EXPERIMENTS

...TO DETERMINE...

THE EFFECT OF FUEL CONSUMPTION

DUE TO SCALE DEPOSITS ON FLUES OF LOCOMOTIVE BOILERS

...BY...

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THESIS

For the Degree of Bachelor of Science in the School of Mechanical Engineering, College of Engineering. a

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UNIVERSITY OF ILLINOIS

...1899...

THE EFFECT OF SCALE ON THE EVAPORATION OF A LOCOMOTIVE BOILER.

On May and June 1898 with the assistance of the Mechanical Engineering department a series of tests were run on locomotive boiler 420 of the I.C.R.R. after having been in service 21 months to find the effect of scale deposited during that time. After taking the first series of tests with the boiler in the condition in which it came from the 21 months run it was sent to the shop for general repairs. All scale was weighed and samples taken from different places and a chemical analysis made to determine the constituents . It was then sent back to be tested for evaporation under the same conditions as before.

Details of test.

The locomotive was set in the round-house , over a pit, and the tender removed. A car of coal was then run in back of the engine and on this car was arranged scales for weighing the coal. All the water was weighed and delivered into tanks that were on top of the car and connected to the suction pipe of the injector. The tank was placed on car because the injector refused to work on any lift whatever. By disconnecting the valve rod the slide valve was moved back far enough so that the steam generated could pass directly into the exhaust pipe, and out through the nozzle and produce the necessary draft in the usual manner. To be on the safe side a 2 inch pipe was run from the dome to the atmosphere and a valve in this pipe furnished additional means of disposing of steam.

The tests were made by the standard method, i.e. raising steam to the running pressure, drawing the fire and starting with weighed wood. At the end of the test the ashes were all weighed and a sample taken and dried to determine the per cent of moisture. Several samples were taken at different times through the car of coal and dried to determine the per cent of moisture of the coal. One of the regular firemen fired for all the tests and the boiler and the furnace were under as near road conditions as possible. Before making the trial with the clean boiler the locomotive was allowed to make one or two trips on the road so as to have it perfectly clean.

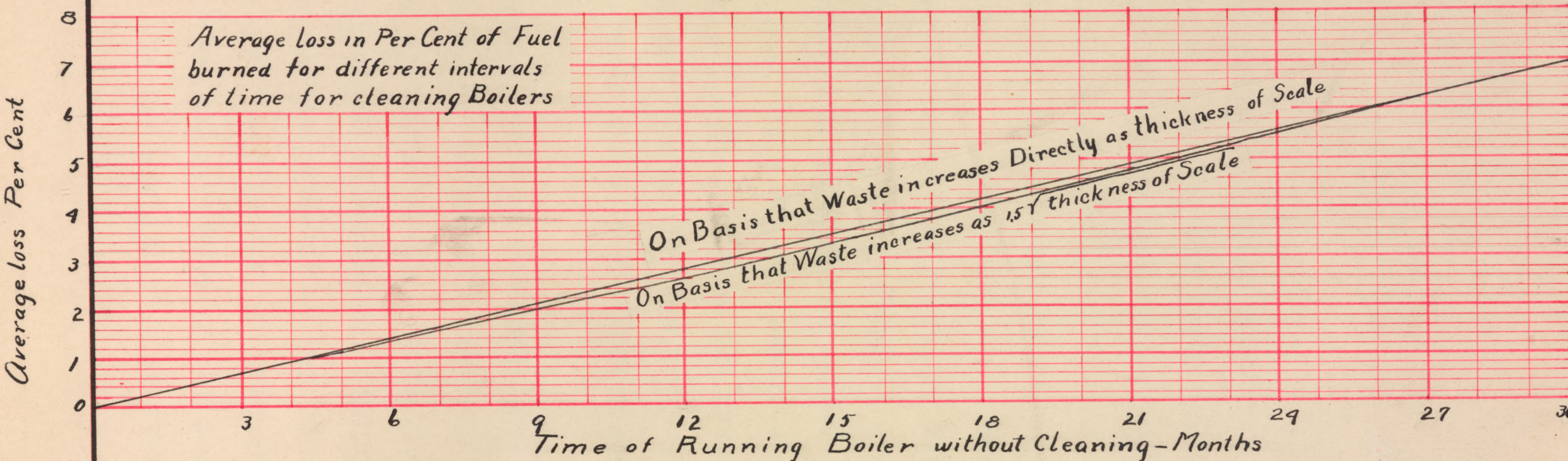
To avoid all trouble in feeding the boiler it was thought best to connect both injectors. This being done we were ready to start. After running about an hour both injectors failed and test had to be stopped. We then placed tank in a platform at height of car ,as seen in photograph. but still the injectors failed to work. The check valves were then taken out and cleaned after which we had no trouble.

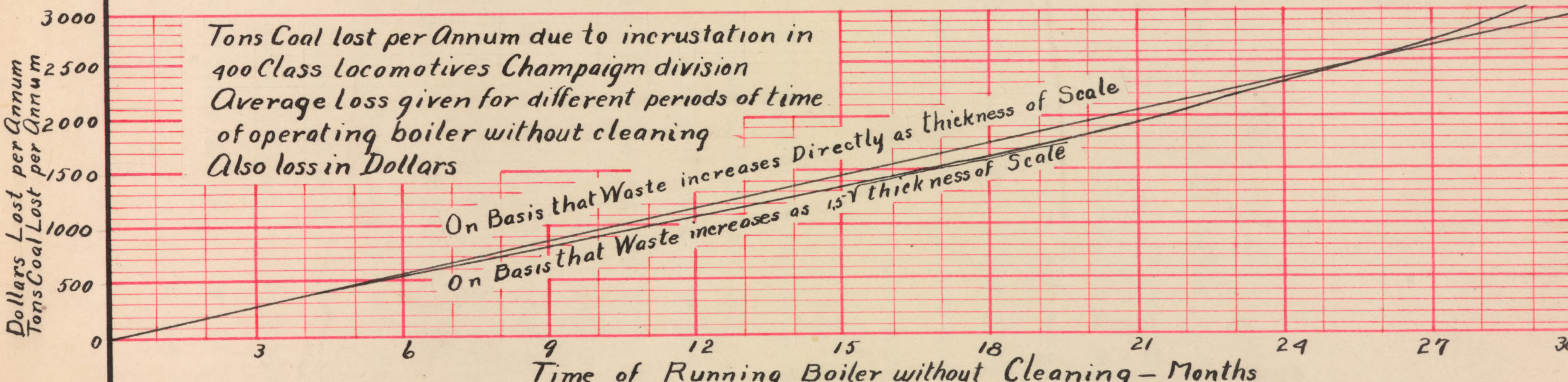
The locomotive on which the tests were made was a mogul freight. No 420, built by Rogers Locomotive Works and was one of 19 of this type used on the Champaign Division of the Illinois Central, between Champaign and Centralia. The leading dimensions and proportions are as follows:

Cylinders.	19 inch.
Stroke.	26 inch.
Diam. of drivers.	56½ inch.
Weight on drivers.	106400 pounds.
Weight on trucks.	19600 pounds.
Total weight of engine.	126000 pounds
Diam. of boiler.	62 inch
Number of tubes.	236
Diam. of tubes.	2 inch
Length of tubes over tube sheets	11 feet 15/16 inch
Length of firebox	114⅛ inch
Width of firebox	33⅜ inch
Depth of firebox front end	67⅞ inch
Depth of firebox back end	59⅞ inch
Length of grate	114⅛ inch
Width of grate	33⅜ inch
Diam. of dry pipe outside	8 inch
Diam. of steam dome	29⅛ inch
Height of steam dome	28 inch
Kind of lagging	Magnesia Sectional
Grate area	26.45 Sq. ft.
Total heating surface	1531.65 Sq. ft.
Area of draft through tubes	573.48 Sq. in.
Ratio of grate to heating surface.	1 to 57.91 Sq ft.

Fuel used.

Commercial name	Odin
Commercial size	Mine run
Lumps	75 percent
Small coal	20 percent
Slack	5 percent
Heat units per pound of dry coal, by calorimeter	12.240 B.T.U.





Average Cost of Coal per ton = $1.00 very nearly. Number of 400 class locomotives used = 19

District = 124.58 Miles. $\frac{1}{32}$" taken as unit thickness = Average thickness of 10.5 Months formation.

The two graphical diagrams show at a glance the average loss of fuel, in per cent of fuel burned for different intervals of time for cleaning a boiler and also the loss in tons of fuel, and in dollars, when coal costs $1.00 per ton, for 19 locomotives used on this division of the Illinois Central. In making diagrams it was assumed that all of the 19 locomotives accumulate scales at the same rate. They also indicate a probable loss of any locomotive used on this division as the average thickness of scale would be very near the same.

The loss due to scale in this boiler was 9.55 per cent. The average thickness of scale on principal heating surface was about $\frac{3}{64}$ inch. The locomotive was cleaned and tubes put in the Burnside Shops and when the boiler was opened all the scale removed was carefully weighed, the weight of scales on tubes being determined by weighing tubes before and after cleaning. The weight of scale from tubes was 360 pounds, and the weight of scale that could be removed from shell and firebox sheets was 125 pounds; thus making a total weight of 485 pounds. The internal condition of the boiler was noted and samples were taken from nine points for analysis. The thickness of the scale at these points were carefully measured and numbers refer to the points from which samples were taken. The same number will be used in the following table for reference.

RESULTS of BOILER SCALE ANALYSIS.

Scale constituents calculated to compounds

Ingredients	Composition in percent								
Scale from point No.	1	2	3	4	5	6	7	8	9
Silica	7.70	25.20	8.00	7.89	15.89	11.25	18.25	13.05	22.70
Iron and aluminium oxide	3.20	7.10	4.99	3.27	4.30	7 70	6.90	7.85	12.75
Calcium carbonate	65.81	20.92	48.90	61.17	30.36	67.08	45.51	24.33	28.32
Magnesium carbonate		3.05		8.14	8.71				5.86
Calcium sulphate	10.86	16.45	21.22	4.38	21.38	1.97	1.95	40.03	11.73
Magnesium sulphate									
Calcium oxide			1.90				5.69	1.14	
Magnesium oxide	9.55	19.52	448	5.47	7.66	9.29	16.77	9.12	18.45
Loss on ignition and undetermined	2.78	7.67	10.51	9.73	11.70	2.71	4.93	4.98	0.11

POINT NO. 1. Near injector discharge; hard and soft scale $\frac{1}{8}$ inch thick.

POINT NO. 2. On upper tubes, hard. smooth scale, uniform thickness $\frac{1}{32}$ inch.

POINT NO.3. On lower tubes, hard scale near middle, $\frac{1}{16}$ inch thick,

POINT NO. 4. Mud covering hard scale at No. 3 $\frac{3}{32}$ inch thick.

POINT NO. 5. Scale from side sheet, flue sheet, and tubes rough and scaly.

POINT NO. 6. From bottom of barrell 4ft. from flue sheet.

POINT NO. 7. On crown stays from 3 to 6 inches from crown sheet.

POINT NO, 8. On crown sheet, rivet heads and base of stays.

POINT NO. 9. From water line on vertical stay bolts.

As the calcium carbonate deposits easily we find the most of it around the injector discharge; while the calcium sulphates are brought down by a high temperature and therefore are found around the crown sheet and back end of tubes. It should be here noted that these boilers get comparitively good water, because this amount of scale is small, covering such a long period of time.


420
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RESULTS OF BOILER TRIAL AT Illinois Central Roundhouse

KIND OF BOILER (Commercial name) Locomotive

Test number	1	2	3	4
Date of trial	May 2	May 3	May 31	June 1
Duration of trial	8.33	8.17	8.03	8.16
Number of boiler (Plant number)	420	420	420	420
Type of boiler	Locomotive	Locomotive	Locomotive	Locomotive
DIMENTIONS AND PROPORTIONS.				
Outside diameter of shell in inches	62	62	62	62
Number of tubes-Horizontal	236	236	236	236
Outside diameter of tubes, inches	2	2	2	2
Length of tubes, Horizontal, feet	11 1/12	11 1/12	11 1/12	11 1/12
Diameter of steam dome, inches	29 1/8	29 1/8	29 1/8	29 1/8
Length of steam dome, inches	28	28	28	28
Length of furnace, feet	9.5	9.5	9.5	9.5
Width of furnace, feet	2.77	2.77	2.77	2.77
Kind of grate bars	Rocking	Rocking	Rocking	Rocking

	1	2	3	4
GOVERNING PROPORTIONS-				
Grate surface, square feet.	26.45	26.45	26.45	26.45
Heating surface	1531.65	1531.65	1531.65	1531.65
Area of draught through tubes, square feet.	573.48	573.48	573.48	573.48
Ratio of grate to heating surface.1 to ?	57.91	57.91	57.91	57.91
Grate surface, square feet.				
AVERAGE PRESSURES				
Steam pressurein boiler, by guage, pounds per square inch.	143	140	116.4	114
Atmosphericpressure, pounds persquare inch.	14.7	14.7	14.7	14.7
Absolute pressure in boiler, pounds per square inch.	157.7	154.7	131.1	149.3
Force of draught in inches of water.	2	2	2.9	3.1
AVERAGE TEMPERATURES.				
Of external air, degrees, Fah.	78	73	82	85
Of fire room, degrees, Fah.	72	62	79	92
Of feed water, degrees, Fah.	57	54	58	59

Of escaping gases, degrees, Fah.	623	670	652	700
FUEL.				
Moist coal consumed, pounds.	13,200	13,046	13,200	14,100
Moisture in coal, per cent.	6	6	6	6
Dry coal consumed, pounds.	12408	12263	12408	13254
Wood consumed, pounds.	403	340	530	
Coal equivalent of wood.	161	136	212	
Total dry coal consumed including wood equivalent, pounds.	12569	12399	13412	13254
Total dry refuse, pounds.	2495	2010	2115	1937
Total dry refuse, per cent.	182	162	15.7	146
Total combustible, pounds.	10074	10389	11297	12317
Dry coal consumed per hour, pounds.	1500	1500	1545	1666
Combustible consumed per hour, pounds.	1214	1271	1412	1549
DESCRIPTION OF FUEL.				
Commercial name.	Odim	Odim	Odim	Odim
Commercial size.	Mine run	Mine run	Mine run	Mine run

Lumps, per cent.	90	90	90	90
Small coal, per cent.	8	8	8	8
Slack, per cent.	2	2	2	2
Appearance of coal.	poor	poor	poor	poor
WATER.				
Total pumped into boiler, pounds.	68250	69095	77123	82795
Water actually evaporated, corrected for quality of steam, pounds.	66724	67540	75426	80435
Equivalent water from and at 212 degrees Fah., pounds.	79184	79725	98578	95561
Equivalent water from and at 212 degrees Fah., per hour, pounds.	9540.3	9758.3	122762	120202
EVAPORATIVE PERFORMANCE.				
Water actually evaporated, per pound of dry coal, pounds.	5.31	5.44	6.08	6.07
Equivalent water from and at 212 degrees Fah., per pound of dry coal, pounds.	6.30	6.43	7.35	7.21
Water actually evaporated per pound of				

combustible, pounds.	664	650	667	672
Equivalent water from and at 212 degrees Fah., per pound of combustible, pounds.	802	800	813	826

THE DESIGN AND CONSTRUCTION OF AN APPARATUS FOR TESTING THE CONDUCTIVITY OF BOILER TUBES.

After making the above tests on the boiler of locomotive 420 I.C.R.R., apparatus was designed and made, to compare clean tubes with tubes covered with different thicknesses of scale. This apparatus was also used for comparison between plain tubes and serve ribbed tubes. (described later).

Four different types of apparatus were used before satisfactory results were obtained. These types were as follows:

TYPE A consisted of a small sized boiler with which ordinary boiler tests were to be made; tube to be changed between tests, thus giving a comparison between tubes used.

TYPE B was a much smaller boiler through which water was allowed to flow and was heated by one tube only. The furnace for this type was a cast iron box in which gas was burned as a fuel and a compressed air jet at opposite end of tube produces a draft. The only difference between types B,C, &D was in the furnace construction.

TYPE C had a blast lamp, or horizontal burner in place of the box furnace. The large variation in pressure of air and gas caused an adoption of TYPE D which differs from C in having pressure equalizing tanks for both air and gas.

TYPE A.

The boiler for this type was designed as shown in PLATE II, to carry two hundred pound pressure. Eight tubes were used, four serve and four plain tubes, and were arranged as shown in PLATE II. that each set might have an equally advantageous position in reference to the fire box.

A furnace was to be constructed of a size proportional to the boiler in which either coal or coke would be burned.

Draft was to be obtained by connecting rear end of boiler to large chimney flue which has a draft of .4 to .8 inches of water.

The method of testing was to be that of an ordinary boiler test with the four plain tubes plugged at the furnace end.

After making several tests that agreed closely, the plugs were to be removed from the plain tubes and the serve tubes plugged. Under these conditions more tests would be made.

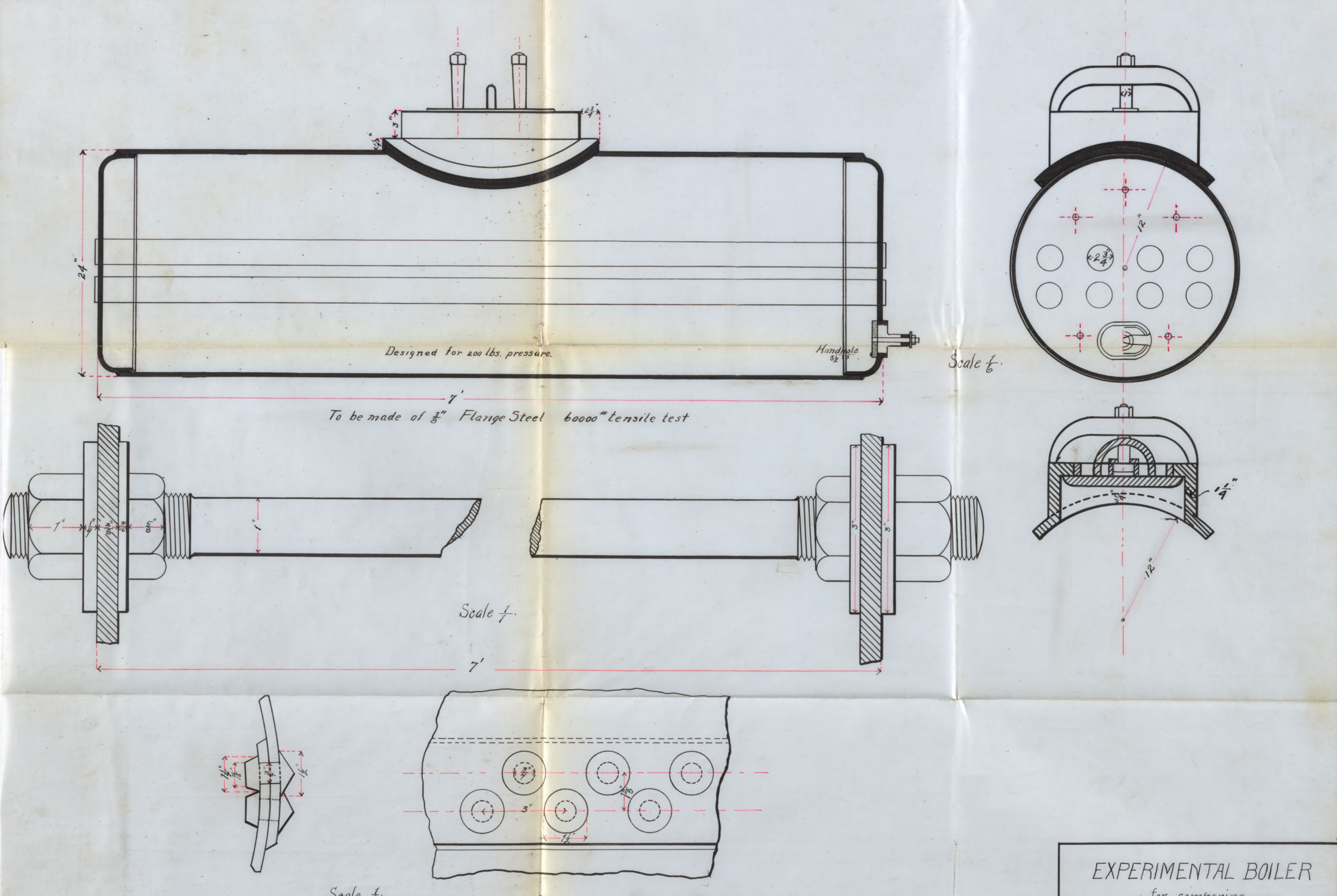
The amount of heat given to the water through the tube sheet would be the same in each case and the four idle tubes would have nothing to do with the test in either case. Thus with one boiler, comparative tests could be made under practically the same conditions.

DISADVANTAGES OF TYPE A.

1st. It would be very difficult to maintain a constant temperature in the furnace owing to its small size.

2nd. In the comparison of plain tubes, clean and scaled, the apparatus would be very inconvenient because of the many times tubes would have to be changed. Each change would require a cutting out of the old tubes and putting in and expanding the new ones.

3rd. Because of its size, the boiler would be very difficult to make, hence increasing the expense. For these reasons this plan was abandoned.



EXPERIMENTAL BOILER
for comparing
SERVE and PLAIN TUBES
THESIS DRAWING
MECH. ENG. DEP'T. U of I.
January 10, 1899. PLATE II. Armstrong Henig

BOILER FOR TYPES B, C, and D.

This boiler consists of a ten inch pipe seven feet long with a flange on each end, sixteen inches in diameter.

Several plates were cast 16 inches in diameter and 1 inch thick. having different sized holes in the center for tubes of different diameters. These holes were counter-bored from the outside of the plate, half the way through, of a size one inch larger in diameter than the tube to be used.

A ring was made to slip over the tube and into the counter bore, thus forming a gland which can be easily packed with asbestos packing.

About three inches from each flange on the top side of the pipe, holes were drilled and tapped for a 1 inch pipe. Water was piped to one of these from the city main, and from the other to a pair of accurate scales.

Just above the boiler where the water enters and where it leaves were placed accurate Fahrenheit thermometers. A thermometer reading to 600 degrees Fahrenheit was placed in a thermometer cup in the tube at the rear end of the boiler as shown at B, PLATE III.

A one inch globe valve was put in the inlet pipe and a 3/4 inch valve in the bottom of the boiler to drain ~~diameter~~ it before changing tubes.

A clear conception of the boiler can be had from PLATE III. The larger drawing shows sectional views of the ends and the blast apparatus used in types C and D. The smaller drawing shows the boiler alone.

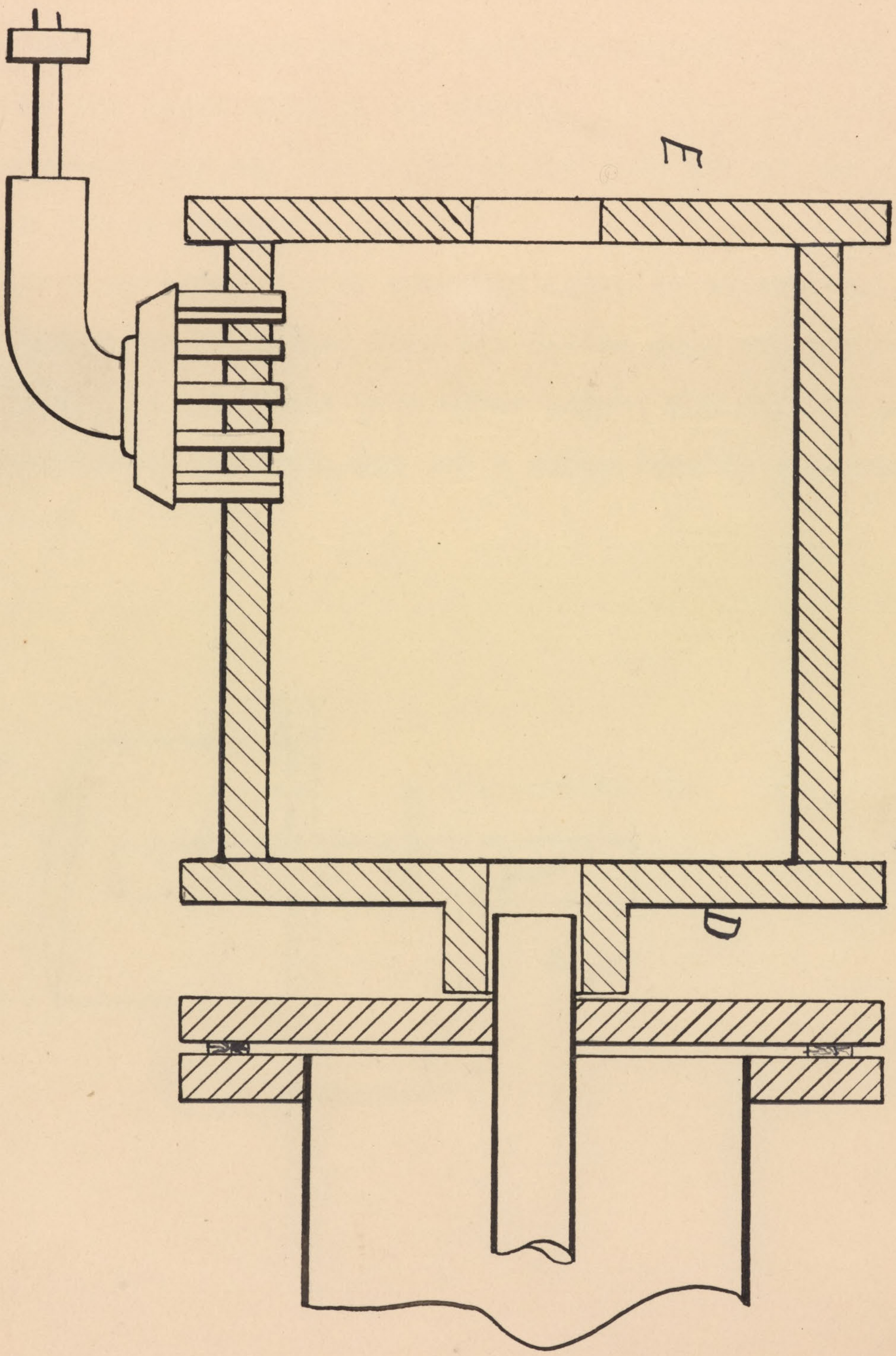
TYPE B.

The distinguishing feature of type B from C and D is the furnace which consisted of a cast iron box 14 inches square and 16 inches long outside.

Two plates were cast for the ends of this box, one of them with a hub that slipped over the projecting end of the tube. The following sketch shows this plate at D. The other plate was flat having a 3x5 inch hole in it provided with a damper for regulating the supply of air admitted through the hole. This plate is shown at E.

In the center of the bottom of the box twelve holes were drilled in a circle to fit the twelve burners of a large gas burner formerly used with a hot air engine. The burner works on the same principle as the Bunsen burner but had the fault that it could not supply nearly enough air in proportion to the gas used, to get much heat from the gas.

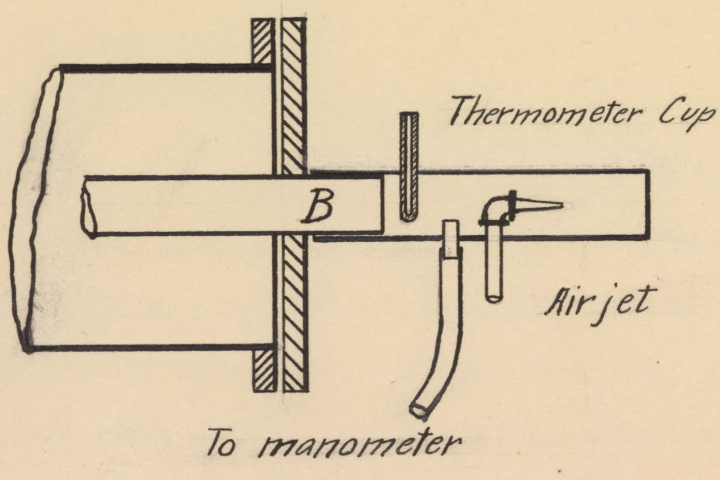
The sketch below shows furnace and connections.


E
D

A six inch galvanized iron pipe was made connecting the rear end, B, of the tube to a chimney in the laboratory. It was expected that the hot gases would produce sufficient draft, but on trial failed to make the least sign of any draft.

Compressed air was now piped to the rear end of the boiler and used in a jet to produce a draft.

A piece of pipe of same internal diameter as external diameter of tube and about 18 inches long was fitted over the projecting end of the tube. In this pipe were three holes, one for the air jet.one for a thermometer cup, and one for a connection to a manometer, as shown below.



METHOD OF TESTING. WITH APPARATUS B.

To start a test the valve in the water pipe is opened allowing water to run into the boiler. When the boiler is full and the water flowing into the tank on scales, the gas is ignited in the furnace.

By means of the compressed air jet, the draft could be regulated, and by this means the temperature at the exhaust end maintained constant. By means of the valve in the water pipe the amount of water which flowed through could be regulated, thus enabling the difference in the temperature between the inlet and outlet water to be regulated.

By keeping the temperature of the flue gases constant and the difference in the temperature of the inlet and outlet water constant, a comparison could be made between two tubes by the different amounts of water heated per hour.

ERRORS IN APPARATUS: TYPE B.

After making several tests of from one to three hours duration, it was found that cold air was drawn through the tube, getting around or over the burning gas without becoming heated. This caused a large variation of temperature at the rear end of the tube.

To remedy this fault several thicknesses of wire screen were put in the furnace just in front of the tube. All the air then had to pass through it, and as it was at a bright red heat, the air was heated. This improved matters but a further improvement was made when the furnace was lined with fire brick. The draft was very irregular because of variation in air pressure.

The following table shows results obtained with this apparatus.

PLAIN TUBES.
2" outside diameter.

	Clean			Scale 1/16" thick				
Column No.	1.	2.	3.	4.	5.	6.	A.	B.
Date.	3/25	3/25	3/30	3/27	3/27	3/27		
Cu.ft.gas burned per hour.	700	840	880	680	780	730	806	730
Duration of test, hours.	1.5	2	1.5	1.5	1.5	1	1.66	1.33
Temperature of laboratory.	76	74	62	74	66	66	70	68.8
Average temperature of inlet water.	55	56.2	52	54.8	52	56.3		
Average temperature of outlet water.	84.8	86.6	72	84.9	72	87.5		
Average difference in temperature.	29.8	30.4	20	30.1	20	31.2		
Pounds of water heated per hour.	433.3	493.5	778.6	398	768	345		
No. B.T.U. passing through tube per hour.	12,913	14,902	15,660.	11,980	15,374	10,764	14,491	12,706
Average temperature of flue gases.	350	336	345	345	339	346	343	344

In the above table column A is the average of the three tests on the clean tube: column B, of the three tests on the scale covered tubes.

By comparing the number of B.T.U. passing through the tubes per hour in column 1 & 3, and columns 4 & 5, a variation of 20% and 24% for the same tube is seen.

A comparison of the average number of B.T.U. passing through tube per hour shows a loss of 12.3% due to scale.

Because of the great variation in results these results cannot be depended on.

On this account and because of the excessive use of gas, this apparatus was abandoned.

Apparatus C.

The blast lamp, shown in larger drawing of PLATE III. was now substituted for the furnace. The compressed air was piped to the other end of the boiler where it was connected to a blast lamp and to a manometer.

The temperature at the exhaust end could now be regulated by the amount of gas burned, the air pressure being kept as near constant as possible, which was from $3\frac{1}{2}$ to $4\frac{1}{2}$ inches of water.

The following table shows results obtained with this apparatus in a comparison of two plain tubes of same size, one clean and the other scaled $\frac{3}{32}$ inches thick.

PLAIN TUBES.
2" outside diameter.

	Clean		Scale $\frac{3}{32}$" thick			
Column No.	1.	2.	3.	4.	A.	B.
Date.	4/7	4/8	4/6	4/7		
Cu. ft. gas burned per hour.	245	240	180	164	242.5	172
Duration of test, hours.	2	3	$2\frac{3}{4}$	$1\frac{1}{2}$	2.5	2.12
Temperature of laboratory.	68	63	73	71	65.5	72
Average temperature of inlet water.	53.8	53.9	55.09	58.4		
Average temperature of outlet water.	64	68.8	66.03	73.7		
Average difference in temperature.	10.2	14.9	10.94	15.3		
Pounds of water heated per hour.	1272	716	726	418		
No. B.T.U. passing through tube per hour.	12,847	10,740	8,160	6,395	11,793	7,277
Average temperature of flue gases.	285	298	301	301	292	301

In the above table, column A is the average of columns 1 & 2; B, of columns 3 & 4.

By comparing the number of B.T.U. passing through the tube per hour, it will be seen that there is a variation of 16% in columns 1 & 2 for the same tube, and a variation of 23% in column 3 & 4. This shows results to be very inaccurate.

If the clean plain tube be considered to have an efficiency of 100%, the tube with $\frac{3}{32}$ inch scale has an efficiency of 61.7%, a loss of 38.3%.

The results although fairly constant showed such an immense loss due to scale.i.e. 40%, that an investigation was made as to its cause, in which the following conclusions were arrived at.

If the temperature at the rear end of the tube be kept constant for different tubes, as was attempted, the advantage of the clean tube over the scale covered, will be greatly magnified because of the following reason:

If a certain temperature is obtained at the rear end of a scaled tube, much more heat will have to be put in at the front end of a clean tube to obtain the same temperature at the rear end because so much more heat goes through the clean tube to the water than through the scaled tube. For this reason, this method of testing and all previous tests had to be abandoned.

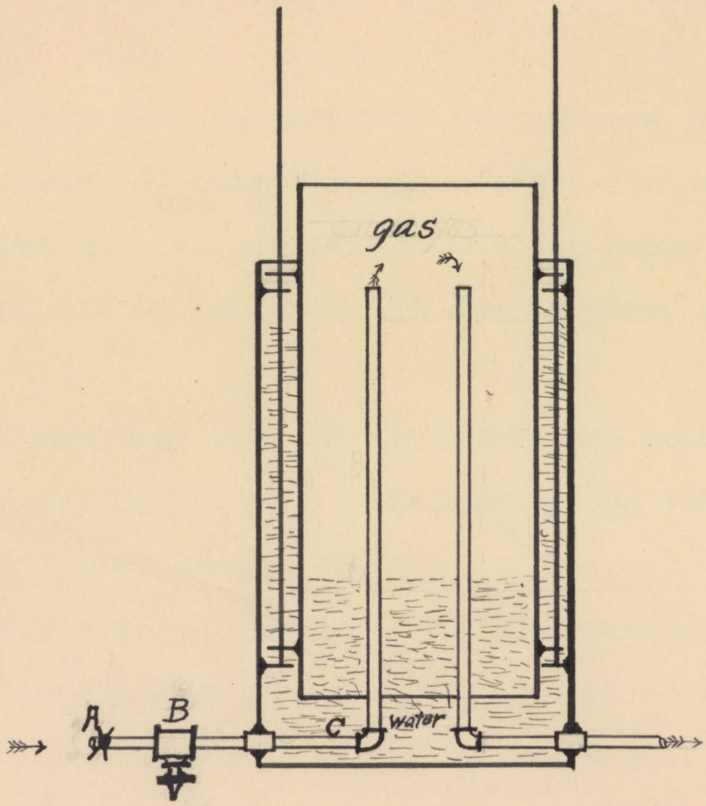
It was decided that if the temperature at the furnace end, instead of at the rear end, be kept constant the results would be correct.

The rear end temperature would be constant during each test but different for different kinds of tubes, the worse the tube, the higher the temperature. The same is true of a locomotive boiler provided the draft and temperature of the fire box be constant.

A different method of testing was tried with apparatus of type C. The blast pipe was moved back about 18 inches from entrance of tube. A piece of pipe 20 inches long and of an internal diameter equal to external diameter of tube was placed over the tube. The blast lamp was put in the other end of this tube. A thermometer reading to 800° Fahrenheit was placed in this pipe near the tube. The temperature was too high to be measure by any apparatus that was obtainable.

TYPE D.

It was decided that a constant temperature could be maintain- at the entrance to tube, if a constant pressure of air and gas be maintained. To do this type D was used, which differed from C in having two pressure equalizing tanks as shown in the following sketch.



The two tanks were alike, both being made of galvanized iron, except the inner tank for the gas, which was made of tin to make it lighter. As will be seen from the following tests, the temperatures of flue gases at rear end are very constant, showing that the entrance temperature and quanity of gas are constant.

ERRORS IN APPARATUS AND METHOD OF ELIMINATING.

In several tests, the gas pressure dropped until it was not high enough to lift the constant pressure tank, thus spoiling the test.

It was found that the moisture accumulated in the small pipe C, shown in sketch of tanks page 29. To get rid of this a tee was put in the pipe at B with a pet cock on the under side. By blowing this out every one or two hours the gas pressure could be maintained constant.

It was found that the water pressure was much more constant at night than during the day. For this reason the majority of the following tests were made at night.

In the tests with type D, Centigrade thermometers were used for getting temperatures of the inlet and outlet water, because they could be read more accurately than the Fahrenheit thermometers reading to 600°.

Log of test made on serve tube.

Date. May 13. 1899. $2\frac{3}{4}''$ outside diameter.

Time	Gas Cu.ft.	Temperatures. Lab.	Flue gases	Water Inlet	Outlet	Wt. on scales	Dif.
3:45	40670	68	104	15.4	22.1	295	
3:50		68	104	15.5	22.8	372	77
3:55		68	104	15.5	22.4	451-51	79
4:00	40722	68	104	15.5	22.5	127	76
4:05		68	104	15.4	22.2	208	81
4:10		68	104	15.5	22.2	287	79
4:15	40772	68	104	15.5	22.2	365	78
4:20		68	104	15.4	22.5	442-46	77
4:25		68	104	15.5	22.0	124	78
4:30	40823	68	104	15.5	22.2	201	77
4:35		68	104	15.5	22.1	277	76
4:40		68	104	15.5	22	353	76
4:45	40880	68	104	15.5	22.2	430-50	77
4:50		68	104	15.6	22.5	125	75
4:55		68	104	15.5	22.3	200	75
5:00	40930	68	104	15.5	22.5	278	78
5;05		68	104	15.4	22.2	352	74
5:10		68	104	15.4	22.2	426	74
5:15	40980	68	104	15.5	22.3	500	74
Average		68	104	15.48	22.3		

Log of test made on serve tube.

Date, May 13.1899. *2¾" outside diameter.*

Time	Gas Cu.ft	Temperatures. Lab.	Flue gases	Water Inlet	Outlet	Wt. on scales	Dif.
10:45	39834	68	106	15	21.1	51	
10:50		68	106	15	21.1	147	96
10:55		68	105	15	21	239	92
11:00	39881	68	106	15	20.9	329	90
11:05		68	106	15	21	417-49	88
11:10		68	106	15	21	141	92
11:15	39940	68	106	15	20.8	230	89
11:20		69	106	15	21	320	90
11:25		69	106	15	21	408-49	90
11:30	39984	69	106	15	21.1	131	82
11:35		69	107	15.1	21.3	213	82
11:40		68	108	15.1	21.2	296	83
11:45	40041	68.	106	15.1	21.3	386	90
Average		68.3	104	15.02	21.07		

Log of test made on clean plain tube.

Date, May 18, 1899. *2 3/4" outside diameter.*

		Temperatures.					
	Gas.		Flue	Water.		Wt.on	
Time	Cu.ft.	Lab.	gases	Inlet	Outlet	scales	Dif.
7:00	42553	76	298	17	24.1	29	
7:05		76	298	17	24.2	74	45
7:10		76	300	17	24.3	118	44
7:15	42610	76	300	17	24.2	206	43
7:20		76	302	17	24.4	206	43
7:25		76	302	17	24.5	251	45
7:30	42662	76	280	17	24.4	296	45
7:35		76	292	17	24.5	341	45
7:40		76	300	17	24.5	386	45
7:45	42717	76	300	17	24.7	432	46
7:50		76	300	16.9	24.5	477-21	45
7:55		76	298	16.9	24.6	66	45
8:00	42778	76	296	16.9	24.5	110	44
8:05		76	296	16.9	24.5	155	45
8:10		76	300	16.9	247	201	46
8:15	42831	76	300	16.9	24.5	246	45
8:20		76	300	16.9	24.5	290	44
8:25		76	300	16.9	24.6	334	44
8:30	42888	76	300	16.9	24.5	379	45
Average		76	298	16.95	24.5		

Log of test made on clean plain tube.

Date, May 19, 1899. *2¾" outside diameter.*

		Temperatures.					
	Gas		Flue	Water		Wt. on	
Time	Cu.ft.	Lab.	gases	Inlet	Outlet	scales	Dif.
8:00	42190	76	294	17	22	37	
8:05		76	298	17	22.2	91	54
8:10		76	306	17	22.3	145	54
8:15	42145	74	306	17	22.5	200	55
8:20		74	304	17	22.6	254	54
8:25		74	304	17	22.8	309	55
8:30	42200	74	304	17	22.9	364	55
8:35		74	304	17	23.0	419	55
8:40		74	306	17	22.9	474-24	55
8:45	42255	74	306	17	22.9	78	54
8:50		74	304	17	22.9	132	54
8:55		74	300	17	23	186	54
9:00	42303	74	300	17	23	240	54
9:05		74	300	17	23	293	53
9:10		74	300	17	23	347	54
9:15	42358	74	300	16.9	23	400	53
9:20		74	300	16.8	23	454-21	54
9:25		74	302	16,8	23	74	53
9:30	42418	74	302	16.8	23	128	54
Average		74	302	16.94	*22.97*		

Log of test made on clean plain tube.

Date, May 20, 1899. *2" outside diameter.*

Time	Gas Cu.ft.	Temperatures. Lab.	Flue gases	Water. Inlet	Outlet	Wt. on scales	Dif.
8:15	42982	70	320	15,6	22	29	
8:20		70	320	15,6	21.8	109	80
8:25		70	320	15.5	21.8	188	79
8:30	43040	70	320	15.5	21.2	268	80
8:35		70	320	15.5	21.3	348	80
8:40		70	338	15.3	21.2	428-20	80
8:45	43095	70	320	15.2	21.1	99	79
8:50		70	320	15.1	21	180	81
8:55		70	320	15.1	21	260	80
9:00	43150	70	320	15.1	20.9	341	81
9:05		70	322	15.1	21	420	79
9:10		70	322	15.1	20.9	502-20	82
9:15	43218	70	320	15.1	21	99	79
9:20		69	320	15.2	21	174	75
9:25		69	318	15.3	21.1	249	75
9:30	43262	69	318	15.2	21.1	324	75
9:35		69	320	15.3	21	4000	76
9:40		70	320	15.2	21	478-25	78
9:45	43318	70	318	15.1	21	110	85
Average		70	320	15.25	21.15		

Log of test made on clean plain tube.

Date, May 23. 1899. *2" outside diameter.*

Time	Gas Cu.ft.	Temperatures. Lab.	Flue gases	Water Inlet	Water Outlet	Wt. on scales	Dif.
7:00	43628	78	320	15.9	21.3	32	
7:05		78	320	15.9	21.8	118	86
7:10		77	320	15.9	21.6.	203	85
7:15	43686	78	320	15.9	21.6	288	85
7:20		77	320	15.8	21.0	374	86
7:25		77	320	15.8	21.1	459-23	85
7:30	43738	77	320	15.8	21	107	84
7:35		76.	320	15.8	21	192	85
7:40		76	320	15.7	21	277	85
7:45	43789	76	324	15.7	21	362	85
7:50		76	324	15.8	21	447-14	85
7:55		76	326	15.8	21	90	86
8:00	43839	76	324	15.9	20.9	176	86
8:05		76	320	15.9	21	262	86
8:10		76	320	15.9	21	345	83
8:15	43900	76	318	15.9	21	428	83
8:20		76	320	15.8	21	512-51	84
8:25		76	320	15.7	20.8	135	84
8:30	43955	76	320	15.8	21.0	219	84
Average		77	322	15.83	21.1		

Log of test made on plain tube. 2" outside diameter.

Date, May 24, 1899. Thickness of scale, 3/32 inch.

Time	Gas Cu.ft.	Temperatures. Lab.	Flue gases	Water Inlet	Water Outlet	Wt. on scales	Dif.
9:30	44244	76	350	17	24	200	
9:35		75	350	17	24	253	53
9:40		75	340	17	24	308	55
9:45	44292	74	340	17	24.1	363	55
9:50		74	340	17	24.2	418	55
9:55		74	344	17	24.6	473-21	55
10:00	44348	74	350	17	24.7	76	55
10:05		74	350	17	24.6	130	54
10:10		76	350	17	24.9	184	54
10:15	44400	76	350	17	25	238	54
10:20		76	350	17	24.9	293	55
10:25		76	350	17	25	347	54
10:30	44455	76	350	17	24.9	402	55
Average		75	346	17	24.4		

Log of test made on plain tube. 2" outside diameter.

Date, May 25, 1899. Thickness of scale $\frac{3}{32}$ inch.

Time	Gas Cu.ft.	Temperatures. Lab.	Flue gases	Water Inlet	Water Outlet	Wt. on scales	Dif.
9:15	44542	76	330	17.8	24	28	
9:20		76	340	17.9	34.5	78	50
9:25		76	340	17.8	25	129	51
9:30	44595	76	340	17.8	25	180	51
9:35		76	340	17.8	25.2	229	49
9:40		76	340	17.8	25.5	279	50
9:45	44653	76	340	17.8	25.6	328	49
9:50		76	340	17.8	25.9	377	49
9:55		76	340	17.6	26	426	49
10:00	44708	75	340	17.5	26	475-5	49
10:05		75	340	17.5	26	54	49
10:10		75	342	17.5	26	103	49
10:15	44765	75	342	17.6	26	153	50
10:20		75	342	17.5	26	202	49
10:25		75	342	17.6	26	252	50
10:30	44825	75	344	17.5	26	302	50
10:35		75	344	17.5	26	352	50
10:40		75	344	17.2	26	401	49
10:45	44866	75	344	17.4	76	450	49
Average		75.5	342	17.6	25.6		

RESULTS.

	Average difference in temperature C. = F.	Pounds of water per hour	B.T.U. passing through tube per hour	% Variation	Average B.T.U. passing through tube per hour
Serve Tube	6.82 = 12.27	920.6	11,300		
2.75 inches				2.3	11432
Outside diameter	6.05 = 10.89	1062	11565		
Clean plain tube	7.55 = 13.59	538	7411		
2.75 inches				3.3	7288
Outside diameter	6.03 = 10.85	660	7166		
Clean plain tube	5.90 = 10.62	949	10078		
2 inches				13.9	9873
Outside diameter	5.27 = 9.49	1018	9668		
Plain tube	7.40 = 13.32	656.8	8748		
2inches o.d.				2.1	8660
Scale $\frac{3}{32}''$ thick	8.00 = 14.40	595.3	8572		

Per cent gain of serve tube over plain tube......... ....56.8

Per cent loss with plain tube due to $\frac{3}{32}''$ of scale...........11.2

DISCUSSION OF RESULTS.

The most noticeable thing in these results is the fact that more heat units go through the clean, or even the scaled plain tube of two inches in diameter, than through the plain tube of $2\frac{3}{4}$ inches in diameter.

An investigation was made which showed that much air was drawn into the tube by the blast lamp. With larger tubes more air was taken in which had to be heated, thus leaving less heat units to go through the tube.

A serve tube (described later) of same external diameter as a plain tube has less area for the passage of gases than the plain tube.

In the size tested, ($2\frac{3}{4}$ inches diameter) the plain tube has an area of 5.94 square inches: the serve tube has an area of 4.05 sq. inches. This difference favors the serve tube in this apparatus because less cold air can be drawn through and the same number of heat units enter it as enter the plain tube.

Hence it would have been better if a ring had been used limiting the size of the opening through which the external air is drawn into the tube, to one size for all tubes tested.

Because of this air being drawn through the tube, the temperature in the laboratory should be the same during all tests. This would also eliminate practically all losses of heat by radiation.

The temperature of the air in the receiver of the air compressor should be at the same temperature and same pressure during each test.

It was thought that much more accurate result could be obtained if two tests were made at the same time. By having another apparatus identical to the one used in these tests, and using air and gas from the same tanks, the comparison between the two tubes would be more accurate.

THE "SERVE" RIBBED TUBE.

The object of the serve tube is to increase the internal heat-absorbing surface. In any tube the inner and outer surface are the heat-absorbing and heat distributing surfaces, respectively.

The heat-distributing surface in a clean plain tube is usually able to give to the water all the heat that the heat absorbing surface can collect.

In a serve tube this absorbing surface is greatly increased by having projecting ribs running the whole length of the tube.

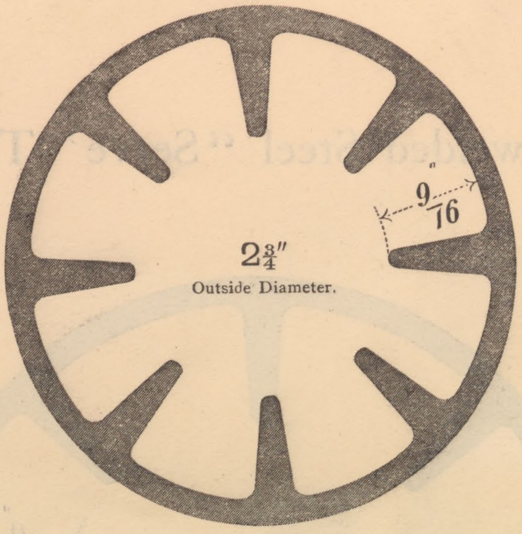
USE OF THE SERVE TUBE.

In 1891, 450 locomotives, most of them in France, and about ninety steam-ships were using serve tubes. Serve tubes have been in use 8 years in France and 6 years in Great Britain.

In most places, ordinary wire brushes are used to clean the tube, but locomotives use a steam jet.

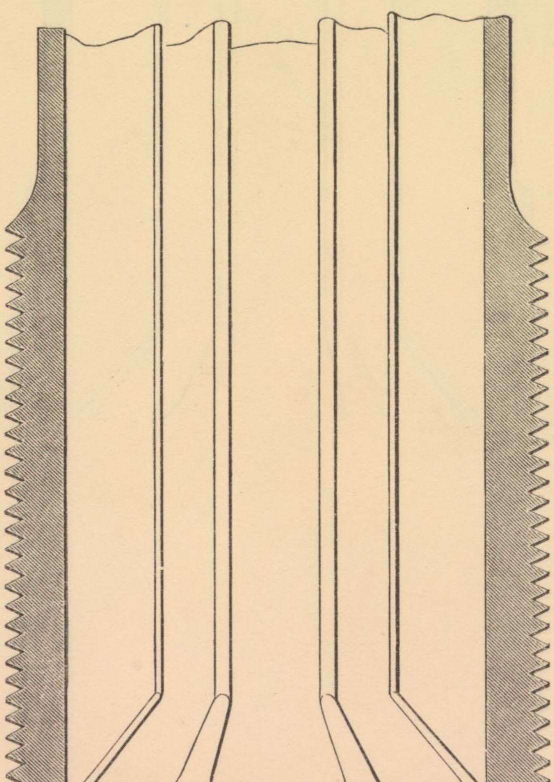
The following pictures thoroughly illustrate the serve tube and the kind of stopper used.

Lapwelded Steel "Serve" Tubes.



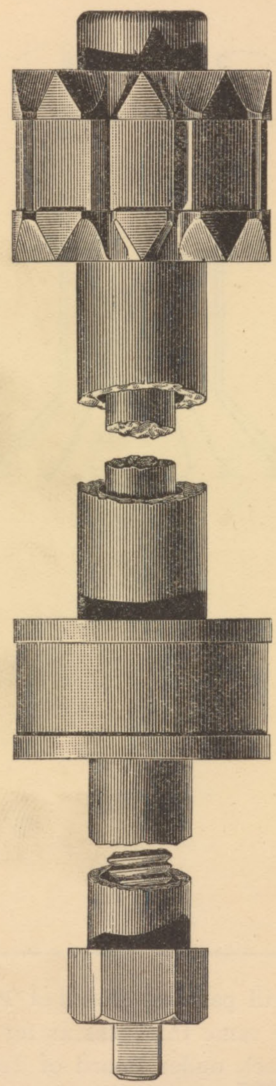
Serve "Stay" Tube End.

(With the Ribs left in.)



Stopper,

Designed and Patented for "Serve



The following comparative boiler tests with plain and serve tubes were copied from tests taken by H.B. Roelker of New York. Each test lasted eight hours, steam was kept at 70 lbs., pressure and water level at 7 inches. The boiler was an upright tubular, 42 inches in diameter with a 36 inch furnace, 24 inches high and with 63 tubes $2\frac{1}{2}$ inches outside diameter by 6 feet long. 7 square feet of grate surface; 287 square feet of fire surface.

Date of Trial April 1891.	Draft in inches of Water.	Average Temperature of Chimney Gases per Pyrometer.	Average Temperature of Feed Water.	Pounds of Water Evaporated during Trial.	Pounds of Coal Fired during Trial.	Pounds of Ashes and unconsumed Coal on grate and in ashpit at end of Trial	Pounds of picked out unconsumed Coal in this.	Pounds of Ashes in ashpit and on grate at end of Trial.	Pounds of Ashes per 100 pounds of Coal.	Pounds of Combustible Consumed during Trial.	Pounds of Water evaporated per pound of Coal fired	Pounds of Water evaporated per pound of Combustible	Pounds of Combustible consumed per sq. ft. of grate in Trial.	Weather.	Barometer.	Outside Temperature.
							Plain Tubes.									
6	1/8	679.05	191.03	4230	855	194	119	91.5	"	676	4.95	6.28	12.05	Clear day very light breeze	29.91	42
7	1/3	685.15	189.54	4975	861	210.5	97.25	91.5	90.5	665	5.20	6.73	11.87	Clear day still	29.98	42
8	1/2	800.6	186.72	8325	1388	239.75	107.5	142.5	9.27	1162.25	5.997	7.16	20.17	Clear	30.23	48
9	1/2	856.4	186.60	8380	1400	259.75	143	152.5	984	1159.25	5.985	7.26	20.61	Clear light breeze	30.96	51
10	27/32	990	187.30	8460	1777	298	173	155	7.99	1493	4.76	5.66	26.67	Dull, no rain	30.53	49
11	7/8	922.73	186.75	8190	1780	369.5	183	196.5	1015	1425	4.60	5.74	25.99	Rainy, Coal wet ashes damp.	30.17	5.3
							Serve Ribbed Tubes									
15	7/64	395.6	198.11	5025	745.5	266.25	183	83.25	9.3	493.25	6.74	10.10	8.80	Fair	29.78	73
16	1/8	492.45	194.27	5250	655.5	164	75.25	88.75	11.01	505.5	8.01	10.38	9.02	Fair	29.98	66
17	1/2	468.78	186.3	10830	1487	325.5	141.25	184.25	11.25	1176	7.28	9.21	21.0	Clear	30.09	62
18	1/2	438.22	191.77	11050	1394.5	299.75	144	155.75	1008	1108.75	7.92	9.96	19.80	Clear	29.38	59
20	7/8	502.	179.1	12180	1808.75	375.25	172.75	202.5	10.34	1497.5	6.73	8.41	25.84	Clear	30.15	63
21	7/8	519.68	181.	12200	1800	350	123.5	226.5	11.60	1464	6.77	8.33	26.19	Cloudy	30.36	53
23	1 3/16	742.73	183.21	13935	1879.5	339	114.5	224.5	11.037	1554.5	7.41	8.32	27.57	Clear	29.56	70
25	1 9/16	678.33	170.	14000	2149.5	342.75	160.75	182.	7.93	1815.75	6.52	7.71	32.41	Fair.	29.58	52

REFERENCES TO LITERATURE.

London Engineer, Oct. 24 and 31, 1891.

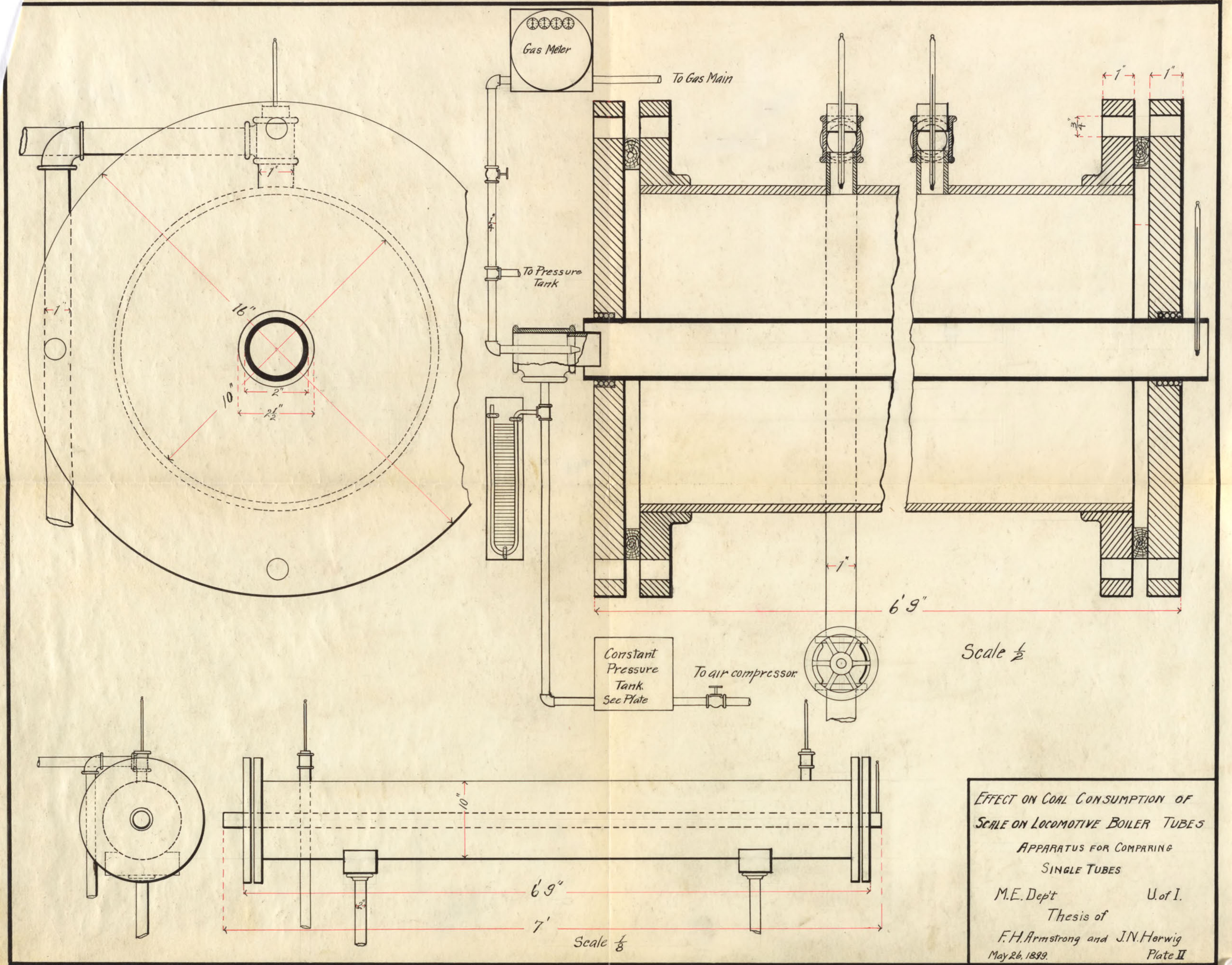
Engineering News, Nov. 8; 1890.

Engineering News, May 9, 1891.

Railway Review, May 9, 1891.

In Engineering News of Feb. 1892, an apparatus is described for finding the effect of a coating of oil in boiler tubes.

It consisted of an apparatus very similar to the one used in these experiments, with a horizontal Bunsen burner in place of the blast lamp. The results obtained with one tube showed a loss of from 8 to 15 per cent. The loss was taken as 11.5 per cent!



EFFECT ON COAL CONSUMPTION OF SCALE ON LOCOMOTIVE BOILER TUBES

APPARATUS FOR COMPARING SINGLE TUBES

M.E. Dep't U. of I.

Thesis of

F. H. Armstrong and J. N. Herwig

May 26, 1899. Plate II