STEAM BOILERS.

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C. L. DENNETT

Steam Boilers.

The writers object, in the selection of the above subject, was not to present an original investigation. The subject is a very practical one, and one with which I wished to become practically acquainted, especially as the subject of steam generation naturally precedes that of steam using. Hence I have chosen the subject, since, by giving it the study required in order to present it in thesis form, I should at the same time gain a knowledge of it, that will be practical and useful. The knowledge has been gained from no one source. Personal observation has been a material aid; and numerous works have been examined from which the best matter on particular points has been gleaned.

The importance to the engineer of the present day, of a good theoretical and practical knowledge of the construc-

-tion and management of the steam boiler, no one will deny, who has any conception of the great boiler making and steam using industries of the world.

The construction of a steam boiler is apparently very simple, so simple that it would seem to many to require very little science or ingenuity to properly arrange the materials. It does not require much ingenuity to make a vessel in which steam can be generated, and to manage it; but to make a steam boiler, which shall be safe under given conditions, without having any great excess of strength; that, in its efficiency shall approach the results which theory points out; and to manage the boiler so that its efficiency shall be the highest possible, not only requires great skill, but involves for its fulfillment, some of the most delicate and difficult questions of science.

The dispute of two scientific gentlemen of this city, on the mysterious or non-mysterious influences of boiler explosions; the articles, that have appeared in scientific journals, connecting boiler explosions with electric waves, and the like, show what mysterious and dangerous instruments, steam and steam boilers are yet considered by many to be.

An article on Steam Boilers written in 1842 says "There is, perhaps, no branch of practical art in which so much remains to be determined and improved, and scarcely any which science has done so little to advance." Within the last thirty years, however, science has done much for the problem of steam generation.

Burgh, in his treatise on Steam Boilers, says "Boiler making requires more primary consideration, talent, scientific education, and practical knowledge of construction than any other branch of engineering yet known."

But to know how to make a good boiler is by no means the limit of the knowledge required. The boiler maker may furnish a boiler apparently sound and strong, but whether its life shall be long or short, depends as much, and in most cases even more, upon the treatment it receives while being used. The subject of boiler management becomes then, as important as that of boiler construction.

The leading points concerning boiler construction will be first taken up very briefly.

——Requirements——

There are many considerations to influence the construction of a steam boiler. It must be strong and yet light. Its strength should be uniform throughout. Its first cost must be small. The space occupied should be small. Its construction must be such as to admit of its being easily cleaned and repaired. The different parts should be properly proportioned to insure efficiency, and so on.

No one of these considerations can be worked out alone without conflict-

-ing with others. The skill of boiler design lies in the proper proportioning of each condition, so that the sum total of the efficiencies shall be the greatest possible. A boiler may be designed that, when first worked, will give a very high evaporative power, but at the expense of such intricacy of design, as to make cleaning or repairing impossible. The result of proportioning its parts with regard to but one requirement is, that its efficiency soons falls below that of the average, even if the boiler does not become useless.

——General Form——

The typical form of the steam boiler of the present day is the cylinder. This form is not so strong as the spherical, but possesses the advantage of presenting a greater heating surface, for the same cubical capacity.

The ends are generally flat; the want of strength of a flat surface being compensated for by staying.

The primitive forms of boilers

have received various modifications, in order to increase their heating surface and their efficiency, and to adapt their form, size, and weight, to the purposes for which they are intended. For example, the various forms of marine boilers, with rectangular shells and horizontal fire tubes, or vertical water tubes. The horizontal fire tube boilers for factory use; and the multitubular and firebox boilers for locomotives, fire, hoisting and agricultural engines, combining light weight with rapid generation of steam.

The various types will be especially mentioned and illustrated further on.

——Boiler Material——

The principal material of boiler construction, and especially of the shell, is wrought iron. Before the working of wrought iron was understood, cast iron was generally used. A parliamentary committee, appointed in 1817, on account of a very fatal boiler explosion in London in 1815, recommended among other things, that boilers should be made of wrought iron, instead of cast iron or copper, which formerly had been mainly used.

Cast iron was abandoned on account of its rather treacherous nature, and inability to withstand the severe strains of contraction and expansion. Its use is being to some extent revived, in the construction of sectional boilers, of which we will speak hereafter. It is also used for the various castings, which are attached to almost all boilers, in situations where it is not exposed to large variations of temperature.

Wrought iron has generally taken the place of cast iron. Its recommendations are its great tensile strength, ease of working, power of bearing shocks and strains, moderate cost, and general reliable nature when well worked. Its most common defects are laminations and blisters, the result of poor working.

Steel is used for boiler tubes,

boiler shells, and fireboxes. Its recommendations are its superior tensile strength, and superiority for flanging, due to its homogeneous nature as manufactured for this purpose. The defect, which troubles locomotive builders, is its tendency to crack when used for fireboxes. The experience of Mr. Thompson of the Eastern R.R. has been, that it cracks, sometimes through the solid plate, sometimes through the rivet holes, but always when the firebox is cold.

Copper is used for fireboxes and tubes. It is recommended by its ready transmission of heat; and homogeneous nature. Its defects are its small tensile strength and loss of strength at high temperatures, liability to corrosion from sulphurous products of combustion, and wearing from mechanical attrition. Its small tensile strength is compensated for in the flat surfaces of fireboxes, by frequent staying. Its use for fireboxes in American locomotive building is being supplanted by steel, and brass is preferred for fire tubes.

—— Strength of Material ——

The mean tensile strength of English boiler iron is placed at 49000 lbs. That of Bay State C#1, 53000 lbs. for short, and 46000 lbs. for long specimens. This grade constitutes the majority of the boiler shell iron rolled by this firm. Bay State flange, 53500 lbs. for short, and about 47000 lbs. for long specimens. C#1 or charcoal #1 is so called because charcoal is used as fuel in the blast furnace. The pig metal is converted into wrought iron in charcoal fires, and rolled into plates 1" thick. Boiler clippings are placed between two of these plates, and the "pile" is reheated and rolled. This iron is a fair quality for boiler shells when well worked.

Data on Strength. Trowbridge's "Heat and Heat Engines"

In making C.H#1 or charcoal hammered #1, the slabs are piled directly upon each other, reheated and rolled sev-

-eral times.

Firebox iron is similar to C.H.#1, except that greater care is taken in the selection of the materials, and it receives more heating and rolling.

Wilson gives the following as the distinguishing characteristics of good and bad wrought iron. When broken suddenly, the best qualities of plate and bar exhibit a fine, close grained, uniformly crystalline fracture, even silky, of a light, silvery color. The appearance of inferior qualities is coarser, usually of a darker color, more or less uneven, or open, exhibiting large facets. When broken gradually, good iron presents a well drawn out, close fibre, of light, grayish hue; whilst inferior qualities give a shorter, more open and darker fibre. Wilson emphasizes the fact, that the character of an iron cannot be determined by the fracture, unless you take into consideration the manner in which the fracture was produced.

Wilson on "Steam Boilers"

Even then judgment may be at fault. A short time ago, at the Bay State Rolling mills, they examined a number of specimens of iron made as nearly alike, in every respect, as possible, and which chemical analysis showed to be the same. When fractured in the same way, they presented quite different appearances, and the iron apparently most granular, stood bending the best.

English steel plates average about 85,000 lbs. tensile strength.

Bay State homogeneous metal gives about 70,000 lbs. This is the metal sometimes known as Siemens-Martin steel. It is manufactured by melting small pieces of pure wrought iron in melted cast iron, adding wrought iron until the amount of carbon introduced with the cast iron, bears the proper proportion to the whole mass.

Boiler plates made of this iron are rolled from one ingot, so that they are homogeneous. This iron is much used for fireboxes and is a good iron for shells.

Cast iron has an average tensile strength of about 16,000 lbs. It is poorly adapted for withstanding sudden shocks or varying strains.

Copper has a mean tensile strength of about 33,000 lbs. It loses strength for every rise in temperature, and at 212° F. it has lost 5% of its strength at 32° F.

Strength of Shell &c

A cylindrical shell possesses only one half the strength, to resist an internal pressure, along a longitudinal element, that it has to resist the same pressure along a transverse element. Hence the shell is made strong enough, to resist the tendency to burst along a longitudinal element, by the formula $pr = ft$ where $\underline{p}$ = working pressure in lbs. on the sq. inch, $\underline{r}$ = radius of shell in inches, $\underline{t}$ = thickness of shell in inches, and

f = the tensile strength of the material of the shell, in lbs. to the sq. inch, divided by a proper factor of safety.

The values of the tensile strengths of the metals employed, we have already mentioned, but in finding the values of f, the weakening effect of riveting must be taken into account.

The strength of a double riveted seam is reckoned at about 70%, and of a single riveted seam about 55%, of the strength of the entire plate. Taking the strength of the wrought iron plate at 25 tons, the strength of a double riveted seam will be 17½ tons, and of a single riveted seam will be 13¾ tons. These values, divided by the proper factor of safety, gives the required values of f for double and single riveting respectively.

Wilson on "Steam Boilers"

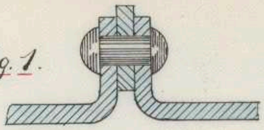
The common factor of safety is 6. So large a factor is necessary, to allow for the wear and tear to which all boilers are subject. Bourne thinks that the value of f, for wrought iron, should not exceed 4000 lbs. per sq. inch of sectional area. This is a rather small value for American iron and American work.

The strength of a plate iron flue to resist a collapsing pressure is found by the formula $p = 9,672,000 \frac{t^2}{ld}$ where $\underline{t}$ is the thickness of the iron, $\underline{l}$ the length of the flue, and $\underline{d}$ its diameter, all expressed in the same unit of measure, and $\underline{p}$ = the collapsing pressure in lbs. on the sq. inch. By applying strengthening rings, such as those shown in figs. 1 and 2, $\underline{l}$ may be taken as the distance between these rings, and the trying strains of expansion and contraction are obviated.

Rankines' "Steam Engine"

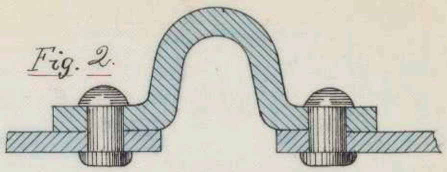
Flat surfaces are generally stayed so that the entire pressure is borne by stay rods, put in close enough to prevent the plate from bending between the stays.

Fig. 1.



Adamson.
See Fig. 35.

Fig. 2.



Bowling Hoop.

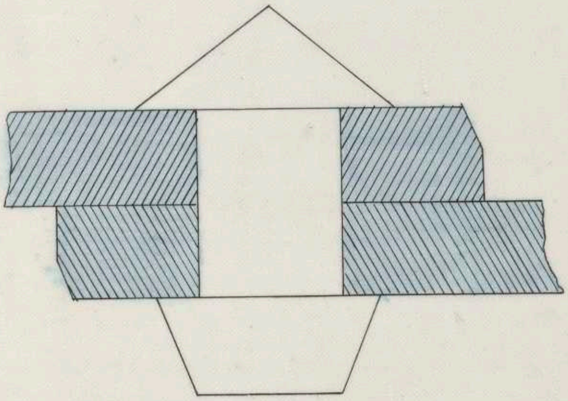
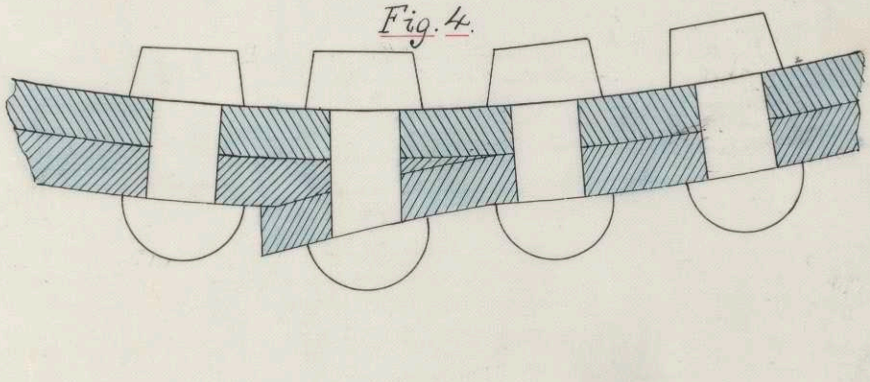


Fig. 3.

Fig. 4.



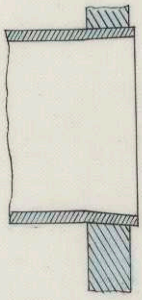


Fig. 5.

— Rivets —

Rivets are made of the best wrought iron, combining strength and softness. A good 3/4 inch rivet should have a single shearing strength of about 10 tons. In shell riveting, they generally have a diameter of twice the thickness of the shell, and are placed one diameter clear from the edge. With 3/8" plates and 3/4" rivets the pitch is generally 1 3/4" or 1 7/8". They are closed up by hand or by machinery

The rivet holes are punched or drilled. Punching is the cheapest, but strains the metal more than drilling. Drifting, which is often resorted to, to bring together inaccurately punched holes, should never be allowed. Drilling insures greater accuracy than punching, and does not strain the plate, but costs a little more. Drilled work is considered about 15% stronger than punched.

A lap joint and hand closed rivet are illustrated in Fig: 3

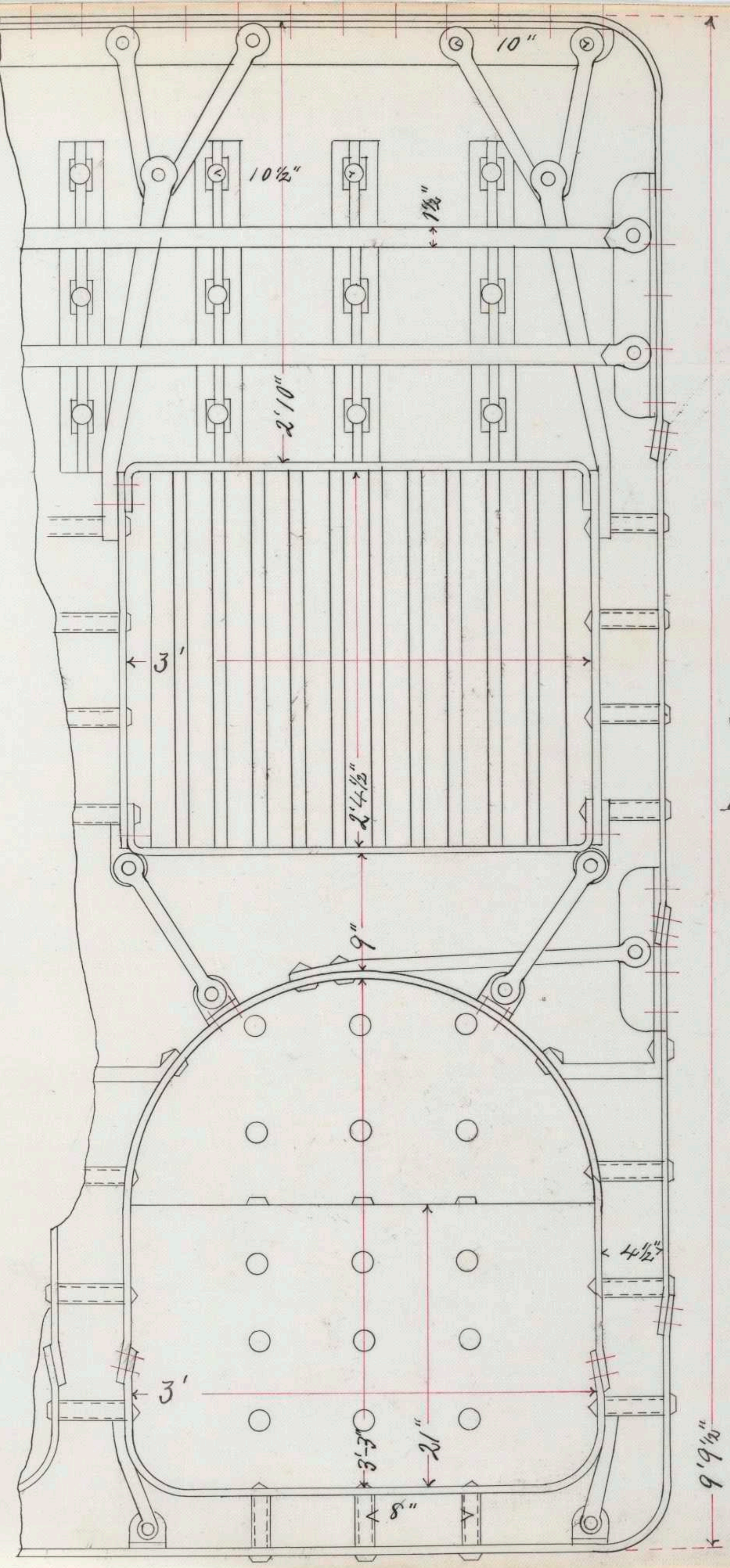
Hand riveting is also illustrated in Fig. 35 . Fig 4 illustrates a three plate connection with machine closed rivets.

Stays

Stays are generally made of a fine tough quality of wrought iron.

The different kinds of stays and general principles of staying will be best understood by reference to Figs. 6 and 35

Fig. 6 is from a sketch of a Martin boiler, made at the Charlestown Navy Yard. It shows quite fully the general principles of the staying of rectangular marine boilers. The long stays running lengthways and crossways the boiler, and also the stays of the top, have forked ends, which are pinned to T irons riveted to the shell. Another method of securing such stays is shown in Fig. 35 where bolts are screwed through from the outside into sockets in the enlarged end of the stay. The stays



Staying
of
Martin
Boiler.

Fig. 6.

are sometimes passed through the shell, and riveted over or fastened by a nut, on the outside.

The end plate of the locomotive and common tubular boiler are commonly stayed by diagonal stays, pinned at one end to T irons riveted to the end plate, and riveted at the other end directly to the shell.

The common method of staying all narrow water spaces is also shown in Figs. 6 and 35. These stays are generally screwed through at each end and riveted over, and are also generally surrounded by ferules. 4" centre to centre is a common rule in locomotive practice for firebox staying.

The general principles of the staying of locomotive firebox crowns is shown in Fig 35, by the staying of the top of the narrow chamber at the back end of the furnace. In locomotives, each girder is usually made of two thin plates with a water space between, the object being, to interfere as little as possible with the rapid circulation, that should exist over the firebox. These girders are attached to the firebox crown by several short stays running down between between the two plates of the girder, and rivetted over on the under side of the firebox crown.

Angle irons and gusset stays are now but comparitively little used.

Tubes.

Boiler tubes are generally made of wrought iron, sometimes of copper, brass, or steel. The experience of American railroad men has been, that ordinary copper fire tubes will wear out, by attrition of particles of coal, in about a year. They give the preference to brass tubes, as resisting this action, and making steam, better than iron. In European practice, they last from six to seven years. Steel tubes wear well and give good results, but give more trouble in setting and resetting than iron.

The tube ends are attached

to the tube sheets, sometimes by merely riveting over, sometimes by riveting over on the outside and expanding on the inside, and sometimes by screwing into ferules which are screwed into the tube sheets, and in various other ways. Two methods are shown in Fig 35. Both ends of the tube were originally secured by ferules. The heat at the back end was so great that the screw ferules had to be taken out, and the method of riveting over resorted to. Another method of securing tube ends is shown in Fig 5.

Grate bars.

Grate bars are made of wrought iron and cast iron. Wrought iron can be straightened when warped. Cast iron is the cheaper, and more commonly used. For anthracite coal, wrought iron water tubes are commonly used.

The simplest grate bar is the old fashioned 3/4" wide at top 3/8" wide at bottom, and bellied on the under side. A similar bar and the mode of setting

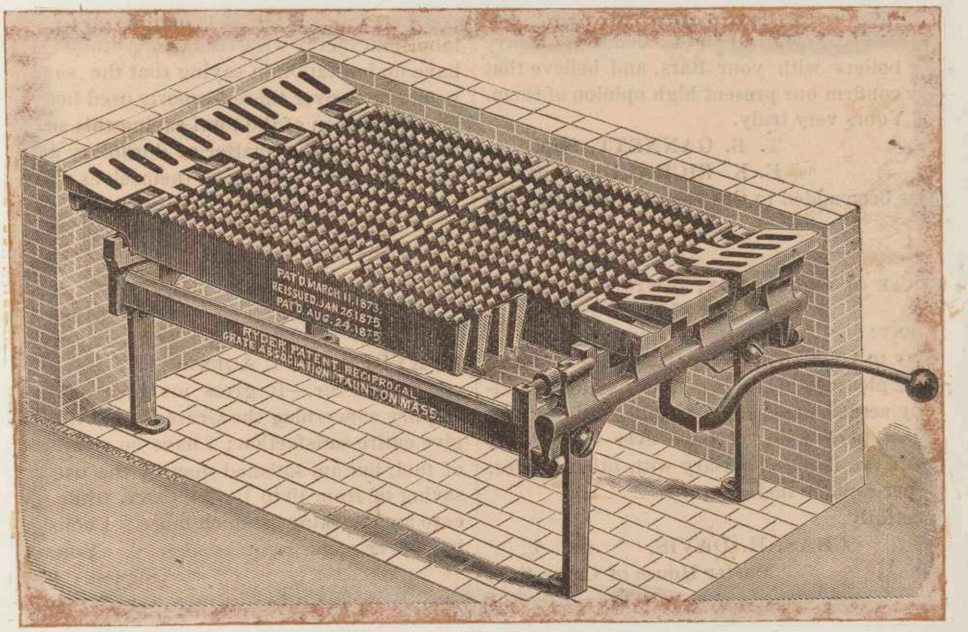

PAT'D. MARCH 11. 1873.
REISSUED JAN 26 1875
PAT'D. AUG. 24. 1875
RYDER PATENT RECIPROCAL
GRATE ASSOCIATION TAUNTON MASS.

Fig. 7.

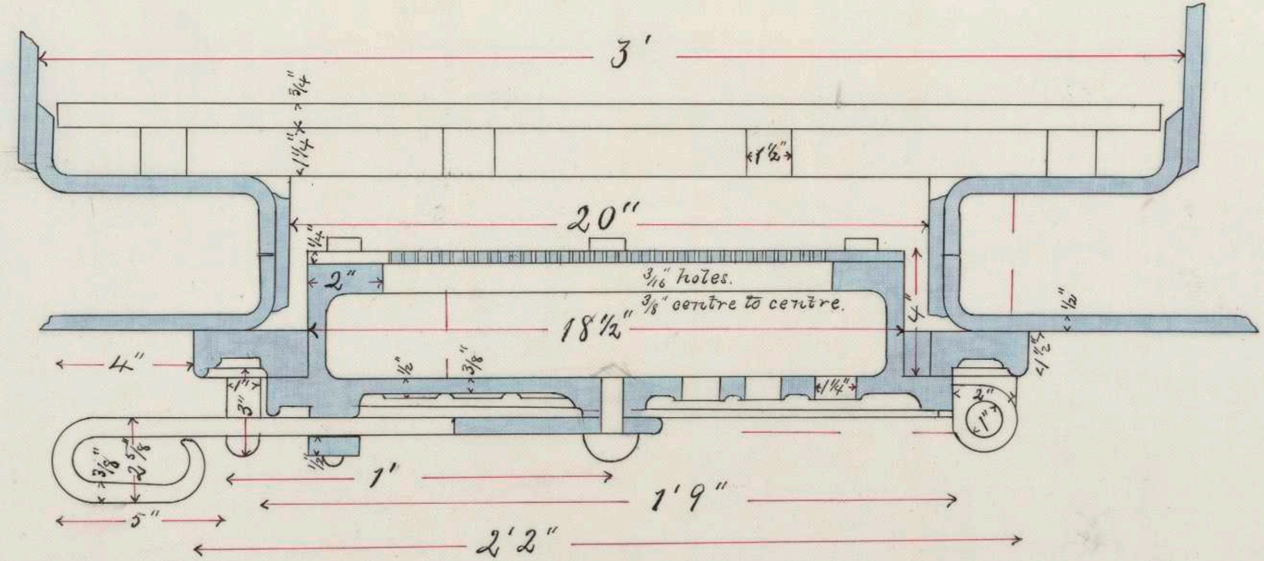
it is shown in Fig 35. Various devices have been patented, to secure better draught, and to clear of clinkers by shaking. An efficient form, the Ryder grate, in use under the Institute boilers, is shown in Fig 7.

Furnace Doors.

The most common form of furnace door is probally the plain door without air holes and with a fire brick back.

A common form for marine boilers with air holes and perforated baffle plate is shown in Fig 35. A cross section of a similar door taken from the sketch of a Martin boiler is shown in Fig 8.

A convenient form of pendulum furnace door, hinged on the upper edge, and balanced so as to stand in any position, is in use at the Charlestown Navy Yard.



Section through Fire-Door.
Martin Boiler.
Scale 2" = 1'
Fig. 8.

Pressure Gauges.

One of the best high pressure gauges is the Lane's improvement on the Bourdon gauge, which is sufficiently described by the illustration on page 21a. The tube being connected with the middle of the steam pipe, has the advantage of not retaining water or collecting dirt. They should always be connected with the boiler in such a way, that the steam pressure shall be transmitted by a column of water, so as not to overheat the tube.

For vacuum gauges, the old form of Bourdon gauge, also illustrated on page 21a, is used, since it is more sensitive, and gives a wider range of indication for a small range of pressure.

As the boiler pressure is principally regulated by the gauge, it is important that these should be often tested. There is a great diversity of practice on this point. Some railroads make a practice of testing their gauges every

Master Mechanics Report for 1874

21a

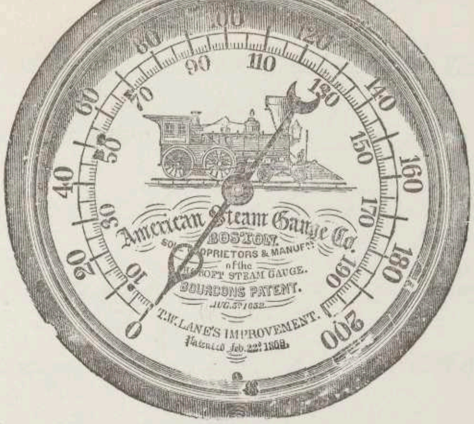


Fig. 9.

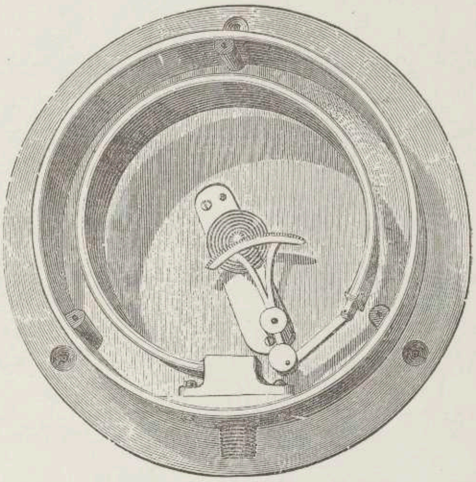


Fig. 10.

Bourdon Gauge.

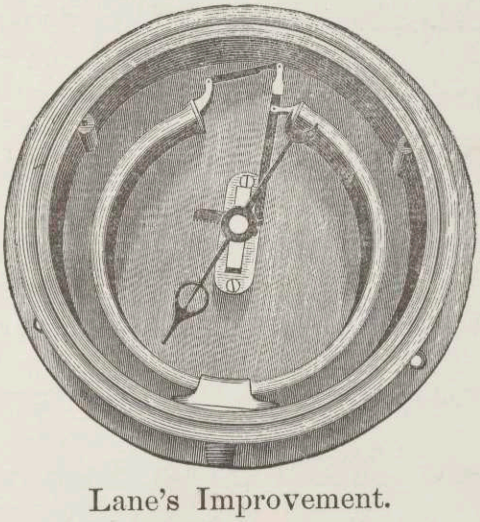


Fig. 11.

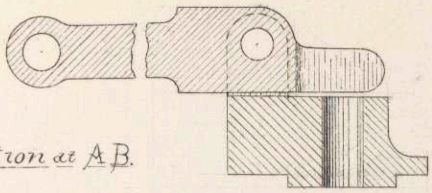
Lane's Improvement.

month; some every three months. On the majority of roads, the practice is to test them when the engines are in for repairs, or when there is any reason to suppose they need testing. A committee on steam gauges, appointed by the Master Mechanic's convention of 1873, recommend the testing of gauges, by a mercury column, at least every three months. Gauges on stationary boilers are often used for years without testing.

Safety Valves.

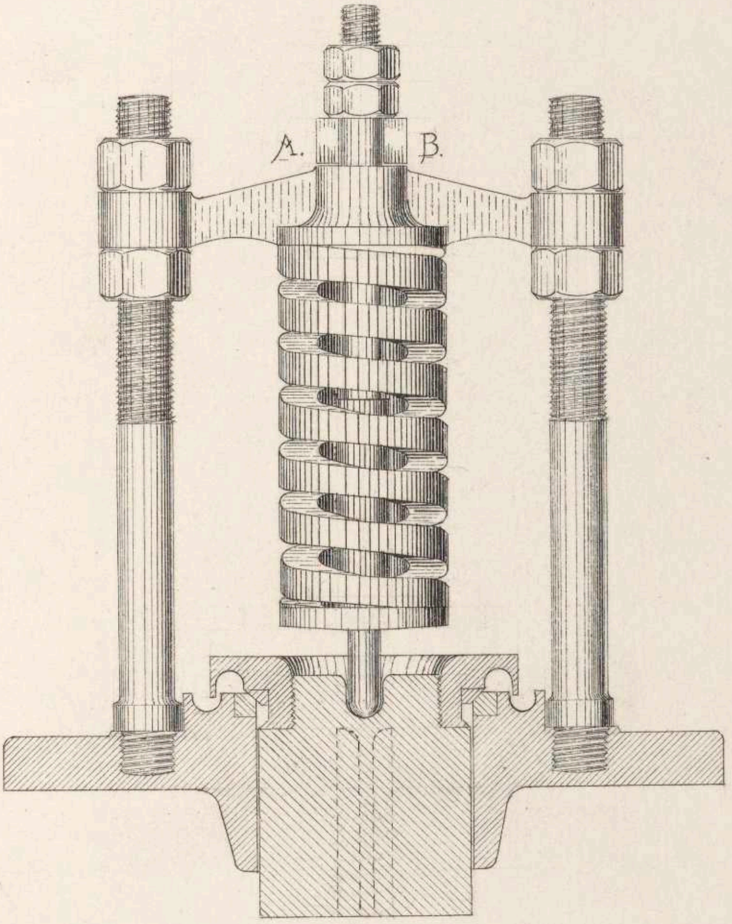
One of the best safety valves is the Richardson valve. The annexed drawing Fig 12, from sketches taken at the Charlestown Navy Yard, shows a form of this valve as applied to vessels of the U. S. Navy. It does not differ materially from those applied to locomotive and stationary boilers. For stationary boilers however, the old fashioned, weighted lever valves are generally used.

The peculiarity in the Richardson valve, is the valve ring, and groove



Section at A B.

Fig. 12.



'POP' VALVE.

C.L.D.

in the valve seat. As the valve lifts, the tension of the spring is increased. But the moment the steam begins to escape, it is thrown by the valve ring down into the groove, and the increased resistance, consequent upon this motion, increases its power over the valve. The valves are recommended for their promptness of relieving pressure, and promptness of closing, when the pressure begins to fall.

In order that safety valves should perfectly fulfill their office, the area of valve opening, should be sufficient to pass off the steam at the blowing off pressure, as fast as the boiler can generate it. The different rules for finding the proper area of safety valves, give very different results. Seven of the principal rules, applied to a particular case, give results varying from 6.94 sq. inches to 23.63 sq. inches area.

Safety valves, like steam gauges, require frequent examination, on account of their liability to stick. It will be no-

-ticed, on the annexed drawing, that provision is made for lifting the valve from its seat while steam is up, so as to insure that it is in working order.

——— Blow-off Pipes ———

All boilers are provided with bottom blow-off pipes. With some waters, surface blow-outs and sediment collectors are also necessary. To guard against the danger accompanying leakage from the bottom blow-off valve, open bottom taps are generally preferable to the ordinary seated valve, since their tightness is less liable to be interfered with by the chips of scale &c. which pass through the valve.

Blow-off pipes and blowing off will be further mentioned under boiler management, boiler injuries and incrustation

——— Gauge cocks should be supplemented by glass water gauges.

——— Man-holes and the openings for steam domes should be cut no larger than absolutely necessary, and the plates around should be properly strengthened.

—— A sufficient number of properly strengthened mud-holes should be added to give access to all parts of the boiler where sediment is apt to accumulate. Their arrangement is illustrated in the case of the two boilers Figs. 20 and 35.

—— Testing ——

As before stated, boilers are generally calculated to have a bursting strength of about six times the working pressure. When built, they should be tested with from 2½ to 3 times their working pressure. Various methods of testing are employed. The most common is to apply hydraulic pressure by a force pump. Another method is to fill the boiler full of water, and start the fires. The expansion of the water gives the required pressure. Another method is to obtain the test pressure by steam, by firing the boiler in the ordinary way.

As to the best plan, there is a great diversity of opinion. The cold hydraulic test can be applied with comparative safety to the inspectors. The cold condition of the boiler allows, moreover, a close examination of the plates, seams &c., for signs of weakness, shown by bulging or other alteration of shape, and for leaks.

The steam test is more dangerous, does not allow of so accurate an examination, but subjects the boiler to the ordinary strains of working, due to unequal expansion of different parts.

The best plan would seem to be, to first use a hydraulic pressure of from 2½ to 3 times the working pressure, and, if satisfactory, supplement it by a steam test of from 2 to 2½ times the working pressure.

The danger of all tests is, that the unusually severe strain may weaken some parts, so that they will not stand so long under the ordinary working pressure, as they would have if they had retained their original Strength

The best method of inspection for old boilers, is a close external and internal examination for signs of corrosion, fractures, blisters, grooving &c., followed by a hydraulic pressure of about 1½ times the working pressure. A careful examination of an old boiler tells better its true state, and its future chances, than the application of a test pressure, and is principally relied upon by the Inspectors of Boiler Insurance Co's.

—Boiler setting, and general proportions—

Furnace— The average practical values of grate to heating surface are, according to Trowbridge for

Plain cylindrical	Boilers	1:12
Flue "	"	1:21
Tubular "	"	1:28
Marine Tube and Flue	"	1:25
Locomotive	"	1:75

Isherwood says in regard to marine tubular boilers, "The ratio of heating to grate surface, with a combustion of 12 lbs. anthracite per. sq. ft. grate area per. hour, for good results should not be less than 35:1 for vertical water tube boilers, and 45:1 for horizontal fire tube boilers." For illustrations of the boilers referred to see Figs 33 and 34.

The practice of the Navy department is to allow 8 lbs. anthracite coal per. hour, to evaporate 1 cu. ft. water from 212°, at a pressure of 30 lbs., which requires 2/3 sq. ft. grate and 16 2/3 sq. ft. heating surface, a ratio of 1:25.

The ratio of grate area to grate opening, also according to Trowbridge, is for Plain Cylindrical boilers 4:1, and for Tubular and Flue boilers 2½:1.

Deep fireboxes and large combustion chambers are generally preferable, as allowing room and time for thorough combustion. Fireboxes for bituminous coal are usually made deeper and shorter than those for anthracite, as illustrated by Figs 13 and 14, from sketches furnished by the Grant Loco. Works. The width of locomotive fireboxes is about 35 inches.

In this connection, it is interesting to note the change that has been made in engine No. 2 Eastern R.R.

This engine was designed and built for an anthracite coal burner, and had a flue surface of 653.9 sq. ft., and a furnace surface of 110.3 sq. ft., making a total heating surface of 764.2 sq. ft. The grate surface was 23.1 sq. ft., making the ratio of grate to heating surface 1:33. On account of the cost of anthracite coal, it was considered advisable to change the engine to a soft coal burner. This was done by simply changing the first 36" of grate into a dead plate, thus reducing the grate area to 13 sq. ft., and making the ratio of grate to heating surface 1:58. The change has given

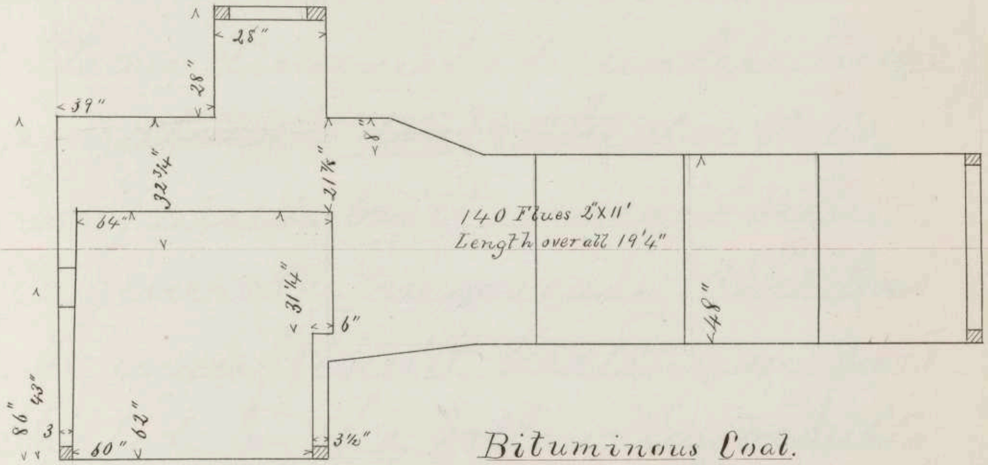


Fig 13.

Bituminous Coal.

Grates-cast iron-movable.

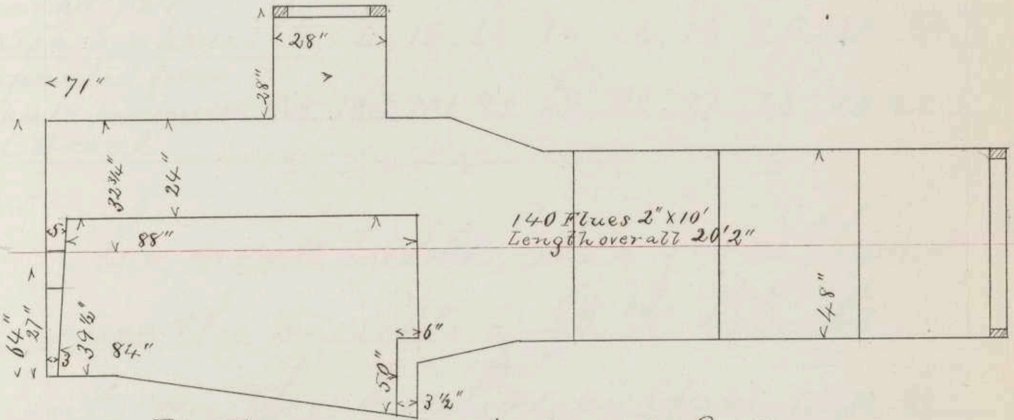


Fig. 14.

Anthracite Coal.

Grates-iron tubes-2"x½".

Boilers for 16 inch cylinder Engine.

good satisfaction.

The ratio of heating to grate surface, had in most cases better be increased than diminished, unless, in the case of a natural draft, the draft is greatly impaired by the longer run which is generally necessary. The loss caused by insufficient heating surface is illustrated by the following results of Isherwoods experiments.

Marine tubular boiler, burning anthracite coal. Heating surface constant and equal to 25 X grate area.

Trowbridges "Heat and Heat engines"

Lbs. coal burned per sq. ft. grate area per. hour.	6	8	10	12	14	16	18	20	22	24
Lbs water evaporated from 212° at atmospheric pressure by one pound of coal	10.5	10.4	10.1	9.5	8.9	8.2	7.7	7.3	7.0	6.8

The next table, also from Trowbridge, gives the results of D. K. Clark's experiments on the heating surface required to keep the evaporation per. lb. of coke constant, and equal to 9 lbs. water per. lb. coke.

Lbs. coke burned per hour on 1 sq. ft. grate surface.	14	25	38	56	76	98	125	153
Sq. ft heating surface	30	40	50	60	70	80	90	100

According to Isherwood, "more important than the ratio of grate to heating surface, is the ratio of the draft area to grate surface." He says, the best ratio for all types of boilers, rates of combustion, and ratios of grate to heating surface is 4/31. This ratio may be reduced without loss to 1/9, but cannot exceed 1/7, without serious sacrifice of economic result.

Bridges are often built too high, making the flame passage too contracted.

Care should be taken in boiler setting, not to confine the shell too rigidly, so as to interfere with its contraction and expansion.

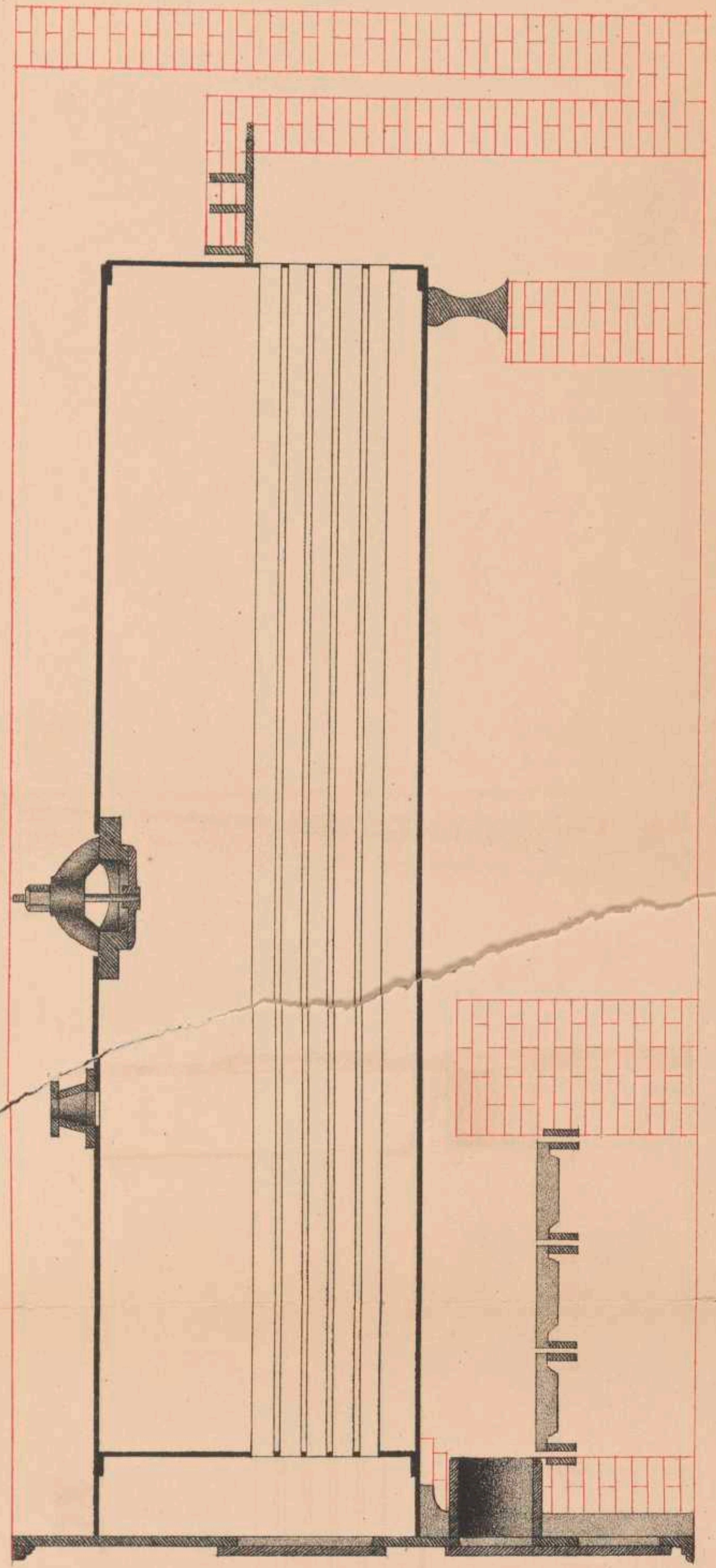
The general method of setting the common, factory, tubular boiler is sufficiently described by Fig 15, showing Kendall & Roberts method. The setting of several sectional boilers is also shown with their respective illustrations.

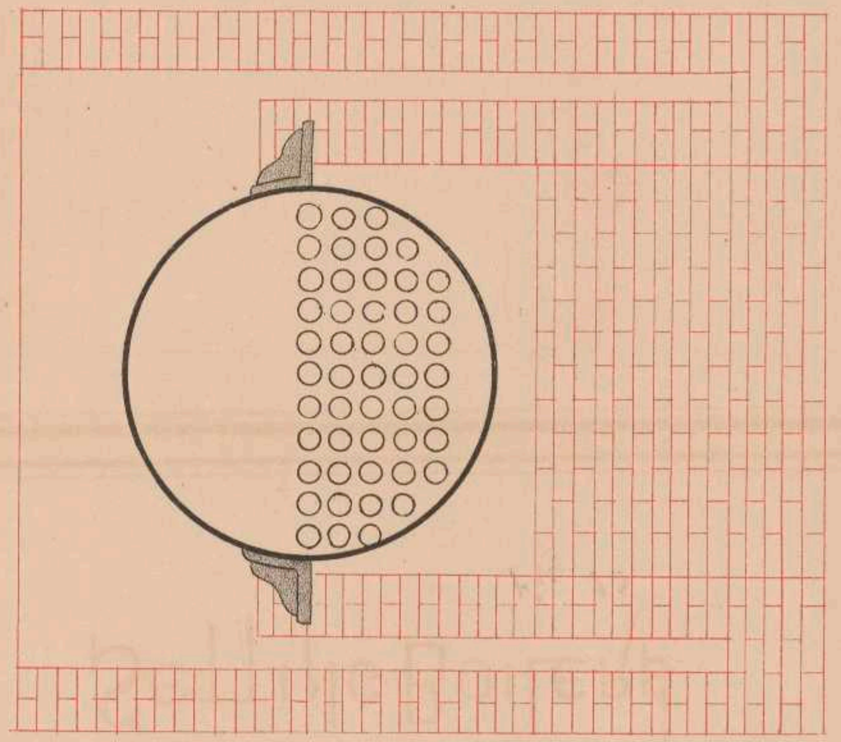
The object of inclosing boiler shells in brickwork, is to prevent loss of

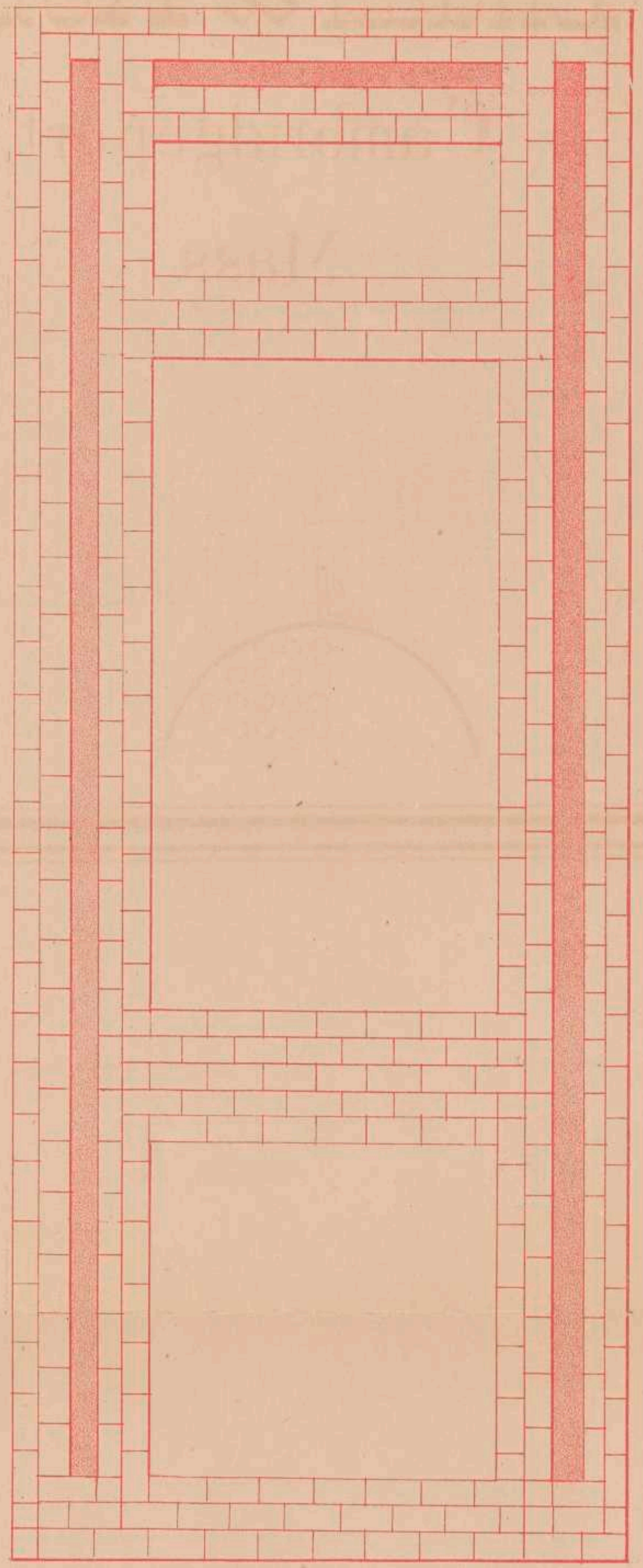
Fig. 15.

Kendall & Roberts

Cambridgeport,
Mass.







IMPROVED METHOD
OF
SETTING BOILERS.

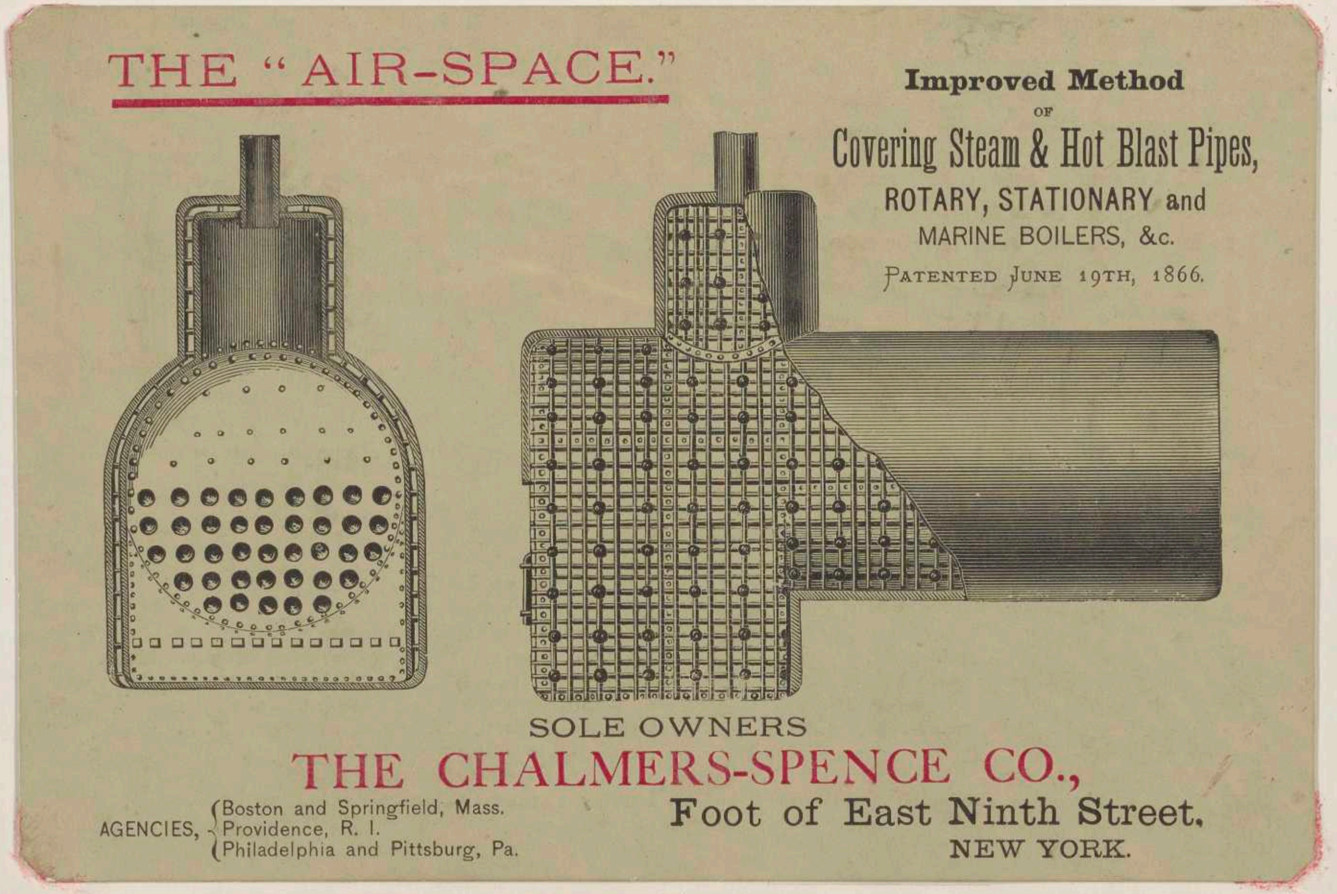
Fig. 15.

J. Mc AVEH & Co. 9 STATE ST. BOSTON.

heat by external radiation. The objection to the plan is, that the brickwork by harboring moisture, is apt to hasten external corrosion. A covering, that to some extent obviates this difficulty, is the Chalmers'-Spence, shown in Fig. 16. It has the advantage of keeping a jacket of air around the shell, and of showing leaks by softening when exposed to hot water or steam.

The heights of chimneys for certain requirements, can be approximately determined by considerations of the volume and density of the gases to be passed, to give the required draft &c, considerations which we have not time to describe and investigate. Chimneys are often built much larger than necessary for their first use. Being built at the beginning of a new enterprise, requiring the use of steam boilers, they are generally designed to accomodate more boilers, which the growth of the enterprise may demand.

The following results, showing



THE "AIR-SPACE."

Improved Method
OF
Covering Steam & Hot Blast Pipes,
ROTARY, STATIONARY and
MARINE BOILERS, &c.
PATENTED JUNE 19TH, 1866.

SOLE OWNERS
THE CHALMERS-SPENCE CO.,
Foot of East Ninth Street,
NEW YORK.

AGENCIES,
Boston and Springfield, Mass.
Providence, R. I.
Philadelphia and Pittsburg, Pa.

Fig. 16.

the heights of chimneys for producing certain rates of combustion, the ratio of grate to section of chimney being 8:1, are taken from Trowbridge, and are the results of experiments. A chimney 60 ft. high burns 116 lbs. coal per hour per sq. ft. chimney section, and 14.5 lbs. per sq. ft. grate. With the same ratio of 8:1, a difference of height of 8 ft. equals a difference in combustion of about 1 lb. per sq. ft. grate area per hour.

A chimney designed by Harrison Loring of South Boston is show x in Fig 17. The air space at the bottom, prevents excessive radiation from the hot gases, and removes the danger of the cracking of the outside walls, which is apt to follow if they are exposed directly to the hot gases on the one side, and the outside air on the other. (See page 84)

x Shown

Boiler management and injuries

We have already said, that the life of a boiler depended often more upon the usage it received, than upon the original construction. We should

Fig. 17.

Fig 17

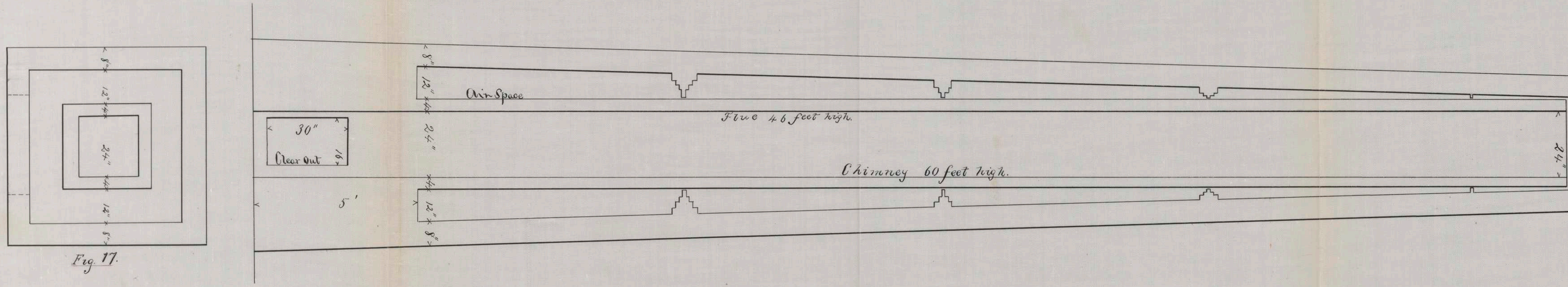

8"
12"
4"
24"
4"
12"
8"
Air Space
Flue 46 feet high.
30"
Clear Out
16"
24"
Chimney 60 feet high.
5'
8"
12"
4"
24"
4"
12"
8"
24"
8"

Fig. 17.

have also added that the efficiency of a fairly designed boiler, depends as much upon the stoker as upon the design. A skillful stoker accomodates his method of stoking to the conditions that are imposed.

False economy often places the care of boilers, in the hands of persons having scarcely the least knowledge of the nature of the materials, with which they have to deal. More intelligent men are not as a rule employed, because the employers themselves are too little acquainted with the questions of science and skill that relate to boiler using.

The great waste that may result from unskillful using is well illustrated by the experience of the Manchester Mills of Manchester N. H. Some years ago, they employed Mr Harris of Providence R. I. to superintend the steam department for a short time, in order that he might remedy the existing evils, and render the working more economical. The result of Mr. Harris' efforts, was a reduction of the expenses of steam production and using of about $30.00 per day.

The difference in the care used in the management of boilers is illustrated by the following examples.

At the pumping station of the Salem Water Works, the water used is of remarkable purity, containing but 2.22 grains total impurity per gallon. Yet the engineer in charge causes the boilers to be blown down, one or two rings by the Worthington gauge, every morning, and has them opened, inspected, and cleaned, every three months.

At the E.R.R. Car Works in Salem Mass. a water of less purity is used. The engineer here blows off once in a month or six weeks, and then is sometimes troubled by finding the blow-out valve clogged by sediment. The height of the water is determined only by gauge cocks, and these are often clogged up, so that it is necessary to clean them out with a wire, before the water level can be found.

In regard to the ignorance often displayed in the management of boilers, and in regard to the injuries to which steam boilers are especially liable, much valuable and interesting information can be gained from the reports of boiler insurance companies.

In the reports of the English "Boiler Insurance and Steam Power Co", constant mention is made of the carelessness and ignorance of boiler attendants, and the backwardness of boiler owners to incur any expense, to keep their boilers in good condition.

Safety valves are found fastened down, water dials are fixed to always indicate high water level, scale is removed by blowing out the boilers with steam up, and then quickly filling them with cold water, and so on.

In their lists of defects found in boilers inspected, corrosion of plates and angle irons, and inoperative or overloaded safety valves, are generally found to outnumber all others. Next rank fractures, then pressure and water gauges out of order, and lastly overheating caused by deposition of sediment.

Attention is especially called to the danger of overloading safety valves, or allowing them to stick. Great stress is laid on the malconstruction of boilers, in which the longitudinal seams are nearly or quite continuous, depriving the shell of the strength, which a more uniform distribution of the seams would give.

Leakage from the blow-off valve is mentioned as a fertile cause of boiler injuries, since this is a valve which is especially liable to leakage, and this leakage, by lowering the water level, and allowing overheating of the plates, when the boilers are left for a length of time unwatched, is especially liable to lead to disastrous explosions. The importance of testing steam gauges is noted, and instances are given in which gauges, on being tested, were found even 15 or 20 lbs slow.

The reports show that, on an average, taking a few years before and after 1870 as a basis, 50 boilers exploded yearly in Great Britain, with a loss of 1½ lives to each explosion, besides the numbers injured.

Corrosion of plates, stays, and rivet heads, due to the action of acids in the water, and sometimes increased by galvanic action, often occurs. The rivet heads in the ash pits of Martin boilers are often corroded by the wet ashes. Rivet heads exposed to a fierce flame also corrode.

Grooving frequently occurs, caused sometimes by too great, and sometimes by too little rigidity of the parts grooved. It occurs especially around the edges of end plates, and is due to the freedom of action of the middle, and rigidity of the edges of the plate, where fastened to the shell. Also at the edges of lap seams, due to the bending action caused by the deviation from the circular form.

External corrosion, already mentioned under Boiler setting, is a more frequent occurrence than internal. A great many cases are found, of boilers resting on midfeathers, whose plates along the brickwork, are found upon examination to be almost eaten through.

Recently, while repairing the brickwork of a boiler at the E. R. R. Car works in Salem Mass., a mason found a place, where he could easily put his cold chisel through. Upon examination it was found that the steam, leaking from the manhole at a (see Fig 18) had condensed, and run down between the brickwork and shell to the seam bc, and just above this seam, had corroded a place about 2½" × 1½", so that it could be easily broken through. The corrosion was extending as shown. Boilers should be so covered, that a frequent external

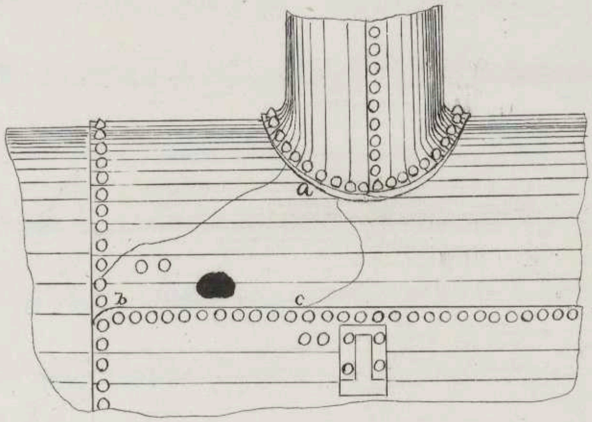


Fig. 18.

examination can be had without much difficulty or expense.

Circulation

Efficient circulation is evidently necessary for the economic, rapid, and safe generation of steam. If the circulation is retarded, there is little interchange of heat. The hot water next the plates, not being changed for cold water, is converted into steam, which repels the surrounding water. The result is overheating and bulging of the plates, as often seen in furnace plates next to narrow water spaces

The boilers of the steamer "Liverpool" had ten furnaces, separated by water spaces 4" wide and 5' deep. The currents in all these were of course ascending. They were supplied by a bottom water space 5" deep. The result was that the side plates of the furnace bulged, cracked, and burned through. On introducing a pipe into one of the vertical water spaces, it was found that nothing but steam issued, although there was plenty of water over the furnace crown.

The efficiency of boilers is often improved by removing fire tubes, which hinder the circulation. The spaces marked with a cross in Fig. 35 were occupied by tubes, which were removed to promote the circulation.

Some boilers are designed with drop flues, so that the hottest gases are applied to the upper, and hence hottest strata of water. Isherwood thinks that the advantages of the method are more than balanced by the inferior circulation. He says "My own experience has been that "ceteris paribus" the highest evaporative economy was found in boilers having the most rapid circulation, though obtained by applying the gases at their greatest temperature to the bottom instead of the of the top strata of water"

Incrustation

Almost all waters contain salts in solution, differing in character and quantity, according to the nature of the soils, through which the waters flow.

The salts vary in quantity from a fraction of a grain to 165.77 grs. per gallon found in the waters of the Dead sea. Croton water averages 6.65 grs. On examination of the water of seventeen watering stations on the N.Y.C.R.R., gave for the purest water 9.53 grs., and for the worst 42.17 grs. impurity per gallon. Eight analyses of filtered Cochituate water, made at this Institute and extending over an interval of six months of 1873, give 2.83 grs. solid residue per gallon. Average Wenham water, according to Dr. Jackson, contains 2.22 grs. impurities to the gallon. The waters of wells are generally harder than those of surface reservoirs.

Prof. Chandler's report on "Water for Locomotives, and Boiler Incrustation" made to Officers of N.Y.C.R.R.

Salem Water-Works Records.

The salts particularly trouble-

-some in boiler using, are the bicarbonates of lime and magnesia, and the sulphate of lime, and we will consider these only.

These salts are precipitated by boiling the water containing them. The bicarbonates are precipitated, because heat drives off the excess of carbonic acid, reducing them to carbonates, which are insoluble. Sulphate of lime is precipitated, because although soluble in 400 parts of cold water, it is nearly insoluble in hot water.

Carbonate of lime settles as a soft granular mass, which can generally be washed out, if not allowed to bake hard, by blowing out the boilers, with steam up. Sulphate of lime, settles as a hard crystalline scale, often very difficult to remove.

Although sulphate of lime forms the hardest scale, yet carbonate of lime is the more dangerous impurity. The latter, settling as a loose powder, transmits heat less readily than the harder scale, and hence more often leads to overheating.

The Hartford Ins. Co. report for one period 40% more cases of defective boilers that were dangerous from deposition of sediment, than from incrustation.

Bicarbonate of lime becomes especially dangerous when the feed water is heated by direct contact with the exhaust steam, thus introducing grease into the boiler. The grease and carbonate of lime combine mechanically, forming a greasy, pasty mass, preventing the transmission of heat, and too heavy to be moved by the circulation of the water.

According to the reports of the English Ins. Co. before mentioned, many cases of overheating, necessitating frequent and extensive repairs, have been traced directly to this cause, and almost all trouble has been removed by ceasing to heat the feed water in this way.

A slight coating of sul-

-phate of lime is often even advantageous, since it protects the iron from the action that will take place, if the water is at all acid. But when the scale accumulates to any great extent, it not only causes a great expense by waste of heat, and by the necessity of its removal, but it becomes highly dangerous, filling up the water spaces, choking the feed pipe, impeding the circulation, and causing overheating of the boiler plates, softening them, and damaging them by the consequent inequality of expansion; e.g. To obtain 90 lbs steam pressure, the water must be heated to 320° F. If the boiler is clean, inside and out, the temperature of the outside of the boiler plate, will probally not exceed 325° or 330°. But if there is 1/2 inch of scale, the boiler plate may require heating to 700°; since the scale is a poor conductor. The iron, at a low red heat, soon burns out, or softens, and is liable to bulge.

As illustrations of the troub-

-le and expense that impure water often causes, the following examples may be given. In the report of the Hartford Ins. Co. for three months of 1876, it is stated, that one half of the whole number of defective boilers, become so, from deposition of sediment. On the Chicago, Alton, & St. Louis R.R. the locomotives are blown and washed out, once or twice a week. The master-mechanic of a road crossing the state of Ohio, reports that in the case of boilers run from twelve to fourteen months, it is necessary to remove one half or all the flues, crown bars, and sometimes the crown sheet, in order to clean them thoroughly. The flues will have a scale from 1/8" to 3/8" thick, and sometimes will be connected together in one solid mass, for nearly the whole length of the boiler. In the fifth report of the Master Mechanics Association, it is stated that the expense to each locomotive, employed in most of the Middle and Western States, due to impure water and in-

Master
Mechanics
Reports
1873 & 4.

-crustation, is more than $750.00 a year. On the N.Y.C.R.R., as much as 1300 lbs. of incrustation & sediment have been taken from a boiler at one time, but this is an extreme case.

Mr. Thompson of the Eastern road says, that a few years ago scale was almost unknown on that road, whilst now the tubes become coated with a scale from 1/8" to 1/4" thick. The only marked change that has been made in locomotive running, in the last few years, is the change from pressures varying from 80 lbs. to 90 lbs., to pressures varying from 120 lbs. to 135 lbs. The temperature of boiling water under 80 lbs. pressure is 324.1° F., and under 135 lbs. pressure is 358.3° F., a difference of about 34°. Whether this elevation of temperature is sufficient to account for the increase of scale, an analysis of the scale might show.

Innumerable methods for removing incrustation have been resorted to, mechanical, chemical and electrical.

Once for all, if there is much sediment, blowing off from the bottom, or from the surface, or from both according to the specific gravity of the sediment, should be frequently practiced. Without it, agents for removing the scale, or for preventing the formation of scale, by changing the character of the sedimentary matter, are of no use. Without it the evil will, in many cases, be increased by the use of chemical agents, since their effect is often to change the hard sediment into a fine, loose powder, which is still more dangerous, unless removed.

Sediment collectors, and improvements in circulation, are often available in mitigating the effects of bad feed water.

Innumerable patent compounds have been devised to prevent and remove scale, some of which we have record of as doing good service.

Leaving these, we will consider only the different chemical agents upon which most of these compounds are based.

Among these agents, the most useful is carbonate of soda. When the impurity is sulphate of lime, the carbonic acid of the carbonate unites with the lime, forming a precipitate of carbonate of lime, which has but little tendency to scale. The second compound from this reaction, sulphate of soda, is soluble. If the impurity is bicarbonate of lime, the soda, having a greater affinity for the carbonic acid, takes the excess, forming bicarbonate of soda and precipitating carbonate of lime. Heat causes the bicarbonate of soda to give up the excess of carbonic acid so that it is ready to act again as before. The soda also acts beneficially in removing scale already formed, and in neutralizing the acidities of the water.

Sal ammoniac is used to a considerable extent when the impurity is carbonate of lime. The resulting chloride of lime is soluble, and the carbonate of ammonia is both soluble and volatile. The latter however will attack the plates and brasswork if concentrated.

Where the use of any chemical agents is necessary, the plates should be frequently examined, to guard against corrosion by the acids formed.

Dr. Rogers method for water containing both the carbonates and sulphates of lime or magnesia, which has had a practical and successful trial, is to introduce tannate of soda, producing the following reactions. Tannate of lime or magnesia, as the case may be, is precipitated in a light, flocculent form. Bicarbonate of soda is formed, which reacts on the sulphate of lime, forming sulphate of soda and carbonate of lime, the latter of which is immediately acted upon by the tannate of soda. Tannin used alone is objectionable, as it quickly attacks the iron, but the presence of the soda neutralizes its acid effect.

The mechanical agents intro-

-duced are very numerous. The general principle of their action is to envelop the particles of solid matter precipitated, by a starchy, glutinous substance preventing these particles from adhering to the boiler plates or to each other. Of these substances we will examine but one, Steatite Talc, a substance first used for this purpose in Europe, and but recently patented in this country.

Steatite Talc is a variety of soapstone, consisting of about 60% silica, 30% magnesia, the remaining constituents being protoxide of iron, magnetic iron, water and alumina. The substance is insoluble, incombustible, and has no corrosive action. In 1872 it was highly recommended by Marie, Chief Engineer of the Paris, Lyons & Mediterranean Railways, who states that its action is to remove, as well as to prevent incrustation, and that it acts upon the piston and piston rod, valve seats, valve stems and so forth, like oil, preventing wear and reducing the friction.

When the water is very impure, it would seem desirable to remove the impurities before the water enters the boilers. This is often done, both by chemical agents, and by heating the feed water.

The subject has been especially agitated on our Western railroads. It has been proposed there, to supply water from reservoirs built to catch the surface drain. Also to purify the water in tanks before it is taken into the engine. For the latter purpose, Clarks' process, which has been extensively used in connection with waterworks in England, where the prevailing impurity is bicarbonate of lime from the chalk strata, has been recommended. It consists of the addition of a quantity of lime, sufficient to take up the excess of carbonic acid from the bicarbonate of lime, the original bicarbonate and the added lime being both precipitated as carbonate of lime. In this case, no alkaline salts are substituted for the carbonate removed, as is the case when the other methods are used.

In this connection, it may be interesting to give Dr Rogers method of roughly estimating the value of any water for boiler use. "A saturated, filtered tincture of soap is prepared of proof spirit, and the soft soap of the pharmacopeia; also a solution of bi-carbonate of lime, by passing carbonic acid gas through lime water till it becomes clear. An ounce of this is carefully evaporated and the residue weighed. To another ounce of this solution the tincture of soap is added, one minim at a time, with shaking after each addition, until a permanent lather is formed. The weight of the above residue in grains is to be compared with the number of minims required to produce a lather. This comparison will show how many grains of hardness will be neutralized by a given number of minims of the soap tincture.

This tincture, thus roughly titrated, is to be added, one minim at a time, with constant shaking, to an ounce of any water to be examined, until a permanent lather is produced; the number of minims required will indicate, by reference to the last operation, the number of grains of hardness. Tincture of soap does not alter by keeping closely stopped, and by this simple agent, with no other apparatus than a minim glass and a vial, the hardness of any water may be determined with sufficient accuracy to decide upon its fitness for boiler use"

The method is not infallible, since the presence of large quantities of some salts, as carbonate or chloride of soda, would render the water hard although not greatly injuring it for boiler use. Since however the presence of these salts is the exception, and of the injurious salts carbonates of lime and magnesia and sulphate of lime are the rule, its prediction can generally be relied upon

On sea vessels surface

condensation is extensively practiced to keep the boilers supplied with pure water. In this case it is often found advisable to protect the boilers by a slight scale as the accumulating grease and acids otherwise pit the iron.

Sea water contains about 1/32 of its weight of salt. This large percentage is not as troublesome as would at first seem, since it is held in solution until the liquid reaches the point of saturation, which is when the water contains about 3/8 of its weight of salt.

It is advisable not to let the proportion of salt exceed 2/32, in order to do which one half the feed water must be blown off.

The loss from this source can be calculated as follows. Assume the temperature of the feed water to be 100° F., and the pressure of steam to be 80 lbs. to the sq. inch, and the degree of concentration to be 2/32. Then for one lb. of water used, one lb. must be blown out. The temperature of the water blown out is that due to a pressure of 80 lbs. or about 326.5° F., hence the number of thermal units it has received is 326.5° − 100° = 226.5°. The number of thermal units in the steam from the lb. of water evaporated, is the sum of its sensible and latent heats at the given pressure minus 100° = 1214.7° − 100° = 1114.7°. The ratio of the former to the latter gives about 19% as heat wasted

The most corrosive agent in sea water is chloride of magnesium, which decomposes at 212° F., forming magnesia and chlorhydric acid.

Before leaving the subject of incrustation, since we have stated the comparative purity of Wenham water, and the practice in boiler working at the Salem pumping station which pumps from Wenham Lake, it may be interesting to note the effect of this water upon the boilers, after the run of three months.

The engines are compound with jet condensers, from which grease is introduced into the boilers by the feed water. The tubes had a greasy appearance, but no coating. The only sediment was along the water line on the boiler shell. This was a soft greasy accumulation, which could be easily scraped off clean, leaving the plates apparently as sound and fresh as new.

Combustion

The securing of economical combustion is one of the most difficult problems of steam generation, and one that is yet far from being practically understood. Science tells us what the results of combustion are under theoretically perfect conditions, but it has not yet been able to cope with the practical difficulties, that arise in every case of steam generation, so that the real results obtained shall approximate closely to the theoretical.

The subject is at the best a complicated one. Economy of combustion not only requires different management for each type of boiler, but for each boiler of this type. Moreover the management for the same boiler must differ according to the demand for steam, variation in draft, nature of fuel and so forth.

A boiler and its setting can only be designed to answer roughly the requirements of the average practice for which it is intended. It devolves upon the skill of the fireman to suit the management to the design, and to the variations in conditions.

The principal substances to be dealt with are gaseous and invisible. In the present state of practice, one of the most important points, the quantity of these gases can only be roughly estimated.

Many, who see every day, firemen of little intelligence or skill managing steam boilers, apparently with so little difficulty, may think that too much stress is laid upon the importance of the subject

The fires are managed, that is they are supplied with the fuel needed and the required quantity of steam is generated, but the chances are that it is being done at a great waste. The boilers of the Manchester Mills were probably managed to all outward appearances well enough, but you have already seen the waste that an intelligent examination revealed. Trowbridge says "There is no doubt that a saving of 20% and often 30% of the quantity of coal now consumed in many manufacturing establishments might be effected by the introduction of more perfect proportions and arrangements, and especially by the employment of thoroughly skilled and intelligent stokers"

Large manufacturing and railroad corporations have deemed the subject one especially worthy of study as a means of reducing expenses.

The principal fuels, and the

only ones which we will consider, are anthracite and bituminous coals and wood. We will examine these with regard to their constitution and the principles involved in their combustion.

Anthracite coal is very nearly pure carbon. Its average constitution is about 90% carbon, about 4% hydrogen and 3% oxygen.

Bituminous coals contain from 70% to 90% carbon, and varying proportions of hydrogen and oxygen.

Dry wood contains about 50% carbon. The residue is hydrogen and oxygen, but as a large portion of the hydrogen unites with the oxygen to form water, the total heat of combustion is considered to be that due only to the 50% carbon.

Let us examine the total heat of combustion of these three substances. In so doing we will follow the methods given by Rankine, Wilson &c. considering the hydrogen, beyond that required to form water with the contained oxygen, as being effective, and taking also their data in regard to carbon. W. R. Johnson however says "There is no true proportion between the amount of fixed carbon and the heating power" and in regard to the hydrogen "Indeed the hydrogen appears from the practical tests thus far adduced, no more to merit consideration as an element of evaporative efficiency in a coal, than an equal weight of silica or other inert substance".

Treatise on "Practical values of American & Foreign coals"

Take a specimen of anthracite coal containing in one lb. .915 lbs. of carbon, .035 lbs. hydrogen, and .026 lbs. oxygen, the rest being earthy matter. Experiments have shown that one lb. of carbon burned to carbonic acid gives out 14,500 units of heat, hence our .915 lbs. will give 13,268 units of heat. We have next .035 lbs. hydrogen. But this is not all available for the generation of heat, for there is also present .026 lbs.

oxygen. A quantity of hydrogen, sufficient to unite with all the oxygen to form water, must be taken out. Since hydrogen unites with oxygen in the proportion of 1:8 by weight, the quantity of available hydrogen will be $.035 - \frac{.026}{8} =$ .032 lbs. 1 lb. hydrogen burned to water generates 62,032 units of heat, hence our .032 lbs. will give 1,985 units. Hence the total heat of combustion will be 13,268 + 1985 or about 15,250 thermal units, an amount of heat sufficient to raise $\frac{15,250}{966} = 15\frac{3}{4}$ lbs. of water from 212° to steam at atmospheric pressure.

In the same way we find that 1 lb. of bituminous coal, containing 80% carbon 5.4% hydrogen and 1.6% oxygen will generate sufficient heat to evaporate 15.3 lbs, and 1 lb. of dry wood, containing 50% carbon, 7.5 lbs. of water under the above conditions.

Let us next examine the elevation of temperature that will result from the combustion of the above specimen of anthracite coal under theoretically perfect conditions.

First, in order to get the amount of the total heat of combustion that is available to raise the temperature of the products of combustion, we must subtract from the total heat, the amount of heat that is required to convert the water that is in the coal, and the water that is formed by the combustion of the hydrogen in the coal, into steam. This leaves us 15,250 − (.317 × 966) = 14,947 units. To obtain the elevation of temperature, we must divide this by the quantity of heat necessary to raise the temperature of the products of combustion one degree. The .915 lbs. of carbon requires 2.434 lbs. oxygen, forming 3.349 lbs. carbonic acid. The .032 lbs. hydrogen requires .256 lbs. of oxygen, forming .288 lbs of water. To this must be added the water contained in the coal making in all .317 lbs of water. The total amount of oxygen that is required is 2.434 + .256 =

2.69 lbs. If this amount of oxygen is furnished by the air, there must be added 9.415 lbs. of nitrogen. The sum of the products of these quantities of carbonic acid, nitrogen and steam, multiplied by their respective specific heats, gives the heat required to raise the temperature of the products of combustion one degree and equals 3.172 thermal units. $\frac{14,947}{3.172}$ = about 4712° as the resulting elevation of temperature, assuming the method of calculation to be correct.

This temperature is never obtained in practice and on an average not more than 50% of the total heat of combustion is utilized. Prideaux estimates the average duty obtained in marine boilers at 7½ lbs. of water evaporated per lb. of coal, or about one half the theoretical duty. The writer has found by the examination of the records of 34 war and merchant vessels that the average evaporation per lb. of coal was

Lecture before the United Service Institution on "Economy of Fuel in Ships of War"

7 lbs. and of 21 river steamers was 6 lbs.

Let us examine the difficulties which prevent us from obtaining more economical results.

In the first place we have assumed in our calculations, that it is only necessary to admit a quantity of air containing just the amount of oxygen required.

This is evidently far from being the case. If we could bring each atom of oxygen introduced with the air, into intimate contact with the right number of atoms of the combustible, then our assumption would be true.

But this intimate mixture we are unable to obtain, and so we admit such an excess of air, that all the combustible must find enough oxygen to effect its combustion.

That such an excess of air should be necessary is not surprising, when we notice the care that is always considered necessary for the intimate mixture of gases in a laboratory experiment, and compare the circumstances of the latter with the ruder conditions of furnace combustion. Moreover, the air is not only to be brought into intimate contact with the gaseous hydrocarbons, but also with the solid particles of carbon, which remain after the gases have distilled off.

In our calculations, we found that about 12 lbs. of air if intimately mixed, would be sufficient for the combustion of 1 lb. of coal. The additional quantity that must be supplied to insure perfect combustion, will of course depend upon a great many considerations, but may be roughly estimated as from 6 to 12 lbs., making the total supply of air necessary for the combustion of 1 lb. of coal from 18 to 24 lbs. This air must be heated to the temperature of the furnace gases. If we assume that the combustion was perfect before its admission, the total heat of combustion will not be increased by its presence, and hence the temperature of the gases will be reduced from 4900° to about 2570° or by about 1/2.

If by any mechanical means we can make the mixture more intimate, we shall not need to admit so much air for complete combustion. A moments consideration of this point will show the advantage of admitting the air in small jets. The fine streams of air, especially if their velocity is increased by a blast, force their way in among the gases, agitating and separating the particles in the most thorough manner. The same amount of air admitted in one large stream might retard rather than aid the combustion. The agitation of the gases is only local, it produces a great cooling effect on the gases in its immediate vicinity, and finally a large amount of it passes off. carrying away heat without having contributed to the production of heat.

Every fireman recognizes the evil of admitting large volumes of air through one opening, in his care to keep the fuel evenly spread over the grate.

The effect of such large openings is well shown by the annexed curve Fig 19 taken from C. Wye Williams treatise on Combustion. A charge of three cwt. of coal was thrown into the furnace, and the fires allowed to burn without being disturbed in any way. During the first 35 minutes the temperature rose from 760° to 1220°. It then commenced to fall, and in 40 minutes, had fallen from 1220° to 1040°. The fires had not been disturbed for 75 mins. and in some places had burned through. They were now leveled, and the effect was a rise in 3 min. from 1040° to 1150° and the temperature did not fall again to 1040° till 15 mins. after the fires were levelled.

Although the total amount of air admitted was perhaps no greater

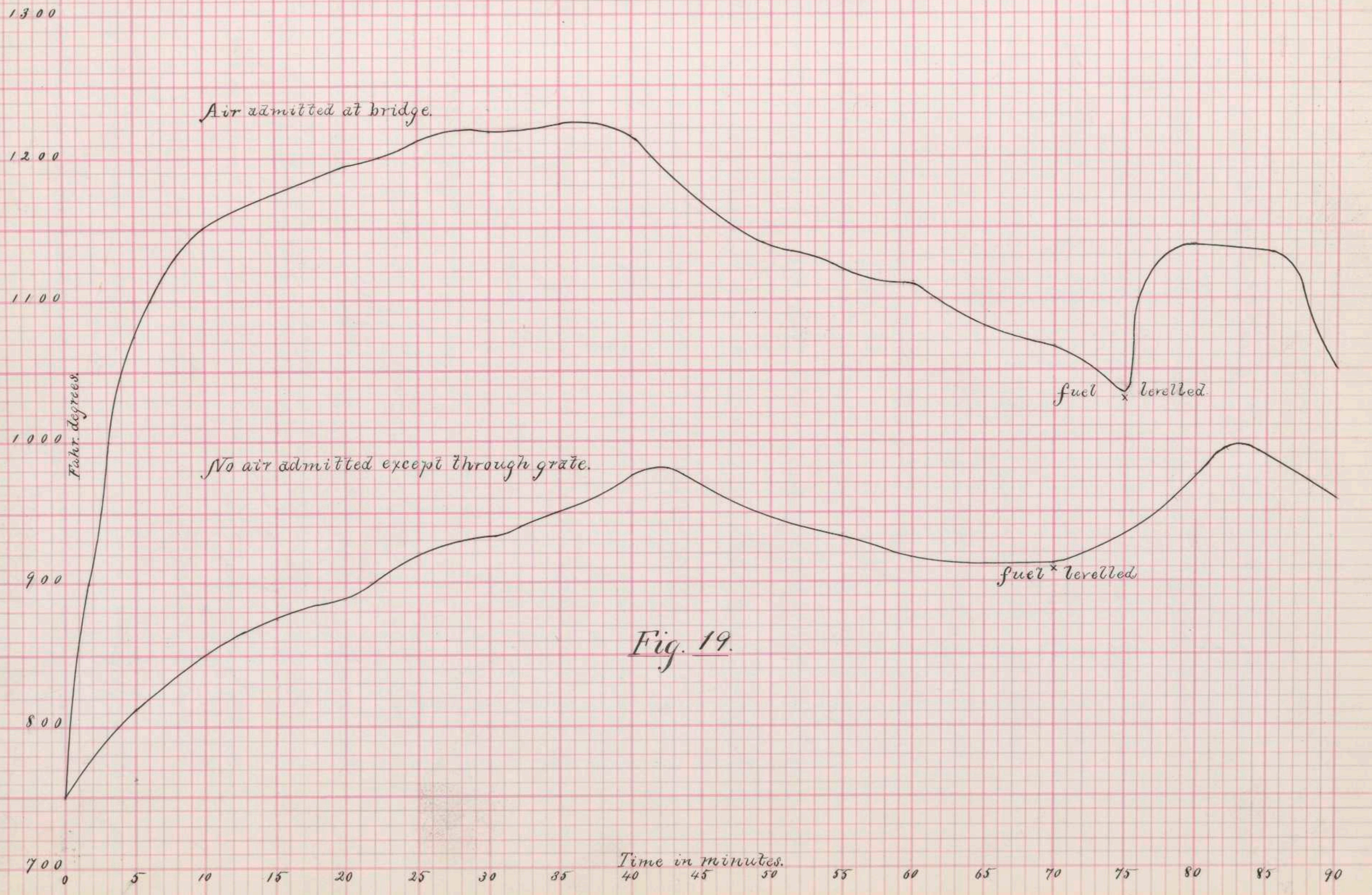

1300
1200
1100
1000
900
800
700
Fahr. degrees.
Air admitted at bridge.
fuel × levelled.
No air admitted except through grate.
fuel × levelled
Time in minutes.
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90

Fig. 19.

than would be necessary for good combustion if well distributed, yet there was a local excess. The effect produced is similar to that of admitting at all points more air than is necessary.

We have already noticed that an excess of air carries off some of the heat of combustion, and lowers the temperature of the fire. If this excess of air is very great, the temperature of the gases may be lowered below their point of ignition, and consequently pass off from the furnace unconsumed. But the trouble with which we have to deal is the introduction of too little air.

When a fresh charge of bituminous coal is thrown into the furnace, the heat first distills off the hydrocarbons. In order that these shall be consumed, they should be supplied with a sufficiency of air while at a sufficiently high temperature to ignite. Suppose that too little air is admitted. The hydrogen of the hydrocarbons has a greater affinity for oxygen than the carbon has. The result is the combustion of the hydrogen and the liberation of the carbon. Whilst united with the hydrogen the carbon was invisible, but when freed from the hydrogen it is in the form of little particles of carbon, recognized as soot; and forming with the escaping gases, smoke.

The proper remedy for this evil is not to attempt to consume the smoke already formed, but to strike at the root by preventing the formation of smoke. Most of the smoke consuming processes are worthless. At the moment of the ignition of the hydrogen in the hydrocarbons, the carbon is intensely heated and is in the proper condition to unite with oxygen and pass off as carbonic acid. If the air is not supplied, it is cooled down and becomes soot. In order to consume this it must be reheated to a high temperature, and this is useless unless at the same time sufficient air is admitted.

Economy evidently requires the combustion of this carbon when first heated. The air for their combustion should be admitted into the furnace chamber over the layer of coals. At this point the hydrocarbons are at their highest temperature. The air admitted in this way has its full proportion of oxygen, and the quantity supplied can be regulated. Of course the admission of this air at a point where the hydrocarbons are cooled down below their igniting temperature is worse than useless.

In considering the combustion of hydrocarbons, it is well to notice that the absence of smoke is no proof of their perfect combustion, for its absence may in some cases indicate a less degree of economy than its presence. We have seen that if the supply of air is too small, the hydrogen of the hydrocarbons is consumed and the carbon becomes visible as soot. We obtain the heat due to the combustion of the hydrogen, but lose that which the carbon is capable of giving. But now suppose that there is no air admitted to the hydrocarbons until they are cooled below their igniting temperature. The hydrogen is not ignited. There will be no smoke formation, for the carbon has not been liberated and the hydrocarbons themselves are invisible. Yet the loss is greater than when there was a smoke formation, for whilst before we received heat from the combustion of the hydrogen, and only lost that which the carbon would give by its combustion, we have now lost the heat from both.

A dense smoke is supposed to indicate a very great waste of fuel. During the combustion of a ton of bituminous coal containing 82.1% Carbon 5.3% Hydrogen and 5.7% Oxygen, there will be formed and given off from the furnace, on an average, about 956 lbs. water as steam, 6000 lbs. carbonic acid, 31000 lbs. nitrogen and 2600 lbs. oxygen.

This enormous quantity of gaseous matter constitutes the body of the smoke. The carbon is merely the coloring matter. Nor will the quantity of carbon required to blacken the cloud of vapor be large. C. Wye Williams in his treatise on Combustion says "the weight of this carbon, in a cubic foot of black smoke, is not equal to that of a single grain," and also says, "if a single grain weight of soot is intimately mixed with a gallon of water the mixture will have the color of ink."

Up to this point, in our discussion of imperfect combustion we have scarcely mentioned one product of imperfect combustion, viz. carbonic oxide. On examining this product we shall see still greater reasons why the waste of combustion is not to be measured by the smoke produced, and why air admission above the fuel even after the combustion of the hydrocarbons, may be beneficial.

Carbon forms with oxygen two compounds, carbonic acid, the product of perfect combustion, and carbonic oxide the product of imperfect combustion of carbon. Suppose that all the hydrocarbons have been consumed, and there is left a layer of incandescent fuel on the grate. The air first meets the fuel at the surface of the grate bars. It's oxygen unites with the carbon in the ratio of 1 lb. of carbon to 2⅔ lbs. oxygen, to form carbonic acid. If the layer of coal is thick, the carbonic acid as it rises through the coal meets with an excess of carbon. The result is that it takes up another equivalent of carbon, so that we now have instead of 3⅔ lbs. carbonic acid, 4⅔ lbs of carbonic oxide. Now 1 lb. of carbon burning to carbonic acid, gives 14500 units of heat, whilst 1 lb. of carbon burning to carbonic oxide, gives only 4400 units of heat. Hence, although in the above example the final result has been the combustion of 2 lbs. of carbon yet the total heat of combustion is only 8800 thermal units, or 5700 less than that furnished by the combustion of 1 lb. of carbon to carbonic acid. The fact that 1 lb. of carbon burnt to carbonic oxide furnishes less than 1/3 the heat, that the same carbon would give if burned to carbonic acid, shows how enormous is the loss of heat when the process of combustion stops at this stage, and the gas passes off as carbonic oxide.

But now suppose we admit enough air to burn this carbonic oxide to carbonic acid. 2 1/3 lbs. carbonic oxide burned to carbonic acid give 10100 thermal units, and hence our 4 2/3 lbs. would give 20200 thermal units. We have already received 8800 thermal units from the combustion of the 2 lbs. of carbon to carbonic oxide. Now if we burn this carbonic oxide to carbonic acid, we shall obtain from the 2 lbs. of carbon a total heat of 20200 + 8800 = 29000 thermal units, the same heat which would be generated by the combustion of the 2 lbs. of carbon directly to carbonic acid. By admitting enough air to burn the carbonic oxide to carbonic acid, instead of allowing it to pass off as carbonic oxide, we have raised the total heat of combustion by 20200 units of heat.

The waste attending the admission of too little air, in all cases where solid carbon is to be burnt, is evident and yet there is a waste that goes on without the formation of smoke. It may indicate itself however in another way. Burgh cites an instance of a vessel steaming in the Pacific Ocean in the night time. The furnace combustion was so imperfect, and the heat carried off by the escaping gases so great, that large quantities of carbonic oxide were burning at the funnel head. We will add for the credit of the navy, that the event was so unusual, that vessels in the distance mistook it and afterwards reported it, as the eruption of a distant volcano. The remedy for such waste is the admission of enough air to the furnace. Admit it in small jets and at a point where the temperature of the gas is high enough for ignition.

The experiments of Isherwood give us proof of the necessity for air admission above the fuel for anthracite as well as for bituminous coals. The experiments were made on a three furnace marine boiler having in each furnace door a total area of 7.854 sq. in. for air admission. With anthracite coal fires 5" thick and consuming 8 lbs. coal per square foot of grate area per hour, the loss resulting from the closing of the air holes was 5.48%. With the same coal, fires 8½" thick, and a maximum consumption of 11 lbs. coal per square foot grate area per hour, the loss was 3.45%. With semibituminous coal fires 8½" thick, consuming 11⅓ lbs. coal per square foot grate area per hour, the loss was 1.81%. In regard to these results Isherwood says "It appears that the admission of air through holes in the furnace doors, are more beneficial with anthracite than semibituminous, a result contrary to popular belief, but which in several cases has been verified by the writer". "A larger admission of air would have been probably beneficial."

He also says "These tables show also the economic effect of burning anthracite with thin fires." I have copied just enough of the results to show the gain in this experiment of thin over thick fires.

Fires 5" thick.	Lbs. water evap. from 212° by 1lb coal
Holes open	12.044
" closed	11.547
Fires 8.5" thick	
Holes open	11.060
" closed	10.412

Another important feature necessary to secure perfect combustion especially where only a natural draft is used, is to give the gases time to mix.

thoroughly with the oxygen. This effect is gained by slow combustion, which also has the advantage of allowing the gases enough time to impart their heat to the water.

Isherwood says,"from a number of experiments on different types of boilers "It will be observed, that whatever be the type of boiler, the slower the combustion "ceteris paribus" the higher the economic effect from the combustible. This does not result from more perfect combustion or any less air dilution, but simply from the fact that the maximum heat absorbing surface given with the best types of boilers is too small to reduce to the same temperature in the same time, a larger quantity of heated gases than that due to the minimum weight of combustible per square foot grate area per hour". I can hardly agree however with Isherwood in his statement that a part of the increased economy is not derived from more perfect combustion.

Combustion is aided by combustion chambers, which retard for a moment the onward flow of the gases and cause them to eddy around insuring more thorough mixing. Most practical boiler men lay great stress on the combustion chamber. Burgh says "The combustion chamber in all cases is the main portion of the boiler". The benefit derived from them is analogous to that derived from a long run. When using bituminous coal, the flame may be from 10 to 20 feet long. If the gases are forced into the tubes of a tubular boiler near the furnace, the flames are extinguished, and the benefit of their long run is lost, and the combustion of their hydrocarbons rendered imperfect. For the same reason, the firebox should be deep and roomy, so that the gases shall not be burried off. If the top of the fuel is too near the boiler shell, the gases are cooled down below their igniting point by contact with the shell before their combustion is effected. This is the evil of carrying high

Fires

A great amount of heat is carried off by the waste gases. In the case of a chimney draft, the draft is caused by the difference of weight between the column of heated gases in the chimney, and that of an equal column of cold air outside the chimney; a high chimney temperature is then conducive to good draft, whilst it detracts from the economic efficiency of the coal burned by carrying off more heat with the waste gases.

Rankine says "It may be laid down as a practical rule, that to insure the best possible draft through a given chimney, the temperature of the hot gas in the chimney should be nearly, but not quite sufficient to melt lead" i.e. about 600° F.," and "it is more advantageous to raise the temperature above this limit."

Trowbridge however says that this statement of Rankine's seems to be an error, and refers to Peclet, who says that the maximum draft occurs only with an infinite degree of temperature, and that a temperature of about 600° F. gives 7/10 of the maximum. The advantages of a blast are that the specific heat of the products of combustion are less under pressure and the waste from the escape of heated gases can be reduced to a minimum since they are not needed for draft.

In regard to the value of American coals Johnson says "It will not fail to be remarked that the justly celebrated foreign bituminous coals of Newcastle, Liverpool, Scotland, Pictou and Sidney, which constitute the present reliance of the great lines of Atlantic steamers, are fully equalled or even surpassed by all the free burning coals of Maryland and Pennsylvania; and that an equally decided advantage is enjoyed by the anthracite over the foreign coals tried, whether we consider them under equal weights or equal bulks.

For rapid evaporation Indi-

-ana coal is inferior to no highly bituminous coals. In heating power and freedom from impurity it surpasses the Cannell of Scotland. He gives the constitution of Lehigh coal as 87.15 fixed carbon, 5.28 volatile matter 5.56 earthy matter, and of Lackawanna 87.74 fixed carbon, 3.91 volatile matter, 6.35 earthy matter. Lehigh burning 6.95 lbs. per. sq. ft. grate area per. hour evaporates 9.626 lbs water from 212° at atmospheric pressure. Lackawanna burning 6.45 lbs. per. sq. ft. of grate area per. hour evaporates 10.764 lbs. water from 212° at atmospheric pressure. Trowbridge gives as the calculated heat evolved from the anthracite of Pennsylvania, from the combustion of 1 lb. 14,114, and from the mean of bituminous coals 14,400.

Chimneys (See page 32).

The following matter in regard to chimneys is taken from an article on Steam boilers and Chimneys by Robert Briggs. C. E. and was received too late to be presented under it's proper head. He says, "If the cross area of the chimney is taken at 0.7 the area of the grate divided by the square root of the height of the chimney, and a half square foot of area be added to equalize the friction of the sides, an approximate rule for the least area desirable will be obtained for square or round chimneys, sufficiently accurate for practice. The following table is appended and is deduced by this rule. In the calculation the area of the grate is taken as the actual area minus 2 sq. ft. This is deducted to allow for the inefficiency of the corners of the grate, which are not kept as clean of ashes and clinkers as the middle.

Journal
Franklin
Institute
April 1876.

Proper sectional areas of chimneys for grates of various surfaces.

Actual surface of grate.	Max. quan. coal burned per hr. at 12 lbs. per ft. (less 2 ft. actual area)	Horse power at 55 sq. ft. grate (less 2 ft.)	Height of chimney in feet.										
			25	30	40	50	60	70	80	90	100	120	140
6	48	7.07	1.06										
7	60	9.09	1.20	1.14									
8	72	10.91	1.34	1.27	1.16								
9	84	12.73	1.48	1.39	1.27	1.2							
10	96	14.54	1.62	1.52	1.39	1.3	1.23						
12	120	18.18	1.90	1.88	1.61	1.5	1.41	1.34					
14	144	21.81		2.03	1.82	1.7	1.59	1.50	1.44				
16	168	25.45			1.93	1.9	1.77	1.67	1.60	1.53			
18	192	29.09				2.1	1.96	1.84	1.75	1.68	1.62		
20	216	32.72					2.14	2.00	1.91	1.83	1.76	1.65	
22	240	36.36						2.17	2.07	1.98	1.90	1.78	1.66
24	264	40.00							2.22	2.12	2.04	1.91	1.78
28	312	47.27								2.27	2.32	2.16	2.01
32	360	54.54									2.60	2.42	2.25
36	408	61.81										2.67	2.47
40	456	79.08											2.71
1 ft. grate without constants.			.1400	.1278	.1107	.0990	.0911	.0837	.0783	.0738	.0700		

Land Boilers

The common factory tubular boiler is shown in Fig. 15. Its efficiency is good. It is simple in its parts and hence easily managed, cleaned, and repaired. The gases of combustion pass under the shell to the rear, back through the tubes to the front, and then to the chimney, sometimes directly and sometimes after passing along the top of the shell back to the rear end. The tubes give a large amount of heating surface for the cubical capacity, whilst the ends at which the gases enter are so far removed from the furnace, as not to interfere with the run of the flames. The tube door gives access to the tubes for cleaning them of soot. The manhole at the top gives access to the interior above the tubes, for cleaning and repairs, whilst the sediment that collects on the bottom is washed out through mudholes not shown.

Trowbridge gives 1:28 as the

ratio of grate to heating surface for cylindrical tubular boilers with chimney draft, and the consumption of coal as from 9 to 15 lbs. per. square foot of grate area per. hour. The evaporation is from 7 to 10 lbs. of water per. lb. of coal.

Wilson says "In multitubular and other boilers where the heating surface is to the grate area as from 30:1 to 40:1, 9 square feet of surface will evaporate 1 cubic foot of water, or require 4½ square feet of total heating surface per horse power.

Messrs. Kendall & Roberts of Cambridgeport have kindly furnished me with the following as their average practice in the manufacture of horizontal tubular boilers. Their letter says. "Below we give you the dimensions of one of our boilers, the proportions being about the same for all sizes e.g.

48" C. T. Boiler x 16' shell
49 – 3" Tubes x 15' long. We call it a 43 H. P. boiler taking 15 sq. ft. heating sur-

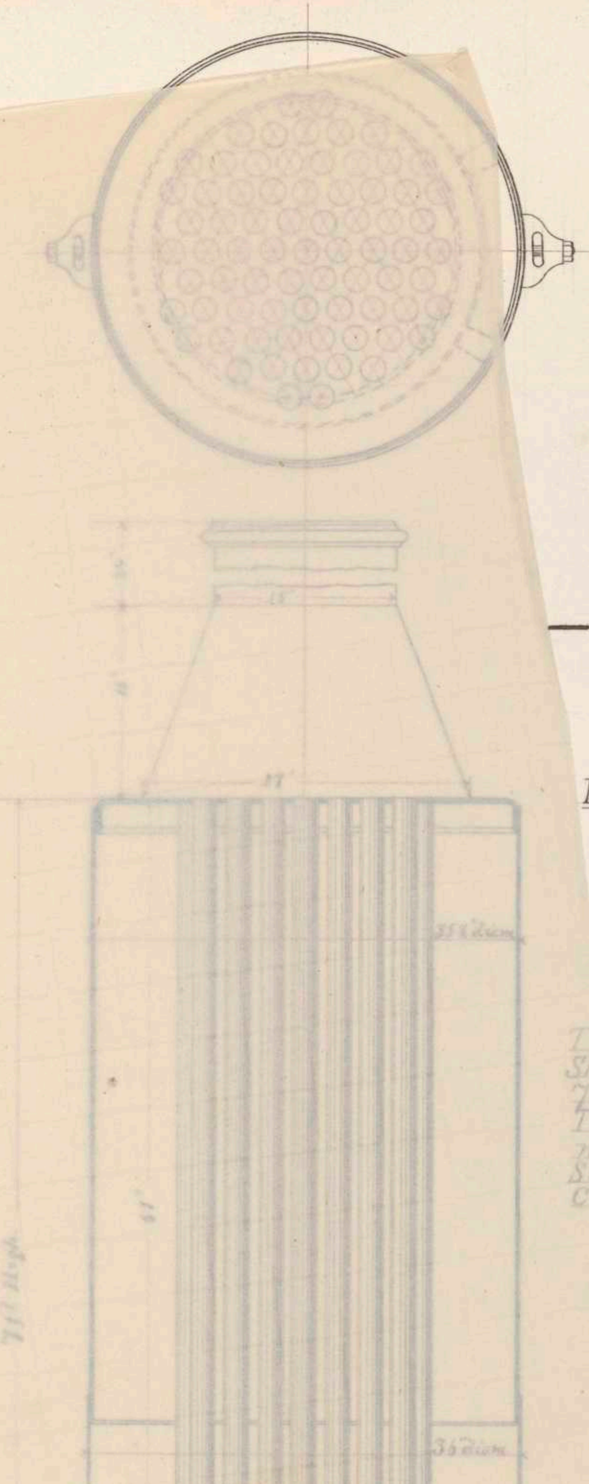
face per H.P.

Heating surface	645	square	feet.
Grate "	19⅓	"	"
Draft area	2	"	"

The draft area we reckon as 2/3 the area of tubes."

The ratio of grate to heating surface is about 1:33. The boiler could probably be worked much higher than it is rated.

Fig. 20 represents a vertical tubular boiler. This form is much used for hoisting engines, agricultural purposes &c. where small cost ease of management and transportation, small bulk and rapid generation of steam are desired. A combined pump and boiler of this class as manufactured by Geo. F. Blake & Co., is shown in Fig. 21.



BOILER
for
HOISTING
—ENGINE.—

Scale 3/4" = 1'

FIG. 20.

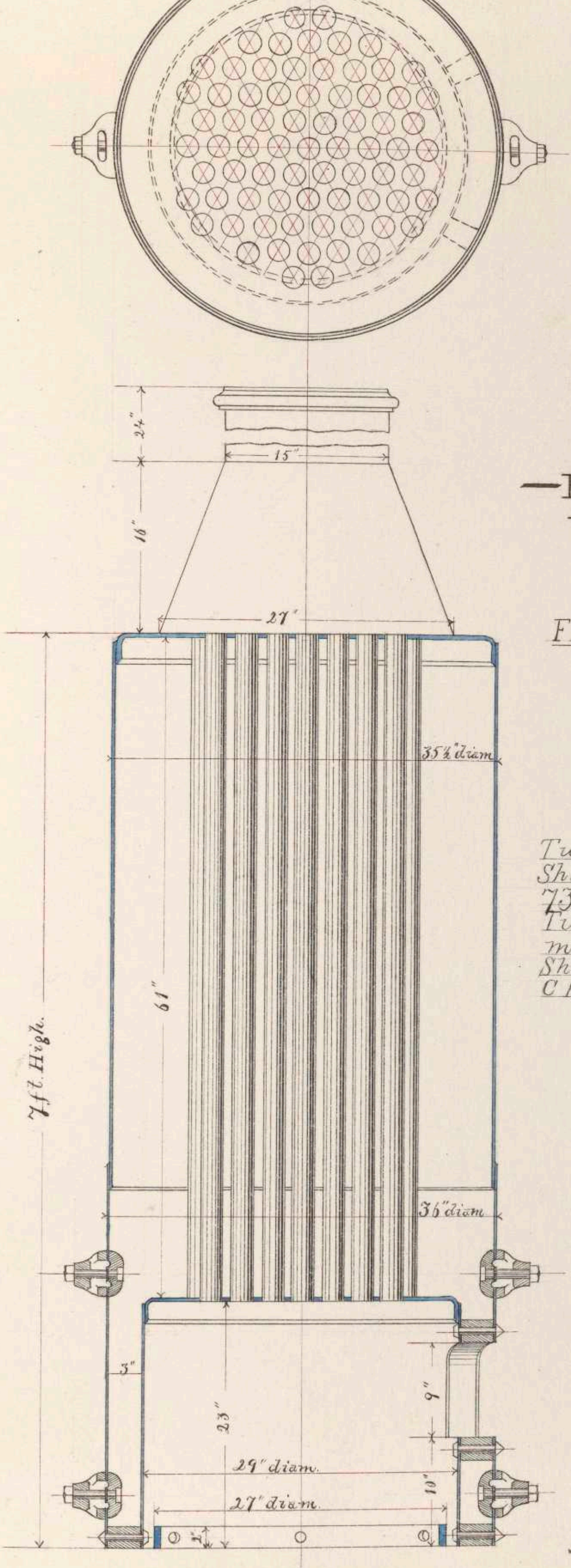
Tube Sheets 3/8" Thick.
Shells 1/4" do.
73 – 2 inch Tubes.
Tube Sheets and Firebox
made of best Firebox Iron.
Shells made of best
C No. 1 Iron.

C.L.D.

BOILER
for
HOISTING
—ENGINE.—

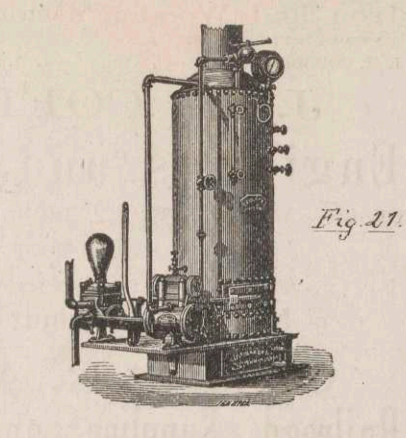
Scale ¾" = 1'

FIG. 20.



Tube Sheets ⅜" Thick.
Shells ¼" do.
73 – 2 inch Tubes.
Tube Sheets and Firebox
made of best Firebox Iron.
Shells made of best
C No. 1 Iron.

C.L.D.

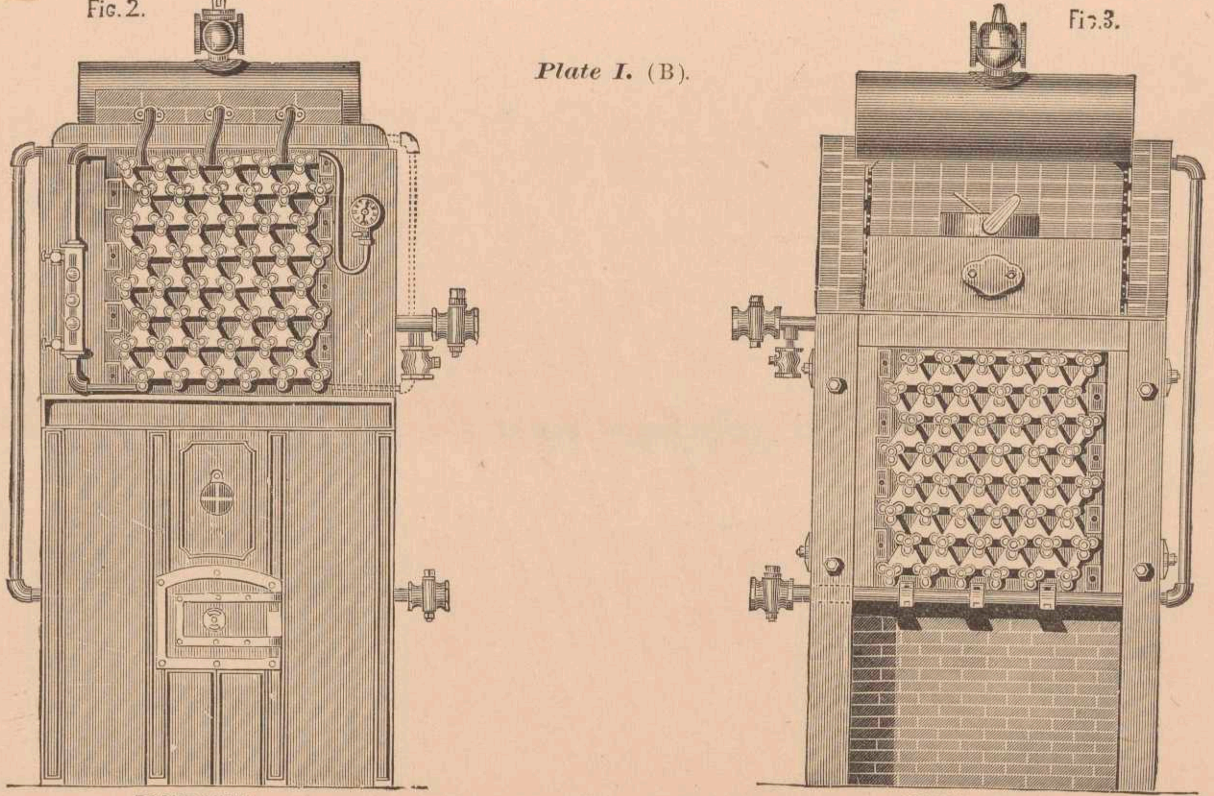


COMBINED PUMP AND BOILER.

The tubes are easily cleaned from the smoke stack end. All heavy sediment collects, when the boiler is quiet, on the lower tube plate, and in the water spaces, from which it is easily removed by the upper and lower mudholes. The draft and circulation being both direct are good. The exhaust steam as shown in Fig 21 is generally carried into the smoke stack. The draft being so direct, large quantities of gas pass off without coming in contact with the surface of the tubes; hence these boilers are generally wasteful of fuel.

Plate I. (B).

Fig. 2. Fig. 3.



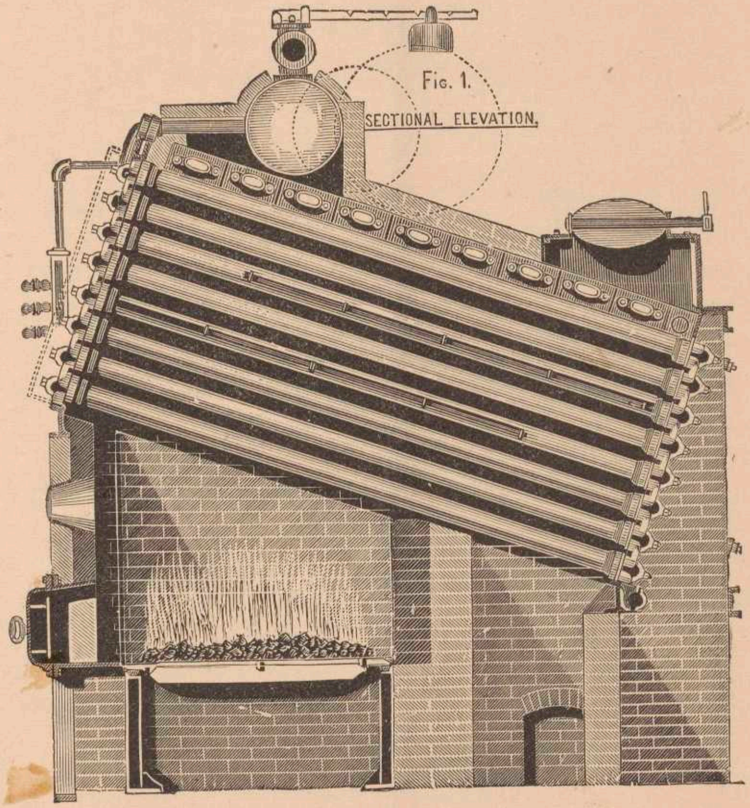
FRONT VIEW

BACK VIEW

THE ROOT BOILER.

Fig. 22.

Plate I. (A).



THE ROOT BOILER.

Fig. 23.

The fire engine boiler, especially designed for rapid generation of steam, is constructed on the same principle.

The following data have been kindly furnished me by the Amoskeag Steam Fire Engine Co. of Manchester N. H.

"1st class boiler - 172 sq. ft. heating surface - 301 tubes, each 1¼" diameter and 18" long. Grate 29½" diameter.

2nd class boiler - 150 sq. ft. heating surface - 265 tubes, each 1¼" diamter and 18" long. Grate 28¼" diameter"

ALLEN BOILER.

75 HP

Plate 2

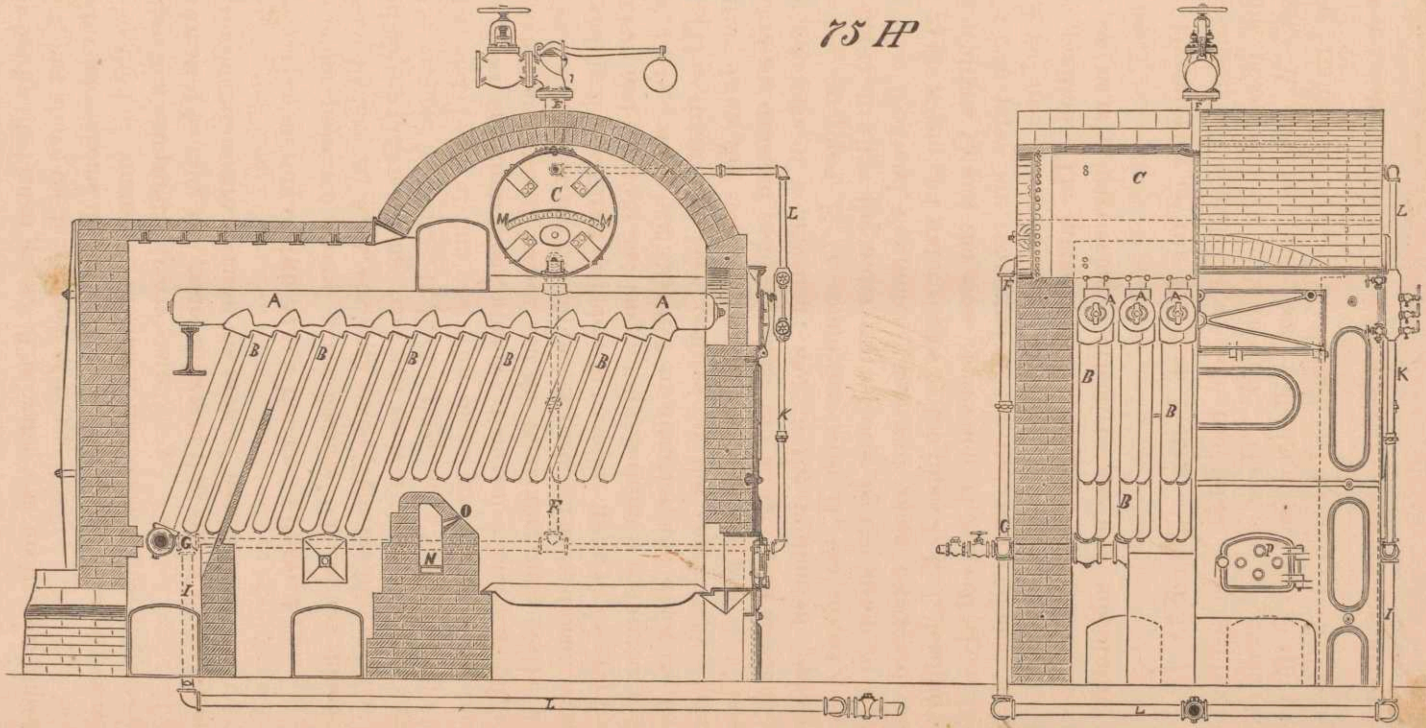


Fig. 24.

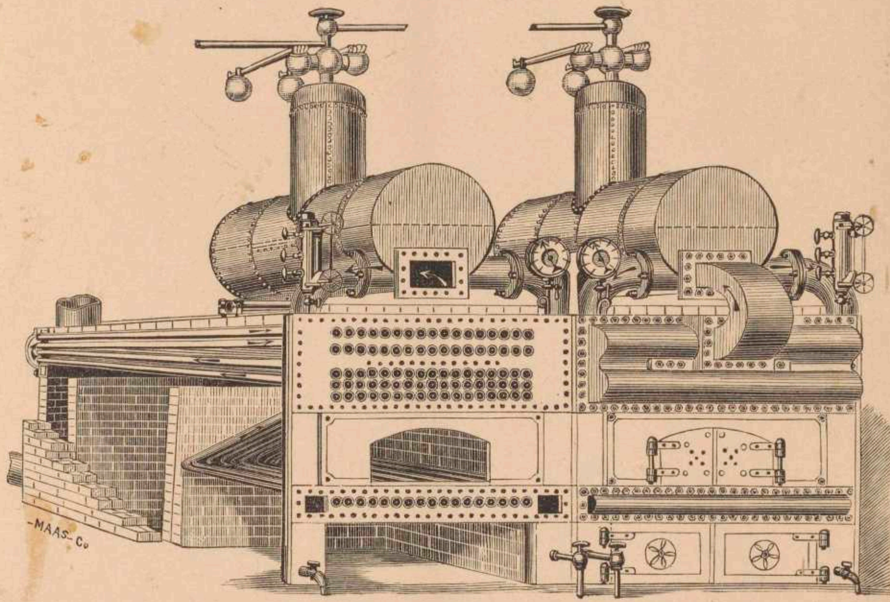
The ratio of grate to heating surface in each case is about 1:28

The principle of the locomotive boiler is the same, except that the tubes are horizontal. Figs 13 and 14 represent the general forms, and especially the dimensions of the furnaces of two locomotive boilers, designed for burning bituminous and anthracite coal respectively. The peculiarities of the furnaces have already been noticed.

P. 141 "Heat & Heat Engines"

Trowbridge gives as the ratio of grate to heating surface derived from actual practice 1:28. In another table he gives the ratio of grate to heating surface as varying from 1:40 to 1:100 and as averaging 1:75. In engine No. 75 Eastern R.R. burning bituminous coal this ratio is 1:57, and the heating surface is twice the area of the cylinders. The firebox is 66" long, 62½" deep, and 35½" wide. Engine No. 2 E.R.R. burning anthracite coal had a ratio of grate to heating surface of 1:33, and burning

Plate III.



THE PHLEGER BOILER.

Fig. 25.

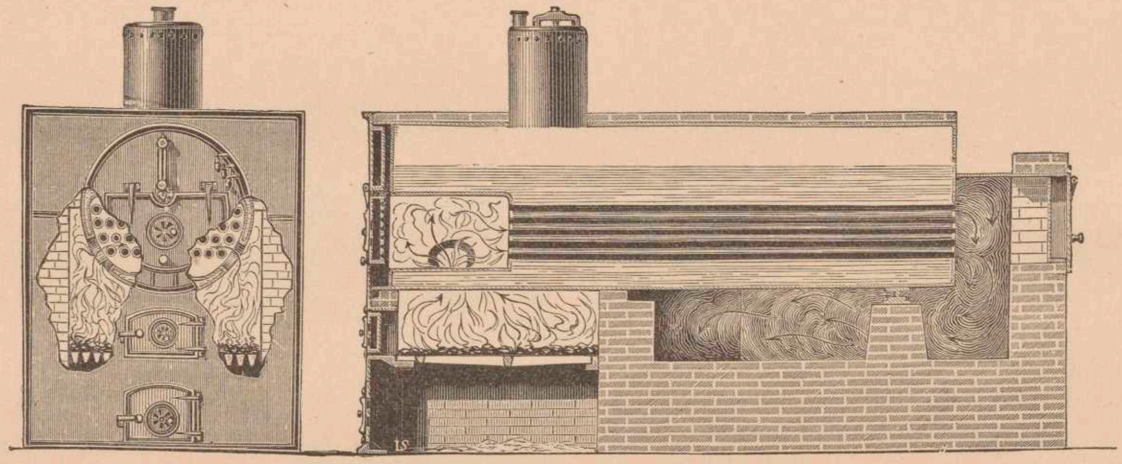
bituminous has a ratio of 1:58.

The rate of combustion per square foot grate area per hour is, according to Rankine, from 40 to 120 lbs.

Wilson gives an average of 3 square feet of total heating surface per indicated H.P., for locomotive boilers having a ratio of grate to heating surface of from 1:60 to 1:80.

Fig. 36 represents one of the boilers set for the new pumping engine at the Hope pumping station in Providence R.I. The boiler is however especially designed for marine use. The gases of combustion pass from the furnace through two flues 18½" dia. to the rear of the boiler, and back through 52 tubes 3" dia. to the uptake. The uptake passes through the steam dome, hence the steam is slightly superheated. The grate surface is 19 (app.) sq. ft., and the total heating surface 500 (app.) sq. ft., and the ratio of grate to heating surface is 1 to 26

Plate IV.

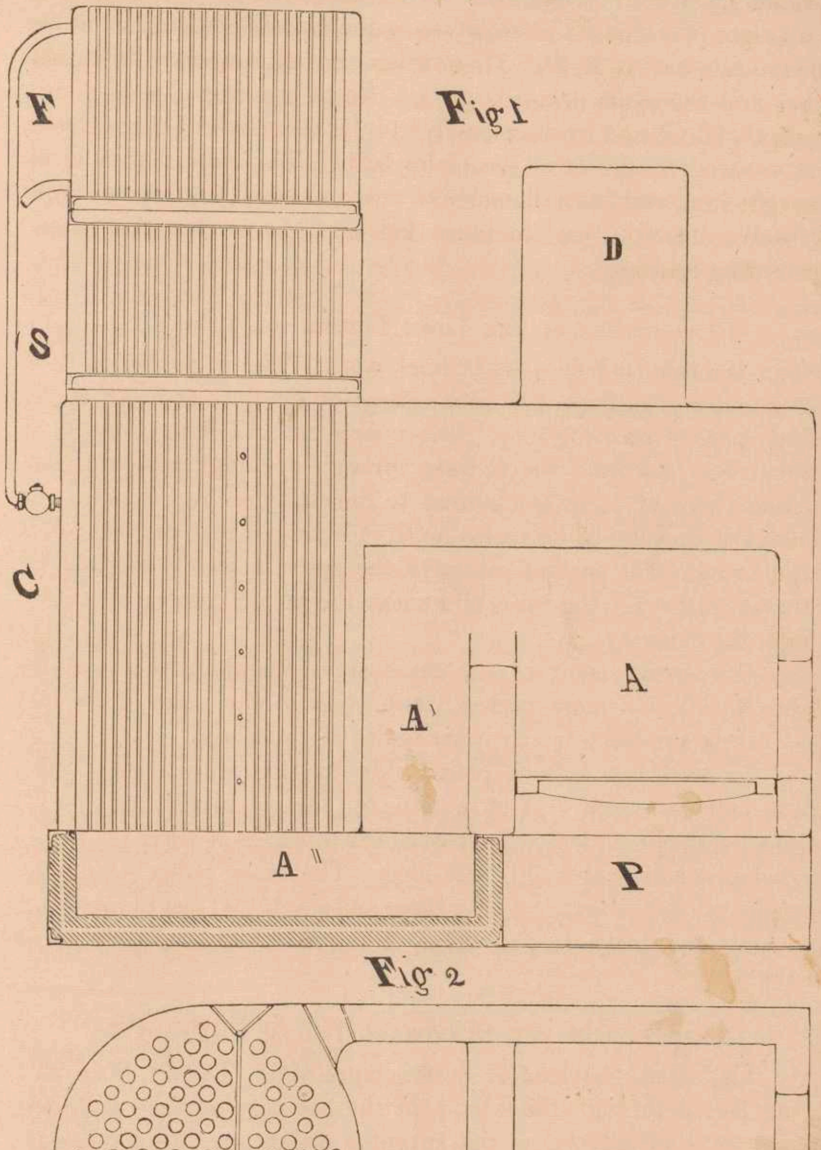


THE LOWE BOILER.

Fig. 26.

Within a few years a large number of sectional boilers have been introduced. The principle of these boilers is the partial division of the whole amount of water in the boiler into small masses, so as to bring it into better contact with the heated gases, and so that in case of rupture, there shall be no large free reservoir of highly heated water ready to be converted into steam. The circulation is also promoted by placing the sections containing water so that their temperatures vary.

Figs. 22 and 23, 24, 25, 26, and 27 represent five boilers tested at the American Institute Exhibition of 1871 by a committee of which Prof. R. H. Thurston of the Stevens Institute of Technology was chairman. Of these boilers, the first three the Root, Allen and Phleger are sectional. The tubes of the sectional boilers are wrought iron. In the Allen boiler these tubes connect with cast iron cylinders and in the Phleger



F. B. Blanchard's Steam Boiler.

Fig. 27.

are attached to cast iron tube plates.

The Lowe is a horizontal tubular and the Blanchard a vertical tubular boiler with superheater and feed water heater. A full description of these boilers and the mode of conducting the test is given in the Report of the American Institute Exhibition for 1871, and the three sectional boilers are also fully described in "Trowbridges "Heat and Heat Engines."

In regard to safety, the committee rate the boilers as follows on a scale of 10

Root.	Allen.	Phleger.	Blanchard.	Lowe.
9	8.5	7	6	5.5

and as regards durability

Root.	Allen.	Phleger.	Lowe.	Blanchard.
9	8.5	6	5.5	5

The evaporation per. lb. of coal, of water at atmospheric pressure, with the feed at 212° F. was

Root.	Allen.	Phleger.	Lowe.	Blanchard.
10.64	10.60	10.49	10.40	11.34

In conclusion the committee say.

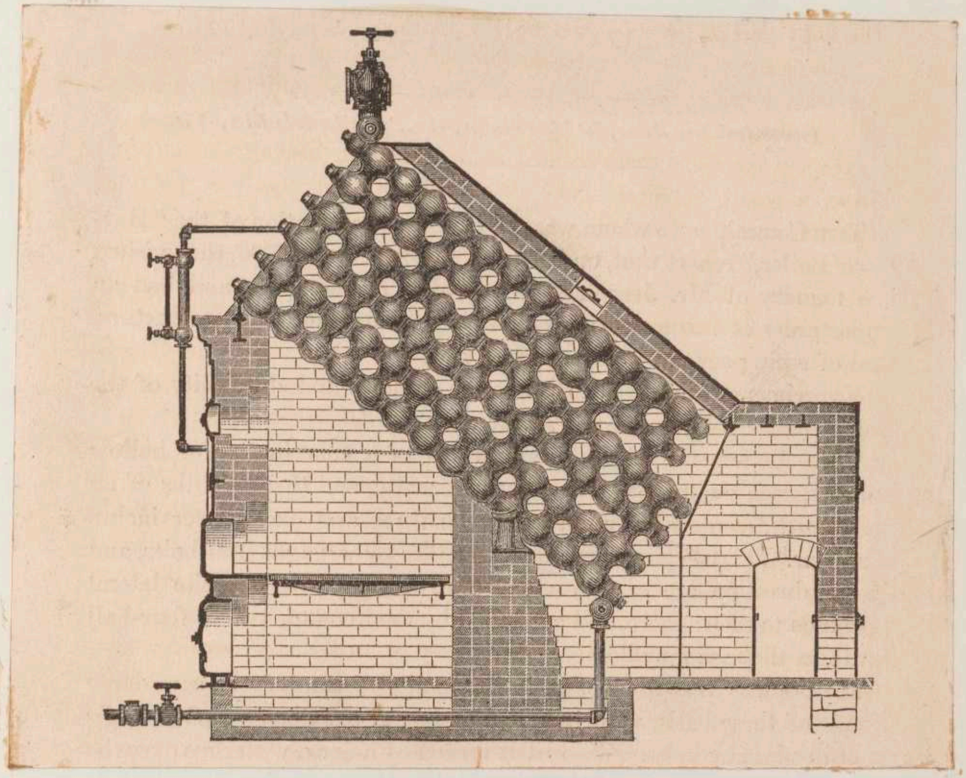


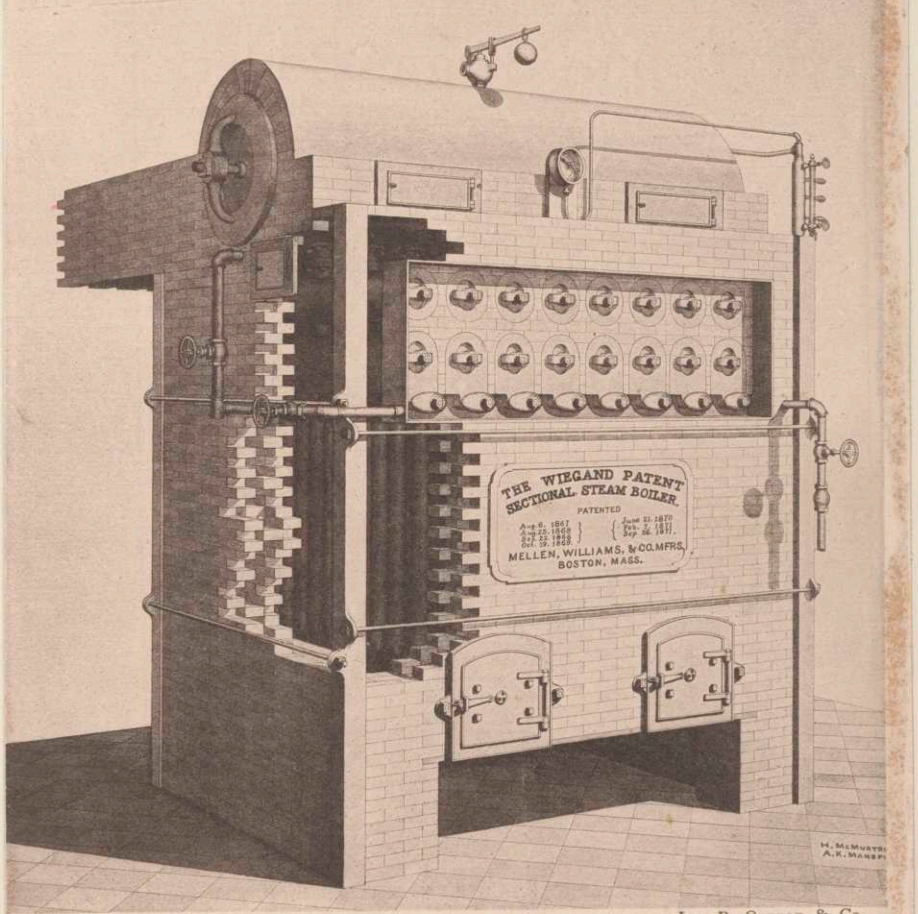
Fig. 28.

1st. "That the results of this trial indicate that, in steam boilers as now built by the best manufacturers, the differences in most respects are exceedingly small, and a purchaser can hardly fail to be well served if he go to a really intelligent and reliable builder.

2nd. That the introduction of boilers having exceptionally large proportion of heating surface, and with large feed water heaters, and depending upon a mechanical draft, will, when properly designed and constructed, be attended with a marked economy, which, the Committee judge, should more than compensate for the increased trouble and expense involved if large boiler power is required.

3d. That the steaming capacity of a boiler depends largely upon its form, as well as upon the method of working its fires."

Fig 28 illustrate the Harrison sectional boiler. The boiler is



HELIOTYPE. JAS. R. OSGOOD & CO.

The above cut represents 8 Sections, or an 80 Horse Power Boiler complete; occupying a ground space of 9 feet 9 inches front, by 6 feet 5 inches depth, outside brick work.

Fig. 29.

made of cast iron spheres connected with each other by curved necks, and bound together by tie rods passing through the spheres from end to end of the boiler. These spheres are commonly made 8" external diameter and scant 3/8" thick. Four of these spheres cast together make a four ball unit, and two make a two ball unit. One section composed of these four and two ball units, breaking joints is shown in the figure. Any number of these sections connected with each other at the upper end, can be placed side by side according to the boiler power required. The section shown in Fig. 28 is one of 6 H.P. The advantages claimed for the boiler are ease of manufacture, transportation, setting up and repairs; strength and freedom from the danger usually attending boiler explosions. It is also claimed that the spheres cast off by their expansion and contraction all scale

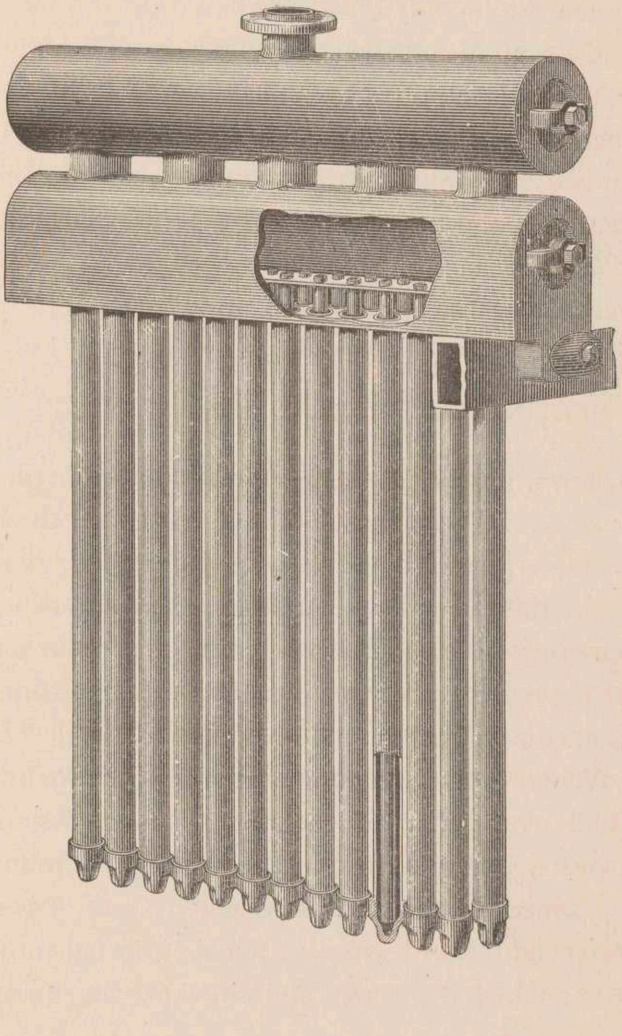
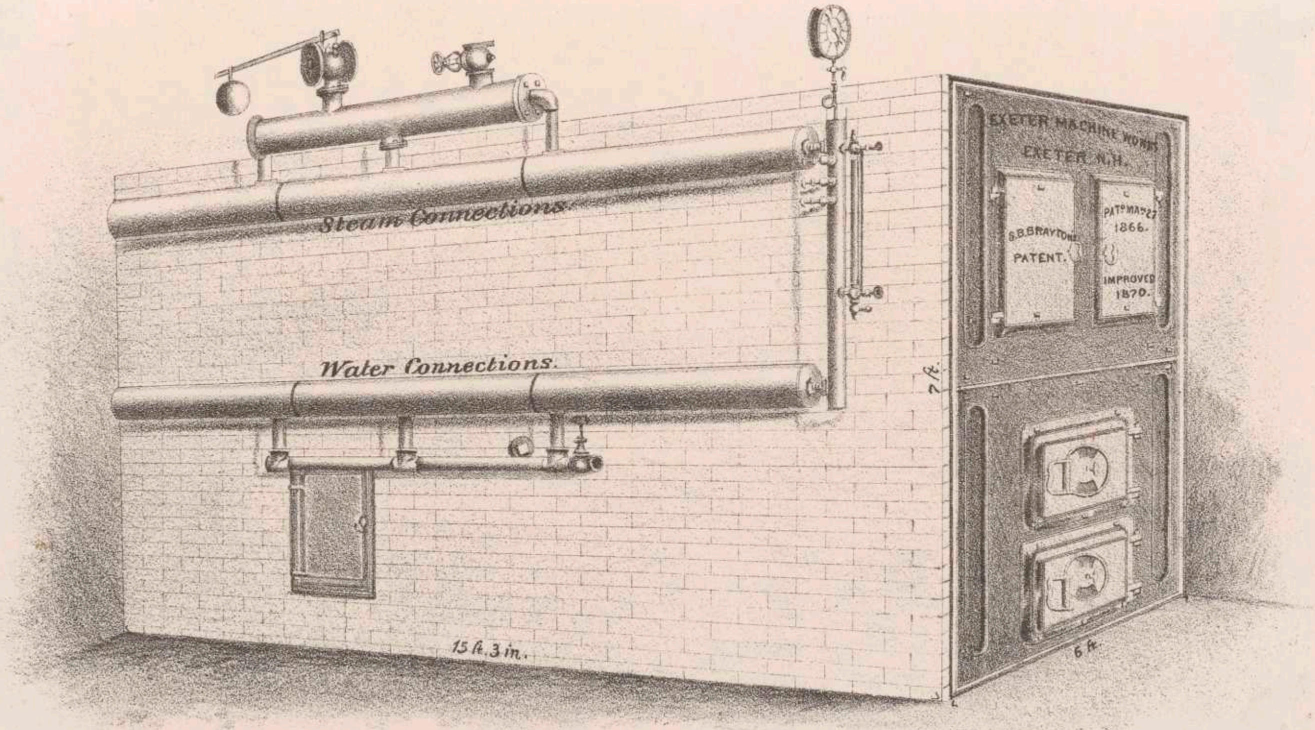


Fig. 30.

so that it can be blown off. The exterior of the boiler is cleared of soot by means of a steam jet

At the American Institute Fair of 1869 two 50 H.P. Harrison boilers, with feed water at a temperature of 47° furnished 1 H.P. for 3 19/100 lbs. of coal per hour.

Fig. 29 shows the Wiegand sectional boiler, and Fig 30 shows the arrangement of the parts of which it is made up. Each section is composed of twenty-four wrought iron tubes, 3" external diameter closed at their lower ends by cast iron screw caps, and screwed at their upper end into a tank. Circulation is provided for by inserting in each 3" tube, as shown, a 1 3/5" internal diameter wrought iron tube. The current in the small tube is downward and in the large tube upward. It is claimed that the circulation is so rapid, that no sediment will collect in the tubes



VIEW of FORTY HORSE POWER EXETER BOILER,

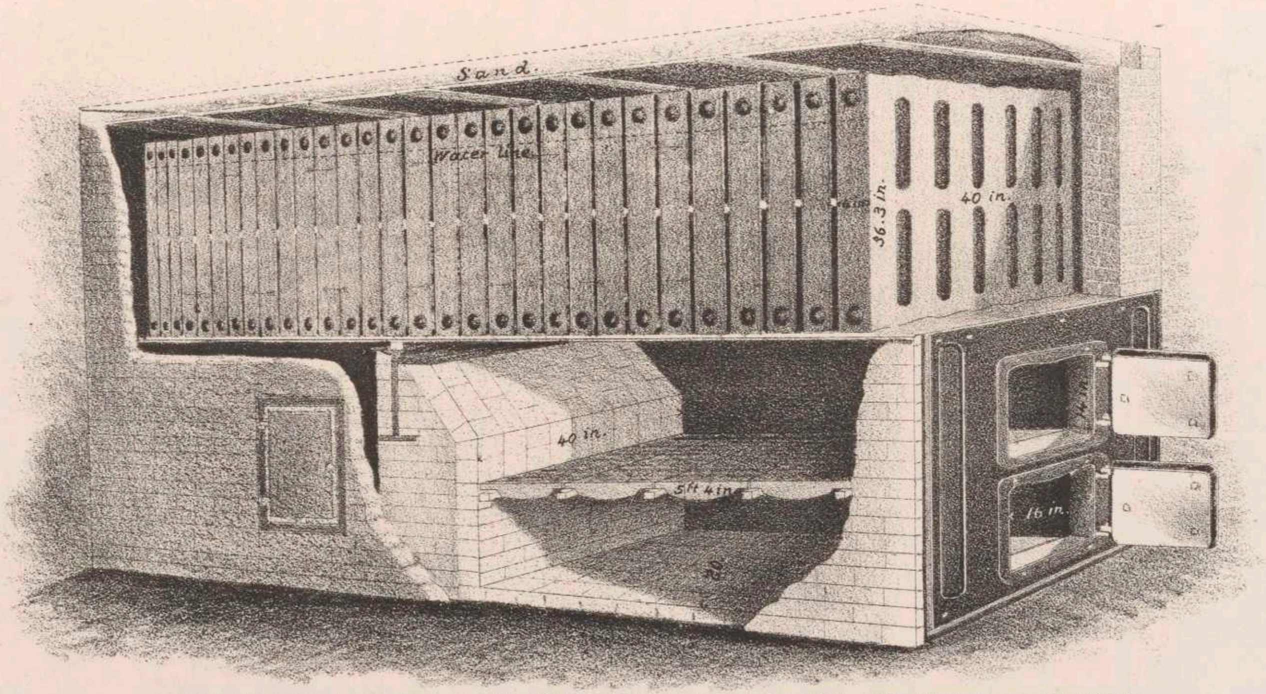
Fig. 31.

if the blow-off pipes be properly used. Safety, durability, simplicity, and ease of transportation are claimed for it, also freedom of all parts from the strains of expansion and contraction.

One section forms a 10 H.P. boiler, the Government standard of horse power, viz: the evaporation of 900 cubic inches of water per hour, being adopted.

A trial of a 60 H.P. boiler of this type was made in Dover N.H. in 1875. The ratio of grate to heating surface was 1:33; lbs. of combustible consumed per hour per square foot grate area, 10; lbs. of water evaporated from 212° F. and at atmospheric pressure by one lb. of combustible, 13.15

Figs 31 and 32, illustrate the Exeter sectional boiler. This boiler is made as shown in Fig 32 of cast iron sections, made of iron 1/32" thick. Each section is a seperate boiler, except as it is connected at the top



INTERNAL VIEW of FORTY HORSE POWER EXETER BOILER.

Fig. 32.

to a common steam pipe, and at the bottom to a common water pipe. The hot gases pass through and between the lower half of the sections to the rear, and back to the front and chimney through the upper half of the sections. Ten of these sections, having 270 sq. ft. of effective heating surface are rated as equivalent to 14 H.P., being 1 H.P. to about 20 sq. ft. of heating surface.

Marine Boilers

Figs. 33 and 34 represent two types of marine boilers. Fig 33 is the Martin vertical water tube boiler, and Fig 34 the English horizontal fire tube boiler. After the year 1864 the principal steamers of the U. S. Navy were furnished with the vertical water tube boilers. In 1858 the superiority of these over the horizontal fire tube boiler being questioned, the Navy Department tested their rel-

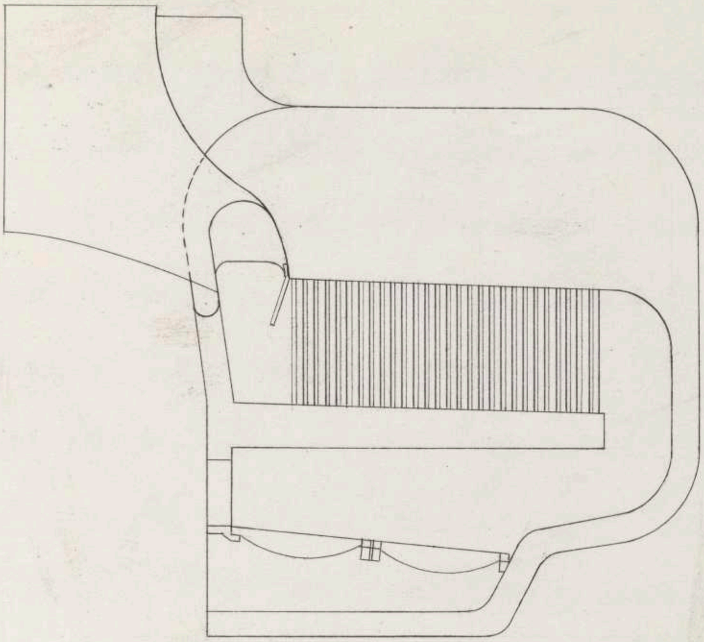


Fig. 33.

VERTICAL WATER TUBE BOILER.

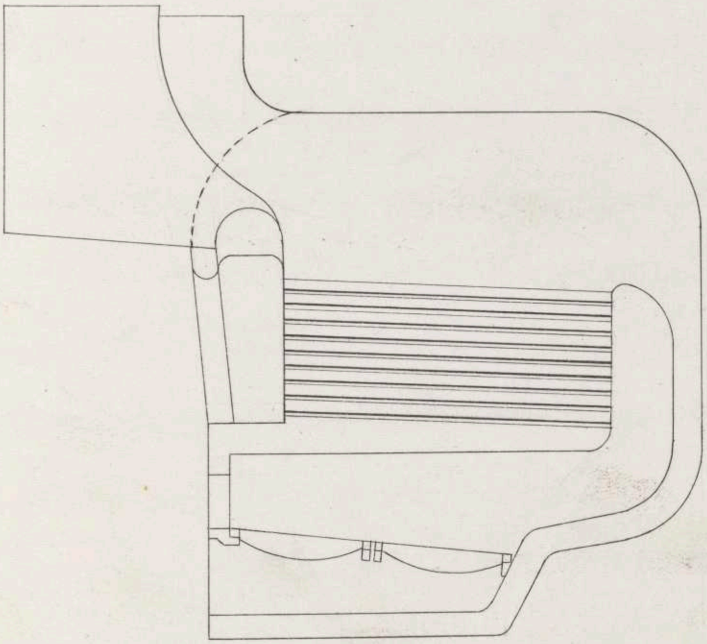


Fig. 34.

HORIZONTAL FIRE TUBE BOILER.

ative merits. The results of the test are as follows.

1. With equal grate surface and steam room, in shells of the same form and dimensions and with maximum combustion with natural draft, the water tube boiler evaporated 14.79% more water per. lb. of anthracite combustible than the fire tube boiler, and furnished 2.25% more steam in equal times.

2. With equal steam room and ratio of heating to grate surface, in shells of the same form and dimensions, with maximum combustion with natural draft, the water tube boiler evaporated 8.1% more water per. lb. anthracite combustible than the fire tube boiler and furnished 27.60% more steam in equal times.

3. In each, the deposition of soot was insignificant and would not require removal during an ordinary voyage.

4. With the same conditions as in (1), but with the rate of combustion doubled by a forced draft, the water tube boiler evaporated 8.3% more water per lb. anthracite combustible than the fire tube boiler, and furnished 8.13% more steam in equal times.

5. With the conditions existing (4), the deposition of refuse in the water tube boiler was twice as great as in the fire tube boiler, but would not require removal in less than 8 days consecutive steaming.

6. The rate of maximum combustion with natural draft was 8% greater for the fire tube boiler than for the water tube boiler.

7. With the conditions of (1), the combined weight of metal and water of the water tube boiler was 5.23% less than for the fire tube boiler.

8. With the conditions of (1) "ceteris paribus" the water tube boiler cost 8% more per lb. than the fire tube boiler.

9. The best ratio of grate surface to draft area between the tubes in one, and through the tubes in the other was 31:4.

10. The highest economy was obtained by the slowest rates of combustion.

The committee say "Finally in view of the much greater evaporative efficiency of the water tube boiler and of the facility with which it may be scaled, the two qualities of paramount importance in marine boilers, we would express our decided opinion that its superiority over the fire tube boiler is so strongly marked as to unquestionably entitle it to the preference."

One of the leading defects of the water tube boiler is the difficulty of stopping a leak in a water tube. This cannot be done without draining the boiler and entering it. A leak in a tube of the fire tube boiler can be remedied temporarily by plugging up

Fig. 35.

BOILER OF 8 FEET DIAMETER

FOR 80 LBS. PRESSURE.

Fig. 35.

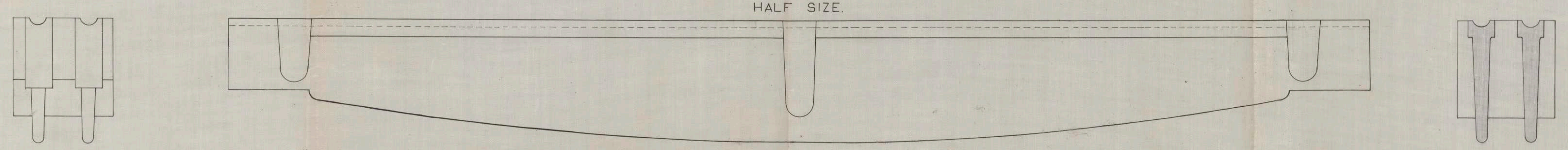
HEATING SURFACE IN SQ. FT.

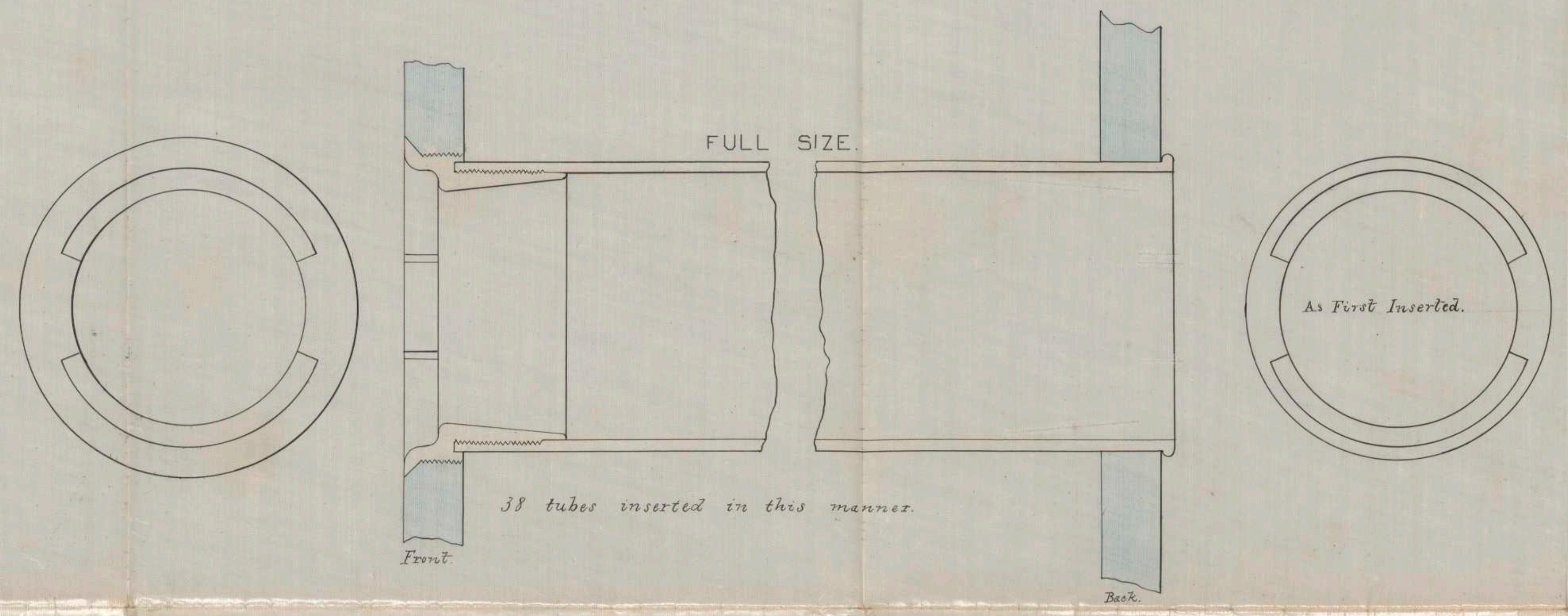
FURNACES	57.66.
BACK CONNECTION	55.5.
FRONT HEAD	26.35.
TUBES	458.7.
TOTAL	598.21.

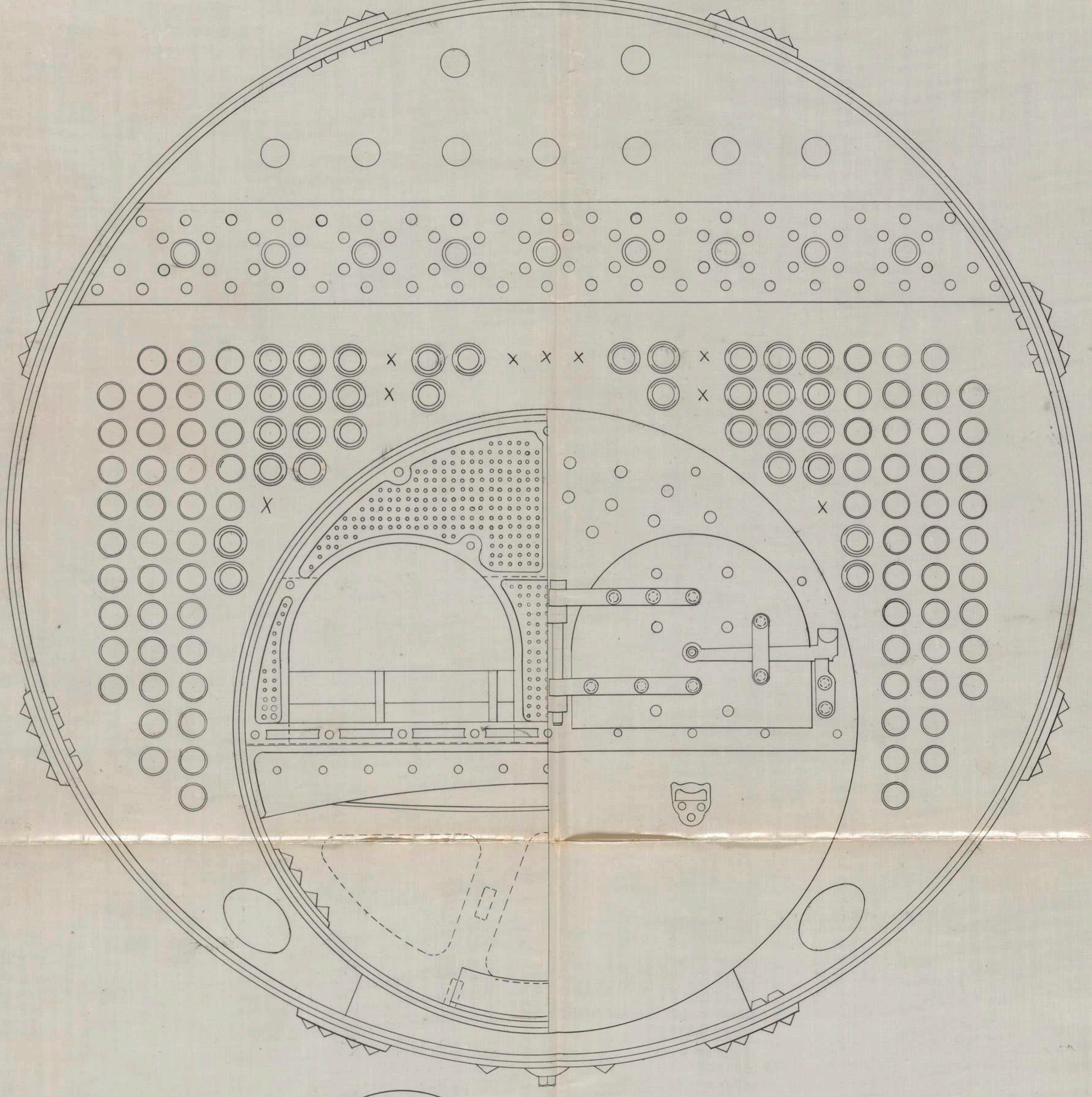
GRATE SURFACE	24 SQ. FT.
AREA THROUGH TUBES	3.186.
RATIO OF AREA THROUGH TUBES TO GRATE	1 TO 753.
RATIO OF GRATE TO HEATING SURFACE	1 TO 24.93.
NUMBER OF TUBES	119.

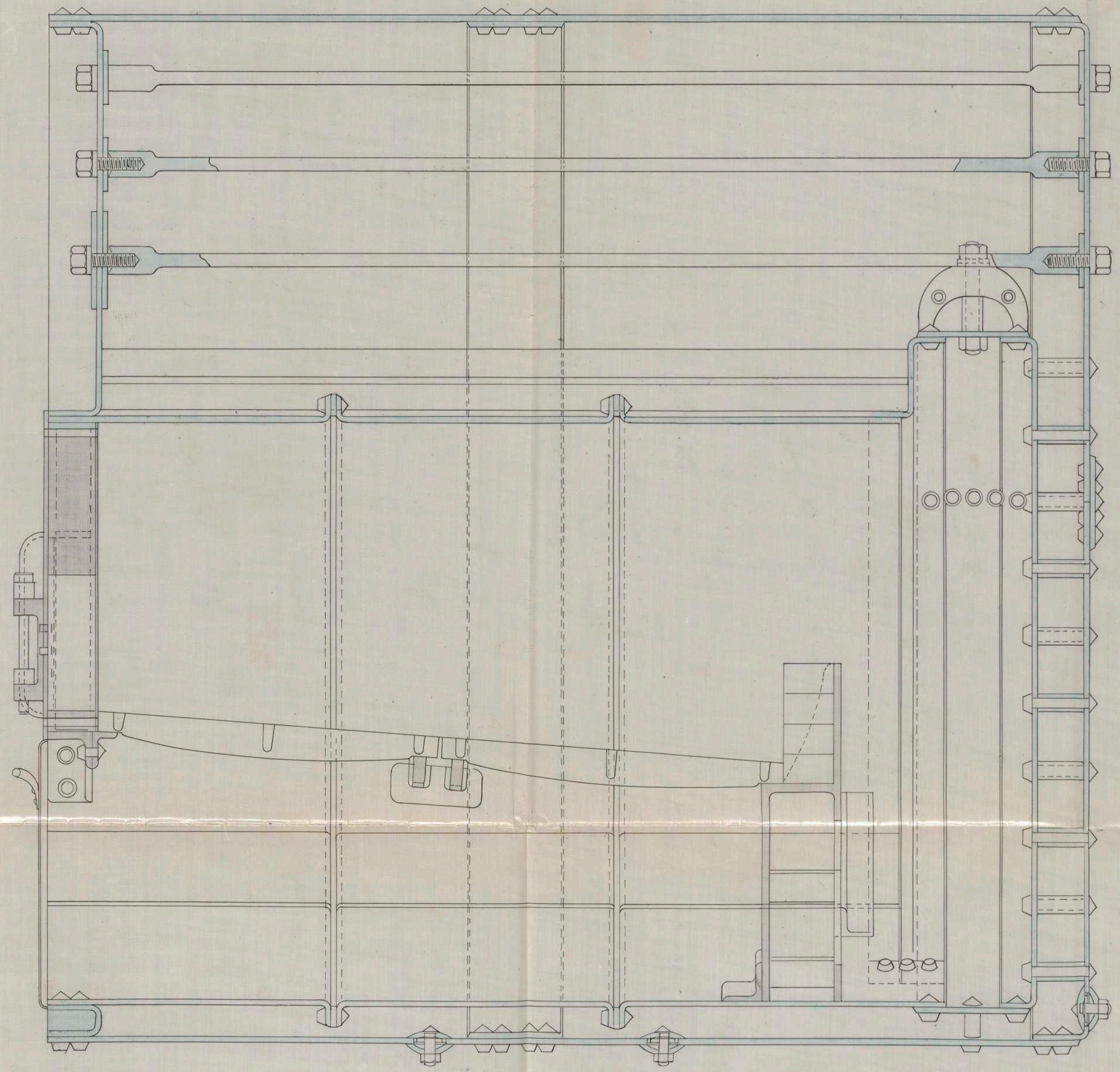
THICKNESS OF PLATES

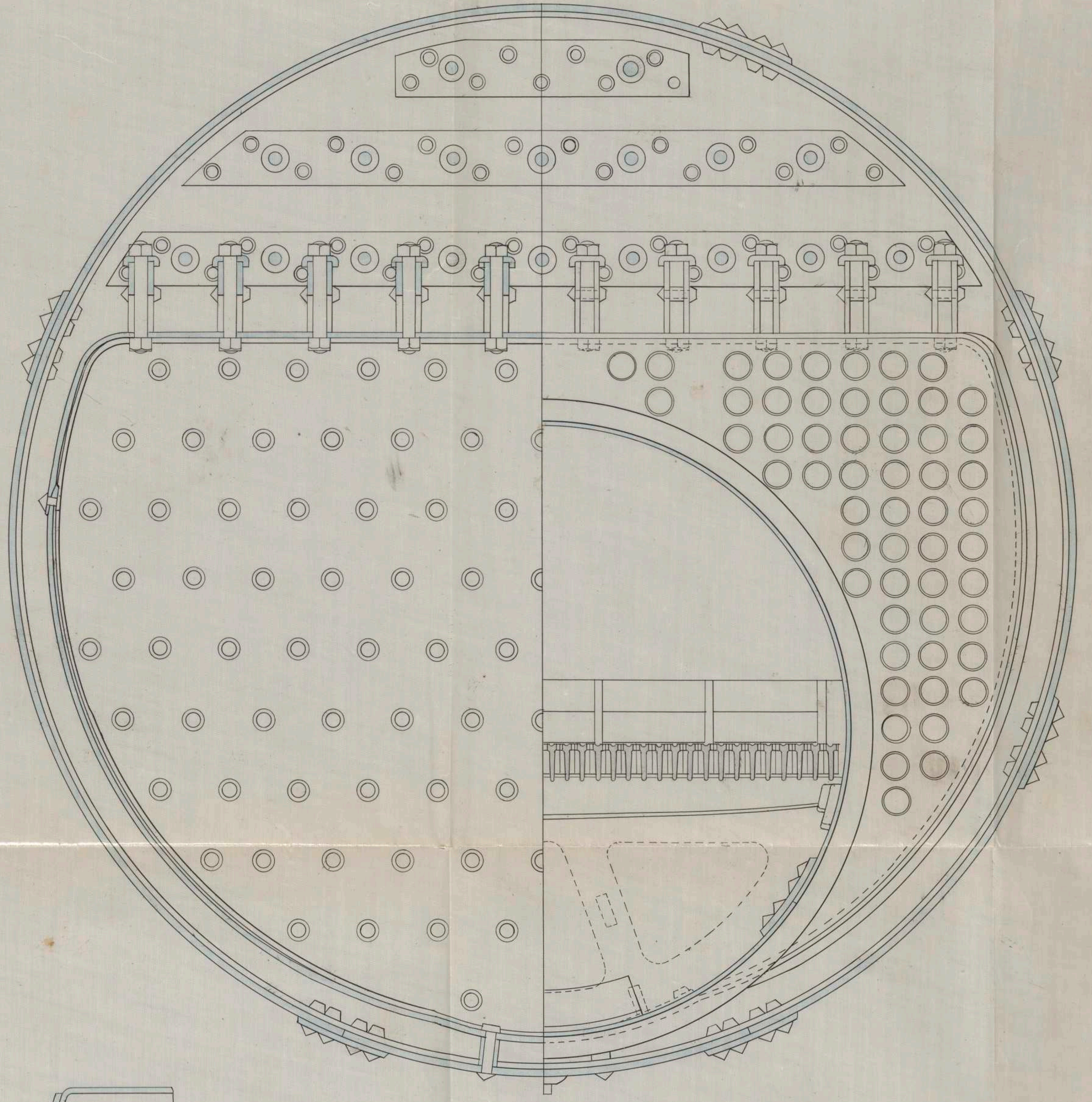
TUBE PLATES	½ INCH
FURNACE	½ "
BOILER SHELL	9/16 "
HEADS	½ "
BACK CONNECTION	½ "
STAY ROD PLATES	⅝ "
FURNACE RINGS	½ × 2½ INCHES
STAY RODS	1¼ "
STAY ROD BOLTS	1¼ "



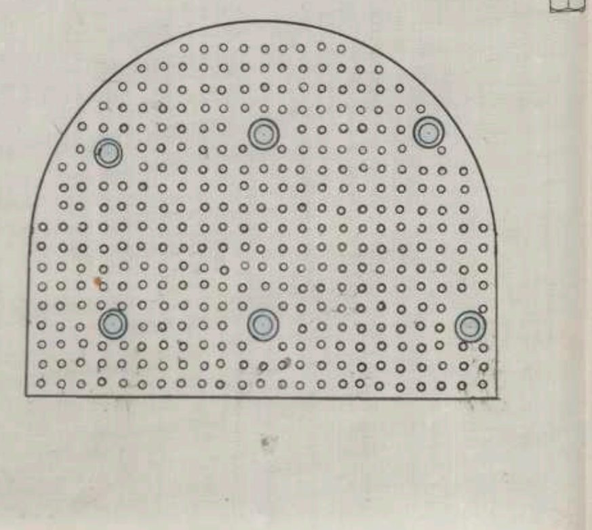


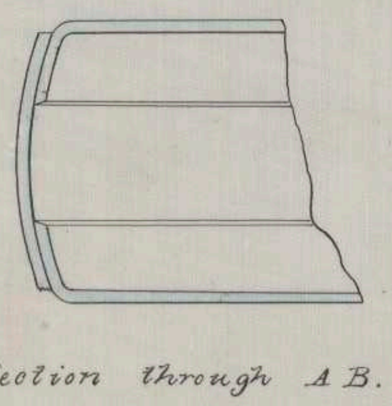






1½ INCHES = 1 FOOT





Section through A.B.

C.L. Dennett.

the end of the tube, without emptying the boiler or greatly impairing its efficiency. The fire tubes are rather more easily cleaned of soot; but the advantage is not marked.

A Martin boiler sketched at the Charlestown Navy Yard has 7 furnaces, and is 24 ft long, 10 ft high, and 11½ ft deep. Over each furnace are 33 tubes, 2" external dia. and 2' 5½" long. The staying of the boiler is shown in Fig 6, which also shows the general method of staying all rectangular shells. Their strength depends almost entirely upon the staying, and they are not usually designed to carry over 40 lbs. pressure.

Fig. 35 shows the form of boiler in use on the Steamship Vandalia. The details on the drawing are so complete that explanation here is unnecessary.

Fig. 36 has already been referred to as a form of marine boiler.

Fig. 36

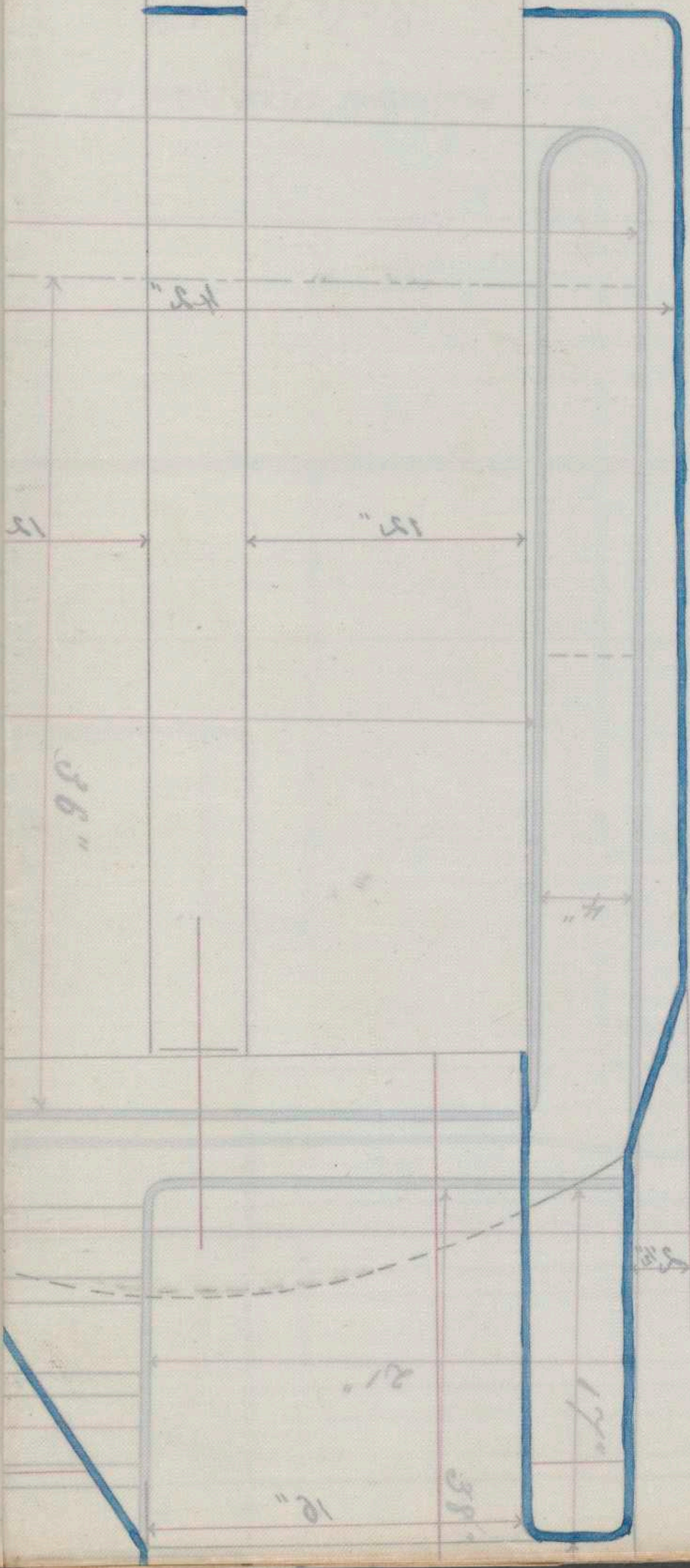


Fig 36

PROVIDENCE STEAM ENGINE CO.

Scale 1½" = 1 ft.

C. L. Dennett.

Fig. 36.

March 2 1876.

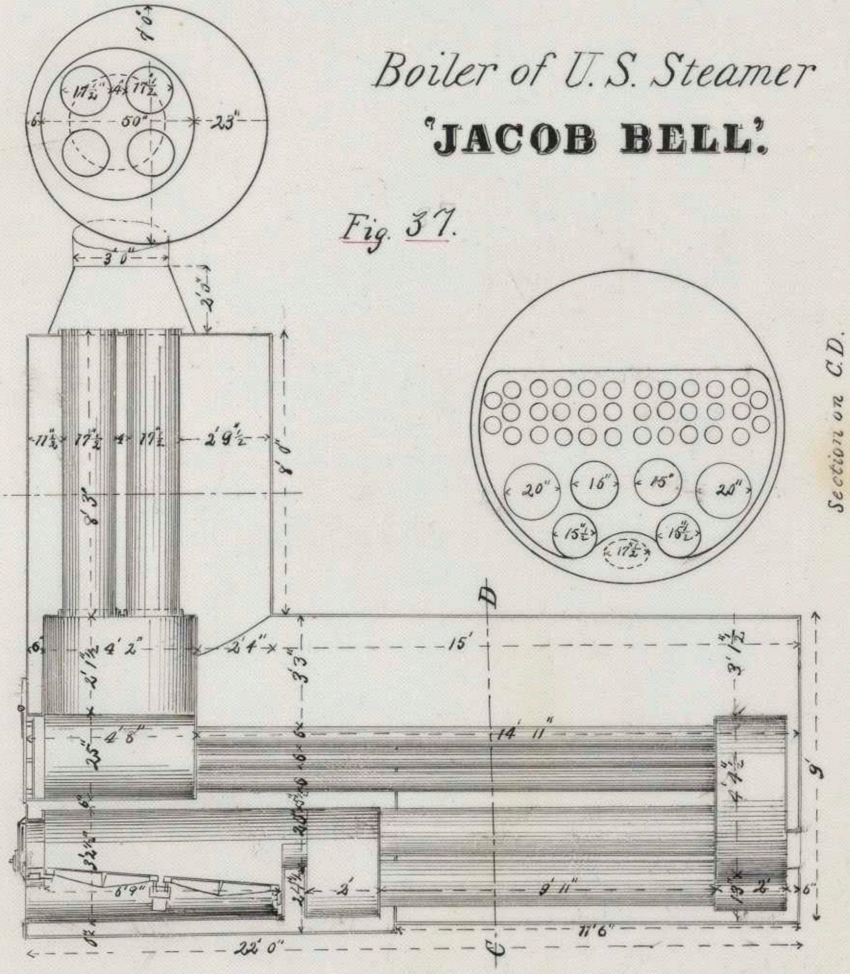
A similar boiler is shown in Fig. 37 as the boiler of the "Jacob Bell". This boiler has three furnaces, 47¼ sq. ft. grate surface, 1484 sq. ft. heating surface, ratio of grate to heating surface 1:31.4, and ratio of grate area to cross area of tubes 7.7 to 1. In Isherwoods experiment upon this boiler 11.383 lbs. anthracite coal were burned per hour per sq. ft. grate area, and 9.319 lbs. anthracite combustible; 10.399 lbs. water were evaporated at atmospheric pressure from 212° F. by 1 lb. anthracite coal, and 12.127 by 1 lbs anthracite combustible

Isherwood says "It will be observed that the evaporative efficiency of this boiler is very high. All the conditions are favorable for a maximum result. The boiler being new was perfectly clean; the combustion was regular and unforced; the calorimeter (i.e. ratio of cross area of tubes to grate area) was smaller than the proportion to grate usually given in practice; the

Boiler of U.S. Steamer

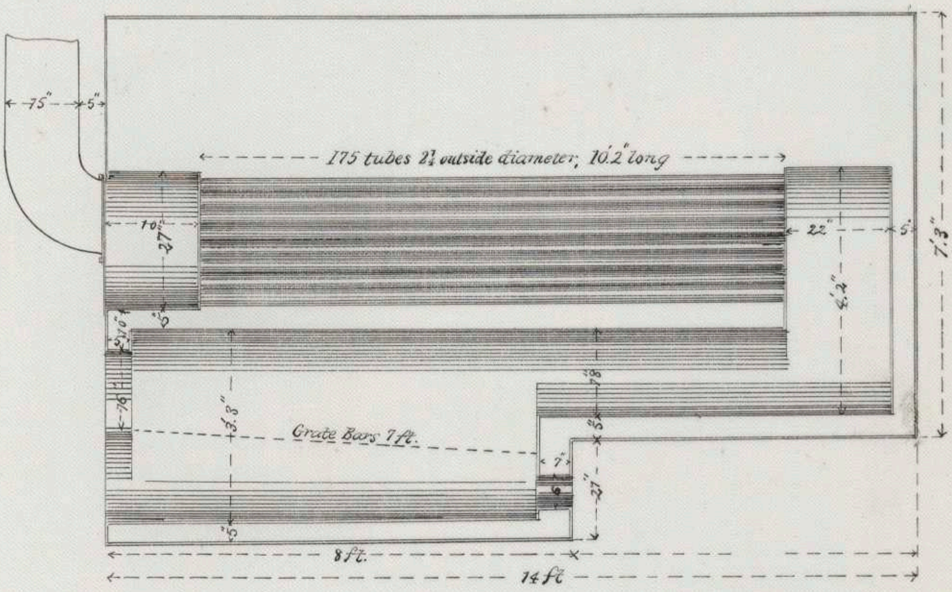
"JACOB BELL."

Fig. 37.



heating surface was unusually large in proportion to grates; there was a constant admission of air to the furnace above the fuel; the thickness of the bed of coal upon the grate was in good proportion to the size of the lumps; the lower flues afforded an ample mingling chamber for the gases, and, the smoke connection being in common for all the furnaces, maintained a uniform temperature in the flues and tubes, notwithstanding the alterations of firing and cleaning in the different furnaces".

Fig. 38 represents one of the boilers of the U. S. Battery Monitor. The boilers are rectangular and each has two furnaces. The grate surface of each is 47.25 sq. ft.; area heating surface 1253 sq. ft.; ratio of grate to heating surface 1: 26.52; ratio of grate surface to cross area of tubes 11.982 : 1, about 12.5 lbs. of steam were evaporated from water at 212° F. by 1 lb. anthracite combustible.



Boiler of U.S. Iron Clad Steam Battery

MONITOR.

Fig. 38.

In regard to the results Isherwood says "Comparing the weight of water evaporated by the pound of anthracite combustible with the same quantity given by boilers, both of other and the same type, it appears that this result from the "Monitor's" boiler approaches the maximum obtained from the best types, and is a maximum for its own. It becomes of value, then, to ascertain to what cause this superiority over other boilers of its own type is due. The form of the furnace and its collocation with the combustion chamber, smoke connection, horizontal fire tubes, and uptake are the same as in other boilers of its type.

The proportion of heating to grate surface is a medium (26.52 : 100), but the proportion of the length of the tubes to their inner diameter is a maximum, being in the ratio of 60:1, while the proportion of the calorimeter (i.e. ratio of grate surface to cross area of tubes) is a minimum, being only about 1/12 of the grate surface. It is to the latter proportion, principally, that the high economic evaporation is due, as, by restricting the admission of air to the furnace to the minimum required for the combustion, it maintained a high furnace temperature and, consequently, proportionally reduced the per. centum of the loss by the heat passing off in the products of combustion with the uptake temperature. This high furnace temperature also rendered the heating surface of maximum efficiency in consequence of the great difference between it and the temperature of the water in the boiler.

The rate of combustion was very low, the maximum being only 6 pounds of anthracite consumed per. hour per. square foot of grate area, although as much was fed to the furnaces as they would consume with clean fires 7" thick." This low rate was due to the small cross section of of chimney.

The general practice of the Navy Department, in the design of boilers has been already given viz: allow 8 lbs. of anthracite coal per hour, to evaporate 1 cubic foot of water from 212°, at a pressure of 30 lbs., which requires 2/3 square foot grate and 16 2/3 square feet heating surface, a ratio of 1:25.

Isherwood advocates 3 1/4 as the best ratio of grate area to cross area of tubes.

PATENT AUTOMATIC

DAMPER REGULATOR.

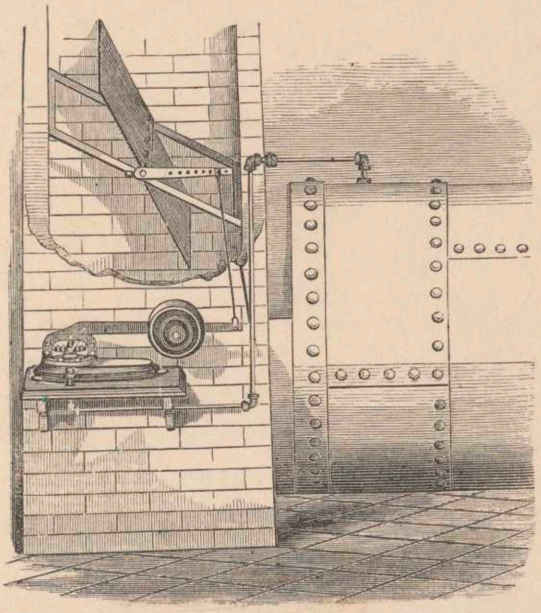


Fig. 39.