment will be described in the following paragraphs.

Cation Exchanger

The cation exchanger used in the V.P.I. Power Plant is of the Zeo-Karb type. It is a hard, black, granular, organic cation exchange material commonly called a "carbonaceous zeolite". It is non-siliceous and acid resistant and has found extensive use because of these desirable properites. The Zeo-Karb is also a sulfonated organic coal derivative. On the hydrogen exchange cycle the metallic ions are given up in exchange. Upon regeneration, the acid used removes the accumulated metallic ions and restores hydrogen ions to the exchanger.

When a water containing bicarbonates of calcium, magnesium, sodium, potassium, iron or manganese is passed through a hydrogen cation exchanger, the metallic cations are removed and held by the exchanger which gives up an equivalent amount of hydrogen ions in exchange. These unite with the bicarbonate radical to form carbonic acid and this breaks down to form carbon dioxide and water. Using calcium bicarbonate as an example, and using the letter Z to represent the complex exchanger radical, the reaction can be shown as follows:

$Ca(HCO_3)_2$	+	H_2Z	=	CaZ	$2H_2O$	+	$2CO_2$
Calcium		Hydrogen		Calcium	Water		Carbon Dioxide
Bicarbonate		Cation Exchanger		Cation Exchanger			(soluble gas)
(soluble)		(insoluble)		(insoluble)			

Similar reactions can be written for other bicarbonates.

A majority of the carbon dioxide thus formed is removed when the water is passed through a degasifier. The remaining carbon dioxide is taken out when the effluent from the degasifier is next passed through a strongly basic anion exchanger.

When a water contains sulfates, chlorides or nitrates of calcium, magnesium, sodium or potassium is passed through a hydrogen cation exchanger, the metallic cations are removed and held by the exchanger which gives up an equivalent amount of hydrogen in exchange. Since an equivalent amount of the anions of sulfate, chloride or nitrate are also present, the net effect is a dilute solution of sulphuric, hydrochloric or nitric acids. Using calcium sulfate as an example and Z as the symbol for the complex exchanger radical, the reaction may be indicated by the following equation:

$CaSO_4$	+	H_2Z	=	CaZ	+	H_2SO_4
Calcium sulfate (soluble)	+	Hydrogen Cation Exchanger (insoluble)	=	Calcium Cation Exchanger (insoluble)		Sulphuric Acid (soluble)

Regeneration of Cation Exchanger

When the useful capacity of the cation exchanger is exhausted, the exchanger is regenerated with sulphuric acid, which removes the accumulated cations of calcium, magnesium, sodium or other cations and simultaneously gives up an equivalent amount of hydrogen cations in exchange, thus restoring the cation exchanger bed to its original hydrogen stage. Using the calcium cation exchanger as an example, the symbol Z for the complex cation exchanger and sulphuric acid as the regenerant, the regeneration process takes place as follows:

CaZ	+	H_2SO_4	=	H_2Z	+	$CaSO_4$
Calcium Cation Exchanger (insoluble)	+	Sulphuric Acid (soluble)	=	Hydrogen Cation Exchanger (insoluble)	+	Calcium Sulfate (soluble)

Anion Exchanger

The anion exchanger at the V.P.I. Power Plant is of the strongly basic type(Permutit S-1 and S-2), which removes strongly ionized acids, such as, sulphuric, hydrochloric and nitric acids. In addition, the strongly basic anion exchanger will also remove weakly ionized acids, such as the silcic (H_2SiO_3) and carbonic (H_2CO_3), as well. Using sulphuric acid as an example and the symbol R_4N to represent the complex anion exchanger radical, the reaction may be expressed by the following equation:

H_2SO_4	+	$2R_4NOH$	=	$(R_4N)_2SO_4$	+	$2H_2O$
Sulphuric Acid (soluble)	+	Strongly Basic Anion Exchanger (insoluble)	=	Anion Exchanger Sulfate (insoluble)	+	Water

Practically all natural water supplies contain silica, either in insoluble form as turbid suspension, or in soluble form. The insoluble silica can easily be removed by the common process of settling, coagulation and filtration, while the soluble silica is but little affected by such treatments. In the demineralizing process, the silica after passage through the hydrogen cation exchanger, is present as the weakly ionized acid. The reaction can be expressed by the following equation:

H_2SiO_3	+	R_4NOH	=	R_4NHSiO_3	+	H_2O
Silicic Acid	+	Strongly Basic Exchanger Silicate	=	Anion Exchanger Silicate	+	Water
(soluble)		(insoluble)		(insoluble)		

Regeneration of Anion Exchanger

When the strongly anion exchanger is exhausted, it is regenerated with caustic soda which removes the accumulated anions in the form of their soluble salts, and restores the anion exchanger to its original state. Using the sulfate of a strongly basic anion exchanger as an example and R_4N as the complex anion exchanger radical, the regeneration process takes place as follows:

$(R_4N)_2SO_4$	+	$2NaOH$	=	$2R_4NOH$	+	Na_2SO_4
Anion Exchanger sulfate	+	Caustic Soda	=	Strongly Basic Anion Exchanger	+	Sodium
(insoluble)		(soluble)		(insoluble)		(sol)

The Chemicals Used for Internal Treatments

The objective of internal chemical treatment is to prevent scale formation and deposite from residual hardness concentration remaining in the feedwater after external treatment. Internal chemical treatment also serves to maintain clean boiler heating surfaces in those cases where external softening is not employed and where all chemical treatment for scale prevention must be applied directly to the boiler itself. Because of the consulting contract on water treatment between the V.P.I. Power Plant and the National Aluminate Co.(hereafter called Nalco), the Nalco products employed during the investigation will be discussed individually.

(a) Nalco 728:

<u>Sodium Orthophosphate and Lignins Derivatives</u>

The sodium phosphates are the most common chemicals employed for the precipitation of soluble calcium salts present in the boiler feedwater. To insure that all the calcium will be precipitated as tricalcium phosphates, an excess of phosphate ion must be present in the boiler at all times.

Disodium phosphate is most commonly used in boiler feedwater conditioning. Economically, disodium phosphate is the cheapest way to purchase the necessary P_2O_5 content.

Once calcium and magnesium salts have been precipitated as a sludge in a fluid form, it is necessary to maintain the sludge in the fluid form. Lignin is a complex organic substance and is the chief non-cellulose component of wood. It is believed that the organic materials function to hinder boiler scale formation by several different methods. With Lignins, a major part of Lignins action is believed to be the dispersion of the precipitates. Lignins will also exert, to some extent, a coating action on the precipitated inorganic solids, thus, decreasing their tendency to both cohere and adhere to the boiler metal surfaces. The end result is the formation of a fluid boiler water sludge which may be readily removed by blowdown. Other forms of phosphates may be used, such as trisodiumphosphate, sodium metaphosphate and monosodium phosphate. Once the phosphates enter the boiler, their action is exactly the same. They all convert to trisodium phosphates and, as such, react with the calcium to form tricalcium phosphate.

It should be noted, however, the calcium will not precipitate properly if the pH value of the boiler water is below 9.50.

(b) Nalco 35:

Morpholine Type Neutralizing Amines

Morpholine is outstanding in the amine-type chemicals because of its stability at high temperatures, and its ability to condense with the initial condensate. The vapor pressure of morpholine is such that even at low concentration in the boiler water it will vaporize and the proper proportion will condense with the first droplets of condensate which form in the system. This assures protection to a critically important part of the cycle. Most other presently known amines have vapor pressures which are too low or too high, and consequently either remain in the boiler water or fail to condense in the first formed droplets. In either case, an important part of the system may be left unprotected.

Low pressure system, with the presence of alkalility, usually contains considerable amounts of carbon dioxide, when dissolved in the condensate, reduces the pH values of the condensate and makes it acidic enough to be highly corrosive to steel. Even the condensate which is very pure, nearly neutral and free from acidic ions, has a sufficiently low pH value to dissolve measurable quantity of iron.

When large volume of condensate are circulated, quantities of iron removed from the exposed surfaces alone often present a serious problem. It is therefore, necessary to provide control of pH value in addition to neutralization of carbon dioxide and other acidic components.

Morpholine has the following important advantages as a treatment for prevention of corrosion in steam condensate system:

A. It neutralizes carbon dioxide and other acidic components in the steam and the condensate.

B. It maintains proper pH in all parts of the system, particularly in areas of initial condensation.

C. It is stable at all temperatures found in modern steam power plants, and boiler water conditions usually associated with them.

D. It is readily available in safe, convenient solution form.

E. It can be fed into the feedwater line continuously along with other internal treatment.

(c) Nalco 19:

Catalyzed Sodium Sulfite

Dissolved oxygen is recognized as the major corrosive influence in most water problems. Many factors influence the rate of corrosion: temperature, pH, solids and flow rate. However, if dissolved oxygen is removed, the corrosion potential of that particular water will be greatly minimized.

Chemical deaeration, mechanical deaeration or a combination of both, can be employed to eliminate the dissolved oxygen in water. Sodium sulfite is usually used as a chemical deaerant agent. The chemical reaction can be expressed in the following equation:

$$\begin{array}{lclcl} 2\ Na_2SO_3 & + & O_2 & = & 2\ Na_2O_4 \\ \text{Sodium Sulfite} & & \text{Oxygen} & & \text{Sodium Sulfate} \end{array}$$

The use of sodium sulfite is now a standard practice in the treatment of boiler feedwater in order to prevent corrosion and pitting of boiler metal due to O_2. Best practice dictates the use of a deaerating feedwater heater to remove most of the oxygen from the feedwater by mechanical means and with sodium sulfite to remove the last traces of oxygen left by chemical means. Research directed toward increasing the speed of the oxygen-sulfite reaction has determined that certain materials act as catalysts in speeding this reaction to completion. The most suitable catalysts are the heavy metal cations of two or more valences. Iron, copper, cobalt, nickel and manganese are the substances among the more effective catalysts. Combination of several of these heavy cations have proved most effective in providing a continuously active influence on the reaction speed.

Through the incorporation of suitable catalysts and sodium sulfite in one formulation, catalyzed sodium sulfite has been developed to provide almost instantaneous oxygen removal.

(d) <u>NaOH</u>

In addition to the anion unit regeneration, caustic soda is also used to increase the alkinility of the water in both the cold and hot storage tanks, in order to minimize corrosion and to maintain sufficiently high pH value in the boiler water.

III. EXPERIMENTAL

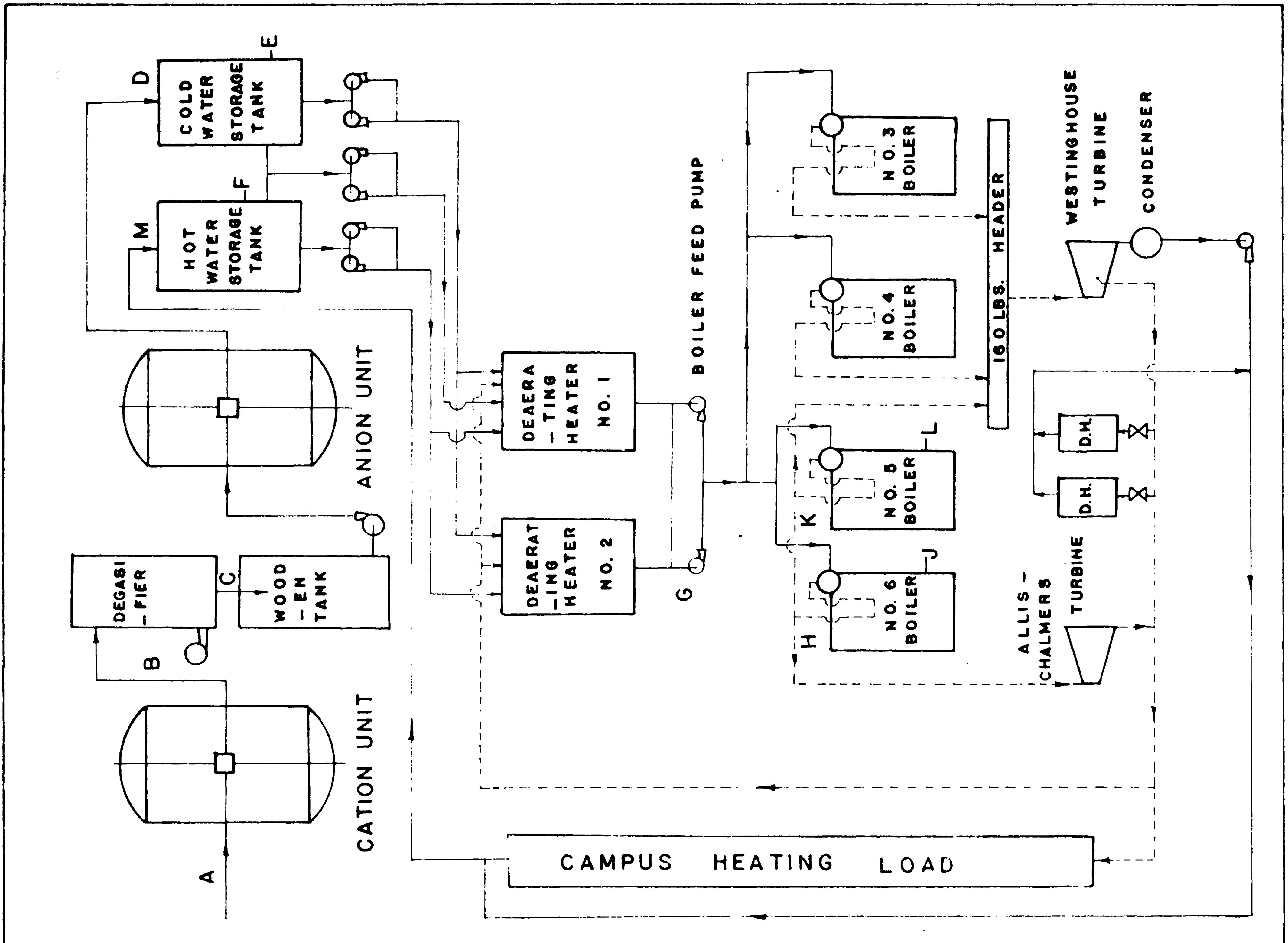
(A) Purpose and Plan

The purpose of this thesis was to study the costs incurred for the present V.P.I. Power Plant feedwater treating system and to investigate the operational economy of the system.

Daily tests around 11 a. m. were conducted for two periods, lasting four weeks each. Since this was a joint study including a number of tests, the total daily work was divided equally among the three investogators. All data for the three studies were recorded at one time. The tests involved complete water analysis at every critical point in the V.P.I. Power Plant and corrosion coupon tests of the condensate at necessary locations on the campus.

Samples were taken daily from the following locations for analysis: (see dwg. No. 1)

Incoming New River water to be demineralized(A)
Cation exchanger effluent(B)
Mechanical degasifier effluent(C)
Anion exchanger effluent(D)
Cold water storage tank(E)
Hot water storage tank(F)
Condensed steam from No. 6 Boiler(H)
Condensed steam from No. 5 Boiler(K)



LEGEND

WATER LINE ————————

STEAM LINE – – – – – – – – –

D. H. : DONESTIC HEATER

A TO M: SAMPLING POINTS

SCHEMATIC DIAGRAM SHOWING THE VARIOUS POINTS WHERE SAMPLES TAKEN IN THE DEMINERALIZED WATER SYSTEM OF THE VPI POWER PLANT

DR. BY: F. CHENG & R. PAI

DATE: 7-27-58

DWG. NO. 1

Boiler water from No. 6 Boiler(J)

Boiler water from No. 5 Boiler(L)

Main return condensate in the plant(M)

Cochrane deaerating heater effluent(G)

Corrosion coupon tests were set up at the following locations:

1. Main return condensate line in the plant(M)
2. Gravity return line in Saunders Hall basement.
3. Pump return line in Saunders Hall basement.

In addition, the quantities and dates of all the chemicals employed for internal treatment, the dates of ion exchanger regeneration, the daily blowdown quantities and the daily raw water make-up and other useful data on the operation of the V.P.I. Power Plant that related to the investigation were also recorded. However, only part of the total testing results and data, which concerned the calculation of costs and the analysis of operational economy of the present water treating system, were used in this thesis.

(B) Materials(Description of Chemicals)

Nalco 35:

General	A stabilized solution of the morpholine type volatile amines
Color	Pink
pH of 1% solution.	10.00
Solubility........	Miscible with water in all proportions
Specific Gravity .	1.017 at 60° F
Flash Point	None
Freezing Point ...	18° F
Weight	8.48 lbs. per gallon

Nalco 728:

General	A combination of sodium ortho-phosphate and sodium lingin derivatives, furnished only in pulverized form
Color	Gray with black specks
Odor	None
Density	60 lbs per cu. ft.
pH of 5% solution	9.20
P_2O_5 Content	39%
Organic Sodium Salt	20%

Nalco 19:

General	A catalyzed sodium sulfite, furnished either in briquette or pulverized form.
Color	Slightly tan or grey
Odor	Slightly sweet
Na_2SO_3 Content ...	80% commercial high grade (ball)
Na_2SO_3 Content ...	98% commercial high grade (pulverized)
pH of 1% solution	9.50 to 10.50
Maximum solubility at 75° F	20 parts per 100 parts water
Density	65 lbs per cu. ft.

(C) Apparatus

Anion Exchanger(see Fig. 3)

Manufacturer	The Permutit Company New York, N. Y.
Type	Permutit S-1
Plant Capacity	36,800 gallons per regeneration
Unit Capacity	36,800 gallons per regeneration
Total Exchangeable ions	22.4 grains per gallon as $CaCO_3$
Capacity per Regeneration	825 kilograins
Average Flow Rate	67 gpm
Maximum Flow Rate	75 gpm
Diameter	66 inches
Vertical Height of Tank	9 feet
Working Pressure of Tank	100 psig
Backwash Rate	24 gpm at 15 psig water pressure(minimum)

Cation Exchanger(see Fig. 3)

Manufacturer	The Permutit Company, New York, N. Y.
Type	Zeo-Karb
Plant Capacity	36,800 gallons per regeneration
Unit Capacity	36,800 gallons per regeneration
Average Flow Rate	67 gpm
Maximum Flow Rate	75 gpm
Diameter	66 inches
Vertical Height	9 feet
Working Pressure of Tank	100 psig

Nalcometer (see Fig 1)

General:	The Nalcometer is an electrical conductivity instrument for measuring the dissolved solids content of water samples.
Manufacturer	The National Aluminate Company, Chicago, Ill.
Type	CMI Nalcometer
Range	0.04 ppm to 10,000 ppm
Power Source	Either on self-contained batteries, or 110-115 volt, 60 cycle external source.
Electrodes	Type C-1 electrode for under 100 ppm on range-switch 1 and 2.
	Type B electrode for above 40 ppm on range-switch 3 and 4.

Phototester (see Fig. 1)

General	The Phototester is an electrical instrument used to determine certain ions in the water samples with the help of the standard reagents.
Manufacturer	The National Aluminate Company, Chicago, Ill.
Type	Model "P"
Power Source	Ordinary flashlight batteries
Ions(unknown)	Alumina, Sulfate, Iron, Orthophosphate, Total Phosphate and Dissolved Oxygen

Conductivity Meter (see Fig.1)

General	The conductivity meter is an electrical instrument used to measure the conductivity, in michromohs, of the water samples

Manufacturer	The Beltz Laboratories, Philadelphia, Pa.
Power Source	125 volt, 60-cycle external source

pH Meter (see Fig. 4)

General	The pH meter is an electrical instrument for measuring the alkilinity, or acidity of the water samples
Type	Portable
Manufacturer	Beckman Instrument Corporation, Newark, New Jersey
Range	pH value from 2 to 12
Power Source	Special batteries

Miscellaneous Equipments

Steam sampling Condensers (2) see Fig. 2

Automatic Burettes (4)

Sampling Containers (40-50)

Beakers of Various Sizes

Sodium Carbonate Titrating Solution(0.02 Normal)

Sulphuric Acid Titrating Solution(0.02 Normal)

Various Color Indicators(National Aluminate Co.)

Various Reagents(National Aluminate products)

The V.P.I. Power Plant

Since the test was conducted within the V.P.I. Power Plant, for additional information concerning apparatus, please consult Appendix A.

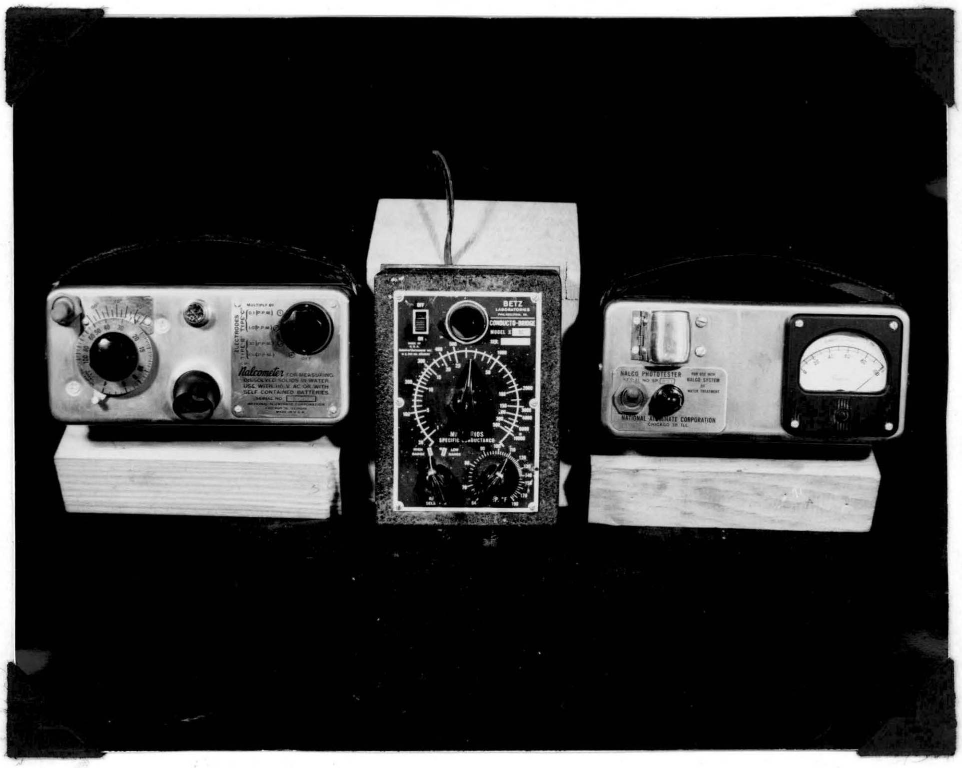


FIG. 1. SOME TESTING EQUIPMENTS

Left: Nalcometer

Center: Betz Conductivity Meter

Right: Nalco Phototester

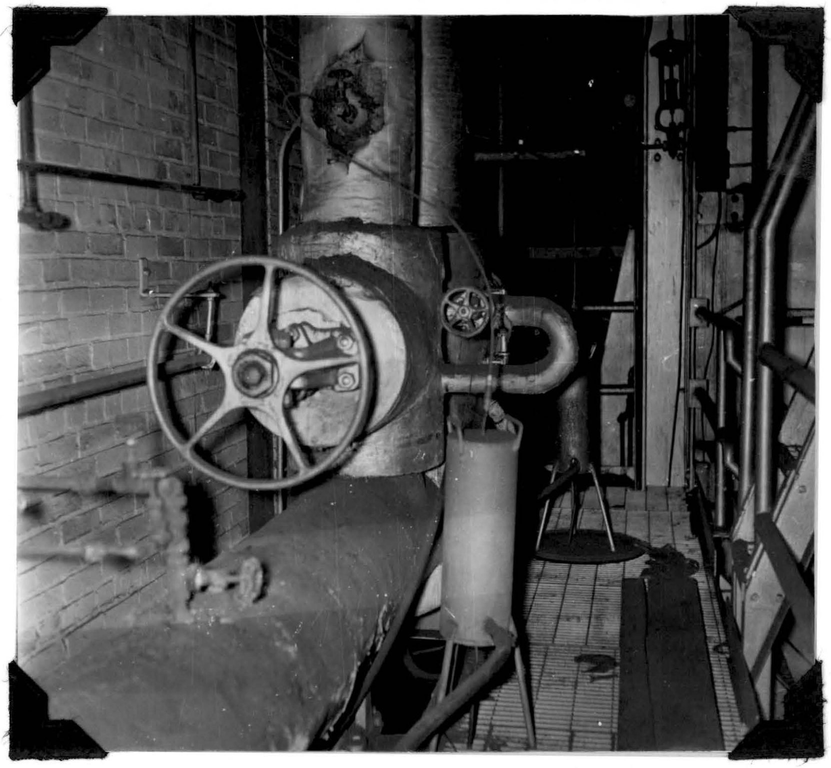


FIG. 2. STEAM SAMPLING CONDENSERS

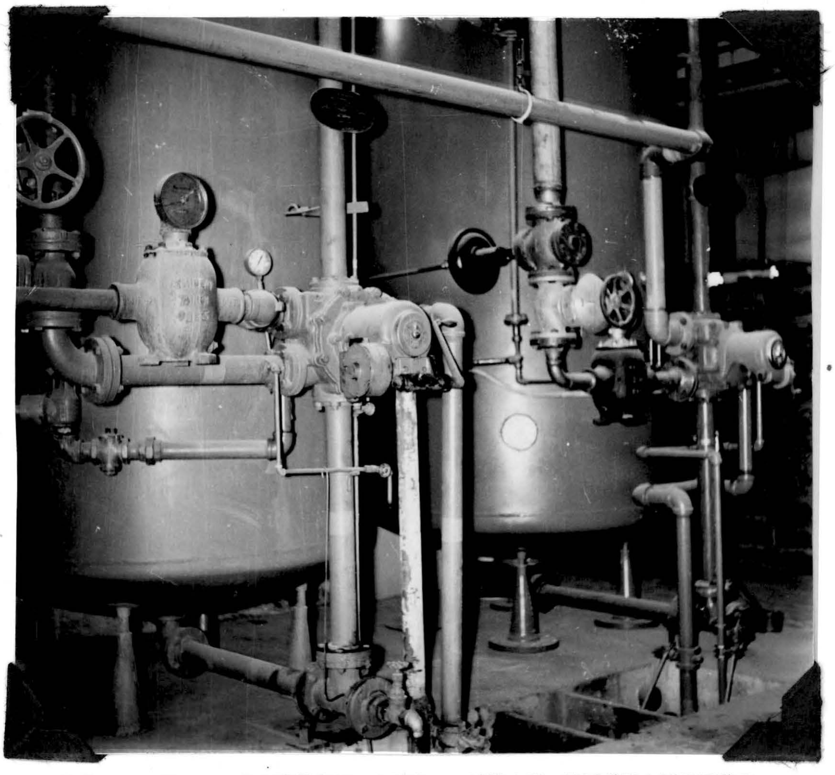


FIG. 3. CATION AND ANION EXCHANGERS

FIG. 4. THE pH METER.

(D) Methods of Procedure

Collection of Water and Condensed Steam Samples

To collect the water or condensed steam sample, the valve of the collecting point was opened widely and waited for at least three to five minutes. While waiting, the glass collecting bottle was washed completely with the discharging liquid. The sample was then collected with care and the container was sealed to avoid contamination.

Boiler No. 6 Blowdown Quantity Determination

The blowdown quantity was obtained by volumetric weighing method. A small tank with a valve on the bottom outlet was placed directly under the blowdown pipe and the boiler water was discharged into the tank continuously before going to waste. The dimensions of this tank were measured and a level was marked so that when the tank was filled to the mark, approximately one gallon of water was discharged. To obtain blowdown quantity, the valve on the tank was closed as fast as possible and the initial time was read simultaneously. As soon as the tank was filled to the mark, the final time was read and the drain valve was opened. This procedure was repeated once more to obtain a check reading. The average time required to fill the tank to the mark was recorded and the blowdown rate was calculated from the time obtained. Five to six readings per day were made to insure an uniform and continous blowdown rate, and the rate of one minute per tank was used as the guide for adjustments.

Operation of the Nalcometer (see fig. 2)

Condensate of distilled water samples did not require preparation before testing. The electrodes, cylinder and thermometer were rinsed throughly with a small portion of the sample to be tested. For other samples, special preparation was used as the following: the Nalcometer cylinder was filled with a sample to half full and two drops of phenolphthalein indicator were added to the sample. If no pink color appeared, enough sample water to cover the electrode entirely was then added and the operation of the Nalcometer was processed. If a pink color appeared, sulphuric acid was added drop by drop until the pink color disappeared, then more sample was added until the faint pink color reappeared.

Operation of the Phototester (see fig. 2)

A test bottle of distilled water was inserted in the Phototester first, and the cover was closed and the switch was held on during all the readings. The needle was turned to zero by adjusting the zero adjustment knok. The test bottle was then removed and a bottle of the sample was inserted in the Phototester instead. As soon as the needle came to rest, the reading was recorded.

The test bottle of distilled water was again used to check the zero reference reading. In the test, Nalco colorimetric comparator bottles were used, they had a capacity of 17 ml when they were filled to the base of the neck.

Care should be taken to avoid interchanging of reagent droppers and contamination. Reagents were to be transferred without touching the test bottle neck, and the instrument was kept away from chemical fumes.

Operation of Automatic Burette

To operate the automatic burette, the reservoir was filled with the solution, and the solution was then pumped up by squeezing the rubber bulb. Just as soon as the solution rose to the glass ball after the burette was filled, the pressure on the rubber bulb was released. The excess solution was allowed to return to the reservoir. In reading the burette, the top of the liquid was curved due to surface tension, and the reading was taken from the bottom of the curve.

Colorimetric Titration Hardness

To test the TOTAL HARDNESS of the liquid, 50 ml sample was measured into the clean casserole or to a 250 ml flask and 1 ml of H-2 solution was added. After mixing, H-3 indicator was added. The correct quantity of the indicator was achieved by inverting the special container over the sample in a salt-shake motion, and sample was titrated with H-1 solution. The color change was from red to blue with an intermediate purple color, and the end point was obtained when the last purple coloration just disappeared. The total hardness was recorded by multiplying the number of ml of titrating solution by 20 as ppm $CaCO_3$.

To test the CALCIUM HARDNESS, 50 ml of clear sample was measured into a clean casserole or to a 250 ml flask and 2 ml of H-6 solution were added. After mixing, H-7 indicator was then added. The sample was next titrated with H-1 solution until the final change of color occurred. The indicator color change was from salmon-orange to blue-violet. The calcium hardness was recorded by multiplying the number of ml solution required for the titration by 20 as ppm $CaCO_3$.

To obtain MAGNESIUM HARDNESS, the calcium hardness was subtracted from the total hardness.

Phenolphthalien and Methyl Orange Alkalinity Test

A 50 ml sample was measured into a porcelain dish and two drops of phenolthalein indicator were added. If no pink color appeared, "P" was recorded as zero and two drops of methyl orange indicator were then added. The burette was filled with N/50 sulphuric acid to the zero mark, making sure that the tip and valve of the burette were filled of acid. The acid was added to the sample through the burette until the pink color just disappeared. The number of ml of acid used was multiplied by 20 to obtain ppm of phenolphthalien alkalinity as $CaCO_3$.

To the same sample two drops of methl orange indicator were added. Without refilling the burette, the acid was added until the yellow color just turned to orange. The total ml of acid added was multiplied by 20 to obtain methyl orange alkalinity as ppm of $CaCO_3$.

Free Carbon Dioxide Test

A 50 ml sample of water was measured into a white porcelain dish and two drops to four drops of phenolphthalein indicator were added. If a pink color resulted, the carbon dioxide was recorded as zero. If pink color did not appear, N/50 sodium carbonate solution was added through the burette until the pink color appeared for ten seconds. The number of ml sodium carbonate solution used was multiplied by 20 to obtain ppm carbon dicxide as $CaCO_3$.

Operation of the pH Meter

To measure the pH value of the water sample, the switch on the pH Meter was slided to "on" position. The electrode sleeve was next slided down below filling hole. The electrode was rinsed with distilled water and dried with tissue. A buffer solution was employed to standardize the meter by inserting the electrode into this buffer solution of known pH value. The electrode was washed again before the testing.

(E) Experimental Data and Results

Table 1 portrays the average analysis of raw water supplied by the New River Water Authority, and is significant in comparing the cost and performance of the feedwater treating system. Table 2 contains the daily total plant steam load of the V.P.I. Power Plant. Table 3 indicates the quantities of raw water treated. The raw water was treated by passing it through the cation exchanger and the anion exchanger in series. Since the meters on both exchangers did not agree after correction, on the quantity of water passing through the units, therefore, the average value of the two meter readings was calculated as the quantity of treated water in the test. Table 4 contains the steam load of Boiler No. 6. The actual evaporation rate was calculated to check the accuracy of the steam meter. Table 5 contains the analysis of blowdown water of No. 6 Boiler and is useful in studying the chemicals which were used for this boiler. Table 6 shows the quantities of blowdown on Boiler No. 6, is important in the controlling the total solids in this boiler. Table 7 indicates the steam load of Boiler No. 5. During the testing period, the steam meter on this boiler was out of order, therefore an average actual evaporation rate of 9.50 was assumed to calculate the adjusted steam output per day. Table 8 contains the analysis of blowdown water from Boiler No. 5 and is useful in studying the chemicals which used

CARBON DIOXIDE AS CO_2 ppm	0
TOTAL HARDNESS AS $CaCO_3$ ppm	52
CALCIUM HARDNESS AS $CaCO_3$ ppm	32
MAGNESIUM HARDNESS AS $CaCO_3$ ppm	20
PHENOL. ALKALINITY AS $CaCO_3$ ppm	4
M. O. ALKALINITY AS $CaCO_3$ ppm	42
SULPHATE AS $CaCO_3$ ppm	15
SILICA AS SiO_2 ppm	12.5
pH	8.55
SPECIFIC CONDUCTANCE, MICROMHOS	100
DISSOLVED SOLIDS ppm	80
CHLORIDE AS NaCL ppm	7.5
CHLORIDE AS $CaCO_3$	6

TABLE 1. AVERAGE NEW RIVER WATER ANALYSIS FOR THE TESTING PERIOD.

Date	Tot. Steam (1000) lbs/day	Raw Water (1000) lbs/day	Make-up % of Tot. Steam	Ambient Temp. °F
3/24/58	1399.75	172.01	12.30	40
25	1352.50	194.09	14.35	36
26	1263.30	208.03	16.45	40
27	1236.65	188.79	15.28	41
28	1283.15	217.35	16.90	44
29	1212.95	194.04	15.98	46
30	1277.60	228.79	17.95	39
31	1236.75	211.58	17.10	38
4/1/58	1267.30	232.20	18.35	45
2	1203.70	184.93	15.32	52
3	1185.85	219.50	18.50	47
4	1235.90	214.08	17.32	44
5	1270.25	189.92	14.90	52
6	1087.70	190.76	17.53	47
7	1319.05	228.24	17.32	52
8	1320.05	212.20	16.10	48
9	1153.20	265.31	22.88	44
10	1317.35	204.72	15.55	47
11	1242.90	169.52	13.62	40
12	1291.80	163.69	12.67	43
13	1125.80	159.15	14.15	46
14	1085.50	175.56	16.18	55
15	1054.30	139.94	13.22	56
16	1030.25	172.01	16.68	56
17	881.20	169.30	19.22	63
18	803.30	204.50	25.50	70
19	746.75	199.92	26.10	73
20	746.10	222.83	29.90	74

TABLE 2. SOME DATA ON THE V.P.I. POWER PLANT TAKEN DURING THE TEST PERIOD.

Date	H-Unit gal/day	H-Unit (corrected) gal/day	Na-Unit gal/day	Na-Unit (corrected) gal/day	Raw Water (average) gal/day
3/24/58	20000	20700	21200	20600	20650
25	22500	23300	24000	23300	23300
26	24200	25047	25700	24900	24973
27	22000	22770	23300	22600	22685
28	25300	26186	26700	26000	26093
29	22500	23288	24000	23300	23294
30	26600	27531	28200	27400	27400
31	24600	25500	26000	25300	25400
4/1/58	37700	39000	28800	27900	(27900)
2	21400	22200	22900	22200	22200
3	25800	26700	26700	26000	26350
4	24900	25700	26400	25600	25700
5	22100	22900	23400	22700	22800
6	22000	22800	33700	23000	22900
7	26200	27200	27500	27600	27400
8	42600	44100	26300	25500	(25500)
9	30600	31700	33200	32200	31850
10	24800	25700	24800	24100	24900
11	21200	21900	19400	18800	20350
12	17800	18500	21400	20800	19650
13	18700	19300	19500	18900	19150
14	20700	21400	21500	20750	21075
15	15700	16300	17800	17300	16800
16	20800	21500	20400	19800	20650
17	30500	31600	20900	20300	(20300)
18	24000	24800	25000	24300	24550
19	23400	24200	24500	23800	24000
20	26100	27000	27300	26500	26750

TABLE 3. DATA ON RAW WATER QUANTITY

TOTAL: 664,567 GALLONS FOR THE TESTING PERIOD.

AVERAGE: 23,600 GALLONS PER DAY.

Date	Steam (metered) lbs/day	Steam (corrected) lbs/day	Coal lbs/day	Evaporation lbs steam / lbs/coal
3/24/58	1364	887250	80000	11.06
25	1350	877500	82000	10.70
26	1242	807300	76000	10.61
27	1201	780650	74000	10.54
28	1301	845650	76000	11.12
29	1193	775450	74000	10.48
30	1264	821600	78000	10.51
31	1275	828750	76000	10.88
4/1/58	1292	838900	78000	10.75
2	1238	804700	72000	11.15
3	1239	803500	72000	11.17
4	1316	855400	74000	11.08
5	1215	789750	72000	10.94
6	1088	707200	66000	10.70
7	1387	901500	80000	11.25
8	1417	921050	78000	11.06
9	1248	811200	74000	10.96
10	1369	889850	80000	11.12
11	1386	900900	82000	10.98
12	1402	911300	80000	11.30
13	1264	821600	76000	10.80
14	1202	781300	73500	10.62
15	1154	750100	70000	10.72
16	1117	726050	67000	10.83
17	1048	681200	68000	10.00
18	972	631800	62000	10.17
19	895	581750	60000	9.70
20	914	594100	60000	9.91

TABLE 4. SOME DATA ON BOILER NO. 6 TAKEN DURING TEST PERIOD.

Date	pH	Dissolved Solids ppm	Sulfite As SO_3 ppm	Total Phosphate PO_4 ppm
3/24/58	11.49	920	17.50	30
25	11.40	850	15.2	25
26	11.58	880	22.5	120
27	11.47	850	17.5	120
28	11.90	800	12.5	120
29	11.61	870	19.0	80
30	11.82	560	19.2	65
31	11.10	600	10.0	50
4/ 1/58	11.00	575	10.0	55
2	11.40	495	22.0	45
3	11.30	600	27.0	45
4	11.50	620	19.0	40
5	11.10	580	27.0	60
6	11.00	760	31.5	80
7	11.40	600	27.0	50
8	11.50	610	20.0	40
9	11.50	525	20.0	30
10	12.00	640	30.0	55
11	11.70	610	29.0	60
12	11.60	600	20.0	45
13	11.20	550	20.5	35
14	11.20	650	20.0	60
15	11.50	400	15.0	40
16	11.60	575	30.0	50
17	11.30	550	27.5	70
18	11.40	640	20.5	70
19	11.30	580	20.5	60
20	11.10	650	28.0	60

TABLE 5. BLOWDOWN WATER ANALYSIS FOR NO. 6 BOILER TAKEN DURING THE TEST PERIOD.

Date	Steam Output lbs/day	Av. Blowdown lbs/day	Av. Blowdown % of Steam Output
3/24/58	887250		
25	877500		
26	807300		
27	780650	7980	1.02
28	845650	6575	0.78
29	775450	7200	0.93
30	828750	8980	0.51
31	821600	4230	0.88
4/ 1/58	839800	7200	1.07
2	804700	8980	1.15
3	805350	8980	0.88
4	855400	7200	0.47
5	789750	4000	1.45
6	707200	10250	1.02
7	901550	7200	0.66
8	921050	5980	0.99
9	811200	8980	0.74
10	889850	10250	1.15
11	900900	8980	0.99
12	911300	7980	0.88
13	821600	5525	0.67
14	781300	11980	1.53
15	750100	8550	1.14
16	726050	6850	0.94
17	681200	7200	1.16
18	631800	5980	0.96
19	581750	6575	1.14
20	594100	4800	0.81

TABLE 6. BLOWDOWN QUANTITY FOR NO. 6 BOILER TAKEN DURING TEST PERIOD.

Date	Steam (metered) lbs/day	Steam (indicated) lbs/day	Coal lbs/day	Evaporation (indicated) lbs steam / lbs coal	Evaporation (adjusted) lbs steam / lbs coal	Steam (adjusted) lbs/day
3/24/58	1343	671500	54000	12.42	9.5	512500
25	1380	690000	50000	13.80	9.5	475000
26	1364	682000	48000	14.20	9.5	456000
27	1354	677000	48000	14.10	9.5	456000
28	1336	668000	46000	14.55	9.5	437500
29	1327	660750	46000	14.38	9.5	437500
30	1347	673525	48000	14.05	9.5	456000
31	1332	660000	43000	15.36	9.5	408000
4/1/58	1317	685000	45000	14.65	9.5	427500
2	1297	648500	42000	15.40	9.5	399000
3	1386	693000	40000	17.35	9.5	380500
4	1285	642500	40000	16.05	9.5	380500
5	1260	630000	40000	15.75	9.5	417500
6	1267	633500	40000	15.85	9.5	399000
7	1279	639500	44000	14.48	9.5	342000
8	1297	648500	42000	15.45	9.5	427500
9	1251	625500	36000	17.30	9.5	342000
10	1325	662500	45000	14.72	9.5	427500
11	1298	649000	36000	18.05	9.5	342000
12	1301	650500	40000	16.25	9.5	380500
13	1268	634000	32000	19.85	9.5	304200
14	1252	626000	32000	19.58	9.5	304200
15	1271	635505	32000	19.85	9.5	304200
16	1248	624000	28000	22.28	9.5	304200
17	1251	625550	21000	29.70	9.5	200000
18	1175	587500	18000	32.62	9.5	171500
19	1185	592590	17000	34.80	9.5	165000
20	1271	635500	16000	39.80	9.5	152000

TABLE 7. SOME DATA ON BOILER NO. 5 TAKEN DURING THE TEST PERIOD.

Date	pH	Dissolved ppm Solids	Sulfite as ppm SO_3	Total Phosphate as ppm PO_4
3/24/58	11.20	530	16.0	50
25	11.50	540	22.0	25
26	11.59	535	12.5	120
27	11.00	525	10.0	120
28	11.33	550	15.0	90
29	11.25	350	16.5	60
30	11.30	272	17.5	35
31	10.60	260	15.5	45
4/ 1/58	10.40	238	19.5	35
2	10.90	248	10.5	30
3	10.90	240	15.5	50
4	11.10	355	13.5	40
5	10.80	385	15.0	32
6	10.90	425	19.0	50
7	11.10	435	19.0	100
8	11.30	425	16.0	65
9	11.10	423	15.0	75
10	11.70	490	19.0	110
11	11.30	450	16.0	90
12	11.10	390	15.5	90
13	10.90	390	15.5	100
14	10.90	400	12.5	60
15	11.30	350	11.0	60
16	11.10	340	14.0	60
17	10.90	240	16.5	55
18	10.70	225	10.5	50
19	10.80	225	16.5	50
20	10.40	205	19.0	40

TABLE 8. BLOWDOWN WATER ANALYSIS FOR NO. 5 BOILER.

for this boiler. Table 9 gives the variation of pH values of steams from Boiler No. 5 and 6, and the main condensate return line in the power plant, and is indicative of the alkalinity in the system. Table 10 shows the carbon dioxide content of the mechanical degasifier effluent indicating the effectiveness of the degasifier. Table 11 is a record of all products manufactured by National Aluminate Corporation that were employed for internal chemical water treatment at the V.P.I. Power Plant.

Date	Return Condensate	Boiler No. 5	Boiler No. 6
3/24/58	8.41	7.60	7.83
25	8.18	8.68	8.25
26	8.29	8.68	8.87
27	8.52	7.52	7.52
28	8.63	8.78	8.80
29	8.58	8.82	8.67
30	8.20	7.80	8.40
31	7.70	7.40	7.50
4/ 1/58	8.00	7.90	7.50
2	7.90	7.65	7.40
3	7.70	7.80	7.70
4	7.80	7.60	7.40
5	7.50	7.50	7.30
6	7.90	7.80	7.80
7	7.80	7.80	7.60
8	7.60	7.50	7.50
9	8.50	7.80	8.00
10	8.60	8.50	8.50
11	7.90	8.00	7.90
12	8.20	8.00	8.00
13	8.20	8.00	7.90
14	8.00	7.90	8.00
15	8.70	8.60	8.60
16	8.40	8.00	8.00
17	8.30	8.30	8.30
18	8.40	7.80	8.10
19	8.20	8.30	8.30
20	7.90	7.50	7.80

TABLE 9. pH VALUES OF STEAMS AND MAIN RETURN CONDENSATE.

Date	CO_2 Content ppm as CO_2
3/24/58	8.8
25	8.16
26	8.8
27	7.92
28	8.8
29	8.8
30	8.8
31	8.8
4/ 1/58	10.56
2	8.8
3	8.8
4	8.0
5	7.92
6	8.8
7	8.8
8	8.8
9	9.68
10	8.8
11	8.8
12	10.56
13	9.68
14	8.8
15	9.68
16	9.68
17	9.68
18	11.00
19	11.44
20	11.44

TABLE 10. CARBON DIOXIDE CONTENT OF DEGASIFIER EFFLUENT.

Date	NaOH lbs.	Nalco 35 lbs.	Nalco 19 lbs	Nalco 728 Boiler 6 lbs.	Nalco 728 Boiler 5 lbs.
3/25/58	3	6	0	0	0
26	3	6	0	0	0
27	3	6	0	0	0
28	3	6	1	1	0
29	3	6	0	0	0
30	2	6	1	1	1
31	3	6	0	0	0
4/ 1/58	3	6	2	0	0
2	3	6	½	½	1
3	3	6	0	½	1
4	3	6	1	0	½
5	3	6	1	½	0
6	3	6	0	00	1
7	3	6	0	0	0
8	3	6	½	1	0
9	3	6	½	1	1
10	3	6	0	0	0
11	3	6	0	0	0
12	3	6	½	1	0
13	2	6	0	0	0
14	3	6	0	½	½
15	3	6	1	1	1
16	3	6	0	0	0
17	3	6	0	0	0
18	3	6	0	0	0
19	3	6	½	½	0
20	3	6	0	0	1

TABLE 11. DATA ON CHEMICALS USED.

COST CALCULATIONS

Capital Investment:

1. Cation Exchanger ....$ 9,000.00

2. Anion Exchanger 18,600.00
   (resins included)

3. Mechanical Degasifier 600.00

4. Degasifier Blower 150.00

5. Chemical Feed Pumps:

	Quantity	Unit Price	
Nalco 728 Pump	3	$ 341	
Nalco 728 Pump	2	174	
Nalco 35 Pump	1	174	
Nalco 19 Pump	1	174	
NaOH Pump	1	174	
Total:		$1,893	......1,893.00

6. Chemical Storage Tanks:

	Quantity	Capacity	Unit Price
Nalco 19 Tank	1	50 gal.	$ 236
Nalco 35 Tank	1	100	229
NaOH Tank	1	100	229
Nalco 728 Tank	1	150	220
Nalco 728 Tank	1	150	220
Total:			$1,134

1,134.00

7. All Piping and Fittings Estimated......... 500.00

TOTAL $31,877.00

Total Investment at $31,877.00

(A) FIXED CHARGES

1. Depreciation figured at 5% annually of capital investment:

$$\frac{\$\ 31{,}877\ (5\%)}{12 \text{ months}} = 132 \text{ dollars per month}$$

Depreciation for the testing period:

$$\$\ 132.98\ \frac{28}{30},\ \text{or } \underline{124 \text{ dollars}}$$

2. Interest charged at 4% annually on capital investment:

$$\frac{\$\ 31{,}877\ (4\%)}{12 \text{ months}} = 106.31 \text{ dollars per month}$$

Interest charge for the testing period:

$$\$\ 106.31\ \frac{28}{30} = \underline{99.45 \text{ dollars}}$$

3. Maintenance figured at 4% annually on the capital investment:

$$\frac{\$\ 31{,}877\ (4\%)}{12 \text{ months}} = 106.31 \text{ dollars per month}$$

Maintenance for the testing period:

$$\$\ 106.31\ \frac{28}{30} = \underline{99.45 \text{ dollars}}$$

Total fixed charges = $\underline{322.9 \text{ dollars}}$

(B) OPERATIONAL COST

Cost of Chemicals:

Nalco 35: 176 lbs(0.355 \$/lb)= 62.50 dollars per period

Nalco 19: 7.50 lbs(0.186 \$/lb)=1.39 dollars per period

Nalco 728: 14.0 lbs(0.213 \$/lb)=2.98 dollars per period

H_2SO_4 Regenerant: 5 tanks(200lb/tank)(5.3 \$/200lb) =

26.50 dollars per period

NaOH Regenerant: $\frac{28}{18}$(400) lbs (18.8 \$/400 lb) =

29.24 dollars per period

At 18 days per cycle, 28 days per period

NaOH for Cold Storage Tank: 86 lbs(18.8 \$/400 lb) =

4.05 dollars per period

Total Chemicals Cost: 126.66 dollars per period

Freight Charges:

Chemicals	Weight lbs.
Nalco 35	176.00
Nalco 19	7.50
Nalco 728	14.00
H_2SO_4	1000.00
NaOH	622.00
NaOH	86.00
Total:	1905.50 lbs.

Freight charge at 23.40 dollars per 900 lbs chemicals

1,905.50 lbs (23.40 \$/900 lbs) = 49.60 dollars/period

Total Freight Charge: 49.60 dollars/period

BLOWDOWN COST CALCULATION

For Boiler No. 6:

Type of Coal Burned: Southwest West Virginia Bituminous

Average Heating Value as Received: 13,500 Btu per pound

Steam Drum Pressure: 250 psig

Saturated Enthalpy Corresponding to Drum Pressure:

1201.70 Btu/lb (h_f)

Saturated Enthalpy Corresponding to 230 F Feedwater:

198.23 Btu/lb (h)

Average Coal Price: \$ 7/ton

Average Blowdown: 7,425 lbs water per day

Average Boiler Efficiency: 75%

Weight of Coal Wasted Due to Blowdown:

$$\frac{7{,}425(28)(1201.70-198.23)}{75\,\%\;(13500)} \quad \frac{\text{lbs/day(days/period)}(h_f-h)\text{Btu/lb}}{\text{Av. Boiler Eff. (H.H.V.)}}$$

Therefore, 20,060 lbs coal wasted due to blowdown for the testing period.

The cost due to blowdown:

$$\frac{20{,}060\ \text{lbs}}{2{,}000\ \text{lbs/ton}} \;(\$\ 7/\text{ton})\ ,\ \text{or}\ \$\ 72.0/\text{period}$$

Since the same cost was assumed for Boiler No. 5, the total blowdown cost for the testing period was:

\$ 72 (2), or 144 dollars

RAW WATER COST

Purchasing price from New River Water Authority :

30 cents/1000 gallon

Total water consumption during the testing period:

664,567 gallons/4 weeks

Therefore,

664,567 gallons(30 cents/1000 gallon) = 199.22 dollars

Raw water cost: 199.22 dollars per period.

ION EXCHANGERS BACKWASH COST

Backwash at 41,000 gallons per period

41,000 (30 cents/1000 gallon) = 12.30 dollars

Backwash cost: 12.30 dollars per period

LABOR COST FOR REGENERATION

An average of 10 manhour labor required at:

1.65 dollars per hour

10 hours (1.65 dollars/hour) = 16.50 dollars

Average labor cost: 16.50 dollars per period

PUMPING COST

Pumping power cost at 1 cent/kw.

The average output of the six pumps was 1/3 hp per pump.

The average input of the six pumps was approximately ½hp per pump.

The pumps were operating continuously at full load at 24 hours per day and 28 days per testing period.

Total power input:

6 pumps ($\frac{1}{2}$ hp/pump)(746 watts/hp)

Or, 2,238 watts

Or, 2.238 kw

Total power cost:

2.238 kw(1 Cent/kw)(28 days/period)(24 hr/day)

Or, 1495 cents per period, or, 14.95 dollars per period

SUMMARY OF COSTS

	Dollars	% of Total Cost
1. Fixed Charges:		
Depreciation	124.00	14.02
Interests	99.45	11.21
Maintenance	99.45	11.21
Total Fixed Charges	$ 322.90	36.44 %
2. Operating Costs:		
Chemicals		
Nalco 35	62.50	7.05
Nalco 19	1.39	0.17
Nalco 728	2.98	0.34
NaOH	4.05	0.45
Regenerants	55.64	6.27
	126.66	14.28
Freights	49.69	5.62
Blowdown	144.00	16.24
Raw Water	199.22	22.48
Backwash	12.30	1.38
Labor(regeneration)	16.50	1.87
Pumping Power	14.95	1.69
Total Operating Costs	$ 563.32	63.56 %
3. The Total Cost of Feedwater Treatment	$866.22	100.00%

The total gallons of water demineralized for the period were 664,567 gallons.

Therefore, the cost per thousand gallons of water demineralized:

$886.22/664,567 gallon, or <u>1.334 dollars per thousand gallons</u>

Note:

The cost per thousand gallons of New River water demineralized was the only average cost for the testing period. This cost can not be taken as the average cost for any other period, though this cost should not deviate too much from the average cost of water treatment during the heating season in the spring of 1958.

IV. DISCUSSIONS

EXPERIMENTAL DIFFICULTIES

(a) Equipment

Since most of the testing equipment was newly purchased and was of modern design, such as the Nalcometer and the Phototester, it took a relatively long time to learn the applications and limitations on these pieces of equipment before data could be taken. The standard procedures for preparing different samples for the various tests had also to be learned.

(b) Experimental Techniques

The first four week period was spent mainly in obtaining stable and accurate results. In order to achieve competent techniques, numerous preliminary tests were needed. For instance, the general chemistry laboratory method of using a 50 cc sample of water to be titrated by 0.02 normal solution of sodium carbonate to find the carbon dioxide content, as was also recommended by Nalco, did not work out for water of very low CO_2 content. Due to the fact that this method had a low limit of at least one drop titrating solution required to reach the end point, the resulting CO_2 content would be at least 1½ ppm, expressed as $CaCo_3$. This was why the carbon dioxide in the return condensate line always appeared high. To overcome this problem, larger samples of water were used, and up to a 1,000 cc sample was tested to find out whether the carbon dioxide in the main condensate return line was actually below 0.0625 ppm as $CaCO_3$. Consequently, no daily tests were necessary owing to the low carbon dioxide content in the main return condensate line, and only spot checks would be sufficient.

Another method to obtain low carbon dioxide content in the water was to use a standardized titrating solubion of low normality, but this was not essential.

(c) Locations for Sample Collecting

To be certain that representative samples were obtainable to furnish vital information needed in the investigation, the location of sampling points was given careful consideration. After several weeks of testing and data compiling, it was observed that the original location for collecting the samples from the effluent of the degasifier was questionable. Since the original samples were collected after the water passed through the wooden tank, some of the dissolved carbon dioxide escaped before collection, introducing errors. A new sampling point was then adopted at a location directly next to the degasifier outlet.

(d) The Supply of Reagents

The quantities of various reagents, buffer solutions and color indicators, supplied with the equipments, were inadequate to sustain the duration of four week testing. The preliminary tests had to be discontinued and the samples discarded because of the lack of supplies. In the beginning, it was very difficult to estimate the required quantities of these chemicals for a four week period without any testing experience. The reordering of chemical supplies was made easier only through the experience gained from the previous tests, making the preliminary testing period essential.

(e) The Blowdown Quantity

The No. 5 Boiler in the V.P.I. Power Plant had leaks somewhere in the boiler circuit, producing a low dissolved solids content in the boiler water. Without continuous blowdown the solids would have remained within the safe limits. Intermittent blowdown was made to avoid the building up of the sludges in the blowdown pipe and possibly some localized deposits. Since it was impossible to measure the blowdown quantity in the No. 5 Boiler, it was assumed equal to the amount of blowdown of the No. 6 Boiler.

A continuous blowdown meter was installed for No. 6 Boiler but unfortunately it failed after several days of testing. The failure could mainly be attributed to the following sources:

1. High alkalinity attack-the average pH value in the No. 6 Boiler Blowdown water was around 11.50.
2. High temperature-the heat exchanger installed at the blowdown outlet did not cool the blowdown water to satisfactory range before entering the meter. The meter was designed for cold water.
3. Sludge agglomeration-the accumulative deposits in the path of the meter.

There were, however, two alternatives to this problem. The first was to install a calibrated orifice inside the blowdown pipe and to measure the flow by means of drop across this orifice. By knowing the boiler water density, the flow time, the pressure drop and the size of the orifice and orifice constant, the blowdown quantity could be calculated analytically. The second method was to weight the blowdown quantity volumetrically as described in the experimental procedure.

As already mentioned in the Review of Literature, this thesis was also a time study to investigate the actual operation of the feedwater treating system of the V.P.I. Power Plant at a definite time everyday. Any discontinuity produced in the course of the testing, therefore, would no doubt influence the results considerably. The second method of measuring blowdown was favored due to its simplicity and reliability.

THE CURVES AND RESULTS

In controlling the feed rates of various chemicals used in the V.P.I. Power Plant, no automatic instruments were available. The best possible way to feed some of the chemicals was to keep certain ions in the boiler water within the safe limits and use these ions as a guide for additional chemical feed.

To control the required quantity of Nalco 728, orthophosphates and Sodium Lignin Derivatives, an endeavor was made to maintain the PO_4 excess in the boiler water between 30 to 60 ppm as $CaCO_3$. From the graphs plotted of excess PO4 in boilers No. 5 and 6, graph 1 and 2, it can be seen that the amount of Nalco 728 fed was satisfactory for No. 6 Boiler, while the amount was excessive for Boiler No. 5. An excessive use of the chemicals did nothing to gain any additional advantage, yet only increased the operational expense. The difficulty lay in the anticipation of a rise or drop of the PO_4 radicals. If the radicals were decreasing, the operator put more Nalco 728 into the chemical storage tank to be pumped continuously into the boilers. The proper feed rate was further complicated by a time lag between the

Graph 1 Excess PO_4 in Boiler No. 6

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Graph 2
Excess PO$_4$ in Boiler No. 5
ppm Excess Total Phosphate as PO$_4$
120
100
80
60
40
20
PO$_4$ in Boiler No. 5
Pounds Nalco "723" Added
1
½
24
26
28
30
1
3
5
7
9
11
13
15
17
19
March
April
1958

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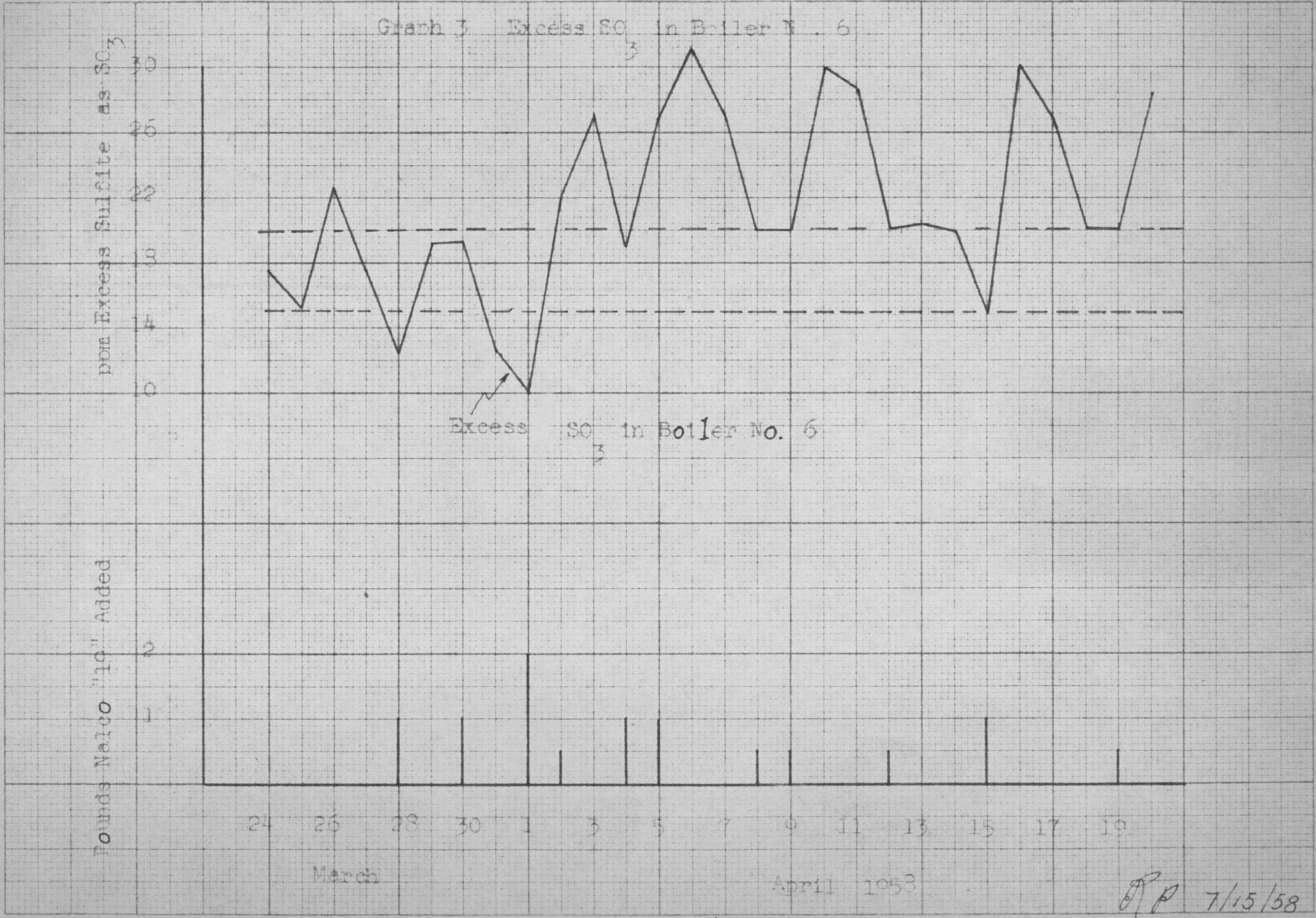
testing time and the feeding time, as well as the fluctuation in steam load.

By the same token, the amount of Nalco 19, Catalyzed Sodium Sulfite, was governed by the SO_3, ions in the boiler water, and the proper ions were given as to be between 15 to 20 ppm of SO_3. From graphs 3 and 4, the excess SO_3 in Boiler 5 and 6 it can be noted that the values of ppm SO_3 were satisfactory in both Boiler No. 5 and 6. Although the ppm SO_3 radicals were somewhat higher on Boiler No. 6, the same argument of inaccuracy as for Nalco 728 was also applicable here.

In spite of the low percentage of blowdown, the dissolved solids in both No. 5 and 6 Boiler were low, especially in No. 5 Boiler. The unusually low value of dissolved solids in No. 5 Boiler could be explained by the presence of leaks in the boiler circuit. From graphs 5 and 6, the dissolved solids in Boiler No. 5 and 6, the comparison made on both boilers raised the question of whether the assumption of considering the same quantity of blowdown for both boilers was reasonable in the calculation of blowdown cost for Boiler No.5. It should be emphasized that the assumption made was only to approximate the blowdown cost in the absence of a better solution. However, the heat waste of blowdown cost, of No. 5 Boiler was actually higher than that of No. 6 Boiler. During the experiment, a constant rate of blowdown on No. 6 Boiler on the order of about one per cent was the aim. Notwithstanding


Graph 3 Excess SO_3 in Boiler No. 6
ppm Excess Sulfite as SO_3
30
26
22
18
14
10
Excess SO_3 in Boiler No. 6
Pounds Nalco "10" Added
2
1
24
26
28
30
1
3
5
7
9
11
13
15
17
19
March
April 1958

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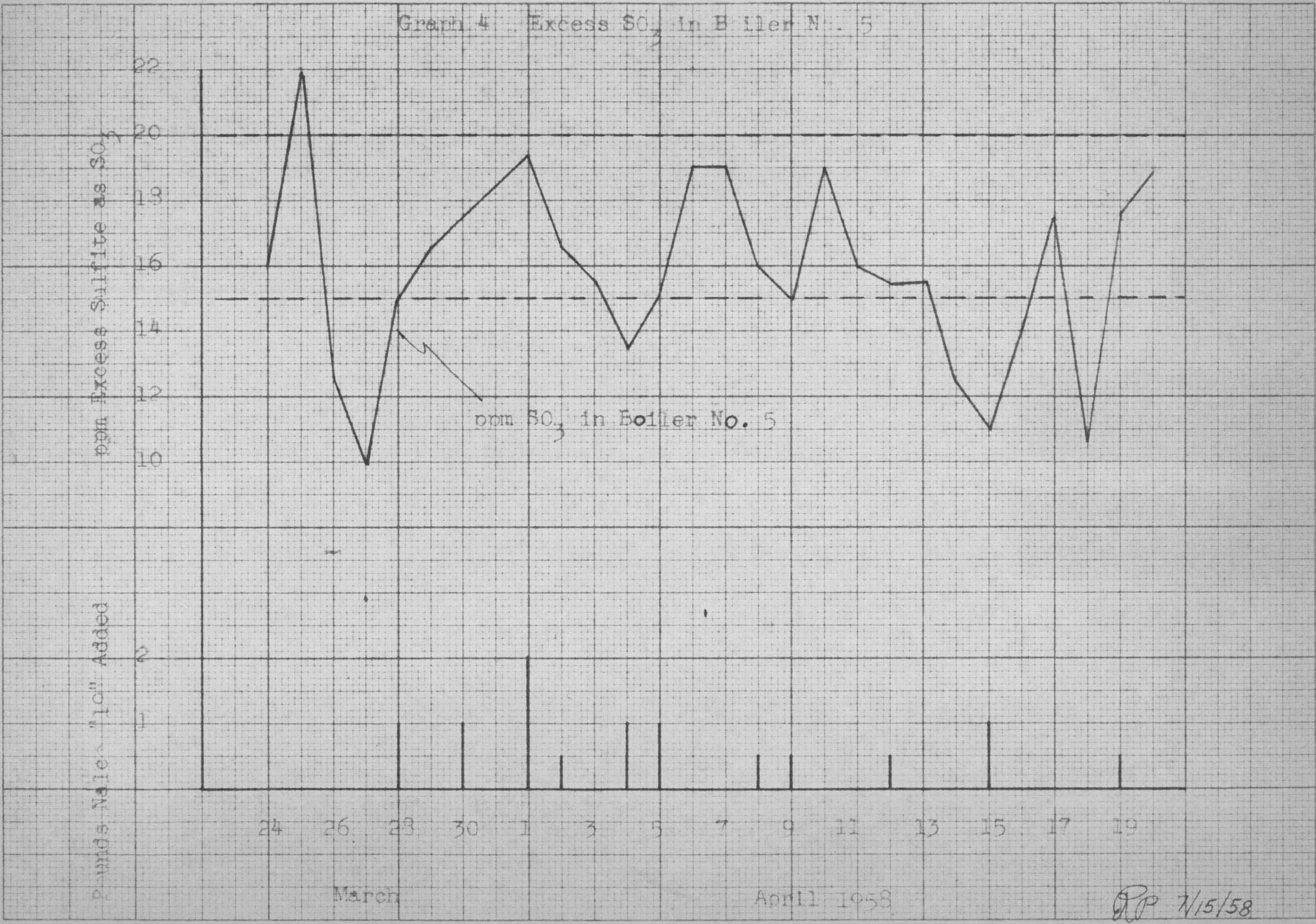

Graph 4 Excess SO_3 in Boiler No. 5

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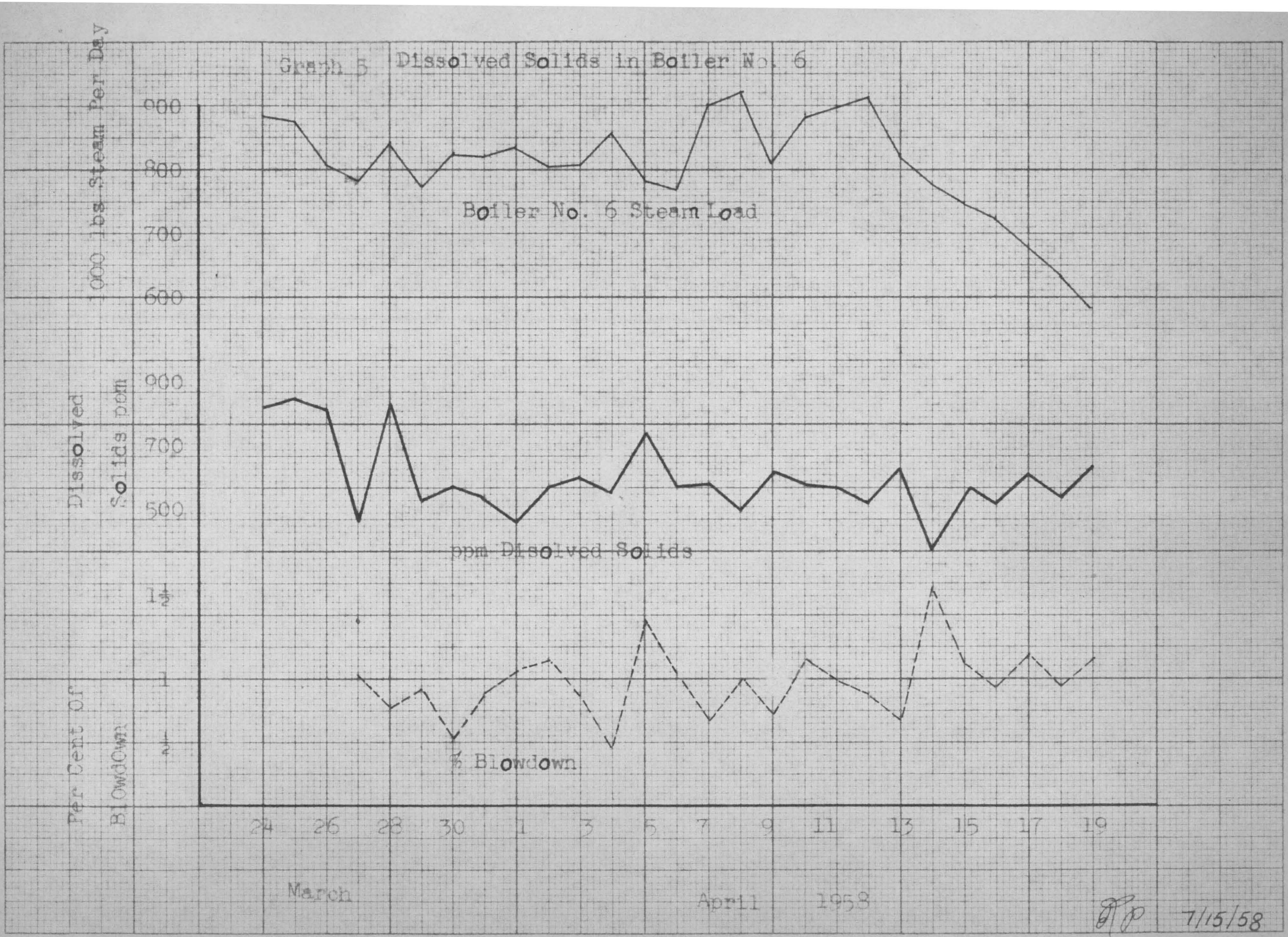

Graph 5 Dissolved Solids in Boiler No. 6

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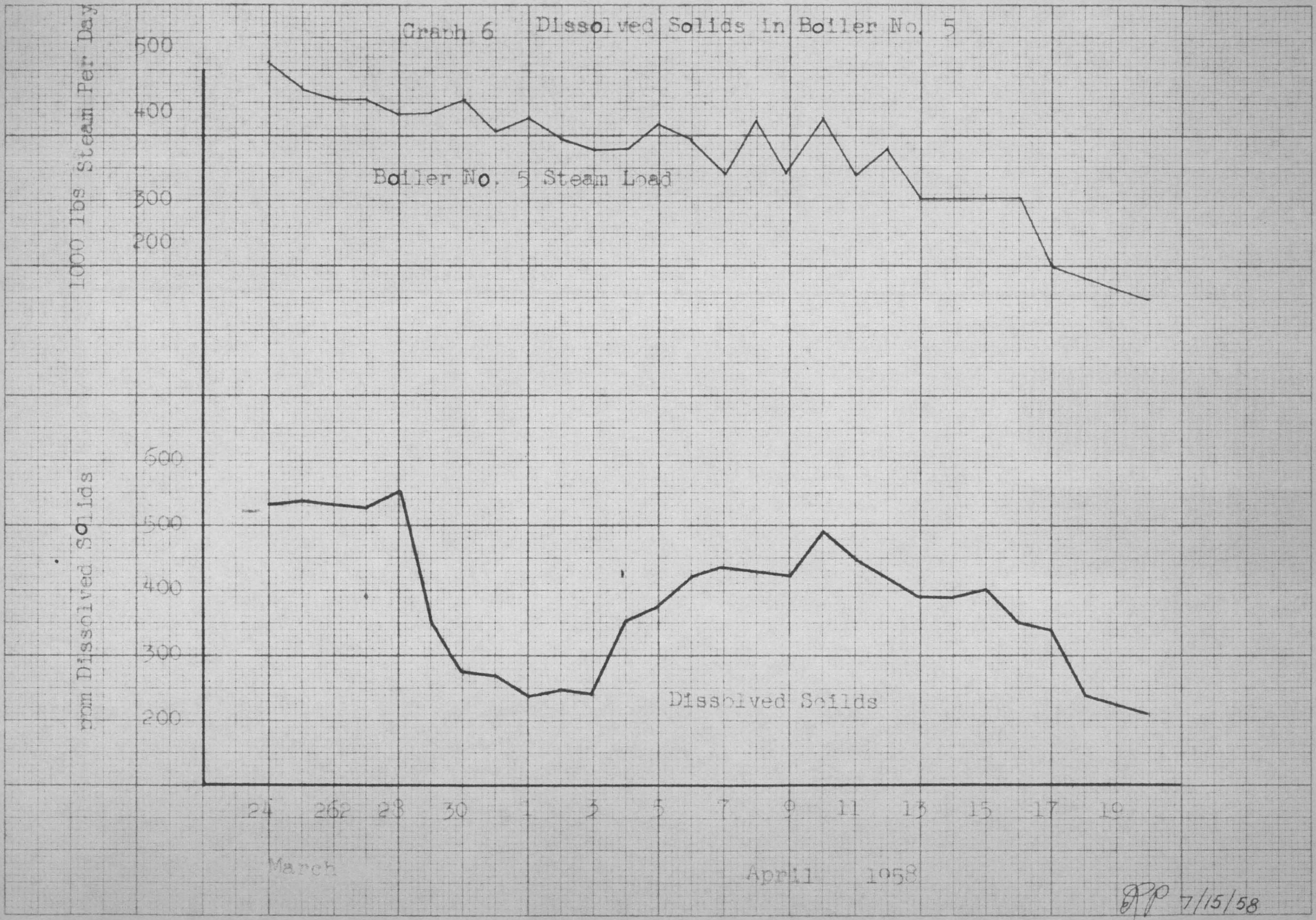
Graph 6 Dissolved Solids in Boiler No. 5

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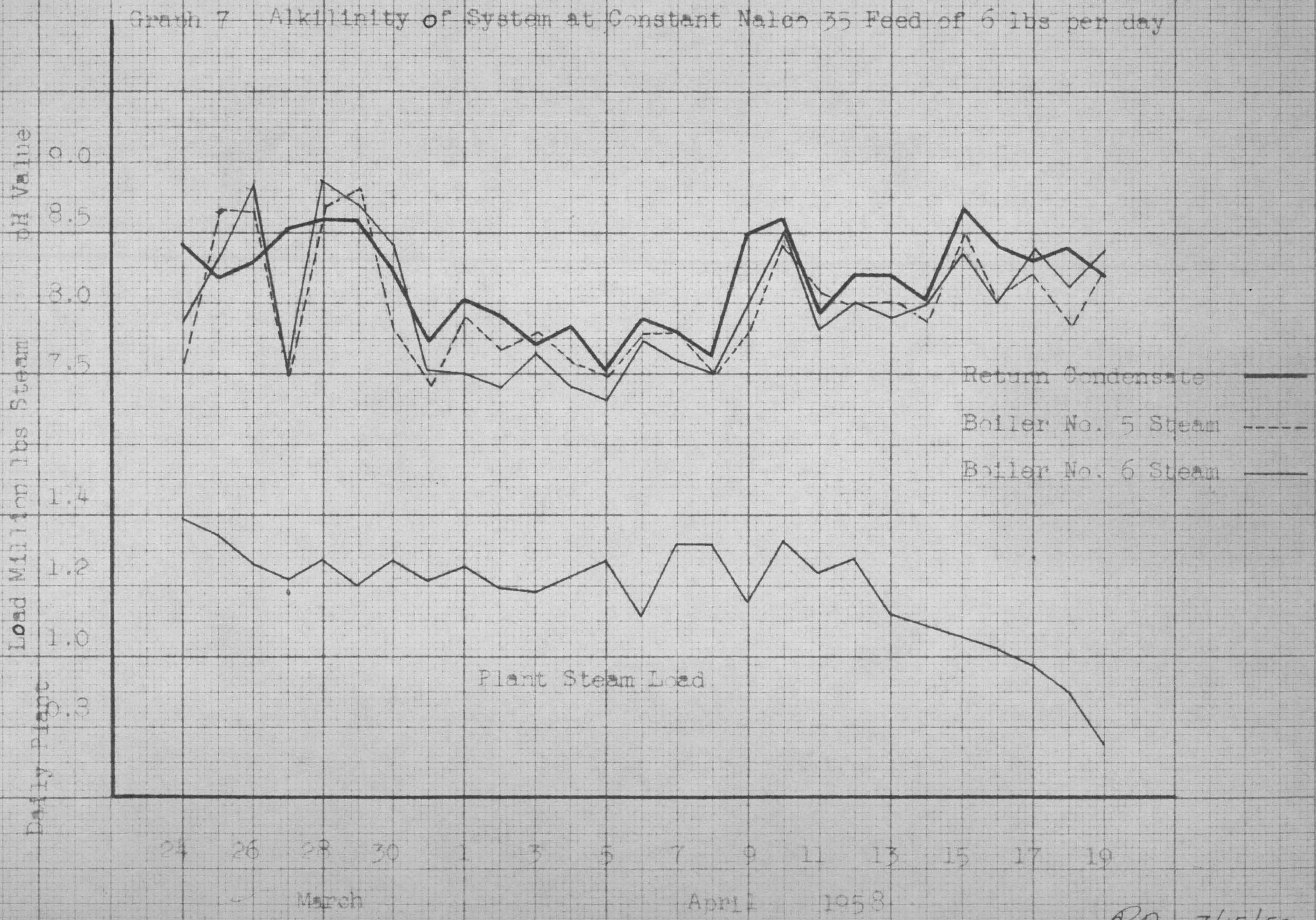
the fact that the blowdown rate varied very often, the average rate, over the whole testing period, would be representative. The recommended range of dissolved solids for both No. 5 and No. 6 was from 850 to 1,000 ppm.

The factor of primary importance to be considered with regards to the feed rate of Nalco 35, Morpholine Amines was the carbon dioxide content in the steam and return condensate. The established method at the V.P.I. Power Plant was to feed six pounds of the amines everyday, independent of the variation of carbon dioxide content in the system.

From the curves plotted, graph 7, it was found that a constant feed of six pounds of amines could not insure, at all times, the sufficiently high pH value for maximum protection against corrosion in the system, since the optimum pH value was 8.50. Only when the total plant steam load decreased to around one million pounds per day could the pH value approach the desired value. The present method of constant daily feed of six pounds of the neutralizing amines, Nalco 35, was actually experimental in nature, since the National Aluminate Company, the feedwater consultant of the V.P.I. Power Plant, did not specify the daily required feed quantity. They did, however, state that the pH value of the system should be maintained around 8.5 to insure maximum protection against corrosion.

The mechanical degasifier(see fig. 5) was found to be



Graph 7 Alkilinity of System at Constant Nalco 35 Feed of 6 lbs per day

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FIG. 5. THE MECHANICAL DEGASIFIER

operated inefficiently during the testing period. From the curve plotted, graph 8, it was observed that the average carbon dioxide in the degasifier effluent was 9 ppm as CO_2, which was 4 ppm higher than the designed value of 5 ppm. The carbon dioxide remaining, after the degasifier had to be absorbed by the anion exchanger, thus decreasing the capacity of the anion unit. As a consequence, the capacity of the anion exchanger would be exhausted more rapidly and the regeneration by means of NaOH was needed. If the carbon dioxide of the degasifier effluent could be reduced to the designed value by creating more effective surface contact between the ascending air and the descending water, the yearly estimated saving on regeneration could be $95.50 (see Appendix C).

The cost of one thousand gallons of New River water treated during the testing period was $1.33. In the year of 1938, Blackman found out in his thesis the cost of feed-water treatment in the V.P.I. Power Plant was $0.288. It is rather difficult to compare today's cost of water treatment with that of twenty years ago of the V.P.I. Power Plant, without all the governing information and plant details. It is interesting to note that the interest plus depreciation today is 473% higher than that of twenty years ago, which reflects the initial investment is much higher in present power plants. (see Review of Literature)

Graph 8 Carbon Dioxide Content in Degasifier Effluent

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The question of whether it is economically justified to spend $1.33 for every thousand gallons of water treated cannot be readily answered. Like buying the automobile or fire insurance, the present extensive program in feedwater treatment at the V.P.I. Power Plant is more of a preventive measure.

Any attempt to compare the cost of feedwater treatment at the V.P.I. Power Plant with other power plants could be misleading and fruitless. Should comparison be made between the V.P.I. Power Plant and another power plant, for instance the Mildland Plant of the Dow Chemical Company (see Review of Literature), the available equivalent base is the cost of regenerant per thousand gallons of water treated. It is noted from the Summary of Costs in this thesis that only 6.27% of the total cost was chargeable to regenerant at the V.P.I. Power Plant, or 8.34 cents per thousand gallons of water demineralized. The cost of regenerant at the Mildland Plant was 6.9 cents per thousand gallons of water demineralized.

Assuming the feedwater treating system of the Mildland Plant of the Dow Chemical Company was operating properly during the month of November, 1951, and the cost spent on regenerants was economically justified, from the previous cost comparison (6.90 cents versus 8.34 cents), it can be safely deducted that the part of the cost of water treatment on regenerants of the V.P.I. Power Plant was within reasonable limits during the test.

RECOMMENDATION

(1) It is recommended the mechanical degasifier be overhauled with respect to its internal structures in order to obtain a more effective surface contact between the ascending air and the descending water. The value of carbon dioxide in the effluent of the degasifier should be reduced from an average of 9 ppm to 5 ppm. Attention should be directed to the volume of air blowing into the degasifier. It is suggested that a temperature correction chart taken from the manufacturer's catalogue be placed near the blower, so that the operator can adjust the rate of air flow easily and accordingly.

(2) For No. 6 Boiler, one per cent of continuous blowdown at the present would be the maximum. It is recommended further studies be made to determine the optimum blowdown rate to yield the dissolved solids between 850 to 1,000 ppm in the boiler water.

(3) For No. 5 Boiler, a thorough inspection is strongly advocated to find out the leaks and to repair them. It is also recommended that the steam flow meter be put in proper operating condition.

(4) For future investigation, the automatic "Feed Proportional to Demand" methods in handling all the chemicals for internal water treatment are recommended. This is quite important in the long run, for it will

not only reduce excessive chemical cost, but will also produce a better and uniform quality of treated water.

(5) The practice of feeding six pounds of Nalco 35, morpholine amines, constantly regardless of the load condition and carbon dioxide content in the system should be discarded. It is suggested that the operator be instructed to read the steam loads and the pH values in the system first before feeding the Nalco 35.

In the absence of more accurate method, it is recommended one million pounds of total plant steam output per day be taken as the optimum load for six pounds of Nalco 35 per day. In this way, at least tentatively, a direct proportionality can be correlated to other loads. In other words, it is believed that 0.006 lb of Nalco 35 per thousand pounds of steam is required to maintain the pH value of 8.50 in the main condensate return line and the steams of both No. 5 and No. 6 Boiler. Further investigation on this matter is warranted.

(6) With the new No. 7 Boiler under construction at the V.P.I. Power Plant, and more campus expansions in the offing, the installation of an automatic pH recorder and a continuous conductivity recorder is recommended and believed to be economically justified.

(7) It is recommended studies be made to compare the use of filming amines with the newtralizing amines, Nalco 35. In addition to CO_2 corrosion, the filming amines are also resistant to oxygen attact. In general, in systems of higher carbon dioxide content, the filming amines are more economical, yet less difficult for feed rate control.

V. CONCLUSIONS

(1) The average cost of feedwater treatment at the V.P.I. Power Plant during the testing period, from March 25 to April 20, 1958, was $1.33 per thousand gallons of New River Water demineralized.

(2) The quantity of Morpholine Amines, Nalco 35 used was insufficient to provide enough chemical concentration to maintain a pH value of 8.50 at all times in the main condensate return line and steams of both Boiler No. 5 and Boiler No. 6. Therefore, no maximum protection against corrosion in the feedwater system at the V.P.I. Power Plant could be insured.

(3) The cost on NaOH for the anion exchanger regeneration could be reduced by improving the performance of the mechanical degasifier, since the carbon dioxide content in the degasifier effluent was higher than five ppm as CO_2, the design value.

(4) The cost of blowdown could be reduced, since the dissolved solids in both No. 5 and No. 6 Boiler were much lower than 850 ppm, the recommended value.

VI. SUMMARY

This thesis is the first of its kind in which a study of the economical aspects of the feedwater treating system at the V.P.I. Power Plant has been made. In carrying out the investigation, two testing periods were conducted, each lasting for four weeks. The first period was preliminary in nature and proved to be of absolute necessity, in order to facilitate the effectiveness, accuracy, indicativeness and continuity of the second period.

During the experiment, various difficulties were encountered with respects to testing equipments, experimental techniques, sampling, chemical supplies and the blowdown quantity. These problems were solved with the best possible means and tools available.

The experimental results revealed that the cost on NaOH could be reduced by improving the performance of the mechanical degasifier; the cost on Nalco 35 was insufficient to insure the maximum protection against corrosion; the cost of blowdown was too high; and the cost on Nalco 728 could be reduced.

Based on the experimental results and plan for future expansion of plant capacity, several recommendations are made. It is recommended that degasifier be overhauled; the optimum blowdown quantity be studied; the No. 5 Boiler be inspected for leaks; a better method found for feeding Nalco

35; the "Feed Proportional to Demand" method be explored for all chemical feed; and that an automatic pH meter and a continuous conductivity meter be installed for the main return condensate line.

The average cost of feedwater treatment at the V.P.I. Power Plant from March 25 to April 20, 1958, was $1.33 per thousand gallons of New River water demineralized.

VIII. ACKNOWLEDGEMENTS

It is the author's very sincere wish to express his gratitude to the following persons in the writing of this thesis:

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Thanks are due also to the author's colleagues, B. Bugar and F. Cheng, for their cooperation in jointly conducting the investigation.

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X APPENDICES

APPENDIX A

The Present V.P.I. Power Plant Data

1. Number of boilers:

No.	Type	Pressure	Rated Capacity
1	1 Drum W.T.	165 p.s.i.	250 h.p.
2	1 Drum W.T.	165 p.s.i.	250 h.p.
3	1 Drum W.T.	165 p.s.i.	350 h.p.
4	1 Drum W.T.	165 p.s.i.	350 h.p.
5	3 Drum W.T.	250 p.s.i.	500 h.p.
6	2 Drum W.T.	250 p.s.i.	60,000 lbs/hr

2. Hours daily at full load		Variable
3. Days operated per week		7
4. Number of boilers used at one time		Summer 1, Winter, possibly 5
5. Blowdown	a/Continuous	Boilers 5 and 6 only
	b/Intermittent	One per day
6. Fuel	a/Daily consumption	30 to 100 tons
	b/Heating value, as received	13,500 Btu per lb
7. Average daily evaporation		
	a/Winter	85,000 lbs per hour
	b/Summer	25,000 lbs per hour
8. Percent of make-up		15 to 30%
9. Source of raw water		New River Water Authority
10. Feedwater heating		
	a/Temperature maintained at	230° F
	b/Back pressure maintained from	3 to 6½ p.s.i.

11. Use of steam....................Heat, power and process

12. Feedwater conditioning

a/External ....Demineralization
b/Internal..........Nalco 728
Nalco 75
Nalco 35
NaOH

APPENDIX B

Calibration of Water Meters(see Fig.3)

To calibrate the water meters on both the cation and the anion exchangers, the inside diameter and the initial water level of the wooden tank and the initial readings on the meters were recorded. A definite quantity of water was then pumped through the demineralizing system and the final water level of the wooden tank was read. The final readings on the meters were also recorded. The actual quantity of water pumped through the system and the correction factors of both the meters were calculated as follows:

$$Q_a = \frac{\frac{1}{4}\ 3.14\ d^2\ (h_i - h_f)}{K}$$

Where:

Q_a : The actual quantity of water pumped, in gallons

d : The inside diameter of the wooden tank, in inches

h_i : The initial water level of the tank in inches

h_f : The final water level of the wooden storage tank, in inches

K : The conversion factor, 231 in^3/gallon

Therefore,

$$Q_a = \frac{\frac{1}{4}\ 3.14(72.375)^2 \text{in}^2\ (104\,3/4 - 6\,3/4)\ \text{in}}{231\ \text{in}^3/\text{gallon}}, \quad \text{or } 1{,}742 \text{ gallons}$$

Meter reading for cation exchanger was 1,683 gallons, therefore the correction factor of cation meter:

(1,742/1,683), or +3.5%

Meter reading for anion exchanger was 1,794 gallons, therefore the correction factor of anion meter:

(1,742/1,794), or -3%

APPENDIX C

ESTIMATED SAVING BY READJUSTMENT OF THE MECHANICAL DEGASIFIER

The designed CO_2 content of the degasifier effluent was 5 ppm as CO_2.

The average CO_2 content of the degasifier effluent was 9 ppm as CO_2 during the testing period.

Therefore, the CO_2 content should be reduced by 4 ppm as CO_2.

To express the CO_2 reduction as ppm $CaCO_3$, the chemical factor was used:

$$\text{ppm } CO_2 \frac{(\text{Molecular Weight } CaCO_3)}{(\text{Molecular Weight } CO_2)}, \text{ or } 4\frac{(100)}{(44)}, \text{ or } 9.1 \text{ ppm } CaCO_3$$

From the performance of the anion unit:

375 lbs HaOH regenerant per regeneration required

825 kilograins $CaCO_3$ per regeneration allowable

Therefore,

$$\frac{375}{825}(10)^{-3} \frac{\text{lbs. NaOH}}{\text{grain } CaCO_3} \text{ needed, or } 0.454(10)^{-3} \frac{\text{lbs.NaOH}}{\text{grain } CaCO_3}$$

Since there are 17.1 ppm in 1 grain/gallon, 9.1 ppm $CaCO_3$ would be equivalent to

$$\frac{9.10}{17.10} \text{ grains } CaCO_3 \text{ per gallon.}$$

The cost of NaOH regenerant at 18.18 dollars per 400 lbs, or

$$\frac{0.0453 \text{ dollar}}{\text{lb. NaOH}}$$

The saving would be:

$$\frac{9.10}{17.10} \frac{\text{grains } CaCO_3}{\text{gallon}} (0.0453 \frac{\text{dollars}}{\text{lb. NaOH}})(0.454.10^{-3}) \frac{\text{lbs NaOH}}{\text{grain } CaCO_3}$$

or $\frac{0.011}{1,000}$ dollars per gallon

or 0.011 dollars per thousand gallon

The total gallons of water treated for the period: 664,567

The saving for the period: (664,567 gallons)

(0.011 dollars per thousand gallon)

or, 7.35 dollars per period

The saving per year if at the same rate:

7.35 $/period(period/4 weeks)(52 weeks/year), or $\underline{\underline{\text{\$95.50/year}}}$

AN ECONOMIC STUDY OF THE PRESENT FEEDWATER TREATMENT SYSTEM AT THE V.P.I. POWER PLANT

by

ROBERT H. C. PAI

ABSTRACT

The purpose of this thesis was to study the economical aspects of the present boiler feedwater treating system at the VPI Power Plant. In carrying out the investigation, two testing periods were conducted, each lasting for four weeks and the first period was preliminary in nature.

The experimental results revealed that the cost on caustic soda(NaOH) could be reduced by improving the performance of the mechanical degasifier; the cost on neutralizing amines (Nalco 35) was insufficient to insure maximium protection against corrosion; the cost of blowdown was too high; and the cost on sodium orthophosphate and ligin derivatives (Nalco 728) could be reduced.

Recommendations are made based on the test results and plan for future expansion of plant capacity. It is recommended that the degasifier be overhauled; the optimum blowdown quantity be studied; the Boiler No. 5 be inspected for leaks; a better method found for feeding Nalco 35; and the installation of an automatic pH meter and a continous conductivity recorder for the main condensate return line.

The average cost for feedwater treatment at the VPI Power Plant from March 25 to April 20, 1958, was $ 1.334 per thousand gallons of New River water demineralized.