

A HIGH PRESSURE BOILER STUDY ON THE  
USE OF ORGANIC CHEMICALS AS SLUDGE  
CONDITIONERS AND SCALE PREVENTATIVES

Thesis for the Degree of M. S.

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This is to certify that the  
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A High Pressure Boiler Study on the Use of Organic Chemicals  
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A HIGH PRESSURE BOILER STUDY  
ON THE USE OF ORGANIC CHEMICALS  
AS SLUDGE CONDITIONERS AND  
SCALE PREVENTATIVES

By

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THESIS /



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## INTRODUCTION

With the trend of the present day boiler being toward higher pressures and the increasing awareness of the problems of scaling and boiler sludge accompanying this trend, it becomes important to evaluate in the laboratory the conditions and factors which tend to eliminate scale, foaming, and metal failure. With this thought in mind, work was begun in 1950 to design a boiler which would enable one to study these effects over the complete range of the water-steam system.

With the trend toward higher pressures the control of internal treatment becomes more critical, and the amount of total solids and scale which can be tolerated without operational difficulties becomes less. Internal treatment has the advantage of eliminating the precipitation of scale forming salts in the feed lines and allows the operator by proper testing to know at all times the conditions in his unit. With internal treatment allowance can be made for a chemical residual as a safety factor so that protection can be maintained against unforeseen variation in operating conditions. The proper conditioning of the sludge is critical because of the intricate design of the boiler unit. Boiler water conditioning which is acceptable in low pressure operation is often intolerable in operation at higher pressures.

Soda ash was the primary conditioning agent used for quite a number of years in the low pressure field even though it was known that soda ash decomposed under hydrolytic action to caustic

soda and carbon dioxide. This decomposition was known to accelerate to elevated pressures. Richter (19) states that the anhydrous carbon dioxide formed adheres to the film of sludge formed and causes corrosion of boiler walls even though no air or oxygen is present. He further states that the tiny bubbles of carbon dioxide which adhere to the boiler walls are protected from being washed away through water circulation because of the protective film of sludge present. Today, carbon dioxide in condensate return lines is known to be the basic cause of corrosion in the return lines. In addition to the adverse action of the carbon dioxide, the caustic soda formed by the use of soda ash increases the possibility of caustic embrittlement of the boiler proper as well as foaming tendencies because of the increase of boiler water alkalinity.

Today, it has become an accepted practice to use sodium phosphates in conjunction with soda ash as a means of conditioning boiler water by internal treatment in the low pressure field operations. In the high pressure field the present day practice has been in the use of phosphates, either alone or in conjunction with caustic, natural organics, sulfites, or some suitable combination of these materials. The phosphate sludge formed from these reagents is more fluid in nature than the carbonate sludge formed with the use of soda ash alone. Since the phosphate conditioner will not decompose as does soda ash, it is much easier to maintain the excess required for satisfactory boiler operation. The boiler water alkalinity can more easily be controlled since phosphates

contribute to the alkalinity depending on the type used. There is also less tendency for a residual hardness to remain after boiler treatment with phosphates since the solubility of the phosphate precipitate formed is less than that of the carbonate precipitate obtained by the use of soda ash only.

The ability to control the alkalinity and phosphate excess by correct addition of caustic and phosphates will prevent the precipitation of magnesium as the phosphate. The magnesium is removed in the more desirable hydroxide form. The correct addition of caustic and phosphates causes the calcium hardness to precipitate as calcium hydroxyapatite,  $\text{Ca}_3(\text{PO}_4)_2 \cdot \text{Ca}(\text{OH})_2$ . This type of precipitate has much better sludge characteristics than the calcium carbonate formed by the use of soda ash only, or the tricalcium phosphate,  $\text{Ca}_3(\text{PO}_4)_2$  obtained by use of excess phosphate.

Even with the sludge formed by phosphate treatment being more fluid than that formed by purely a soda treatment, it has become a major problem to condition this sludge so that stickiness and lack of fluidity are overcome, thereby facilitating periodic or continuous sludge blowdown.

With the present day tendency toward high pressure or high heat transfer at low pressure, it has become a critical function to condition the sludge with the use of natural or modified natural organic materials. The generally accepted practice has been to condition water prior to use in the boiler when either a high percentage of low-hardness water or raw high-hardness water is required.

The present work shows that by proper addition of inorganic and synthetic organic materials, the sludge formed will be of a properly conditioned nature to prevent sticking to and baking on the heating surfaces. As a result of this work the range of boiler operations employed may be extended without the necessity of external water treatment. This results in an increase of total dissolved solids that can be carried in boiler operation with an accompanying decrease in the cost of heat loss by blowdown.

For thirty years claims have been made about the ability of certain natural organic colloidal materials to condition boiler sludge and thus prevent scaling and maintain a fluid sludge. A British patent (5) claims this for natural resins as such or with added tannins. The French navy carried out tests with starch extracted from linseed as a means of overcoming the salt content of sea water (7). Linseed as a source of colloidal action was reported in the United States as early as 1927 (1).

The railroad industry in the United States as early as 1929 used tannins in conjunction with water softeners compounded into balls which were then dissolved in raw feed water (17). Powell (18) in an article on boiler feed conditioning states that early engineers in their desire to correct bad feed water conditions went to the extreme of using dead animals as a scale prevention method. The United States Navy still advocates the use of starch as a conditioning agent in ship boilers (6).

The present day colloidal conditioning agent has been quite clearly defined as to its requirements (3, 10). Among these



requirements are that the colloidal particles have the same electrical charge so as to repel each other and attract oppositely charged particles of precipitate. Thus are formed complex flocs which are able to retain a high proportion of water. The colloidal charged particle is always complex and capable of great adsorptive action. Whether cationic or anionic it must be highly dispersible in water and have the ability to react with calcium or magnesium salts.

With respect to extreme claims for certain organic materials, Bassett (4) states that their action may be the result of being strongly alkaline instead of colloidal effect. This may indicate that several claims may have been the result of alkalinity control in conjunction with the use of phosphates. Thus the magnesium would precipitate as the hydroxide and the calcium as the hydroxyapatite with its better sludge properties.

At the present time there are only a few tannins which can be considered good in their effect as sludge conditioners. With the increased demand and the decrease in availability, high prices have resulted. This problem of price, availability, and acceptability has caused the need for extensive research for new, better, and cheaper boiler sludge conditioners.

One reference (16) was found as to ability of certain tannins and seaweed extracts to prevent scale. However, no data was given as to feed compositions, the boiler concentrations and the effect on the sludge. Substantial scale prevention was reported although the quantity of organic conditioner used resulted in an increase

of 50 percent by weight of the suspended solids in the boiler water. This makes their use prohibitive.

The quality of some of the present day sludge conditioners is not consistant for all types of boiler operations. This establishes an obvious need for new and snythetic products which can be subjected to product quality control and which give better and-or more consistant performance.

Various experimental boilers are now or have been in operation (9, 12, 13, 14, 15, 20). Most of these are designed as single element test units. Thus no check can be made on a specific test run to verify results or heat rates with another surface from that run. Several boilers are designed exclusively as test units for foaming, scaling, or metal failure only; all of these designs lack interchangeability.

This prompted the design of a more ideal experimental boiler in which duplicate test results could be obtained from one test run. This more ideal boiler lends itself well to interchangeability when problems of scaling, foaming, and metal failure are studied.

The design of this more ideal experimental boiler was begun in 1950. The boiler has three heating elements. Removable tubes are provided which can be operated concurrently, but each from an individual heat source. This has the advantage that in case of identical heat input, scale can be removed from the surfaces to show, within an acceptable percentage of variation, nearly equal scale deposit. The removable boiler tubes possess a further ad-

vantage in that they can easily be photographed, descaled, and saved for further reference. They can be discarded and replaced when necessary.

It is possible to make an experimental foaming boiler by adjustment of a sleeve in the boiler head which cuts down the water-steam interfacial surface area. A steam separator can be lowered in such a manner that the foam will be carried over with the steam and the degree of foaming can be tested with a conductivity cell.

Heat input to the heating elements can be made adjustable; more than one heat input rate is available for a given test run. The effect of heat input at three different rates can be tested simultaneously on one run for a given boiler water condition. The design was made such that it is possible to heat by induction as well as by resistance elements. It is thus possible to parallel actual heating conditions, for example, in a cyclone furnace by operating one element on induction heating to give a transfer rate of about 200,000 BTU per hour per square foot. The other two elements may be operated by the resistance wire method to give 20,000 BTU per hour per square foot on one and 40,000 BTU per hour per square foot on the other. Thus any desired combination of heat inputs to the elements can be attained merely by variation of the type of element or heating source used.

A boiler size was selected which allowed a test run to be completed in a reasonable time and yet approach actual industrial

boiler conditions. The design was made to include automatic level control, provisions for boiler water blowdown, and a variable heat input rate within limits of industrial practices.

A synthetic acrylic polymer (8) was tested in this experiment as a scale preventative and a sludge conditioner. This substance being water soluble was of such a nature that definite quality control could be maintained. This insured duplication of results with given sludges.

The method of determining a sludge condition was not limited as to the stickiness tendency of the sludge on standing for a period of time in a glass bottle. This method of sludge evaluation has the disadvantage in that it does not show the complete effect the conditioner may have had in the boiler.

The work reported here was prompted by a definite need for a dependable synthetic-organic-sludge conditioner. A rather comprehensive literature search indicated the need for data on the correlation of scale deposit with respect to heating surface area and heat input. There existed a definite need for the establishment of a standard by which sludge conditioners and scale preventative materials could be compared.

## EQUIPMENT AND PROCEDURES

For the purpose of clarity, the work reported in this presentation is broken down into the following sections: Boiler, Boiler Auxilliaries, Overall Layout, Operation Procedure, Test Procedures, and Results.

### BOILER

The boiler proper, a special design by Dr. M. F. Obrecht and The Wickes Boiler Company was built by the Wickes Boiler Company of Saginaw, Michigan. The major pieces of the boiler are made of SA-105 Gr.-1 forged steel (2). The maximum steam working pressure was 3100 pounds per square inch. A design safety factor of five was used. The boiler was issued the Serial Number 4728 and tested with a hydrostatic head of 4650 pounds per square inch by the Hartford Steam Boiler Inspection and Insurance Company of Hartford, Connecticut (11). The liquid capacity of the boiler was approximately 1.1 gallons.

Three radially located arms extend out and upward (Figures \_\_, 3, 4, 5) from the boiler, the purpose being, that for a given test run, results had three checks instead of only one on the amount of scale on boiler tubes. This arrangement allowed three heating elements to be inserted, one in each boiler tube, each having a heat output of approximately 3000 watts. The three elements also afforded the possibility of comparison of heat variation, either by cutting out a heating element completely or inserting an element of lower heat output than the other two.

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A blowdown line, incorporating a 0.020 inch orifice enabled a periodic controlled rate check or continuous sampling of boiler water by running sample through a cooling coil and Solu-Bridge conductivity cell to drain. A needle valve in the blowdown line along with the orifice further insured controlled blowdown rate.

Attached to the side of the boiler, a liquid level control cell, which by means of three immersed electrodes connected to a master panel board, automatically controlled the water level in the boiler.

#### BOILER AUXILIARIES

The water level control was such that when water reached the top level the pump cut out and the heating elements in the boiler tubes were energized. As boiling and evaporation proceeded, the pump resumed when the water dropped below the center electrode and continued until the water level was again brought to the top electrode. Heat was automatically stopped if the water level at any time dropped below the bottom electrode, thus insuring that at all times, the boiler tubes were under water surface while being heated. The heat then came on again when the pump had filled the boiler to the top electrode level.

Steam from the boiler was released through a 0.070 inch jet orifice having a dead weight placed on it. This method allowed continuous steam release at a fairly constant pressure by mere variation of the dead weight. The jet orifice was in a vertical position and the perfectly seated dead weight was machined to give



a low center of gravity to insure against dislocation when placed on the jet. The housing on the relief system consisted of a four inch cast iron section vented to the atmosphere and also having a drain for condensate to the conductivity cell.

A safety relief valve was incorporated in the line from the boiler to the dead weight valve, thus insuring pressure release should the jet orifice to the dead weight become plugged.

Three gauges in series, one reading from 0-1000, another 0-2000, and the third from 0-5000 pounds per square inch, having shut-off valves in between, gave a constant reading of pressure within range of the gauges. The needle valve shut-offs allowed shutting off a gauge at its maximum pressure and taking readings from the next gauge in series.

In addition to the pressure gauges, the panel control board had a master on-off switch for the pump and heating elements. The elements and pump were wired (Figure 2) for either manual or automatic control. Both the pump and heating elements had master switches ahead of the panel board. Following the panel control board, each of the three heating elements had a switch and fuse box. This provided for operation of the elements separately, intermittently, or continuously.

The feed drum, fabricated from sheet copper, had a capacity of 245 pounds of water and was calibrated along its sight gauge such that each calibration was the equivalent of approximately one boiler concentration. A centrifugal circulation pump as well

as a mounted "lightnin" propellor type agitator insured complete mixing of the feed at all times.

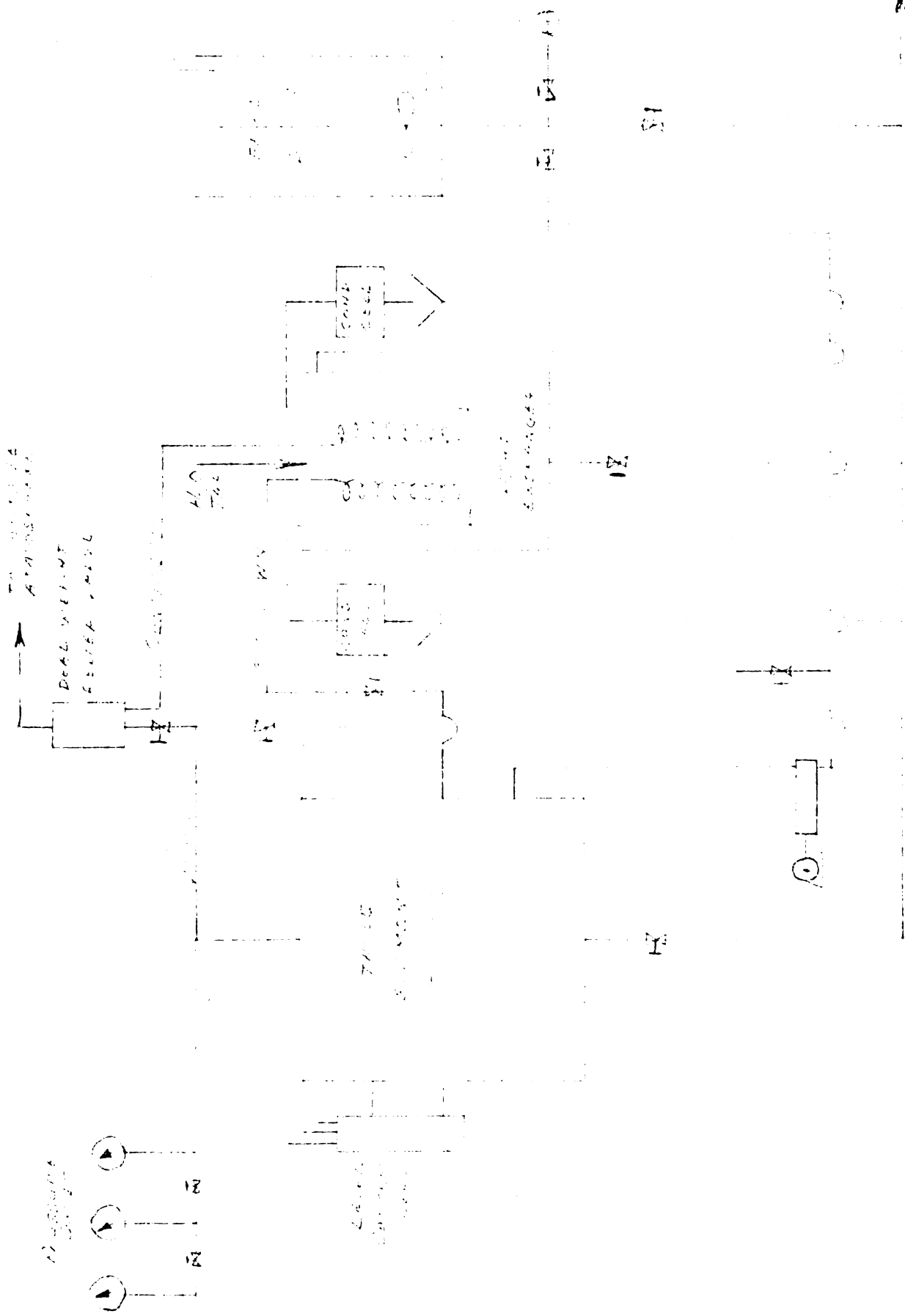
A Nelson Chemical pump connected by means of 1/4" stainless steel piping supplied feed water from the supply tank to the boiler. The pump had a 4000 pounds per square inch positive displacement, being single acting with a bore of 1/2 inch and a variable stroke, 2-1/2 inches being maximum. In this manner, feed could be pumped at a maximum rate of approximately 60 pounds per hour.

A coil serving the dual purpose of the condenser and a cooling coil was made of six feet of 1/8" copper tubing coiled into a helix of 4 inch diameter. Another like coil was connected to the blow-down line. Both coils were immersed in a tank through which ran cool tap water. The exit of each of the coils was connected to separate Solu-Bridge conductivity cells and then to the drain. This system gave continuous checks on conductivity and evidence of steam carryover if any.

All piping on the pressure side of the boiler was of high pressure quality. Gauge and blowdown lines were 1/4 inch double extra heavy. The line going to the steam release system was 1/2" double extra heavy. All fittings as well as piping were designed to withstand 3000 pounds steam working pressure. Boiler gaskets were tongue and groove, stainless steel, concentrically wound with asbestos. The flange head of the boiler was provided with eight bolts. Each of the head flanges on the boiler arms were kept in place with four bolts.

## OVERALL LAYOUT

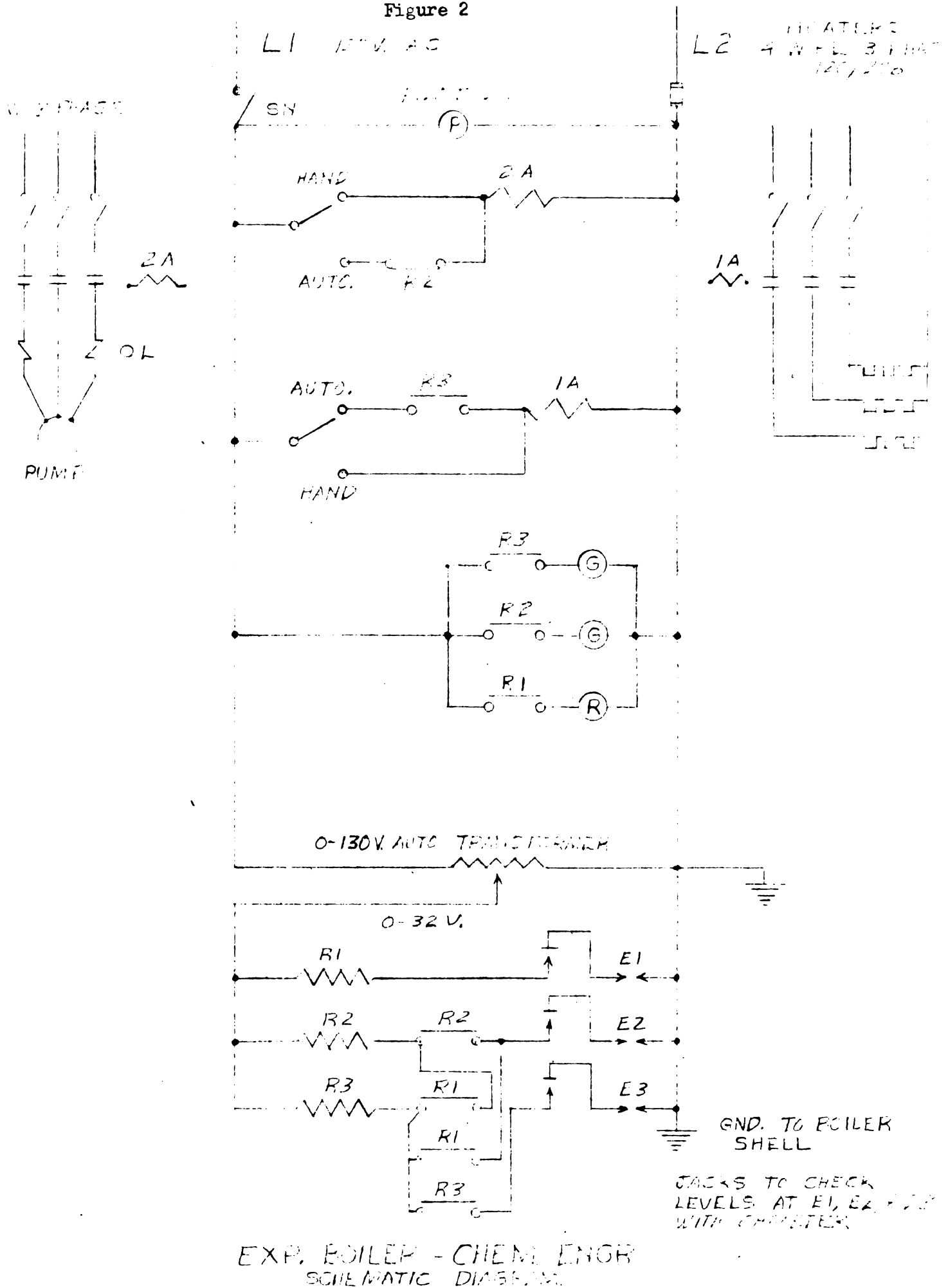
The general overall layout can best be described with a schematic drawing and pictures Figures 1, 5, and 6. The operation and purpose of the sections of this drawing is given under description of boiler and boiler auxiliaries.



SCHEMATIC DIAGRAM OF EXPERIMENTAL ROLL LAYOUT

Figure 1

Figure 2



# CROSS SECTION OF 3100 P.S.I. EXPERIMENTAL BOILER

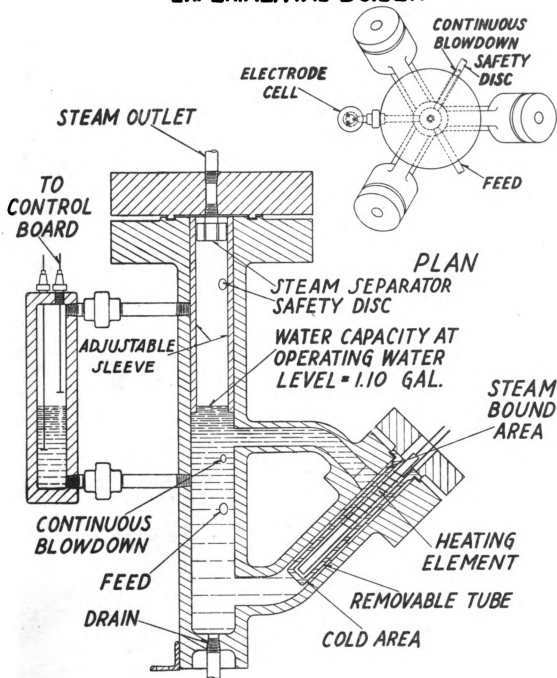


Figure 3

Figure 1



Figure 4



Figure 5



Figure 6

## OPERATION PROCEDURE

In all cases, 100% make-up feed was used. The feed was made by filling the calibrated feed tank with 245 pounds of tap water and increasing the calcium and magnesium content by the addition of  $\text{CaCl}_2$  and  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$  to insure heavy scaling tendencies of the water. The amount of these chemicals added approximately doubled the calcium and magnesium content of the tap water. Further addition of disodium phosphate was made in sufficient quantity to provide an excess of 30 to 50 parts per million in the boiler water after ten concentrations, thus paralleling actual industrial operation. Sodium bicarbonate was added in such amount that the boiler water alkalinity was high enough so that 2P-M was in the vicinity of ten. A typical feed for a blank or control run was as follows:

245# tap water

25.6 gms  $\text{CaCl}_2$

27.9 gms  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$

14.2 gms  $\text{NaHCO}_3$

48.9 gms  $\text{Na}_2\text{HPO}_4$

The excess phosphate was added to insure that all of the calcium precipitated as the hydroxyapatite. The sodium bicarbonate in its added amount insured that the magnesium precipitated as the hydroxide.

On completion of feed make-up, the three boiler tubes were inserted, one into each of the three boiler arms. The head flanges were fitted and bolted into position, and the entire boiler system

closed except for the needle valve leading to the dead weight relief valve. All now ready for operation, the main switches ahead of the panel board were turned on. The panel control switches were thrown to the automatic position and each of the three heating element switches turned on. The pump immediately went into operation until the top electrode level had been reached. The heat turned on automatically, and the boiler pressure rose until steam displacement was permitted by the dead weight relief valve. Periodic recordings were made of the pressure, steam conductivity, and approximate concentration of the boiler water as indicated by displacement of feed from the feed tank.

The feed water was analyzed for P, M, Cl, H,  $\text{PO}_4$ , conductivity, pH, and dissolved solids at least once every run and preferably at the start and midway in the run.

On completion of approximately ten boiler concentrations as indicated by displacement of feed from the feed drum, the boiler system was closed down by shutting off the valve to the relief system, turning off the heat supply, and allowing the pump to remain on automatic control. Leaving the pump on automatic until the boiler was cool insured maintaining the water level in the boiler. Otherwise it was nearly impossible to prevent small leaks of steam throughout the system.

After the boiler had had sufficient time to cool, the boiler water was drained by means of opening the bottom valve on the boiler.

This water was tested in the same manner and for the same data for which the feed water was tested. The boiler tubes were next removed and the scale on each weighed by means of brushing off with a nylon tooth-brush onto a previously weighed paper. The amount of scale in each case was determined by weight differences; the heavy deposit of scale around the steam bound area on the boiler tube was not included in this weight. Figures 7 and 8 are representative of the boiler tubes as withdrawn from the boiler.

For the purposes of comparison and study, the foregoing procedure was duplicated with the addition in varying amounts of organic scale preventatives and sludge conditioners to the feed water make-up and runs made at various pressures.

## DATA AND RESULTS

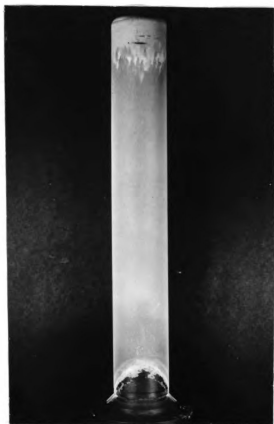


Figure 7

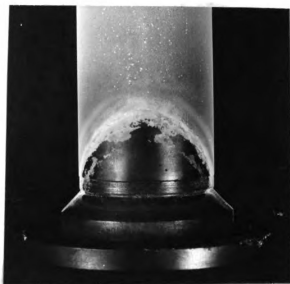


Figure 8



Figure 9

Scale Test Run #12  
Blank Run  
500 PSI



Figure 10

Scale Test Run #13  
0.46 ppm DSC 1005  
500 PSI



Figure 11

Test Run #14  
0.82 ppm DSC 1005  
500 PSI

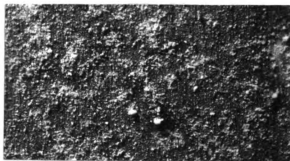


Figure 12

Test Run #16  
1.35 ppm DSC 1005  
500 PSI



Figure 13

Scale Blank Run 30  
550 PSI



Figure 14

Scale Blank Run 38  
550 PSI

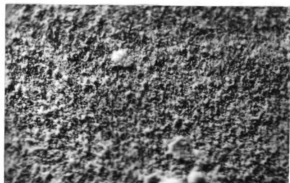


Figure 15

Scale Test Run #31  
0.25 ppm DSC 1005  
550 PSI

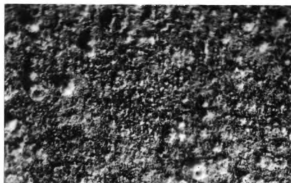


Figure 16

Scale Test Run #32  
0.25 ppm DSC 1005  
550 PSI

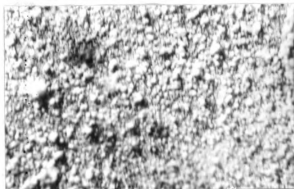


Figure 17

Scale Test Run #34  
0.5 ppm DSC 1005  
550 PSI



Figure 18

Scale Test Run #42  
0.5 ppm DSC 1005  
550 PSI



Figure 19

Scale Test Run #35  
1.0 ppm DSC 1005  
550 PSI



Figure 20

Scale Test Run #36  
1.0 ppm DSC 1005  
550 PSI

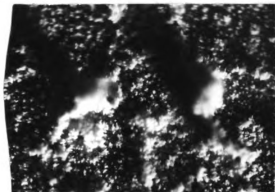


Figure 21

Scale Test Run #19  
7.0 ppm Tannin  
550 PSI

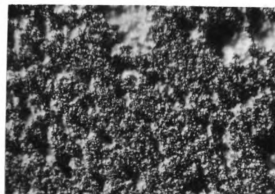


Figure 22

Scale Test Run #20  
7.0 Modified Eltan  
550 PSI

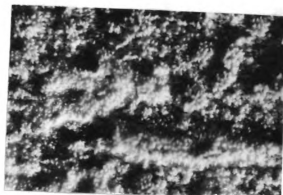


Figure 23

Scale Test Run #21  
7.0 ppm Eltan  
550 PSI

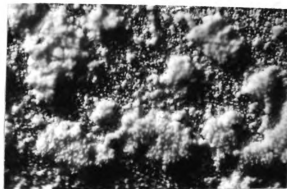


Figure 24

Scale Test Run #22  
7.0 ppm Tannin Blend  
550 PSI

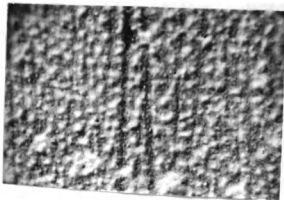


Figure 25

Scale Test Run #48  
Blank Run  
1000 Psi

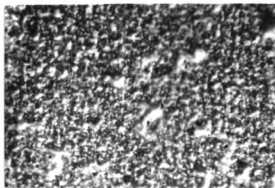


Figure 26

Scale Test Run #52  
Blank Run  
1000 PSI

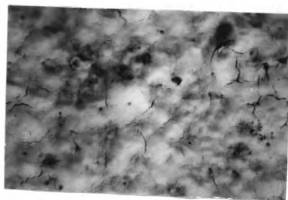


Figure 27

Scale Test Run #49  
0.5 ppm DSC 1005  
1000 PSI



Figure 28

Scale Test Run #53  
0.5 ppm DSC 1005  
1000 PSI

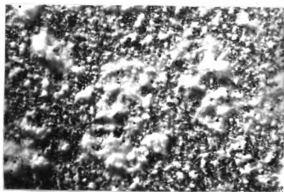


Figure 29

Scale Test Run #54  
1.0 ppm DSC 1005  
1000 PSI

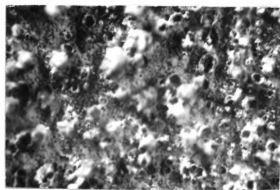


Figure 30

Scale Test Run #55  
2.0 ppm DSC 1005  
1000 PSI

TABLE I  
FEED - G.P.G. BOILER WATER - G.P.G.

| Run | P   | M    | CL   | H    | PO <sub>4</sub> | Cond. | pH  | DS.  | P    | M    | CL   | H    | PO <sub>4</sub> | Cond. | pH   | DS. | T.S. | Conc. |
|-----|-----|------|------|------|-----------------|-------|-----|------|------|------|------|------|-----------------|-------|------|-----|------|-------|
| 5   | -0- | 21.7 | 3.6  | 10.5 | 2.0             | 15.0  |     | 27.6 | 10.3 | 18.1 | 36.7 | 0.1  | -0-             | 45.0  |      |     |      | 10.0  |
| 6   | -0- | 19.8 | 3.3  | 10.6 | 0.5             | 14.5  |     | 22.4 | 0.3  | 5.4  | 39.6 | 5.0  | -0-             | 39.0  |      |     |      | 11.8  |
| 7   | 0.1 | 5.0  | 2.1  | 11.2 | 4.7             | 5.9   |     |      | 28.1 | 56.2 | 11.5 | 0.1  | 17.5            | 70.0  |      |     |      | 5.5   |
| 8   | -0- | 20.5 | 2.9  | 9.9  | 3.9             | 14.7  |     | 27.3 | 24.6 | 44.9 | 31.6 | 0.3  | -0-             | 62.0  |      | 107 |      | 10.9  |
| 9   | -0- | 18.5 | 4.1  | 12.8 | 3.8             | 14.5  | 7.5 | 28.3 | 99.2 | 12.1 | 98.4 | -0-  | 0.3             | 20.8  | 11.8 | 264 |      | 24.0  |
| 10  | -0- | 16.8 | 23.7 | 13.6 | 14.0            | 30.0  | 7.2 | 52.6 | -0-  | 9.6  | 200  | 12.7 | 0.6             | 18.7  | 8.1  | 215 |      | 8.4   |
| 11  | -0- | 13.5 | 24.5 | 11.9 | 3.5             | 24.0  | 7.8 | 46.0 | 0.7  | 3.7  | 222  | 10.3 | 0.3             | 19.4  | 9.0  | 234 |      | 9.1   |
| 12  | -0- | 17.3 | 22.9 | 13.4 | 11.7            | 30.0  | 7.4 | 50.4 | 6.4  | 14.9 | 189  | 0.8  | 1.8             | 14.0  | 10.1 | 217 |      | 8.3   |
| 13  | -0- | 14.9 | 21.8 | 14.3 | 4.1             | 24.0  | 7.9 | 52.9 | 7.5  | 19.1 | 228  | 1.5  | 2.3             | 16.0  | 10.1 | 260 |      | 10.4  |
| 14  | -0- | 16.9 | 22.9 | 17.4 | 4.5             | 31.0  | 7.4 | 60.2 | 1.9  | 14.5 | 160  | 7.4  | 0.5             | 11.3  | 9.0  | 186 |      | 7.0   |
| 15  | -0- | 15.0 | 23.1 | 13.1 | 3.8             | 26.0  | 7.8 | 58.2 | 2.8  | 13.7 | 192  | 8.4  | 0.7             | 13.0  | 9.3  | 218 |      | 8.3   |
| 16  | -0- | 14.4 | 23.0 | 13.5 | 3.8             | 24.0  | 8.0 | 52.8 | 2.1  | 7.3  | 165  | 4.0  | 0.6             | 11.0  | 9.6  | 182 |      | 7.2   |
| 17  | 0.4 | 16.9 | 23.4 | 10.4 | 11.1            | 31.0  | 8.0 | 46.2 | 4.1  | 11.8 | 137  | 6.4  | 1.7             | 9.7   | 9.1  | 160 |      | 5.9   |
| 18  | 0.5 | 17.2 | 23.5 | 10.6 | 8.2             | 28.0  | 8.0 | 64.8 | 1.7  | 10.2 | 144  | 5.7  | 0.6             | 8.5   | 9.2  | 165 |      | 6.1   |
| 19  | -0- | 15.4 | 21.2 | 11.2 | 8.2             | 29.0  | 7.5 | 57.5 | 8.1  | 12.5 | 198  | -0-  | 2.1             | 19.3  | 9.8  | 239 |      | 9.3   |
| 20  | 0.2 | 17.5 | 22.0 | 10.0 | 11.7            | 28.0  | 7.9 | 48.3 | 7.5  | 21.9 | 235  | 1.8  | 2.0             | 15.9  | 9.6  | 281 |      | 10.7  |
| 21  | -0- | 19.8 | 22.1 | 11.0 | 14.0            | 32.0  | 7.8 | 71.0 | 5.6  | 20.7 | 169  | 6.5  | 2.3             | 11.2  | 9.4  | 206 |      | 7.6   |
| 22  | -0- | 18.1 | 22.0 | 17.8 | 13.9            | 32.0  | 7.7 | 48.0 | 4.6  | 20.8 | 204  | 5.7  | 1.7             | 13.0  | 8.8  | 223 |      | 9.3   |
| 23  | -0- | 17.7 | 21.3 | 18.5 | 11.7            | 32.0  | 7.4 | 37.2 | 7.0  | 16.8 | 226  | 1.0  | 1.8             | 15.5  | 9.6  | 258 |      | 10.6  |
| 24  | -0- | 15.3 | 21.9 | 15.8 | 4.7             | 26.0  | 7.9 | 39.0 | 6.1  | 14.4 | 211  | 0.1  | 1.5             | 16.4  | 10.2 | 238 |      | 9.6   |
| 25  | -0- | 18.1 | 21.4 | 18.0 | 11.7            | 29.0  | 7.5 | 42.3 | 8.2  | 16.4 | 211  | 0.2  | 1.2             | 15.2  | 10.2 | 247 |      | 9.9   |

TABLE I CONTINUED

| FEED - G.P.G. |     |      |      |      |                 |       |     |      |      | BOILER WATER - G.P.G. |      |     |                 |       |      |      |      |       |  |
|---------------|-----|------|------|------|-----------------|-------|-----|------|------|-----------------------|------|-----|-----------------|-------|------|------|------|-------|--|
| Run           | P   | M    | SP   | H    | PO <sub>4</sub> | COND. | pH  | D.S. | P    | M                     | CL   | H   | PO <sub>4</sub> | COND. | pH   | D.S. | T.S. | COND. |  |
| 26            | -0- | 17.9 | 21.4 | 18.1 | 12.9            | 31.0  | 7.7 | 41.5 | 6.4  | 16.3                  | 200  | 1.0 | 2.3             | 145   | 9.7  | 232  |      | 9.5   |  |
| 27            | -0- | 17.7 | 21.9 | 16.7 | 7.6             | 27.0  | 7.5 | 42.5 | 11.7 | 25.2                  | 204  | -0- | 2.3             | 145   | 10.0 | 246  |      | 9.3   |  |
| 28            | -0- | 17.9 | 21.7 | 18.7 | 7.0             | 29.0  | 7.2 | 42.3 | 4.5  | 18.3                  | 171  | 3.3 | 1.2             | 120   | 9.8  | 195  |      | 7.9   |  |
| 29            | -0- | 20.0 | 21.9 | 18.6 | 11.7            | 28.0  | 7.4 | 44.0 | 14.8 | 31.4                  | 193  | -0- | 3.2             | 152   | 10.3 | 238  |      | 8.8   |  |
| 30            | -0- | 19.4 | 22.3 | 17.9 | 5.3             | 27.0  | 7.9 | 43.5 | 19.2 | 37.0                  | 217  | -0- | 2.6             | 156   | 10.5 | 272  |      | 9.7   |  |
| 31            | -0- | 18.1 | 21.8 | 18.2 | 12.8            | 31.0  | 8.3 | 49.3 | 19.1 | 37.6                  | 220  | -0- | 3.8             | 160   | 10.5 | 268  |      | 10.1  |  |
| 32            | 0.5 | 17.2 | 22.8 | 15.3 | 3.5             | 25.0  | 8.5 | 49.2 | 19.9 | 35.2                  | 205  | -0- | 2.9             | 155   | 10.5 | 252  |      | 9.0   |  |
| 33            | -0- | 18.7 | 20.5 | 17.7 | 9.3             | 27.0  | 7.9 | 49.1 | 4.6  | 11.8                  | 41.0 | 2.8 | 1.2             | 33    | 8.5  | 5.6  |      | 2.0   |  |
| 34            | 1.0 | 15.1 | 21.1 | 13.2 | 2.9             | 21.0  | 8.7 | 45.0 | 11.7 | 15.9                  | 81.0 | -0- | 1.8             | 65    | 10.5 | 103  |      | 3.8   |  |
| 35            | 0.2 | 19.0 | 20.6 | 18.1 | 7.0             | 25.0  | 8.0 | 50.0 | 22.2 | 33.8                  | 221  | -0- | 3.5             | 170   | 11.0 | 272  |      | 10.7  |  |
| 36            | 0.8 | 16.0 | 20.6 | 13.8 | 2.3             | 20.5  | 8.5 | 45.1 | 18.7 | 26.9                  | 153  | -0- | 2.9             | 125   | 11.0 | 189  |      | 7.4   |  |
| 37            | 0.7 | 16.4 | 22.0 | 15.9 | 5.9             | 25.0  | 8.3 | 46.2 | 17.5 | 28.0                  | 183  | -0- | 3.2             | 145   | 10.5 | 231  |      | 8.3   |  |
| 38            | -0- | 16.4 | 22.9 | 17.1 | 9.3             | 29.0  | 7.8 | 47.5 | 20.6 | 35.2                  | 206  | -0- | 3.2             | 150   | 10.5 | 263  |      | 9.0   |  |
| 39            | 1.2 | 15.4 | 24.3 | 13.3 | 2.9             | 23.0  | 8.4 | 46.8 | 23.0 | 35.0                  | 205  | -0- | 6.4             | 152   | 11.0 | 267  |      | 8.4   |  |
| 40            | -0- | 16.8 | 22.0 | 16.4 | 7.6             | 27.0  | 7.8 | 47.6 | 20.5 | 33.7                  | 194  | -0- | 3.2             | 151   | 10.6 | 253  |      | 8.8   |  |
| 41            | 0.9 | 14.7 | 21.6 | 12.6 | 2.9             | 23.0  | 8.5 | 42.8 | 23.3 | 35.3                  | 201  | -0- | 3.8             | 160   | 10.5 | 268  |      | 9.3   |  |
| 42            | -0- | 19.4 | 22.0 | 16.9 | 5.9             | 24.0  | 8.0 | 50.2 | 25.1 | 38.2                  | 197  | -0- | 3.8             | 160   | 10.5 | 267  |      | 9.0   |  |
| 43            | 0.5 | 17.8 | 23.2 | 18.5 | 3.2             | 27.0  | 8.1 | 49.5 | 19.1 | 32.5                  | 189  | -0- | 3.5             | 149   | 10.5 | 247  |      | 8.2   |  |
| 44            | 1.4 | 17.2 | 25.2 | 5.8  | 2.9             | 21.0  | 8.2 | 49.5 | 23.2 | 35.6                  | 197  | -0- | 3.2             | 152   | 10.5 | 267  |      | 7.8   |  |
| 45            | -0- | 20.8 | 25.0 | 6.6  | 6.4             | 24.0  | 7.6 | 50.0 | 21.6 | 35.6                  | 196  | -0- | 3.5             | 150   | 11.0 | 257  |      | 7.8   |  |
| 46            | 1.0 | 17.2 | 23.0 | 6.5  | 3.5             | 21.0  | 8.0 | 40.7 | 20.8 | 33.6                  | 186  | -0- | 4.1             | 150   | 10.5 | 246  |      | 8.1   |  |

TABLE I CONTINUED

| FEED G.P.G. |     |      |      |      |                 |      |     |      |      | BOILER WATER - G.P.G. |     |     |                |      |      |     |      |      |  |
|-------------|-----|------|------|------|-----------------|------|-----|------|------|-----------------------|-----|-----|----------------|------|------|-----|------|------|--|
| Run         | P   | M    | CL   | H    | PO <sub>4</sub> | COND | PH  | DS.  | P    | M                     | CL  | H   | P <sub>2</sub> | COND | PH   | DS. | T.S. | COND |  |
| 47          | -0- | 17.4 | 18.2 | 9.4  | 8.2             | 28.0 | 7.5 | 53.7 | 36.8 | 53.2                  | 174 | -0- | 5.3            | 160  | 11.0 | 254 | 552  | 9.5  |  |
| 48          | 1.8 | 16.4 | 20.1 | 11.9 | 1.7             | 20.0 | 8.6 | 37.2 | 42.2 | 56.5                  | 171 | -0- | 5.0            | 180  | 11.0 | 251 | 522  | 8.5  |  |
| 49          | -0- | 18.1 | 21.1 | 17.2 | 9.3             | 24.0 | 7.4 | 42.5 | 24.0 | 38.7                  | 199 | -0- | 3.5            | 155  | 10.8 | 257 | 542  | 9.4  |  |
| 50          | 1.0 | 16.4 | 21.1 | 14.2 | 4.1             | 22.0 | 8.2 | 39.0 | 22.0 | 33.3                  | 171 | -0- | 2.9            | 140  | 10.8 | 222 | 600  | 8.1  |  |
| 51          | 1.4 | 16.5 | 19.7 | 13.7 | 3.2             | 21.0 | 8.3 | 39.6 | 21.5 | 34.6                  | 158 | -0- | 3.2            | 135  | 10.5 | 229 | 475  | 8.1  |  |
| 52          | -1- | 18.4 | 21.3 | 16.7 | 9.4             | 27.0 | 7.7 | 43.7 | 17.4 | 29.1                  | 191 | -0- | 2.3            | 145  | 10.5 | 240 | 536  | 9.0  |  |
| 53          | 1.9 | 14.7 | 21.6 | 12.1 | 1.8             | 20.0 | 8.7 | 36.9 | 18.5 | 29.9                  | 191 | -0- | 2.0            | 150  | 10.5 | 243 | 522  | 8.8  |  |
| 54          | -0- | 18.5 | 20.1 | 15.2 | 4.1             | 27.0 | 7.4 | 39.0 | 23.2 | 38.4                  | 196 | -0- | 2.9            | 150  | 10.5 | 244 | 532  | 9.7  |  |
| 55          | 1.3 | 16.3 | 20.4 | 12.2 | 2.9             | 21.0 | 8.6 | 40.7 | 27.2 | 39.3                  | 205 | -0- | 3.5            | 150  | 11.0 | 245 | 567  | 10.0 |  |
| 56          | -0- | 19.4 | 20.8 | 15.8 | 8.2             | 27.0 | 7.3 | 37.2 | 26.6 | 42.3                  | 214 | -0- | 3.2            | 160  | 10.5 | 267 | 593  | 10.4 |  |
| 57          | 1.4 | 15.9 | 20.6 | 11.8 | 1.8             | 21.0 | 8.7 | 38.2 | 27.9 | 40.2                  | 220 | -0- | 3.5            | 175  | 10.5 | 274 | 607  | 10.7 |  |
| 58          | -0- | 19.5 | 20.6 | 16.7 | 7.0             | 28.0 | 7.2 | 41.6 | 23.9 | 39.2                  | 211 | -0- | 3.2            | 150  | 10.5 | 264 | 563  | 10.2 |  |
| 59          | 0.5 | 17.8 | 20.8 | 13.5 | 1.8             | 21.0 | 8.4 | 40.5 | 20.9 | 37.4                  | 208 | -0- | 2.4            | 145  | 11.0 | 254 | 602  | 10.0 |  |
| 60          | 0.1 | 17.7 | 20.4 | 14.4 | 10.5            | 23.0 | 8.5 | 41.2 | 18.0 | 32.3                  | 181 | -0- | 2.3            | 145  | 11.0 | 225 | 485  | 8.9  |  |
| 61          | 0.7 | 16.1 | 20.0 | 12.6 | 2.0             | 22.0 | 8.4 | 39.2 | 22.2 | 38.5                  | 218 | -0- | 3.5            | 170  | 10.3 | 274 | 577  | 10.9 |  |
| 62          | -0- | 16.8 | 20.4 | 13.6 | 5.8             | 23.0 | 8.0 | 40.2 | 22.8 | 38.5                  | 211 | -0- | 3.5            | 225  | 10.5 | 282 | 580  | 10.6 |  |
| 63          | 1.1 | 15.7 | 20.2 | 11.6 | 1.8             | 24.8 | 8.5 | 41.3 | 22.4 | 37.8                  | 223 | -0- | 4.1            | 193  | 10.3 | 280 | 645  | 11.0 |  |
| 64          | 0.7 | 17.2 | 20.2 | 13.5 | 2.9             | 32.0 | 8.4 | 40.7 | 20.3 | 36.9                  | 194 | -0- | 2.3            | 216  | 10.2 | 263 | 490  | 9.6  |  |
| 65          | -0- | 17.5 | 20.2 | 14.5 | 3.9             | 34.4 | 8.0 | 38.3 | 18.2 | 33.6                  | 183 | -0- | 2.0            | 210  | 10.0 | 243 | 510  | 9.0  |  |
| 66          | -0- | 17.6 | 20.1 | 15.1 | 3.2             | 45.0 | 7.8 | 40.0 | 18.0 | 33.4                  | 184 | -0- | 1.2            | 203  | 10.3 | 246 | 527  | 9.2  |  |
| 67          | -0- | 17.8 | 20.2 | 14.9 | 4.1             | 38.6 | 7.8 | 38.4 | 20.8 | 36.0                  | 186 | -0- | 3.8            | 225  | 10.5 | 261 | 515  | 9.2  |  |
| 68          | -0- | 18.2 | 16.3 | 11.7 | 4.1             | 37.0 | 8.0 | 36.7 | 41.0 | 64.5                  | 154 | -0- | 5.8            | 232  | 11.0 | 260 | 495  | 9.4  |  |

TABLE II

| Run #. | D.S.C. ppm | D.S.C. 1005 | g.p.g. Hardness | B.W. | B.W. pH | g.p.g. B.W. $\text{PO}_4$ | Boiler Concentrations | Sludge & Scale Remarks      |
|--------|------------|-------------|-----------------|------|---------|---------------------------|-----------------------|-----------------------------|
| 12     | -0-        | 0.46        | 0.8             | 10.1 | 10.1    | 1.8                       | 8.3                   | Light Tan, Sticky           |
| 13     |            | 0.46        | 1.5             | 10.1 | 10.1    | 2.3                       | 10.4                  | Boiler Wall Scale Less      |
| 14     |            | 0.82        | 7.4             | 9.0  | 9.0     | 0.5                       | 7.0                   | Boiler Wall Un-changed      |
| 15     |            | 1.35        | 8.4             | 9.3  | 9.3     | 0.7                       | 8.3                   | Sludge-Nonsticky Flocculant |
| 16     |            | 1.35        | 4.0             | 9.6  | 9.6     | 0.6                       | 7.2                   | Sludge-Nonsticky Flocculant |

TABLE III

## Scale Composition by X-ray Analysis

| Run Number                                     | 30    | 32    | 33    | 35    |
|------------------------------------------------|-------|-------|-------|-------|
| ppm Conditioner Fed                            | 0     | 0.25  | 0.50  | 1.0   |
| Silica as $\text{SiO}_2$                       | 1.00  | 2.10  | 2.00  | 1.80  |
| Iron and Aluminum<br>as $\text{R}_2\text{O}_3$ | 2.22  | 1.13  | 2.24  | 1.06  |
| Phosphates as $\text{P}_2\text{O}_5$           | 35.03 | 36.27 | 35.40 | 35.34 |
| Calcium as $\text{CaO}$                        | 38.08 | 39.00 | 39.00 | 40.44 |
| Magnesium as $\text{MgO}$                      | 15.12 | 15.15 | 15.22 | 15.12 |
| Carbonate as $\text{CO}_2$                     | 1.10  | 1.78  | 1.82  | 0.78  |
| Water and Organic                              | 6.64  | 4.20  | 3.90  | 5.34  |
| Undetermined                                   | 0.81  | 0.37  | 0.42  | 0.12  |

TABLE IV  
Blank Scale Determination  
at 550 psig

| Run # | Tube<br>Identification | gms<br>Scale |
|-------|------------------------|--------------|
| 29    | A                      | 0.0596       |
|       | B                      | 0.0602       |
| 30    | A                      | 0.0955       |
|       | B                      | 0.0328       |
| 37    | A                      | 0.0730       |
|       | B                      | 0.1337       |
|       | C                      | 0.1127       |
| 38    | A                      | 0.0582       |
|       | B                      | 0.0543       |
|       | C                      | 0.0710       |
| 39    | A                      | 0.0589       |
|       | B                      | 0.0315       |
|       | C                      | 0.0368       |
| 40    | A                      | 0.0817       |
|       | B                      | 0.0690       |
|       | C                      | 0.0690       |
| 41    | A                      | 0.0440       |
|       | B                      | 0.0525       |
|       | C                      | 0.0476       |

TABLE V

Scale Determination for Use  
of 0.25 ppm DSC 1005 at 550 psig

| Run #         | Tube<br>Identification | Gms<br>Scale | Remarks                        |
|---------------|------------------------|--------------|--------------------------------|
| 31            | A                      | 0.0961       | Sludge-fine, settles<br>slowly |
|               | B                      | 0.0535       |                                |
| 32            | A                      | 0.0799       | Sludge-slightly flocced        |
|               | B                      | 0.0723       |                                |
| 45            | A                      | 0.0388       | Sludge-fine, settles<br>slowly |
|               | B                      | 0.0258       |                                |
|               | C                      | 0.0486       |                                |
| 46            | A                      | 0.0576       | Sludge-fine, settles<br>slowly |
|               | B                      | 0.0679       |                                |
|               | C                      | 0.0515       |                                |
| Total Scale   |                        | 0.5910       |                                |
| Average Scale |                        | 0.0591       |                                |

TABLE VI

Scale Determination Using  
0.5 ppm DSC 1005 at 550 psig

| Run #         | Tube Identification | Gms Scale | Remarks                               |
|---------------|---------------------|-----------|---------------------------------------|
| 33            | A                   | 0.0582    | Sludge-Flocculated<br>settles rapidly |
|               | B                   | 0.0044    |                                       |
|               | C                   | 0.0848    |                                       |
| 34            | A                   | 0.0137    | Sludge-slightly flocked               |
|               | B                   | 0.0010    |                                       |
| 42            | A                   | 0.0295    | Sludge-flocculated<br>settles rapidly |
|               | B                   | 0.0302    |                                       |
|               | C                   | 0.0223    |                                       |
| 43            | A                   | 0.0525    | Sludge-flocculated<br>settles rapidly |
|               | B                   | 0.0434    |                                       |
|               | C                   | 0.0513    |                                       |
| 44            | A                   | 0.0243    | Sludge-slightly flocked               |
|               | B                   | 0.0103    |                                       |
|               | C                   | 0.0275    |                                       |
| Total Scale   |                     | 0.4654    |                                       |
| Average Scale |                     | 0.0332    |                                       |

TABLE VII

Scale Determination Using  
1.0 ppm DSC 1005 at 550 psig

| Run #         | Tube<br>Identification | Gms<br>Scale | Remarks                                        |
|---------------|------------------------|--------------|------------------------------------------------|
| 35            | A                      | 0.0385       | Sludge-slightly flocculated<br>settles rapidly |
|               | B                      | 0.0917       |                                                |
| 36            | A                      | 0.0192       | Sludge-flocculated<br>settles rapidly          |
|               | B                      | 0.0216       |                                                |
| Total Scale   |                        | 0.1810       |                                                |
| Average Scale |                        | 0.0453       |                                                |

TABLE VIII

Scale Determinations Using  
Natural or Modified Natural  
Organic at 550 psig

| Run#          | Tube<br>Identification | Gms<br>Scale | Remarks                 |
|---------------|------------------------|--------------|-------------------------|
| 19            | A                      | 0.3604       | 7.0 ppm Tannin          |
|               | B                      | 0.3416       | Sludge-fine, sticky     |
| 20            | A                      | 0.1994       | 7.0 ppm modified tannin |
|               | B                      | 0.2678       | Sludge-fine, sticky     |
| 21            | A                      | 0.2516       | 7.0 ppm Eltan           |
|               | B                      | 0.3033       | Sludge-fine, sticky     |
| 22            | A                      | 0.4299       | 7.0 ppm Tannin Blend    |
|               | B                      | 0.5424       | Sludge-fine, sticky     |
| Total Scale   |                        | 2.6965       |                         |
| Average Scale |                        | 0.3371       |                         |

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TABLE IX

Scale Determinations Using  
Acrylate in Varying Amount  
1050 psig

| Run # | Tube<br>Identification | Gms<br>Scale | Remarks                                             |
|-------|------------------------|--------------|-----------------------------------------------------|
| 47    | A                      | 0.0757       | Blank Run                                           |
|       | B                      | 0.1909       | Sludge-fine, sticky                                 |
|       | C                      | 0.1788       |                                                     |
| 48    | A                      | 0.0923       | Blank Run                                           |
|       | B                      | 0.1034       | Sludge-fine, sticky                                 |
|       | C                      | 0.0963       |                                                     |
| 51    | A                      | 0.0723       | Blank Run                                           |
|       | B                      | 0.0809       | Sludge-slightly flocced                             |
| 52    | A                      | 0.1324       | Blank Run                                           |
|       | B                      | 0.1449       | Sludge-fine, sticky                                 |
| 49    | A                      | 0.3202       | 0.5 ppm DSC 1005                                    |
|       | B                      | 0.3188       | Sludge-slightly flocced                             |
| 53    | A                      | 0.0880       | 0.5 ppm DSC 1005                                    |
|       | B                      | 0.1306       | Sludge-slightly flocced                             |
| 50    | A                      | 0.0562       | 1.0 ppm DSC 1005                                    |
|       | B                      | 0.0644       | Sludge-flocculated<br>settled rapidly               |
| 54    | A                      | 0.1851       | 1.0 ppm DSC 1005                                    |
|       | B                      | 0.2125       | Sludge-flocculated<br>settles rapidly               |
| 55    | A                      | 0.2378       | 2.0 ppm DSC 1005                                    |
|       | B                      | 0.1959       | Sludge-flocculated<br>settles rapidly<br>not sticky |

TABLE X  
Scale Determinations at  
850 psig

| Run #         | Tube Identification | Gms Scale | Remarks                    |
|---------------|---------------------|-----------|----------------------------|
| 56            | A                   | 0.1245    | Blank Run                  |
|               | B                   | 0.1118    | Sludge-sticky              |
| 57            | A                   | 0.0176    | Blank Run                  |
|               | B                   | 0.0245    | Sludge-sticky              |
| 60            | A                   | 0.1342    | Blank Run                  |
|               | B                   | 0.0461    | Sludge-fine, sticky        |
|               | C                   | 0.1123    |                            |
| 61            | A                   | 0.0606    | Blank Run                  |
|               | B                   | 0.0771    | Sludge-fine, sticky        |
| 62            | A                   | 0.0877    | Blank Run                  |
|               | B                   | 0.1212    | Sludge-slightly flocced    |
|               | C                   | 0.0727    | Rust noted on tubes        |
| 63            | A                   | 0.1011    | Blank Run                  |
|               | B                   | 0.0842    | Sludge-fine, settles       |
|               | C                   | 0.0973    | slowly, sticky             |
| Total Scale   |                     | 1.2730    |                            |
| Average Scale |                     | 0.0848    |                            |
| 58            | A                   | 0.1697    | 1.0 ppm DSC 1005           |
|               | B                   | 0.1506    | Sludge-excellent qualities |
| 59            | A                   | 0.0678    | 1.0 ppm DSC 1005           |
|               | B                   | 0.0682    | Sludge-slightly flocced    |
| Total Scale   |                     | 0.4563    |                            |
| Average Scale |                     | 0.1141    |                            |

TABLE XI

Typical Feed and Boiler  
Water Analysis. Run # 41

|                                         | Feed  | Boiler Water |
|-----------------------------------------|-------|--------------|
| Calcium as Ca (ppm)                     | 22    |              |
| Magnesium as Mg (ppm)                   | 39    |              |
| Sodium & Potassium as Na                | 162   |              |
| Bicarbonate as $\text{HCO}_3$ (ppm)     | 268   |              |
| Carbonate as $\text{CO}_3$              | 19    | 215          |
| Hydroxide as OH (ppm)                   |       | 54           |
| Chloride as Cl                          | 225   | 2084         |
| Sulphate as $\text{SO}_4$ (ppm)         | 2     | 25           |
| Phosphate, Ortho as $\text{PO}_4$ (ppm) |       | 54           |
| Sulphite as $\text{SO}_3$               |       | 6            |
| Dissolved Solids (ppm)                  | 737   | 4412         |
| Suspended Solids (ppm)                  |       | 5590         |
| Oil                                     | Trace |              |
| pH                                      | 8.5   | 10.5         |
| Phenolphthalein as $\text{CaCO}_3$      | 16    | 398          |
| Methyl Orange as $\text{CaCO}_3$        | 252   | 604          |
| Hardness as $\text{CaCO}_3$             | 216   | 0            |

TABLE XII

Properties of Steel Used (2)  
in Boiler Construction

|            |               |
|------------|---------------|
| Carbon     | 0.35%         |
| Manganese  | 0.90% Maximum |
| Phosphorus | 0.05%         |
| Sulfur     | 0.05%         |

Minimum Tensile Properties

|                   |                  |
|-------------------|------------------|
| Tensile strength  | 60,000 #/sq. in. |
| Yield Point       | 30,000 #/sq. in. |
| Elongation in 2"  | 25%              |
| Reduction of Area | 38%              |

## DISCUSSION

The work reported here offers rather conclusive evidence that it is possible to evaluate the action of an agent added to feed water for the purpose of sludge conditioning and/or scale prevention. It was found that the synthetic organic employed produced a decided improvement over no conditioning or the use of natural organics.

The term blank or control run was used to specify those test runs in which the standard feed water was used without the addition of a conditioning agent to condition sludge or prevent scale. These blank runs were then used as a standard of comparison with test runs having had proper conditioning agents added. The reproducibility of a blank test run was taken to indicate the reliability of the standard of comparison.

In all cases, the heat input rate was approximately 20,000 BTU per hour per square foot of heating surface. This heat transfer rate was maintained nearly constant throughout all test runs. It was calculated on the basis of elapsed steaming time, feed displacement, and boiler tube area. On the basis of heat input, the rate was approximately 29,000 BTU per hour per square foot of heating surface. The difference in actual heat input and input as calculated by feed displacement was taken to be losses due to radiation, etc.

Over a series of tests on the boiler water after approximately ten concentrations had been made, the total solids determination



by gravimetric methods in every case nearly 9,000 parts per million by weight.

Various operating difficulties were encountered in the initial attempts to produce consistent data. Among these was the original steel, 55-gallon, plastic painted, feed drum. The drum corrosion caused the chipping of slight amounts of rust and paint which clogged feed lines or caused these unwanted materials to be passed with the feed into the boiler proper. This difficulty was remedied by the fabrication of a copper feed tank.

It being possible that operating alkalinity might be pointed to as the reason for scale preventative effects, the first attempts were to establish a blank under the worst possible conditions. Test runs were made at an operating pressure of 500 psig and an alkalinity such that residual hardness was noticed in the boiler water. With the alkalinity low and an excess of phosphates, the formation of the very sticky sludge composed of tricalcium phosphate and magnesium phosphate was assured. The test runs number twelve through sixteen and Figures 9 through 12 show that even at alkalinity which was too low, the acrylates used had a scale preventative effect over that of a blank run.

An analysis of each of the boiler waters of runs twelve through sixteen as given in Table II and a study of Figures 9 through 16 gave definite indication that under adverse operating conditions, the acrylate conditioner used (DSC 1005) gave remarkable results. Each of the photomicrographs was taken at approximately forty

magnifications of a representative part of the boiler tube being examined. The scale preventative effect of the acrylate conditioner is apparent from the photographs and shows an increasing effect with an increase in conditioner added.

The sludge from run number twelve was of a very sticky nature, while from visual observation, the sludge from subsequent tests in the series was flocculated and increasingly so with increased conditioner.

Various observations were made during the entire test procedure. The appearance of the boiler tubes after removal from a test run gave indications of the variation of scale deposit which could be caused by different heat transfer rates. The scale on the boiler walls was also observed after each test run to determine if the wall deposit had either increased or decreased.

Particular attention was given to the condition of the sludge as blown down from the boiler. The degree of flocculation as blown was observed as well as checked by the bottle pour test.

The tube scale was further tested by feeling the coating and noting its powdered condition. The deposit was considered as being of good condition if it came off easily with touch.

Having established the following empirical tests for evaluation, namely:

- a. appearance of tube
- b. appearance of boiler walls
- c. sludge test on blowdown

- d. sludge test in bottle pour
- e. photomicrographs of deposits
- f. feel of coating

It was deemed advantageous to correlate weights of deposits.

Another difficulty arose from the tube water side surface. During the first few runs the tubes were acid cleaned with an inhibited acid and washed prior to reinsertion into the boiler for the next run. This method of cleaning the boiler tubes caused a wide fluctuation in scaled deposit as was shown in run number 26, in which one mechanically polished tube and two acid cleaned tubes were inserted. One acid cleaned tube was inserted with a lower input heating element such that the temperature difference from heating element to water was approximately 1500° F. A polished tube was inserted with a higher input heating element such that the temperature difference from the heating element to the water was approximately 2000° F. Under these conditions, the unpolished tube should theoretically have had less scale than the polished tube, all conditions except heat transfer and method of cleaning the tubes being alike. On removal of the tubes after completion of the test run, the scale of each of these tubes was removed and weighed. The polished tube had 0.0568 grams of scale while the acid cleaned tube had 0.3386 grams of scale.

Having established that the synthetic acrylate conditioner properly conditioned sludge to give it a flocculant nature, steps were taken to obtain reliable and consistent scale formation on

the boiler tubes. The decision was finally reached that to eliminate a number of variables such as tube surface prior to a test run, the same three tubes should be used, with the same three heating elements, each in its position, thus giving identical heat and tube surface to each of the boiler test arms on corresponding test runs.

During this same period of testing, blank runs 17, 23, and 27 revealed that the wire used for heating elements caused different appearance of deposit depending on the method of winding. Using a given amount of wire and extending the winding of this wire over nearly the entire length of the heating element, a heavy steam-bound scale deposit was realized. This was undesirable since the heat transferred in this method did not give a true representation of scale deposit over the entire tube surface.

A uniform deposit was gotten when the heating elements were wrapped at the fore end of the core rather than over the entire length. With this type winding, it was possible to establish a blank or control of uniform appearance of tube scale that gave within an accepted percentage, nearly equal scale deposits on the three boiler tubes employed.

Having now been able to produce uniform scale deposits by using a heating element wound on the fore part of the core (Figure 31), correlation of tube scale weights became a possibility. This was accomplished by brushing the scale from the tubes with a nylon toothbrush onto a previously weighed paper.





Heating element wound at fore part of core, prior to cement coating.

Figure 31

With the foregoing in mind, beginning with test run number 29, a series of blank or control runs as well as runs with DSC 1005 in various amounts were made at a gauge pressure of 500 to 600 pounds. In the case of these test runs, a higher alkalinity was used in the boiler such that actual plant operation was paralleled. In conjunction with these test runs, additional observations were made as to appearance of tubes after completion of a test run, appearance of the boiler walls after test, properties of the boiler water and sludge as removed from the boiler, bottle test on sludge, boiler water analysis, weight of scale of test tubes, and X-ray diffraction test on the sludge proper.

The sludges resulting from test runs, number 30, 32, 33, and 35 were analyzed by X-ray diffraction to determine the composition. Each of these test runs had a synthetic acrylate organic conditioner added in amounts varying from zero to one part per million by weight. The results of this analysis are shown in Table III.

This analysis indicates that the sludge composition is not structurally effected by the addition of the conditioner. However,

with increased dosage, the sludge was of a more fluid and non-sticky nature as determined in the glass bottle pour test.

With the elimination of boiler operation difficulties, and the series of test runs beginning with run number 29, it was determined that the average tube scale for seven blank runs was 0.0659 grams. The weights of 19 tubes scale of these test runs as well as observations that indicate a sticky sludge are given in Table IV. Using one-quarter part per million of the acrylate conditioner in the feed, an average over four runs and scale weights for 10 tubes gave a tube scale of 0.0591 grams. The weights of the individual tube scales are given in Table V. The tube scale using one-half part per million acrylate in the feed gave an average of 0.0331 grams of scale per tube for the 14 tubes tested. The individual tube scale data for this series of test runs is shown in Table VI. Using one-half part per million conditioner produced a 50% scale prevention whereas a scale prevention of 10% was realized when just one-quarter part per million of acrylate was used in the feed.

The photomicrographs taken of test runs made at the gauge pressure of 550 to 600 pounds per square inch are given in Figures 13 through 21. Examination of these pictures shows conclusively that with increased dosage of the synthetic acrylate conditioner DSC 1005, progressively better tube scale results are obtained. This better scale appearance on the tubes is not so apparent using 0.25 parts per million conditioner as it is using one-half and one part per million.

This type of conditioning also produced a boiler sludge which was flocculated such that in the bottle test, no adherence to the bottle wall was noticed and more rapid settling was achieved.

Results of test runs using various other organic conditioners were compared with the results obtained using DSC 1005, and in every case the acrylate proved superior. On the basis of industrial practices, seven parts per million of other natural or modified natural organic conditioners were added to the standard feed in each of several test runs. Each of these organics used gave a less fluid and less flocculated sludge and less scale prevention despite the fact that about 28 times as much conditioner was added than had been used in the case of some acrylate test runs.

Among the various organics tested for comparison were tannins, eltans, modified or upgraded tannins, chestnut extracts, and maracell. Figures 21, 22, 23, and 24 as well as Table VIII substantiates claims from results obtained by use of DSC 1005 as against those of the tested natural or modified natural organics.

Having completed the test runs at a pressure of 550 to 600 pounds per square inch gauge, it was decided to determine the effect of DSC 1005 at a pressure of approximately 1000 to 1100 pounds per square inch gauge. Blank determination established an average of 0.1178 grams scale per tube over a series of four test runs and ten tube scale weights. The scale resulting from test runs following addition of acrylate conditioner did not give satisfactory results, the tubes having an appearance of carbon deposit

as though from decomposition of the organic conditioner added. In all the runs made at this pressure, a fine boiler sludge of a sticky nature was obtained from the blank tests while a satisfactory flocculant and non-sticky sludge was obtained when acrylate conditioning agent was added. Figures 25 through 30 show scale of blank test runs as well as for test runs having one-half, one, and two parts per million DSC 1005. Table IX gives individual tube scale weights for each of several test runs at the pressure in question.

With the thought in mind that a breaking point existed, the operating pressure was reduced to a range of 850 to 900 pounds per square inch gauge. A series of six test runs and scale weights from fifteen tubes from these runs resulted in an average of 0.0848 grams scale per tube. Two test runs at 1.0 part per million acrylate conditioner in the feed, with the scale weights from four tubes gave a tube scale average of 0.1141 grams. The sludge in each case was very flocculated, settled rapidly, and was of a non-sticky nature in the bottle test as compared to the blank runs. Table X gives the individual tube scale weights for test runs made at the pressure in question.

In the test runs at 850 and 1000 pounds per square inch gauge pressure, tests numbered 59 and 50 indicated scale preventative qualities for the acrylate conditioner. This, however, is not regarded as reliable since these tests are isolated examples of a series of tests.

#### FUTURE RESEARCH

It is the belief that the foregoing is a step toward a new field of research in the use of synthetic organics as sludge conditioners and scale preventatives. The acrylate tested being subject to definite product and quality control represents a step toward an industrial material which gives consistent performance over a wide pressure-temperature range.

Further work should be done at 850 pounds per square inch and at even higher pressures with the acrylate conditioner. Possible modifications of the acrylate may produce a product which is more stable and will give satisfactory results over a considerably higher pressure range.

## CONCLUSIONS

It is concluded from the data reported here and from the foregoing discussion that the acrylate conditioner used (also called DSC 1005) operated satisfactorily as a sludge conditioner and scale preventative at an operating pressure of 550 to 600 pounds per square inch gauge.

It is possible to evaluate a boiler water conditioner by noting the resulting tube appearance, boiler wall appearance, sludge condition as blown, sludge condition in a bottle test, feel of coating of tubes, photomicrographs of deposits on tubes, and amount of tube scale deposit.

The boiler design and construction enabled testing with decided advantages over many single unit boilers.



**APPENDIX**

## WATER TESTING

Feed water and boiler water were analyzed for phenolphthalein and methyl orange alkalinity, chlorides, hardness, conductivity, pH, ortho-phosphates, total solids, and dissolved solids.

For the phenolphthalein alkalinity determination, 58.3 milliliters of filtered water were placed into a porcelain casserole and three drops of phenolphthalein indicator were added. The milliliters of N/50 sulphuric acid added to change the original red color to the colorless end point gave the "P" alkalinity reading as grains per gallon of calcium carbonate.

Continuing with the sample used for the phenolphthalein determination, three drops of methyl orange indicator were added and titration continued with N/50 sulphuric acid until the yellow color was changed to the end point of orange or pink. The total milliliters of sulphuric acid used for the phenolphthalein and methyl orange titration gave the "M" alkalinity reading as grains per gallon of calcium carbonate.

To determine the chloride content as grains per gallon of sodium chloride, the sample used for the determination of phenolphthalein and methyl orange alkalinities was taken and eight to ten drops of chromate indicator added. The sample was then titrated with N/58.3 silver nitrate solution until the change in color from yellow to a faint red indicated the end point was reached. The milliliters of silver nitrate solution used gave the chloride concentration directly as grains per gallon of sodium chloride.



The hardness determination was made by taking a 58.3 milliliter sample of filtered water and titrating with a standard soap solution (one milliliter equaled one grain per gallon hardness when a 58.3 milliliter sample was titrated) with vigorous intermittent agitation until an end point was reached as evidenced by a lather which remained unbroken after five minutes with the bottle lying on its side. The hardness reading as grains per gallon of calcium carbonate was equal to the milliliters of soap solution used, less one-half milliliter required to make lather.

Conductivity was determined as grains per gallon of calcium carbonate by immersion of the electrode of a Nalco conductivity cell into the water sample. By adjustment of temperature and indicating dials, the reading was given directly.

The pH in all cases in the laboratory tests was tested by using various ranges of Merco Essential Laboratories pHydriion paper and a color comparison of the tested paper with a standardized color chart.

The phosphate reading as parts per million  $\text{PO}_4$  was made using the LaMotte comparator.

To determine the dissolved solids as parts per million, a fifty gram sample of filtered water was placed into a weighed container and evaporated to dryness at  $160^{\circ}\text{F}$  and the container reweighed. The resulting difference in container weight reported as milligrams times twenty gave the dissolved solids directly as parts per million by weight.

Total solids were determined in a manner like that of dissolved solids except the sample was unfiltered and representative of the water to be analyzed.

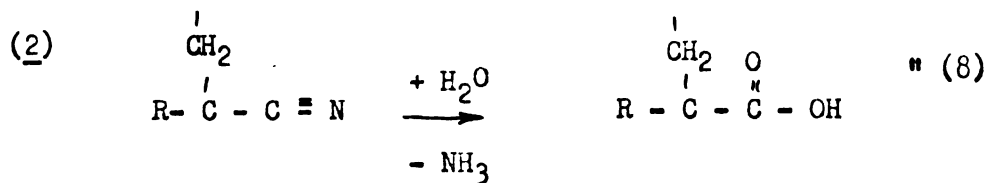
#### HEATING ELEMENT FABRICATION

Fabrication of the heating elements (Figure 31) was accomplished by taking nineteen feet of 16 gauge Nichrome V resistance wire having a calibrated resistance of 0.25 ohms per foot or such that nineteen feet would give an output of approximately 2800 watts when connected to a potential of 110 volts. Eighteen inches of this wire were then doubled back and twisted for use as the center or core lead of the heating element. The 7/8 inch diameter by 12 inch alundum core was then notched at the bottom end and the wire wound by means of a lath eight turns to the inch until only enough was left to form a second lead wire. This end was maintained in position by winding a second wire around the lead a number of times. Final application of a special Norton cement prevented the contact of the wire winding with inner walls of the boiler tube.

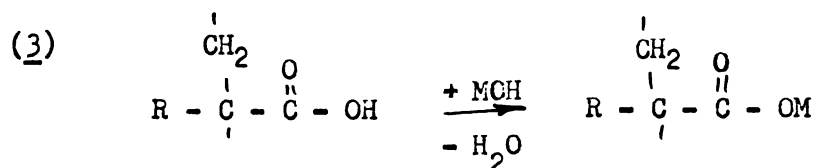
#### SYNTHESIS OF ACRYLATE CONDITIONER

"One method of preparing such alkene carboxylic acid polymers involves the polymerization of methacrylonitrile and/or acrylonitrile ( $\text{CH}_2 = \text{CR} - \text{C} \equiv \text{N}$ ) and the subsequent hydrolysis of the polymer to convert the nitrile radicals to carboxylic

acid radicals, as represented in connection with the chain units in Equation (2) below:

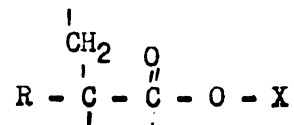


"The neutralization reaction may be carried out by the use of any neutralizingly reactive alkali metal donor, preferably the hydroxide, as shown in Equation (3) below:



wherein M is an alkali metal atom."

"Accordingly, the acrylic polymer preferably employed in the instant invention is one whose polymer chain structure comprises units having the following formula:



wherein R is H or CH<sub>3</sub> and X is H, Na or K." (8)

"Also, such polymeric chain structure may be prepared by methods other than the method hereinbefore described, for example, by direct polymerization of sodium acrylate."

The above quotations give some of the possible procedures for synthesis of DSC 1005 used in this experiment.



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