A STUDY OF A METHOD FOR TESTING BOILER FEEDWATER TREATMENTS IN DUPLEX TEST BOILER

By

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A Thesis submitted to the Graduate Committee
in partial fulfillment of the requirements
for the Degree of

MASTER OF SCIENCE

in

MECHANICAL ENGINEERING

Approved:

Head of Department

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VIRGINIA POLYTECHNIC INSTITUTE

1938

ACKNOWLEDGMENTS

This Thesis is the outgrowth of research begun by and , at V. P. I. in 1937. Thanks are first due these men for their construction and preliminary testing of the Duplex Test Boiler. The photostats used in this thesis were taken from their work.

To Professors W. T. Ellis, J. B. Jones, F. H. Fish, and the author tenders his sincere appreciation for their able and willing assistance in timely encouragement and suggestions, and their material contributions to the work of this Thesis.

To and the author is indebted for their assistance in preliminary repairing and the actual testing of the boiler.

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FIGURES AND TABLES

SCOPE OF THESIS

The fact should be here emphasized that this study has been made from the viewpoint of determining a reliable and practical method of testing various feedwater treatments. The study has been limited to the problem of boiler scale, the apparatus being inadequate to test for corrosion, embrittlement, foaming and priming. The term treatment used hereafter shall refer to internal treatment.

The length and number of test runs has been limited by the lack of funds for the purchase of fuel oil. The boiler has been operated at only one pressure. All tests have been made at approximately 90 % boiler rating.

INTRODUCTION

Boiler feedwater treatment is as old as boilers themselves, and will live as long as steam is used as a medium of energy transfer. The history of internal treatment started in England in one of Watt's early boilers. The story is told by Payen[(1)], after a visit to England in 1831, that one of the boiler operators left his lunch inside the boiler. This lunch, consisting mostly of potatoes, was forgotten and the boiler operated for the customary period of two weeks before cleaning. To the surprise of the operator, upon opening the boiler, he found that the usual hard scale was now in the form of a soft sludge.

Since the discovery of the "potatoe treatment" numerous other methods of scale prevention have been discovered and patented, some of them more ridiculous and much less effective than the potatoes.

The effect of scale on boiler efficiency has long been a matter of considerable dispute. Dr. Joseph G. Rodgers[(2)] says that a scale of one half inch thickness will decrease boiler efficiency more than a hundred per cent. Partridge[(3)] maintains that this scale would not effect the efficiency more than twelve to fifteen per cent. However, it is generally agreed that the presence of scale causes a marked

(1) Dingler's Polytech. J. 10, 254, (1823)
(2) Am. Rail. Master Mech. Assoc. Vol. XXIX, 523, (1896)
(3) Univ. of Mich. Engr. Research Bull. No. 15, (1930)

increase in boiler metal temperature that may result in bulging, sagging, and in extreme cases rupture of the tubes. The removal of scale necessitates a shut down and a periodical outage of the boiler. In the modern boiler these conditions cannot be tolerated, making it necessary to use some method of preventing scale formation.

In order to minimize the cost of testing, and to remove the danger of testing unknown compounds in full sized boilers, this research work has been undertaken. The purpose of this thesis is to determine a reliable and practical method of testing feedwater treatments for their efficiency in preventing boiler scale.

REVIEW OF LITERATURE

H. K. Benson and O. A. Hougen [4] at the University of Washington were among the first men to make a study of boiler compounds. Their method of testing the efficiency of boiler compounds consisted of adding the samples of various compounds to 900 c.c. of feedwater, boiling vigorously in an open beaker, and determining the rate of settling of the precipitate. This test was made on the hypothesis that the function of boiler compounds is to form precipitates which do not settle out readily. The most efficient compound delays settling. No attempt was made to run these tests at any pressure above atmospheric.

In the past, the efforts toward the testing of boiler compounds have been largely in the hands of groups interested commercially in the sale of equipment for scale prevention processes and relatively little time or effort has been devoted to fundamental research concerning the efficiency of boiler compounds.

In 1923, D. K. French [5] made a very thorough study of the chemical composition of eighty-six different patented compounds. Mr. French concluded that in the majority of compounds, "There is shown no effort on the part of the manufacturer to adjust chemical treatment to any individual

(4) Ind. Engr. Chem. 8, 435-436, (1916)
(5) Ind. Engr. Chem. 15, 1239, (1923)

water, and the advertising matter and arguements show such ignorance of chemical facts as to suggest the impossibility of the average compound manufacturer even knowing what he is doing. The firms which are treating water thoughtfully by this method do not give their materials fancy names, nor call them compounds. They refer to them as "Treatments" and recommend a treatment with discretion".

S. T. Powell[6] in 1927 also made a study of the chemical composition of boiler compounds. After analysizing more than thirty different compounds Mr. Powell concluded that the indiscriminate use of boiler compounds is a hazardous procedure. The products are usually sold under trade names, and in the majority of cases the engineer has no knowledge of their composition. The boilers in such instances are merely reaction tanksin which undertreatment or overtreatment of the water frequently results. In the first case, scale formation is not retarded and may be accelerated. In the latter case, in addition to heavy deposits of scale, corrosion, priming and foaming may take place.

The lack of published information on the efficiency of boiler compounds is strikingly evidenced after a thorough search of the publications in the V. P. I. Libraries. This lack of accurate information was felt by Messrs. G. E. Anderson and B. C. Lively and was the factor which lead to their design and construction of the Duplex Test Boiler.

(6) Boiler Feedwater Purification, McGraw Hill Bk. Co.(1927)

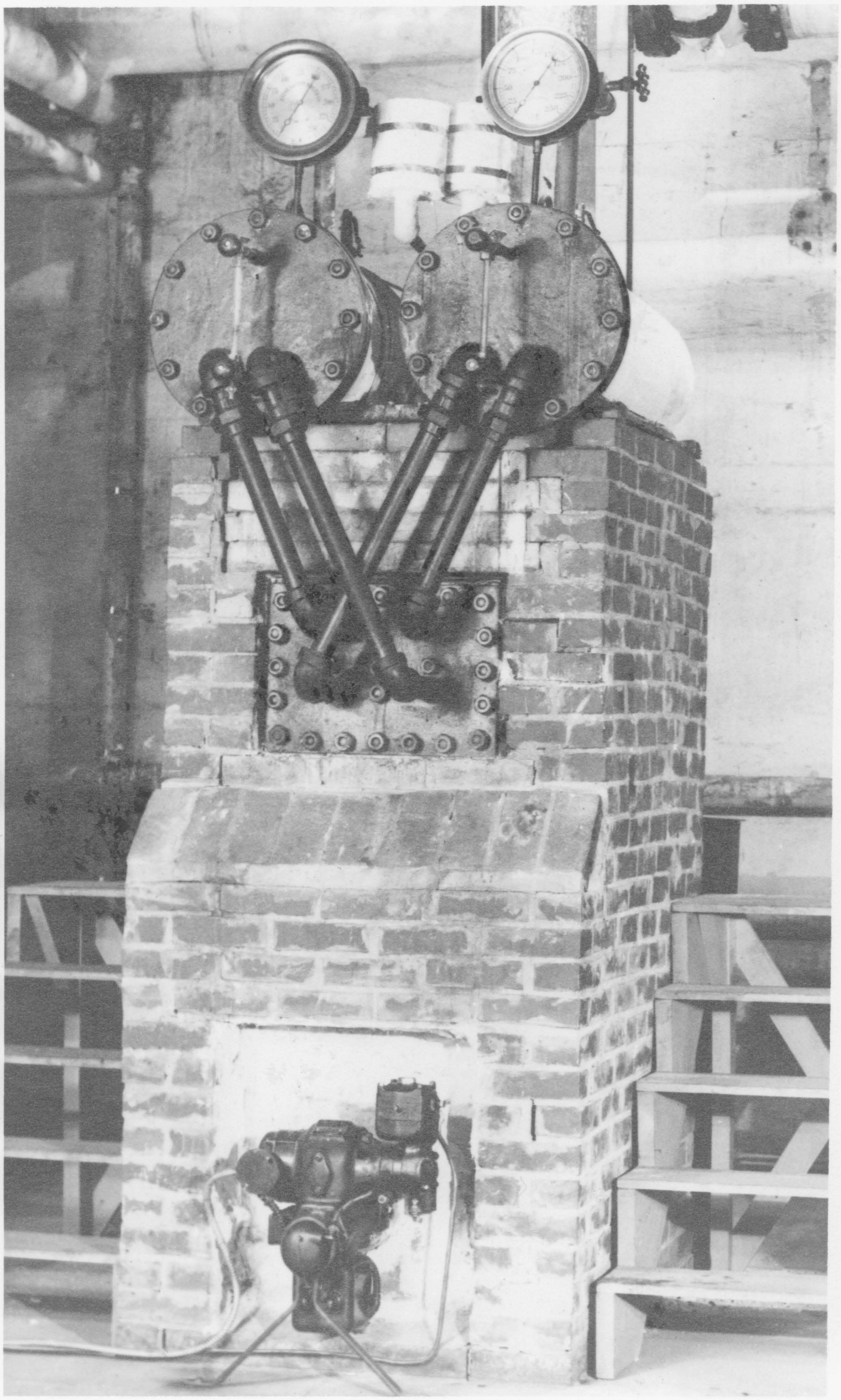
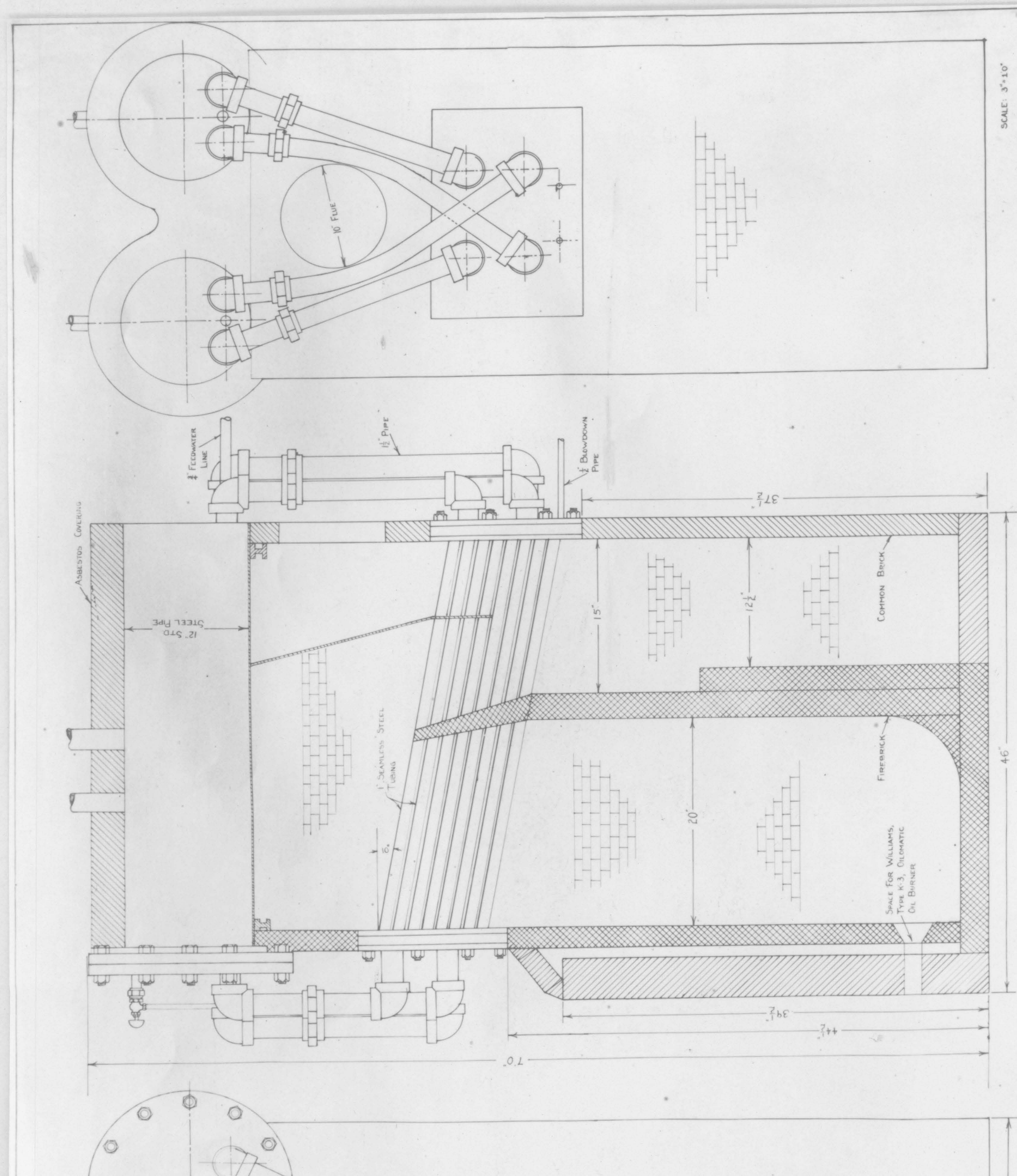


FIG. 1 Photograph of Duplex Test Boiler



Assembly: Duplex Test Boiler

FIG. 2

PART I

Description and Explanation of the Various Features of the Duplex Test Boiler

It was the intention of the designers of this boiler to make a complete unit small enough to be inexpensively operated, and large enough to make tests comparable to tests made on actual boilers.

The most unique feature of the boiler is the fact that the tubes are divided into four banks, each bank having its own separate headers. By referring to the flow diagram, Fig.2 page 11, the piping layout for the unit is clarified. The top right or "B" bank of tubes and the lower left or "D" bank of tubes, have individual circulation connections leading to the steaming drum "F". The top left or "A" bank and the lower right or "C" bank of tubes, each have individual connections leading to the steaming drum "E".

The two drums with the circulating connections leading to the tubes can be readily seen by referring to the photograph on page 8, Fig. 1, or the Assembly drawing on page 9, Fig. 2.

Each steaming drum has its own hot well, feed pump, supply line, water gage glass, pressure gage, steam discharge line, and safety pop valve. These two separate and distinct, yet identical boiler units, are installed over the same combustion chamber and receive energy from a single burner.See Fig.4,page14.) Since the same amount of heat is supplied to each of the units, any test may be run in duplicate using a different water or a different treatment in either unit.

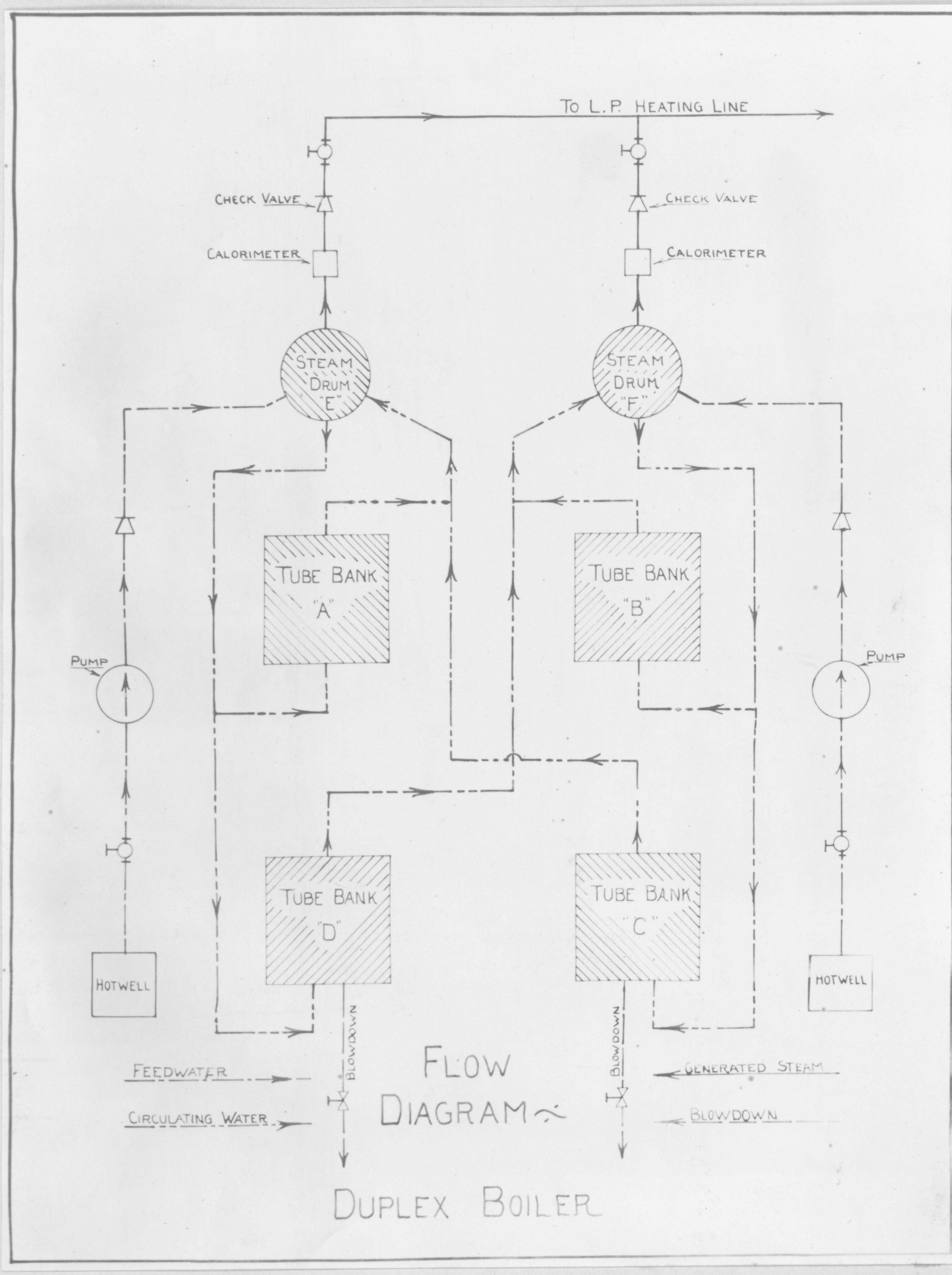

To L.P. Heating Line
Check Valve
Check Valve
Calorimeter
Calorimeter
Steam Drum "E"
Steam Drum "F"
Tube Bank "A"
Tube Bank "B"
Pump
Pump
Tube Bank "D"
Tube Bank "C"
Hotwell
Hotwell
Blowdown
Blowdown
Feedwater
Circulating Water
Generated Steam
Blowdown
Flow Diagram ~
Duplex Boiler

FIG. 3

Two feedwater pumps are necessary in order to supply each unit with its respective water. In order to economize one two-cylinder, 3" X 2" X 3", Worthington pump has been utilized. The intake valves on the water side have been closed off and holes drilled in each side to receive the individual suction lines. A steel dividing sheet brazed into the head serves to divide the discharge of each cylinder. A new discharge line was placed in the top half of each side of the head. Should one boiler unit require more or less water than the other unit, the supply may be regulated by the by-pass valves. Fig. 5, shows the arrangement of the hot wells, pump, by-pass valves, and discharge lines.

OPERATION OF DUPLEX TEST BOILER

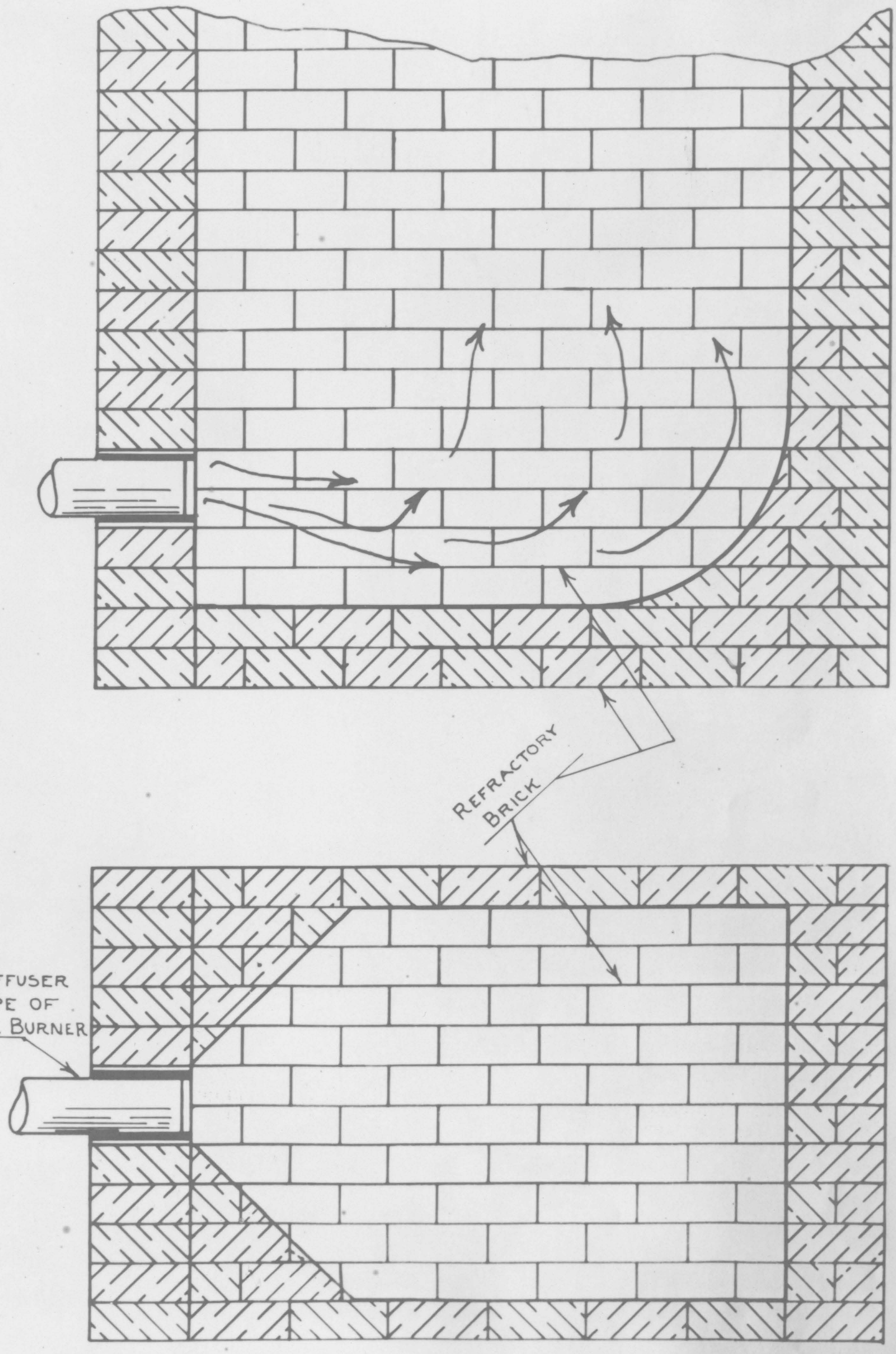
The operation of this boiler should not be undertaken by anyone who has not had some boiler-room experience.

Due to the fact that all the controls are manual, the boiler requires the constant attention of at least one operator.

Before starting the burner, the water level should be brought to one-half the gage glass. To start the feedwater pump, first make sure that the globe valves in the discharge line are open and the by-pass valves closed, and then open the throttle valve on the high pressure steam line. The flow of water may be regulated by the speed of the pump or by opening or closing the by-pass valves. The quantity of water evaporated is too small to be metered accurately and must be weighed before it is placed in the hot wells. The hot wells hold approximately two hours supply of water.

To operate the oil burner, first open the valve in the oil feed line, then remove the large brass nut above the oil inlet connection and allow the oil to fill the straining chamber. Replace the nut. Next close the main fuse switch and then the right (white) knife switch. This starts the ignition arc. The left (black) knife switch is next closed, which starts the burner motor, driving the forced draft fan and the oil metering pump. As soon as the oil is ignited, disconnect the ignition switch. The forced draft and stack draft are regulated by the louvers on the fan housing and the damper in the stack pipe. The air and oil supply should be so regulated as to give a dull orange flame with red tips, no smoke, and a CO_2 content in the flue gas of 10% or above.

It has been found that more accurate tests are made when the runs are continuous rather than intermittent, but should the boiler be operated intermittently or for any reason be allowed to cool, the following procedure should be used: In shutting down the boiler the settings of forced draft, stack draft, and oil metering pump should not be changed. Upon starting it will be noted that a soot will be deposited on the cool walls and tubes. To prevent this formation and to maintain approximately the same outer tube surface conditions, a soot remover is placed in the combustion chamber. This remover is a mixture of one part lead oxide and five parts sodium chloride. Not more than two ounces should be used per application. More than this amount may cause the walls to slag down at the high temperature. A small blow pipe is used to scatter the remover directly over the flame.



COMBUSTION CHAMBER FOR DUPLEX BOILER

FIG. 4

The steam discharge valves should be kept closed until the desired operating pressure is reached. These valves must be operated manually thereafter to maintain a constant pressure. The steam generated is discharged into the low pressure heating main. The operator should be sure that the main line is open before starting the boiler.

Additional Instruments for Making Test Run

1 Thermometer, 32°F to 210°F (room temperature)

2 Thermometers, 32°F to 400°F (calorimeters)

2 Thermometers, 32°F to 300°F (feedwater)

1 Thermometer, 32°F to 600°F (flue gas)

Optical Pyrometer (furnace temperature)

Orsat Flue Gas Analyzer

Draft Gage

Platform scales, 0 to 100 pounds

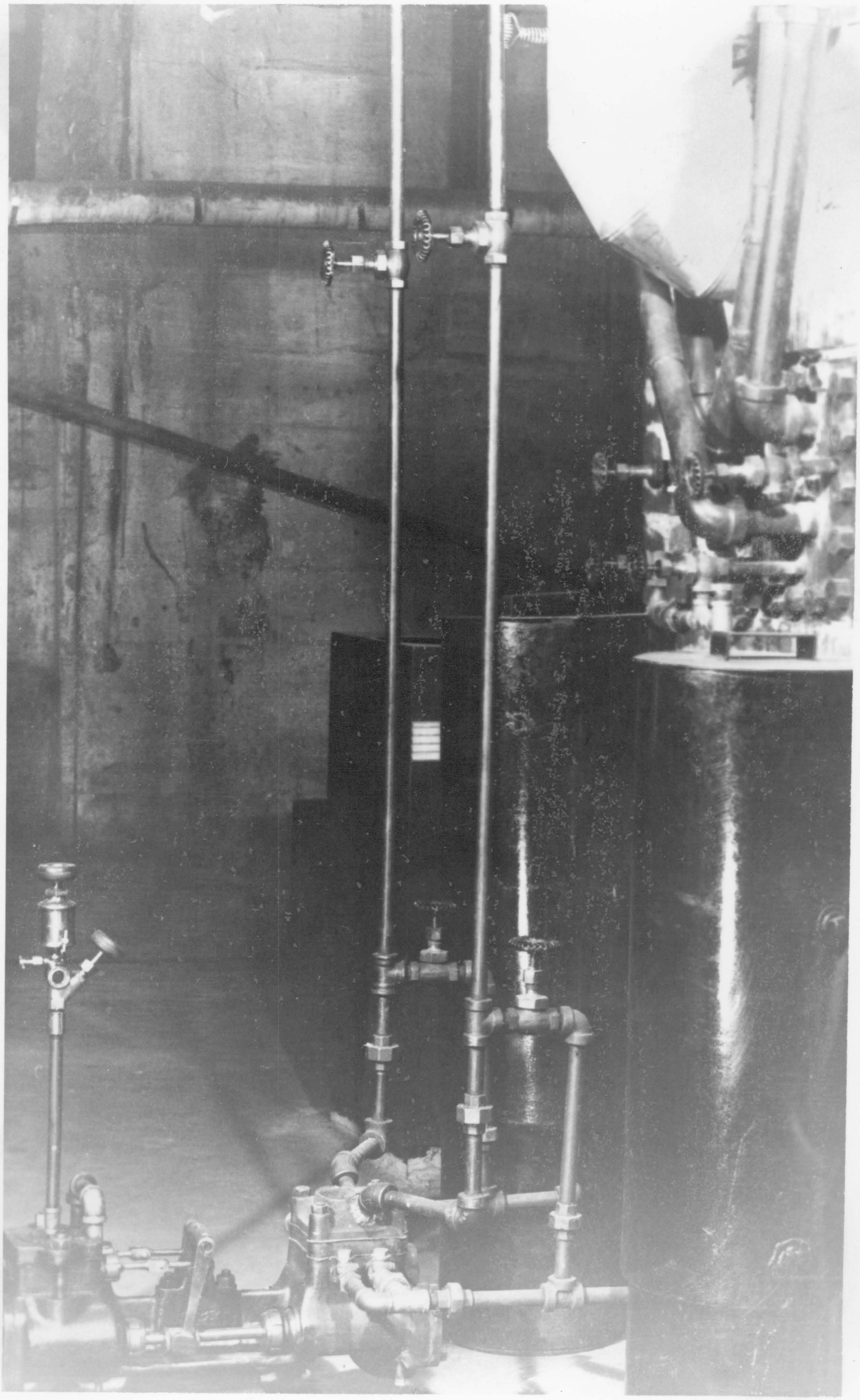


Fig. 5 Rear View of Duplex Test Boiler

PART II

Test Procedure

1. Test No. 1

This test was made, using condensate from the V.P.I. low-pressure heating system as feedwater in both drums. The object of this first test was to balance, as nearly as possible, the two boiler units so that each unit would evaporate the same quantity of water at the same conditions. This was done by shifting the position of the burner on the adjustable support. (See Fig. 1, page 8.) After considerable difficulty and several lengthy tests, it was concluded that due to improper circulation in the upper left bank of tubes, Boiler No. 2 would have a lower evaporation. The test was then continued to obtain the basic data for comparing the results of the tests, using treated and untreated feedwater.

The oil metering pump was set to give an oil consumption of approximately fourteen pound per hour. (See Oil-O-Matic Installation and Service Manual, Part VI, page 40.) At the end of each hour the oil in the supply tank was brought to the "full" mark and the amount of oil added recorded. Hourly, the water in the hot wells was brought up to the respective hook gages and the weight of added water to each well recorded as the water evaporated during the preceding hour. Feedwater temperature readings were made each hour. The boiler pressure was maintained at 110 pounds per square inch.

The throttling calorimeters were designed for atmospheric back pressure so it was necessary to read only the temperature in order to obtain the quality of the discharged steam. The barometer pressure and complete flue gas analyses were recorded for each six hour periods.

2. Test No. 2.

After the last reading for test No. 1 was taken, the hot wells were emptied and filled with V.P.I. campus water. The blow-down valves were then opened and the campus water pumped in, maintaining the same water level. In order to wash out the boiler completely, the blow-down valves were left open, and the raw water pumped through the boiler for two hours.

In adding the treatment to the boiler units, it was necessary to empty the hot well and pump the treatment directly into the boiler without allowing it to stand or settle out. 12 ounces of compound No. 1 was added to Boiler No. 1 and 0.28 ounces of compound No. 2 to Boiler No. 2.

The test was run in the same manner as described for Test No. 1.

After the last reading, a sample of blow-down was taken from each tube bank.

3. Test No. 3.

In order to remove as much of the boiler compound as possible without disassembling the boiler, the two units were washed out in a similar manner as described in Test No. 2. This wash was continued for six hours.

This test was made using untreated water. The same hourly and six hour period readings were taken.

At the end of this run, blow-down samples were taken from each tube bank (It should be mentioned here that these samples were cooled at atmospheric conditions.)

The burner was then cut off and as soon as the boiler cooled down, the front header plate was removed. Photographs were made of the cooled tubes. The thickness of the scale was measured by means of a micrometer.

Units Used in Taking Data

Reading	Abbreviation	Units
Time	Time	hours
Water Evaporated	Water Evap.	lbs./hr.
Oil Added	Oil Added	lbs./hr.
Steam Pressure(gage)	Pressure	lbs./sq.in.
Calorimeter Temperature	Cal. Temp.	°F.
Feedwater Temperature	Feed Temp.	°F.
Exit Gas Temperature	Gas Temp.	°F.
Room Temperature	Room Temp.	°F.
Carbon Dioxide	CO_2 %	percent
Oxygen	O_2 %	percent
Carbon monoxide	CO %	percent

DATA SHEET

Test Number I.

Feedwater: Boiler No.1 Condensate
Boiler No.2 Condensate

Time	Water No.1	Evap. No.2	Oil Added	Pressure No.1	Pressure No.2	Cal. No.1	Temp No.2	Feed No.1	Temp. No.2	Gas Temp	Room Temp	CO_2 %	O_2 %	CO %
2	67.5	66.5	14	110	110	289	293	142	150	353	90			
3	72.5	65.5	13.25	112	105	287	291	140	133	365	89			
4	62.5	67.5	14.5	110	110	285	283	134	148	350	84			
5	77.75	72.0	13.25	110	115	284	287	134	135	348	80			
6	75	70.0	14.0	105	110	283	285	136	136	364	76	10.4	6.6	.1
7	70	67.5	15.5	105	105	282	283	136	135	354	74			
8	69.5	65.0	13.25	115	105	284	283	146	153	362	74			
9	72	66.75	12.75	110	105	282	283	138	129	348	73			
10	63.75	60.5	13.5	120	110	289	286	138	132	353	74			
11	83	75.75	13.75	100	105	280	285	136	132	330	73			
12	76	63.25	12.5	114	107	284	285	129	130	375	73	10.5	6.5	.00
1	87	77.75	13.5	110	105	284	284	127	126	321	73			
2	69	63.0	15.0	110	115	284	286	145	142	335	73			

DATA SHEET

Test Number I.

Feedwater: Boiler No.1 Condensate
Boiler No.2 Condensate

Time	Water No.1	Evap. No.2	Oil Added	Pressure No.1	Pressure No.2	Cal. No.1	Temp. No.2	Feed No.1	Temp No.2	Gas Temp.	Room Temp.	CO_2 %	O_2 %	CO %
3	70.25	62.0	14.25	112	100	284	284	145	142	380	73			
4	71	63.25	13.75	110	108	284	285	138	134	343	71			
5	72	61.5	13.75	95	85	278	274	140	140	389	68			
6	71	68.0	13.25	85	95	272	279	140	140	339	66	10.6	6.7	.1
7	89.75	71.0	14.50	95	103	267	282	142	136	358	71			
8	76.25	78.0	13.25	100	87	272	271	135	145	350	74			
9	64.5	62.5	13.75	110	107	283	284	144	140	392	74			
10	70.5	68.75	11.75	110	115	283	286	140	132	378	72			
11	68.75	63.50	13.75	100	100	280	280	135	142	302	71			
12	88.5	88.0	14.25	117	105	287	287	140	142	361	70	10.8	6.4	.2
1	69.5	65.5	14.25	117	110	287	284	140	135	335	71			
2	75.0	61.25	13.5	107	96	283	278	140	139	366	71			
3	75.5	69.5	13.0	105	105	281	279	137	134	378	73			
4	70.5	69.25	16.75	85	85	274	267	138	132	355	71			

DATA SHEET

Test Number I.

Feedwater: Boiler No.1 Condensate
Boiler No.2 Condensate

Time	Water No.1	Evap. No.2	Oil Added	Pressure No.1	Pressure No.2	Cal. Temp. No.1	Cal. Temp. No.2	Feed Temp. No.1	Feed Temp. No.2	Gas Temp.	Room Temp.	CO_2 %	O_2 %	CO %
5	72.5	64.5	12.0	76	120	284	280	142	130	396	70			
6	69.75	67.5	13.5	102	100	281	279	148	130	309	69	10.3	6.7	.1
7	75.25	69.75	13.75	110	100	287	286	142	130	377	68			
8	69.0	66.5	14.0	105	105	279	281	121	105	329	72			
9	69.5	72.5	14.5	100	110	281	285	138	143	330	74			
10	68.5	66.5	10.0	110	110	284	286	140	140	362	76			
11	70.75	67.25	12.5	111	112	284	287	134	136	351	79			
12	75.75	66.5	13.5	120	120	287	282	140	142	366	94	10.5	6.4	.00
1	70.25	66.75	12.25	115	120	286	282	164	152	372	93			
2	69.5	69.75	13.75	115	110	286	281	162	154	362	92			
3	66.5	64.0	13.5	110	113	283	282	158	148	384	93			
4	81.0	64.75	13.75	110	115	281	280	152	146	336	89			
5	69.0	66.5	13.0	110	110	283	280	150	138	322	85			
6	73.0	69.25	13.25	110	115	281	281	154	146	316	85	10.4	6.7	.2

DATA SHEET

Test Number I.

Feedwater: Boiler No.1 Condensate
Boiler No.2 Condensate

Time	Water No.1	Evap. No.2	Oil Added	Pressure No.1	Pressure No.2	Cal. No.1	Temp. No.2	Feed No.1	Temp. No.2	Gas Temp.	Room Temp.	CO_2 %	O %	CO %
7	74.0	70.75	13.75	115	115	283	282	163	163	310	82			
8	69.5	67.25	13.5	118	116	282	280	164	162	310	82			
9	76.0	69.25	15.0	111	113	279	279	156	155	388	78			
10	75.25	64.25	11.0	106	105	278	276	153	148	368	79			
11	64.0	68.25	13.5	107	105	280	277	146	156	358	78			
12	75.75	69.25	13	104	101	275	272	142	144	342	75	10.6	6.4	.1
Average	72.61	67.52	13.52	107.6	106.9	282.0	282.0	143.2	139.0	352.8	76.9	10.5	6.5	0.2

DATA SHEET

Test Number II.

Feedwater: Compound No. 1 in Boiler No. 1
Compound No. 2 in Boiler No. 2

Time	Water No. 1	Water No. 2	Oil	Pressure No.1	Pressure No.2	Cal. No.1	Temp. No.2	Feed No.1	Temp. No.2	Exit Gas	Room Temp.	CO_2 %	O_2 %	CO %
1	69.5	58.0	12.75	115	115	286	283	148	148	391	75			
2	62.25	57.25	13.0	120	115	285	280	134	132	388	74			
3	73.0	69.25	13.5	117	107	286	279	127	132	390	79			
4	69.75	63.5	13.5	112	118	284	282	130	134	392	83			
5	78.0	68.75	13.5	110	112	284	280	130	128	395	86			
6	73.75	66.25	13.0	115	105	287	280	130	130	395	88	10.5	6.5	0.0
7	74.75	70.5	13.25	110	108	284	280	132	131	391	90			
8	76.25	70.0	13.5	118	115	284	280	140	121	437	91			
9	72.75	68.25	13.75	110	108	283	279	139	130	402	92			
10	71.0	58.0	12.5	115	110	284	280	144	131	400	92			
11	73.25	68.0	13.5	110	110	286	284	132	128	414	92			
12	78	69.5	13.0	115	110	285	281	134	134	414	92	10.2	6.6	0.0
1	70.75	59.75	13.25	111	110	285	281	130	128	422	88			
2	74.75	66.5	12.75	110	113	283	280	131	136	398	85			

DATA SHEET

Test Number II.

Feedwater: Compound No. 1 in Boiler No.1
Compound No. 2 in Boiler No.2

Time	Water		Oil	Pressure		Cal.	Temp.	Feed	Temp.	Exit	Room	CO	O	CO
	No.1	No.2		No.1	No.2	No.1	No.2	No.1	No.2	Gas	Temp.	$\%^2$	$\%^2$	%
3	72.5	66.5	13.5	115	112	287	282	132	132	400	84			
4	67.0	59.5	13.0	115	115	287	284	135	132	401	83			
5	75.75	68.0	12.5	112	111	283	280	132	130	400	80			
6	73.0	62.25	13.25	110	109	284	280	130	134	400	79	10.3	6.4	0.2
7	72.0	65.75	13.25	114	112	285	281	120	124	400	77			
8	73.5	66.0	13.5	110	110	286	284	136	134	399	76			
9	76.0	68.0	13.5	113	113	285	282	136	134	396	77			
10	77.0	67.75	13.5	110	110	285	283	138	138	392	75			
11	71.0	67.0	13.25	115	117	282	280	132	132	392	74			
12	68.25	64.5	13.5	114	115	281	280	137	137	389	74	10.6	6.7	o.1
1	68.0	69.0	13.5	115	114	281	279	136	138	389	72			
2	74.0	69.75	13.5	110	109	280	276	133	131	387	76			
3	69.5	67	13.0	113	113	281	279	129	129	391	80			
4	76.75	75.0	13.25	113	112	281	279	134	138	389	84			

DATA SHEET

Test Number II.

Feedwater: Compound No. 1 in Boiler No. 1
Compound No. 2 in Boiler No. 2

Time	Water		Oil	Pressure		Cal.	Temp.	Feed	Temp.	Exit	Room	CO_2	O_2	CO
	No.1	No.2		No.1	No.2	No.1	No.2	No.1	No.2	Gas	Temp.	%	%	%
5	83.0	82.25	14	118	113	283	279	142	126	392	88			
6	77.5	73.25	14.0	118	117	282	280	134	140	389	88	10.7	6.3	0.3
7	69.0	65.75	12.0	117	113	286	282	142	134	399	87			
8	70.0	63.75	13.75	110	107	283	278	146	142	398	89			
9	78.5	71.75	13.75	113	110	283	279	142	142	402	91			
10	78.5	71.0	13.5	107	107	285	281	138	144	403	94			
11	77.0	71.25	13.5	113	114	286	281	138	148	401	92			
12	76.25	69.25	13.25	110	110	288	284	136	140	402	92	10.8	6.2	0.4
1	74.25	65.5	14.0	119	120	284	281	135	144	401	89			
2	80.5	77.25	13.5	117	117	284	281	143	148	402	88			
3	79.0	83.25	13.75	112	110	281	278	138	141	398	83			
4	73.5	70.75	13.5	115	115	282	280	142	142	392	83			
5	72.5	68.25	13.5	113	110	281	278	141	139	388	82			
6	76.0	72.25	13.5	115	114	281	279	135	139	388	79	10.0	6.8	0.1

DATA SHEET

Test Number II.

Feedwater: Compound No. 1 in Boiler No. 1
Compound No. 2 in Boiler No. 2

Time	Water		Oil	Pressure		Cal.	Temp.	Feed	Temp.	Exit	Room	CO_2	O_2	CO
	No.1	No.2		No.1	No.2	No.1	No.2	No.1	No.2	Gas	Temp.	%	%	%
7	81.25	71.25	12.75	117	114	282	279	131	133	389	79			
8	73.5	70.75	12.75	117	115	283	281	129	130	392	79			
9	71.0	48.5	13.75	112	109	284	280	140	132	390	79			
10	77.0	68.75	13.25	109	110	285	281	144	134	391	79			
11	79.5	68.75	14.0	111	111	285	280	144	143	390	79			
12	77.5	68.25	13.25	115	120	285	282	144	145	390	80	10.4	6.1	o.1

AVERAGE OF EACH 6-HOUR PERIOD

Test Number II

Feedwater: Compound No. 1 in Boiler No. 1
Compound No. 2 in Boiler No. 2

Period	Water No.1	Water No.2	Oil	Pressure No.1	Pressure No.2	Cal. No.1	Temp. No.2	Feed No.1	Temp. No.2	Exit Gas	Room Temp.	CO_2 %	O_2 %	CO %
1	71.04	63.83	13.20	114.8	112.0	285.3	280.6	133.1	134.0	391.8	80.8	10.5	6.5	0.0
2	74.33	67.37	13.25	113.0	110.1	284.3	280.6	136.8	129.1	409.0	91.3	10.2	6.6	0.0
3	72.29	63.75	13.04	112.1	111.6	284.8	281.1	131.6	132.0	403.5	83.1	10.3	6.4	0.2
4	72.95	66.50	13.41	112.6	112.8	284.0	281.6	133.1	133.1	394.6	75.5	10.6	6.7	0.1
5	74.79	72.70	13.54	114.5	113.0	281.3	278.6	134.6	133.6	389.5	81.3	10.7	6.3	0.3
6	74.87	68.79	13.29	111.6	110.1	285.1	280.8	140.3	141.6	400.8	90.8	10.8	6.2	0.4
7	75.95	72.87	13.62	115.1	114.3	282.1	279.5	139.0	142.1	394.8	84.0	10.0	6.8	0.1
8	76.62	66.04	13.45	113.1	113.1	284.0	280.5	138.6	136.1	390.3	79.2	10.4	6.1	0.1

DATA SHEET

Test Number III

Feedwater: Boiler No. 1 Untreated Water
Boiler No.2 Untreated Water

Time	Water No.1	Water No.2	Oil	Pressure No.1	Pressure No.2	Cal. No.1	Temp. No.2	Feed No.1	Temp. No.2	Exit Gas	Room Temp.	CO_2 %	O_2 %	CO %
1	61.25	69.50	14.0	117	110	286	280	133	136	372	83			
2	76.5	70.50	13.75	106	108	284	279	136	133	371	85			
3	68.25	72.00	13.25	115	110	287	280	137	137	375	86			
4	79.0	71.0	13.5	113	112	282	280	139	138	372	86			
5	71.25	72.0	13.5	120	119	285	281	140	134	372	91			
6	76.5	68.5	13.5	107	106	281	277	137	138	370	90	10.5	6.5	0.0
7	83.75	64.75	13.5	119	115	285	280	136	137	365	90			
8	72.75	65.50	13.5	107	105	280	276	134	132	360	89			
9	58.75	77.25	13.5	110	110	282	279	134	130	360	87			
10	42.25	76.5	13.75	103	106	280	278	132	132	349	83			
11	71.0	70.75	13.0	110	108	286	280	130	130	352	76			
12	71.5	70.00	14.75	112	112	284	281	142	136	348	76	10.6	6.3	0.0
1	68.5	70.75	13.00	112	112	285	281	134	140	354	73			
2	78.25	70.25	13.0	110	112	282	278	133	138	349	71			

DATA SHEET

Test Number III

Feedwater: Boiler No. 1. Untreated Water
Boiler No. 2. Untreated Water

Time	Water		Oil	Pressure		Cal.	Temp.	Feed	Temp.	Exit	Room	CO_2	O_2	CO
	No.1	No.2		No.1	No.2	No.1	No.2	No.1	No.2	Gas	Temp.	%	%	%
3	67.1	66.50	13.75	110	108	284	279	136	132	355	70			
4	73.5	66.00	14.0	110	111	282	279	132	128	357	73			
5	66.75	72.00	13.0	110	106	285	278	129	132	358	69			
6	80.75	65.00	13.5	115	111	282	278	128	127	359	68	9.8	6.4	0.0
7	73.75	63.50	13.5	110	110	281	277	131	134	361	70			
8	66.25	74.75	13.5	114	114	281	278	133	132	364	72			
9	65.0	69.50	13.5	107	108	281	278	136	135	366	74			
10	54.75	60.50	13.5	114	113	282	278	131	132	364	75			
11	62.75	70.50	13.5	110	110	283	280	134	124	368	72			
12	72.25	64.50	13.75	110	110	284	279	126	124	372	72	9.9	6.6	0.1
1	75.25	71.75	14.0	109	110	286	282	122	122	364	73			
2	72.25	69.25	13.75	110	109	285	281	120	124	368	73			
3	76.25	69.25	13.5	112	112	285	280	118	122	370	75			
4	71.0	68.00	13.25	111	110	284	279	122	120	372	74			

DATA SHEET

Test Number III

Feedwater: Boiler No. 1 Untreated Water
Boiler No. 2 Untreated Water

Time	Water No.1	Water No.2	Oil	Pressure No.1	Pressure No.2	Cal. No.1	Temp. No.2	Feed No.1	Temp. No.2	Exit Gas	Room Temp.	CO_2 %	O_2 %	CO %
5	70.75	70.25	13.75	110	110	286	279	128	130	370	75			
6	76.75	70.75	13.5	108	109	285	282	125	124	376	74	10.0	6.7	0.1
7	71.75	69.75	14.25	110	112	286	283	125	124	380	73			
8	73.5	68.50	13.25	113	113	281	279	122	120	378	72			
9	71.25	66.00	13.25	117	117	284	280	124	121	376	69			
10	75.00	70.75	13.5	117	117	284	280	124	122	378	71			
11	74.75	70.25	13.5	121	120	286	281	130	131	376	72			
12	76.75	62.50	13.25	114	113	284	280	131	133	372	69	10.2	6.8	0.2
1	59.0	67.25	13.25	116	115	284	279	132	131	380	68			
2	77.0	58.25	13.5	111	111	283	278	128	126	378	66			
3	68.75	54.50	14.25	109	111	282	278	118	120	379	65			
4	75.0	57.00	13.75	110	111	283	279	124	118	382	66			
5	76.25	56.75	13.5	108	109	282	278	122	126	386	67			
6	66.75	68.50	13.75	110	108	285	278	128	126	382	70	10.1	6.1	0.3

DATA SHEET

Test Number III

Feedwater: Boiler No. 1 Untreated Water
Boiler No. 2 Untreated Water

Time	Water No.1	Water No.2	Oil	Pressure No.1	Pressure No.2	Cal.° No.1	Temp. No.2	Feed No.1	Temp. No.2	Exit Gas	Room Temp.	CO_2 %	O_2 %	CO %
7	71.75	70.00	13.75	109	108	284	279	124	124	382	70			
8	76.5	57.75	14.0	110	114	280	280	124	124	384	73			
9	69.5	70.50	13.50	108	111	284	280	122	124	390	75			
10	70.0	62.25	13.75	111	113	285	280	126	122	392	78			
11	74.5	68.50	13.25	115	114	284	280	130	128	384	79			
12	68.75	66.50	13.75	114	112	285	280	136	132	386	80	10.6	6.2	0.2
1	74.0	65.75	13.5	117	117	285	280	136	132	394	84			
2	75.0	66.25	13.0	120	121	286	281	140	142	396	84			
3	79.25	45.75	13.75	115	116	284	280	142	143	398	85			
4	70.0	55.50	13.5	111	113	284	280	144	144	394	85			
5	65.00	62.25	13.5	110	110	283	281	126	126	400	81			
6	74.25	73.25	14.0	111	110	286	280	128	130	398	79	10.8	6.2	0.1
7	73.75	68.50	13.5	110	110	284	280	134	136	402	76			
8	76.25	66.50	13.25	111	109	284	279	136	138	404	74			

DATA SHEET

Test Number III

Feedwater: Boiler No. 1 Untreated Water
Boiler No. 2 Untreated Water

Time	Water No.1	Water No.2	Oil	Pressure No.1	Pressure No.2	Cal. No.1	Temp. No.2	Feed No.1	Temp. No.2	Exit Gas	Room Temp.	CO_2 %	O_2 %	CO %
9	73.0	66.25	14.0	110	110	287	284	140	134	410	73			
10	74.75	58.50	13.25	111	111	286	281	130	134	414	72			
11	73.75	62.00	13.5	110	109	286	281	134	132	406	69			
12	72.75	51.25	13.5	110	110	285	281	136	136	418	68	10.6	6.8	0.1

AVERAGE OF EACH 6-HOUR PERIOD

Test Number III

Feedwater: Boiler No. 1 Untreated Water
Boiler No. 2 Untreated Water

Period	Water No.1	Water No.2	Oil	Pressure No.1	Pressure No.2	Cal. No.1	Temp. No.2	Feed No.1	Temp. No.2	Exit Gas	Room Temp.	CO_2 %	O_2 %	CO %
1	73.79	70.58	13.58	113.0	110.8	284.1	279.5	137.0	136.0	372.0	86.8	10.5	6.5	0.0
2	70.66	70.79	13.66	110.1	109.3	282.8	279.0	134.6	132.8	355.6	83.5	10.6	6.3	0.0
3	72.46	68.50	13.37	111.1	110.0	283.3	278.8	132.0	132.8	355.3	70.6	9.8	6.4	0.0
4	70.79	67.04	13.54	110.8	110.8	282.0	278.3	131.8	130.5	365.8	72.5	9.9	6.6	0.1
5	73.71	70.12	13.62	110.0	110.0	285.1	280.5	122.5	123.6	370.0	74.0	10.0	6.7	0.1
6	73.83	67.95	13.50	115.1	115.3	284.1	280.5	126.0	125.1	376.6	71.0	10.2	6.8	0.2
7	72.12	60.37	13.66	110.6	110.8	283.1	278.3	125.3	124.5	381.1	67.0	10.1	6.1	0.3
8	71.83	65.91	13.66	111.1	112.0	283.6	279.8	127.0	125.6	386.3	75.8	10.6	6.2	0.2
9	72.91	61.45	13.54	114.0	114.5	284.6	280.3	136.0	136.1	396.6	83.0	10.8	6.2	0.1
10	70.04	61.50	13.50	110.3	109.8	285.3	281.0	135.1	135.0	409.0	72.0	10.6	6.8	0.1

PART III

THERMAL CALCULATIONS

The following tables are calculations made from the data by a method outlined by Everett P. Partridge in "The Formation and Properties of Boiler Scale", Bulletin No. 15, University of Michigan Engineering Research Department. In the calculation of K (overall coefficient of heat transfer in Btu./sq.ft./hr./°F.) only the heat transmitted by convection and conduction is considered. In the calculation of the maximum tube temperature, only the heat transmitted by radiation is considered.

From the data obtained it is impossible to determine what portion of the heat is transmitted by radiation or by convection and conduction. For this reason, these calculations are included only for the purpose of comparing the values for different runs. Recommendations for the accurate determination of these values are included in a latter part of the thesis.

TABLE I

Boiler	B	G	W	$\frac{Q}{At}$	dt	K
1	77,600	352.8	342	3110	406	7.65
2	72,800	352.8	341	2910	406	7.15

Units on following page.

Table II

Boiler Number I - Untreated Water

Run	B	$\frac{Ls}{ks}$	G	W	$\frac{Q}{At}$	dT	Kl
1	79,400	0.0232	372.0	344	3,180	490.0	6.50
2	76,000	0.0088	355.6	342	3,040	424.0	7.16
3	78,200	0.0042	355.3	342	3,130	423.0	7.40
4	76,200	0.0247	365.8	342	3,045	473.0	6.44
5	79,800	0.0232	370.0	342	3,190	491.0	6.50
6	80,300	0.0248	376.6	346	3,210	500.0	6.43
7	78,450	0.0381	381.1	342	3,130	528.0	5.92
8	77,700	0.0421	386.3	342	3,110	544.0	5.78
9	78,500	0.0487	396.6	345	3,140	564.0	5.57
10	75,400	0.0522	409.0	342	3,115	602.5	5.18

Boiler Number II - Untreated Water

Run	B	$\frac{Ls}{ks}$	G	W	$\frac{Q}{At}$	dT	Kl
1	75,800	0.0240	372.0	342	3,035	498.0	6.10
2	76,200	0.0000	355.6	341.5	3,045	424.0	7.15
3	73,600	0.0045	355.3	342	2,945	423.0	6.92
4	72,500	0.0230	365.8	342	2,900	473.0	6.13
5	76,000	0.0213	370.0	342	3,040	491.0	6.20
6	73,750	0.0295	376.6	346	2,950	500.0	5.90
7	65,500	0.0698	381.1	342	2,620	528.0	4.77
8	71,500	0.0505	386.3	343	2,860	545.0	5.25
9	66,100	0.0775	396.6	345	2,645	564.0	4.60
10	66,000	0.0875	409.0	341	2,641	602.2	4.40

B = B.t.u. added to boiler per hour.

$\frac{Ls}{ks}$ = resistivity factor

Gt = exit gas temperature.

$\frac{Q}{At}$ = rate of heat transfer in B.t.u./square feet/hour.

dT = logarithmic mean temperature difference from hot gases to boiler water.

Kl = heat transfer coefficient for scaled tubes.

Table III

Boiler No. 1 Treated with Number I Compound

Run	B	$\frac{Ls}{ks}$	G	W	$\frac{Q}{At}$	dT	Kl
1	7,740	0.0462	391.8	346	3,095	547	5.65
2	8,020	0.0567	409.0	343	3,210	601	5.34
3	7,850	0.0547	403.5	344	3,140	583	5.39
4	7,925	0.0462	394.6	344	3,170	562	5.64
5	8,110	0.0358	389.5	346	3,250	542	6.00
6	8,060	0.0462	400.8	344	3,270	578	5.65
7	8,070	0.0384	394.8	347	3,275	553	5.91
8	8,250	0.0372	390.3	343	3,300	555	5.95

Boiler No. 2- Treated with Number II Compound

Run	B	$\frac{Ls}{ks}$	G	W	$\frac{Q}{At}$	dT	Kl
1	6,920	0.0605	391.8	344	2,770	556	4.98
2	7,320	0.0750	409.0	342	2,930	630	4.65
3	6,930	0.0700	403.5	344	2,775	583	4.76
4	7,210	0.0545	394.6	344	2,890	562	5.14
5	7,820	0.0360	389.5	343	3,130	551	5.68
6	7,420	0.0560	400.8	342	2,970	582	5.10
7	7,830	0.0333	394.8	346	3,130	542	5.77
8	7,150	0.0537	390.3	343	2,860	555	5.16

B = B.t.u. added to boiler per hour.

$\frac{Ls}{ks}$ = resistivity factor

G = exit gas temperature

$\frac{Q}{At}$ = rate of heat transfer in B.t.u./square feet/hour.

dT = logarithmic mean temperature difference from hor gases to boiler water.

Kl = heat transfer coefficient for scaled tubes.

Feedwater and Blowdown Analyses

Table IV

Feedwater Analysis

Reported in Parts per Million	V.P.I. Campus Water	Condensate'
Total Solids	243.8	19.2
Organic and Volatile	109.2	2.8
Mineral Residue	133.6	16.4
CO_2	12.3	14.1
M.O. Alkalinity	207.0	19.0
O_2	4.5	1.0
SO_4	8.72	Trace
Hardness (Soap)	204.0	0.0
pH	7.68	7.15
SiO_2	9.2	No Test
Fe_2O_3 and Al_2O_3	31.0	" "
Ca	43.8	" "
Mg	23.8	" "
H_2CO_3	253.0	23.2

(') From V.P.I. low pressure heating system.

Table V

Blowdown Analysis

Test No. II

Reported in Parts per Million

Tube Bank	"D"	"B"	"C"	"A"
Total Solids	14,676	13,924	4,934	4,890
Suspended Solids	8,389	8,158	4,230	4,153
M0.Alkalinity	-	-	56.4	56.8
pH	11.3	11.3	9.3	9.3
Hardness (soap)	2,790	2,860	474	372

Table VI

Blowdown Analysis

Test No. III

Reported in Parts per Million

Tube Bank	"D"	"B"	"C"	"A"
Total Solids	2,945	2,302	3,809	2,520
Suspended Solids	2,208	1,561	3,071	1,859
M.O. Alkalinity	52.8	52.6	31.4	31.0
pH	7.9	8.8	7.3	9.1
Hardness (soap)	370	376	337	387

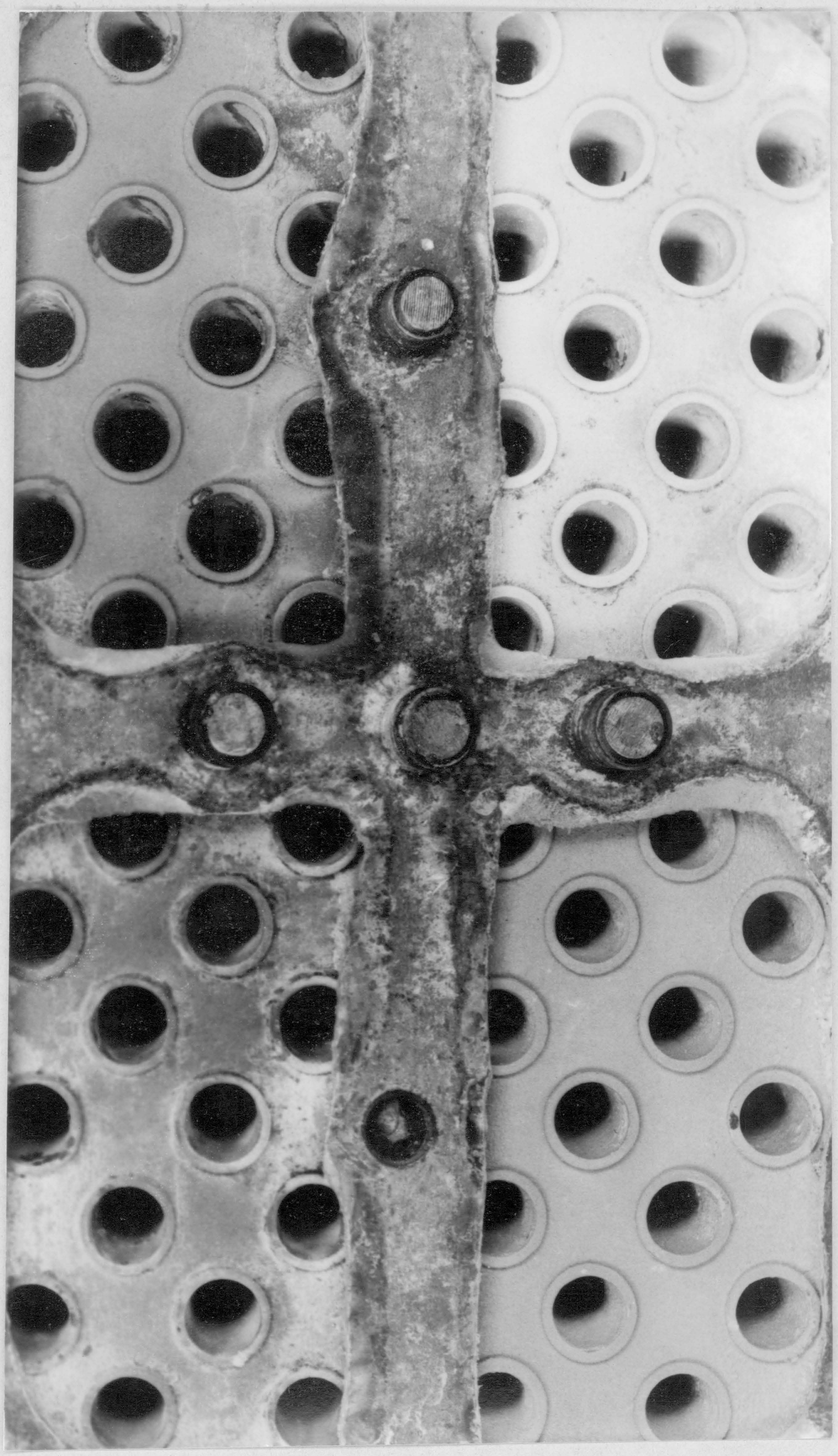
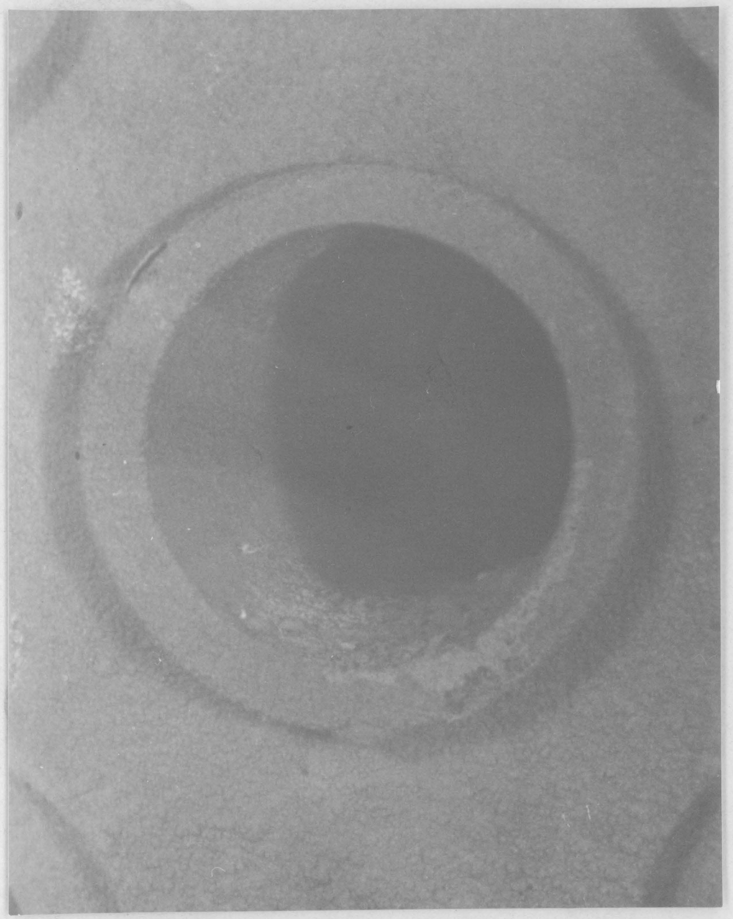
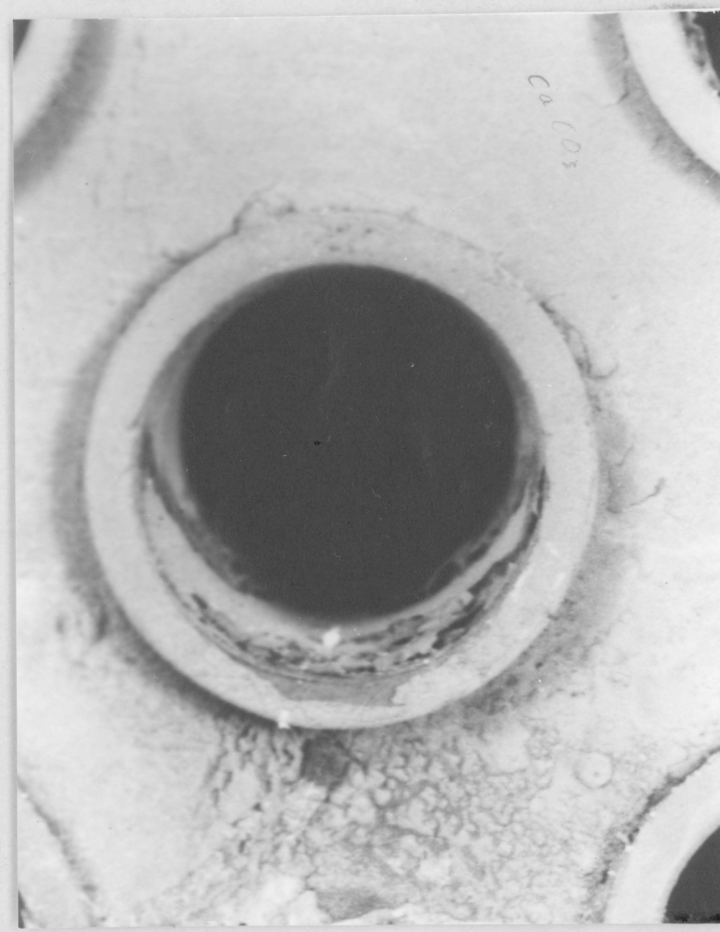


Fig.5 Photograph of Scaled Tubes

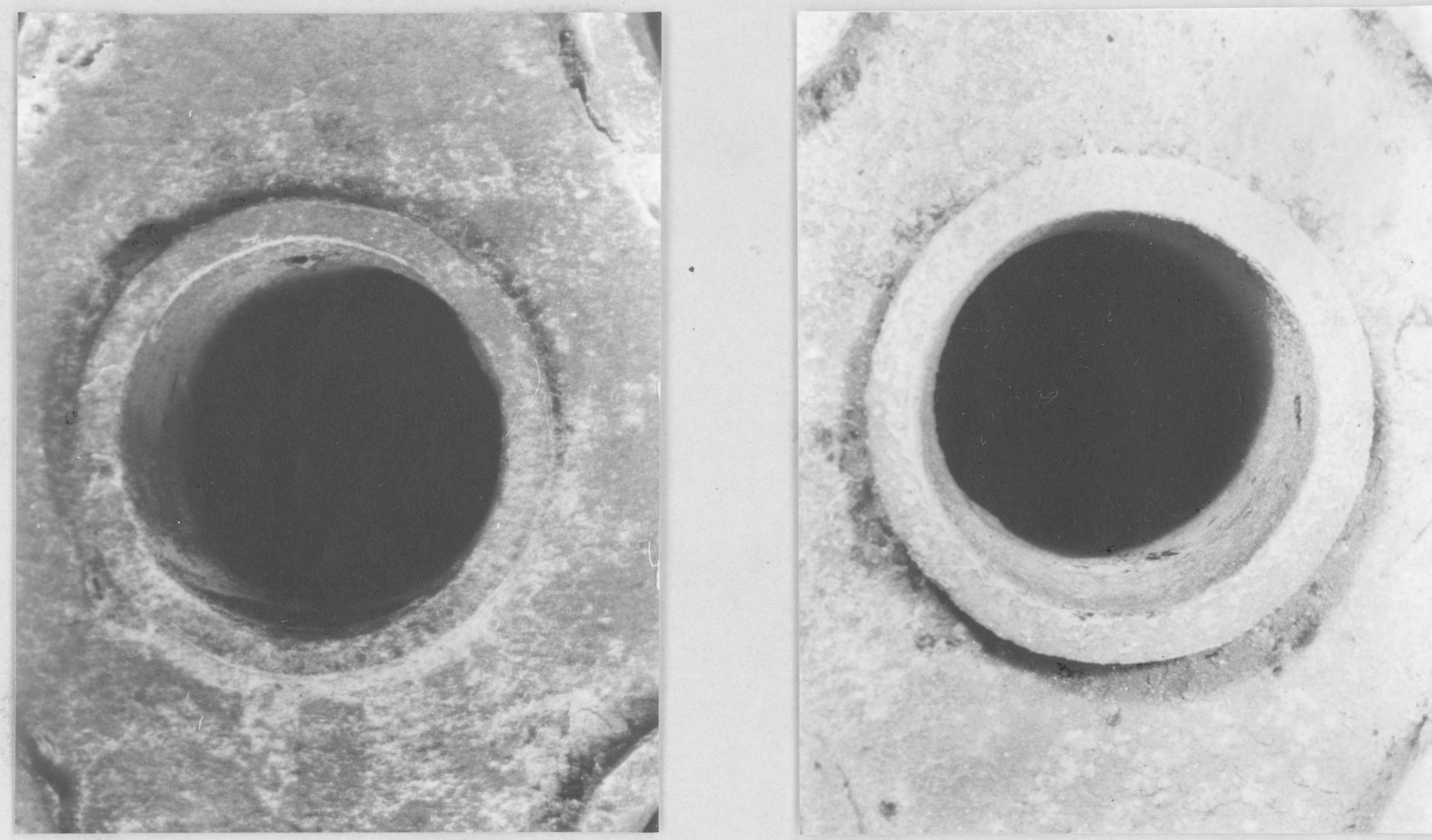


Tube from bank "D"



Tube from bank "B"

Fig. 6 Photograph of Scaled Tubes



Tube from bank "C"　　　　Tube from bank "A"

Fig. 7 Photograph of Scaled Tubes

TABLE NO. VII

Thickness of Scale in Tubes After Test

No. III

	1	2	3	4
Tube Bank A	.063	.051	.044	.053
Tube Bank B	.050	.048	.043	.049
Tube Bank C	.085	.063	.066	.068
Tube Bank D	.048	.058	.045	.045

Measured in inches

PART IV

Discussion of Results

1. Thermal Calculations:

Table VIII

Average Values of K and K1

Test No.	I	II	III
Boiler No. 1	7.65	5.69	6.29
Boiler No. 2	7.15	5.18	5.74

The above table indicates that in Boiler No. 1 the decrease in K when using treated and untreated water was respectively 1.36 and 1.96 B.t.u./sq.ft./hr./°F. or 17.77% and 25.62% decrease. In Boiler No. 2, in which Compound No. 2 was used, the decrease in K when treated and untreated, was respectively 1.41 and 1.97 B.t.u./sq.ft./hr./°F or 19.72% and 27.55%.

Table IX

Maximum Tube Temperature, °F.

Test No.	I	II	III
Boiler No. 1	453	574	704
Boiler No. 2	455	580	707

The above table indicates that the temperature of the tube metal did not reach the danger point in any test. Compound No. 1 had the greater effect in maintaining a lower temperature of the tube metal.

2. Feedwater and Blow-down Analyses.

Refering to Table VI, it will be noted that in test No. II there is a marked increase in total solids. In Boiler No. 1, this increase is approximately fifty times that of the feedwater. In Boiler No. 2, the total solids had increased approximately twenty times. This indicates that Compound No. 1 has the greater effect in keeping the solids from forming a scale on the tube and header surfaces. It is interesting to note that approximately 56% of the solids in the samples from Boiler No. 1 were in suspension. In the samples from Boiler No. 2, approximately 85% of the solids were in suspension. This difference in suspended solids may be taken as an indication of the type of each compound. Compound No. 2 is of the colloidal type, probably composed of an inert colloidal substance and a small amount of active chemicals. No. 1 is more likely to be chiefly an active alkali with other ingredients that cause the high concentration of calcium bicarbonate to be partly precipitated as a loose sludge and partly combined with an ion of the alkali and held in solution in a soluble form.

It will also be noted that the presence of an alkali is, moreover, indicated by the high pH value of the sample from Boiler No. 1.

The sample from Boiler No. 1, Test II, had a dark brown color, making it impossible to determine the Methyl Orange Alkalinity by the standard method. There is some hesitancy on the part of writer in discussing the relation between Methyl Orange Alkalinity and the Soap Hardness of the different samples.

It will be noted that the M.O. Alkalinity is generally and consistently low in all tests, whereas the Soap Hardness is relatively high and approximately eight times that of the M.O. Alkalinity. This indicates a gross error in the analysis or some peculiar combination of the salts in the boiler, due to the addition of compounds. It may be possible that both compounds are high in sulphates or phosphates, which would have a tendency to decrease the M.O. Alkalinity.

The pH values in Test III are different for the samples taken from the two tube banks of the same boiler. The pH is higher in the top tube banks, or cooler portions of the boiler. This may be due to the fact that the chemical reactions are more alkaline in the cooler banks. The fact that the lower banks have more static pressure may be a controlling factor in this incidence. When the boiler compounds were used, the pH values were the same in both banks.

The total and suspended solids in the samples from Test III indicate that much more of the incrustants have been deposited on the tubes.

3. Photographs of Scaled Tubes.

The photographs are of the front ends of the tubes. Since this portion of the tubes is in the first pass of the boiler, the scale is, of course, the heaviest. Referring to Table IX, it will also be noted that the scale is thicker in the lower tubes subjected to radiant heat.

The composition of the scale may be approximated, knowing the analysis of the feedwater and the position of the tube with respect to maximum and minimum heat transfer. Most authorities agree that scales of calcium sulphate, magnesium silicate, and magnesium hydroxide are generally formed in the hotter portions of the boiler and scales of calcium carbonate are generally formed in the cooler portions. This is particularly noticeable in Boiler No. 1. In Tube Bank "B", the scale is very porous and loosely held to the tube surface. This scale is chiefly calcium carbonate. In the Bank "D", the scale is somewhat thicker, more dense, and more tenacious. This is a calcium carbonate scale with some calcium sulphate, magnesium sulphate and perhaps, smaller quantities of hydroxide and silicates.

This formation is not so noticeable in Boiler No. 2. The thickness of the scale is greater in the lower tube Bank "C". The formation is, also, apparently greater in the lower half of each tube. Most authorities agree that, for continuous operation, this is due entirely to heat transfer and is not affected by gravitional force.

RECOMMENDATIONS FOR FUTURE WORK

The writer would like to make the following recommendations to the men who are to continue this work.

1. In order to obtain accurate data for the calculation of the overall coefficient of heat transfer and to obtain the accurate temperature of the tube surface, thermocouples should be placed in the tube surface in each pass of the boiler. One in each tube bank.[7]
2. The header plates should be removed and the tubes thoroughly turbined before each test.
3. All tests should be run in duplicate, first in one boiler, and after cleaning in the other boiler.
4. The length of each run should be at least 300 hours.
5. Blow-down samples for analysis should be filtered and cooled at boiler pressure.[8]

(7) "Measurement of Surface Temperature", D. F. Othmer and H. B. Coats , Ind. Engr.Chem., 20, 124, (1928)

(8) "Plant Tests of Various Methods for Determining Ratios for Boiler-Water Control., Leo. F. Schroeder and W. C. Collins, Ind. Engr. Chem. Anal. 4,218,(1932)

CONCLUSION

As a result of this thesis, it has been concluded that:

1. The data obtained in these tests are insufficient for an accurate determination of heat transfer or of the boiler metal temperature.

2. The length of this run indicates that, for accurate results, all future tests should be conducted for 300 hours.

3. Due to improper circulation, Boiler No. 2 had a lower evaporation. For this reason all future tests should be checked by making one test in each boiler.

It is generally concluded that with the preceding recommendations this is a reliable and practical method of testing boiler feedwater treatments.

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