E. H. Beatty Φ.K.T.

THE EDGE MOOR
WATER TUBE BOILER

GENERAL CATALOGUE
NUMBER SIXTY-THREE

1922

Edge Moor Iron Company

Designers and Builders of

Edge Moor Waste-heat Plants and the Edge Moor Water Tube Boiler

SALES OFFICES

Boston	79 Milk Street
New York	111 Broadway
Philadelphia Territory	Edge Moor, Del.
Pittsburgh, Pa.	309 Oliver Building
Chicago	10 S. La Salle Street
St. Paul	Robinson, Cary & Sands Co.
Charlotte, N. C.	Thomas B. Whitted

Codes Used: ABC, Business, Liebers and Telegraph
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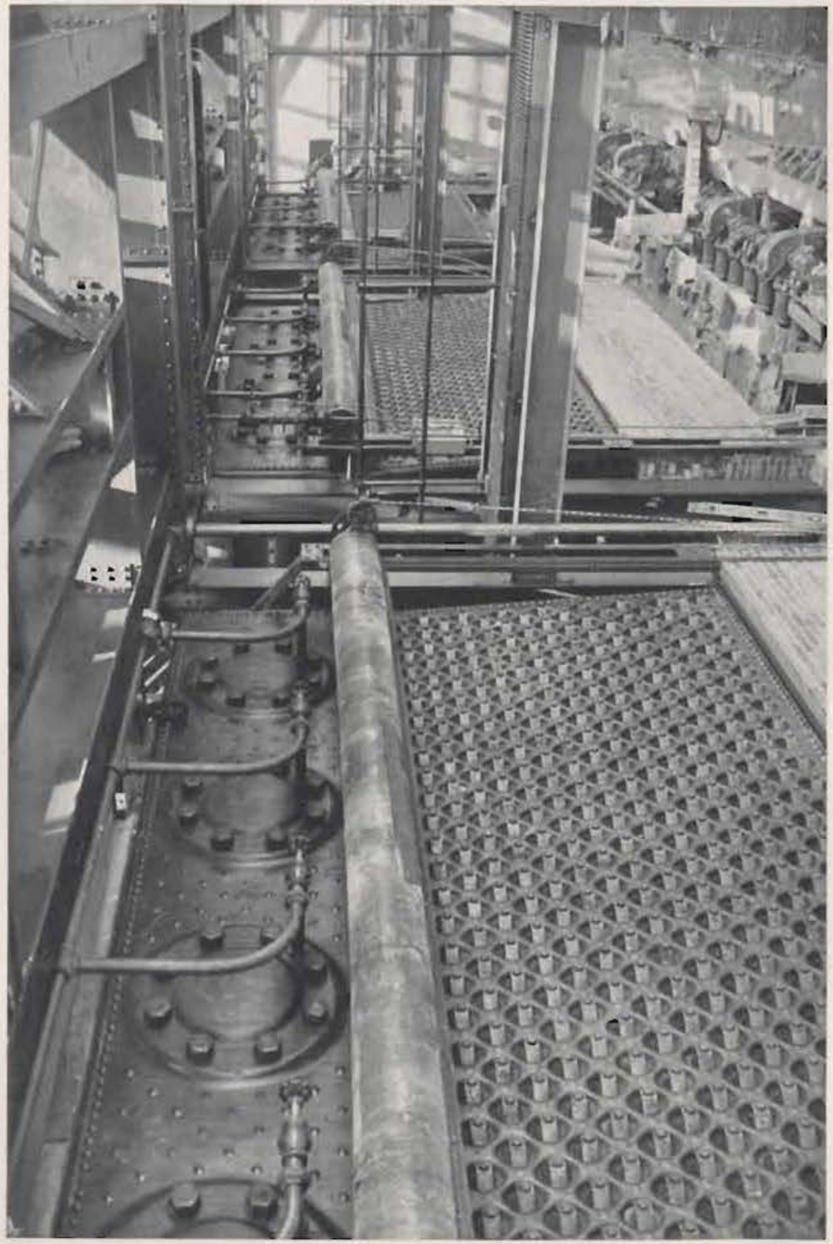
Main Office and Works
Edge Moor, Delaware



Large Edge Moor boilers in the Westport Station of the Consolidated Gas, Electric Light and Power Company, Baltimore, Md. Each boiler has 10,490 sq. ft. of water-heating surface

EDGE MOOR WATER TUBE BOILER

Development and Theory

EVERY highly developed art passes through two stages of progress and has its beginnings in some new conviction; as, for example, power for industrial purposes can be generated from steam. In the earlier stage efforts are necessarily concentrated on the discovery of means to realize this conviction, and the appliances found "to work" are generally more or less crude. In the later stage the efforts are shifted to the development of refinements to overcome objectionable results, to improve quality and to increase quantity. The construction of the modern high-pressure boiler has followed a similar line of development.

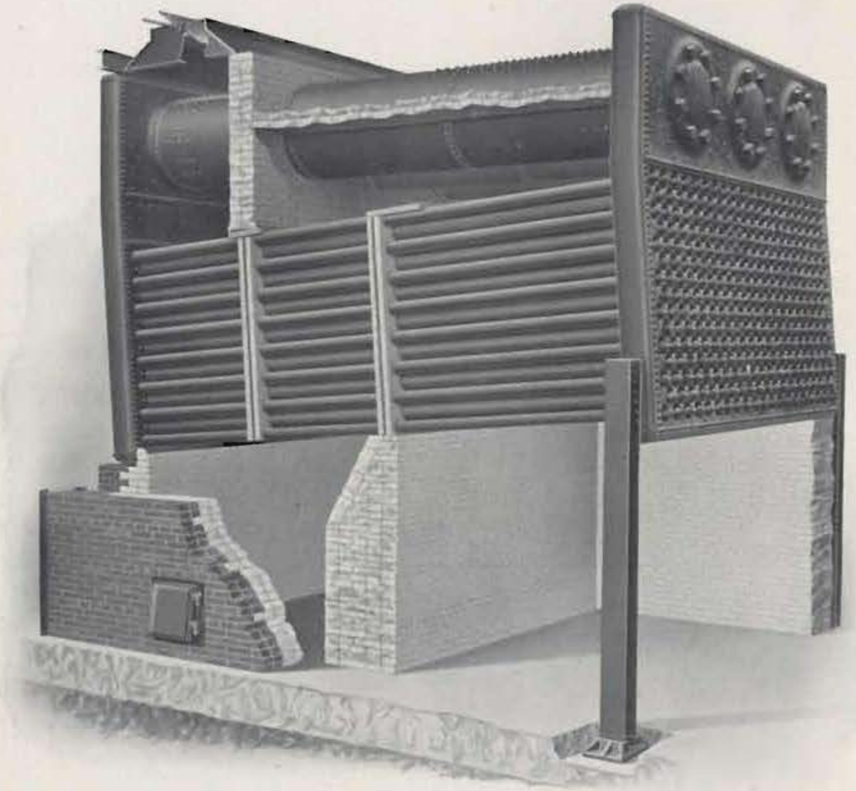
At first, efforts were concentrated principally on the development of the now typical arrangements of the heating surface together with those structural details that are necessary for safety and maintenance. In recent years, the efforts have been confined to those seemingly minor details that affect that very important result—the all-over cost of power.

Since the boiler is an auxiliary to the steam engine, their historical development, as far as steam pressures are concerned, has been parallel. The first steam engine of the piston type actually constructed, the invention of Newcomen and Cawley which seems to have been patented in 1705, did not make use of the "pushing power" of steam. The top of the piston was always open to the atmosphere while the cylinder space below was alternately filled with steam, at about atmospheric pressure, which was later condensed to "lift off" the back pressure, thus causing motion of the piston. This was really a vacuum engine.

Later, in 1765, James Watt invented the separate condenser, put a cylinder head on the Newcomen engine, admitted the steam between cylinder head and piston, and thus produced the first pressure engine. Incidentally, he laid the foundation for the pressure boiler.

Forty years later, steam pressures had crawled from that of the atmosphere to about five pounds per square inch! It was a pressure even modestly less than this that constituted the motive power for the first voyage of a steamboat—the Clermont in 1807.

Between 1850 and 1860, according to Thurston, the customary pressures for new engines was from 20 to 25 pounds. In 1876, at the Centennial Exhibition at Philadelphia, the fourteen boilers there exhibited, which represented the best practice at that time, were tested at 70 pounds.



Note the header construction, the horizontal drums, the straight, inclined tubes, the elliptical handholes and the efficient cross baffling

In 1900, 150 pounds pressure was considered high for land plants, while today the customary pressure for the larger plants is from 175 to 250 pounds per square inch.

But high pressure alone does not distinguish the modern boiler from its predecessors. The tremendous increase in manufacturing, and in the domestic and industrial uses of electric power has created an insistent

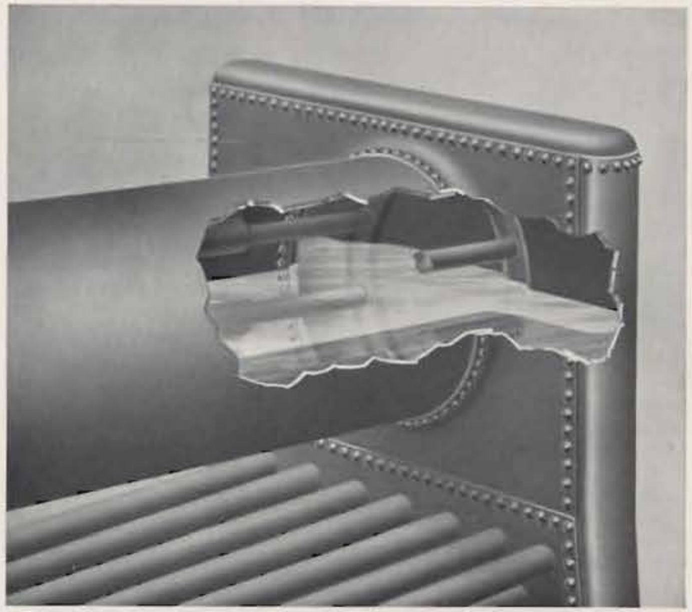
demand for those refinements which have to do with cost of production, certainty of service and economical use of property. Thus, the fact that a boiler gave good satisfaction twenty-five years ago argues nothing as to its suitability for the needs of the present day.

The Edge Moor boiler was designed to meet modern conditions. The first one of this type was built in our shops in 1895 and proved highly satisfactory. Since then there have followed the natural improvements in structural details and in methods of manufacturing, but the original principle, which will be explained presently, has been adhered to.

Reduced to its simplest form, a steam boiler is a plate of metal with hot gas on one side and cold water on the other, the terms hot and cold being merely relative. As is well known, when the temperature of the hot side of a plate remains constant, the amount of heat which will be conducted through the plate will vary with the temperature of the cold side. That is, by lowering the temperature of the cold side more heat will be transmitted, and vice versa. Now the temperature of the cold side of the plate is dependent on the conductivity of the substance in contact with that side; for, if the heat that passes through the plate is conducted away rapidly, the temperature of the cold side will be relatively low but, on the other hand, if the heat is conducted away slowly the temperature of the cold side will be relatively high. Since water is a much better conductor of heat than steam, it follows that the rapid removal of steam from contact with the heating surface, where it is generated, and its replacement with water will increase the transmission of heat into the boiler; that is, the capacity, and therefore the efficiency for a given output, will be increased.

But increased capacity and efficiency are not the only desirable results obtained by keeping the heating surface wet. Since, as stated above, the temperature of the cold side of the plate will rise if the substance on that side is a poor conductor of heat, it follows that the average temperature of the plate will also rise at the same time—that is, the plate will be overheated, which accounts for blisters and burns during forced firing. Therefore, from the three standpoints of capacity, efficiency and cost of maintenance there must be a minimum of retardation to the escape of steam from the tubes.

How is this accomplished in the Edge Moor boiler? It will be seen that the distinctive feature of this boiler is the extension of the headers, at full width, well above the tops of the drums so that, contrary to the usual construction, the drums with their full area enter the headers, giving a much larger throat as shown in the accompanying illustration. The importance of this greatly increased throat area from a theoretical standpoint is easily seen.



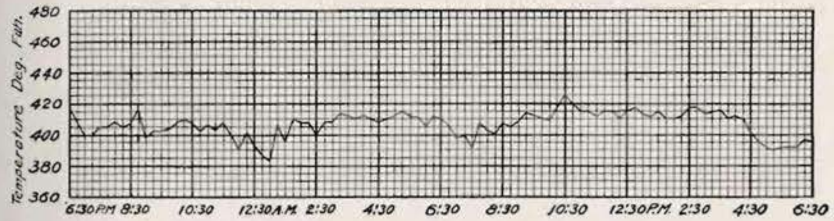
The principal distinguishing feature of the Edge Moor boiler is the unrestricted connection between header and drum

Consider what happens between the injection of a particle of water by the feed pump and its subsequent removal in the form of steam. At some place in the boiler this particle of water reaches the maximum temperature at which water can exist as a liquid in the same vessel with steam at a constant pressure. Sooner or later, it passes into one of the tubes, comes in contact with the hot surface and is transformed into steam.

Now this transformation is accompanied by a very great increase in volume. At 135 pounds pressure one cubic inch of water expands into 150 cubic inches of steam; at higher pressure the ratio of volume is somewhat reduced but is still very large. In consequence, the steam generated in the tube must leave the tube at a very much faster rate than the water coming into it. Now the faster a fluid moves, the greater is the frictional resistance which retards its passage and, since the

resistance to the flow of fluids varies as some power of the velocity, and since velocity must decrease as area increases, the rationality of making throat areas large to minimize the hindrance to the liberation of steam is very apparent.

However, it is always well to check theory with practice. For this purpose, the results of authoritative tests are here given. Since the true function of a boiler is to absorb heat from the gases produced in the combustion chamber, the index to the efficiency of a boiler is the temperature of escaping gases when they contain a high percentage of carbon dioxide, which is proof that the temperature of gases is a consequence of absorption in the boiler and not of infiltration of cold air near the breeching. Table I shows that gas temperatures have been obtained less than 60° above the temperature of the saturated steam, which is conclusive proof of the correctness of the principles underlying Edge Moor design.



Temperature of Flue Gases for First 24 Hours of Test No. 8, Table I

Table I—Showing Temperatures of Escaping Gases from Edge Moor Boilers

Test No.[1]	Per cent. of rated capacity developed	Combined efficiency Per cent.	CO_2 at damper Per cent.	Pressure of steam Lbs.	Temperature of saturated steam Deg. F.	Temperature of flue gases Deg. F.	Gas temperature — steam temperature Deg. F.
3	127	76.9	11.7	128	355	476[2]	121
8	113.4	80.95	13.3	117.6	349	412	63
2	101.5	78.58	14.3	179	379	439	60
10	101.5	81.6	12.5 13.4	145.6	364	421	57

[1] See table on next page.

[2] Note that flue temperature is relatively higher when CO_2 is lower.

Table II is intended to show, primarily, the efficiencies obtained with Edge Moor boilers in different sections of the country. The efficiencies given are the *combined* efficiencies of the boiler and firing equipment, exclu-

TABLE II—TESTS OF EDGE MOOR WATER TUBE BOILERS

Test No.	Date of test	Name and location of plant	No. of passes	Kind of stoker	Kind of fuel	B.T.U. per lb. dry fuel
1	1909	United States Navy Yard, Philadelphia, Pa.	Four	Overfeed	Semibitum. coal	14,790
2	1914	Milwaukee El. Ry. & Lt. Co., Milwaukee, Wis.	Three	Underfeed	Bituminous coal	13,101
3	1908	Lardner's Point Pump. Sta., City of Philadelphia	Four	Overfeed	Semibitum. coal	14,770
4	1908	Lawrence Ave. Pump. Sta., City of Chicago	Four	Chain grate	Bituminous coal	11,557
5	1912	Dill & Collins, Philadelphia, Pa.	Four	Overfeed	Semibitum. coal	14,458
6	1916	Central Park Ave. Pump. Sta., City of Chicago	Three	Underfeed	Bituminous coal	11,962
7	1913	National Tube Company, Kewanee, Ill.	Four	Underfeed	Bituminous coal	11,048
8[1]	1913	National Tube Company, Kewanee, Ill.	Four	Underfeed	Bituminous coal	11,094
9	1911	American Ice Company, Philadelphia, Pa.	Three	Overfeed	Semibitum. coal	14,214
10[2]	1912	United States Navy Yard, Mare Island, Cal.	Four	Oil burner	California oil	18,790
11	1915	Cons. Gas El. Lt. & Pr. Co., Baltimore, Md.	Three	Underfeed	Semibitum. coal	14,454
12	1916	Sanitary District of Chicago, Chicago, Ill.	Three	Underfeed	Bituminous coal	10,624
13	1916	Sanitary District of Chicago, Chicago, Ill.	Three	Underfeed	Bituminous coal	11,600
14	1915	Hershey Chocolate Co., Hershey, Pa.	Three	Overfeed	Semibitum. coal	14,684
15	1915	E. I. Du Pont de N. & Co., Hopewell, Va.	Three	Overfeed	Semibitum. coal	14,032
16	1919	Mayfair Pumping Station, City of Chicago	Four	Underfeed	Bituminous coal	12,660
17	1917	Union Electric Lt. & Pr. Co., St. Louis, Mo.	Three	Underfeed	Bituminous coal	12,771

[1] Journal A. S. M. E., vol. 36, p. 220, 1914; and Bull. 53, Edge Moor Iron Co.
[2] Engineering News, vol. 69, p. 1126, May 29, 1913.

sive of the firing auxiliaries, as determined in practice and as defined in the Power Test Code of the American Society of Mechanical Engineers. The difference between combined efficiency and 100 per cent. includes, of

TABLE II (Continued)—TESTS OF EDGE MOOR WATER TUBE BOILERS

Test No.	Duration Hrs.	Temp. of feed water Deg. F.	Pressure of steam Pounds gauge	Superheat Deg. F.	Draft in furnace In.	Draft before damper In.	Temperature of flue gas Deg. F.	CO_2 at damper Per cent.	Rated capacity H. P.	Per cent. of rated capacity devel'p'd	Co'bined efficiency. Per cent.
1	12	52.0	142.6	79.4	0.21	0.39	468	.....	456	113.3	74.97
2	24	120.0	179.0	83.1	0.04	....	439	14.3	765	101.5	78.58
3	24	39.2	128.0	None	0.33	0.63	476	11.7	505	127.0	76.9
4	12	42.8	156.3	None	....	0.54	518	.....	279	158.0	74.7
5	24	80.3	110.6	None	0.24	0.45	521	10.7	749	116.4	77.9
6	24	158.8	149.3	113.1	0.01	0.16	436	12.7	497	121.0	75.29
7	24	183.9	116.0	91.2	0.01	0.28	450	13.0	613	127.9	80.38
8	72	194.9	117.6	77.9	0.01	0.26	412	13.3	613	113.4	80.95
9	12	155.4	144.9	None	0.15	0.33	...	.....	213	111.7	77.2
10	10	170.8	145.6	90.0	....	0.19	421	12.5 } 13.4 }	458	101.5	81.6
11	12	63.9	183.4	113.8	0.05	0.14	417	13.2	1047	130.5	77.3
12	13	169.9	154.2	86.7	0.05	0.19	429	12.0	499	125.8	78.2
13	23	170.0	153.8	86.4	0.02	0.18	438	10.6	499	108.6	76.7
14	12	55.6	162.5	83.8	0.19	0.29	477	14.0	410	108.9	76.3
15	9	195.6	132.0	None	0.51	0.82	539	.....	600	166.2	74.4
16	12	37.5	159.4	142.2	0.02	0.30	428	12.6	516	118.0	78.21
17	12	181.0	199.0	136.0	0.04	0.48	512	13.6	558	163.0	77.7

course, not only the loss due to escaping carbon monoxide, the loss from excess air, the loss from combustible to the ash pit, etc., which are chargeable to the furnace, firing equipment and firing labor, but also the unavailable heat such as the "hydrogen loss." By separate analysis of the performance of the boiler alone, excluding the losses chargeable to firing and unavailable heat, the efficiency of the Edge Moor boiler has been found to be much in excess of the combined efficiency.

As regards high overload capacity, Table III shows that tests have been made up to 328.6 per cent. of rating based on ten square feet of water-heating surface per horsepower.

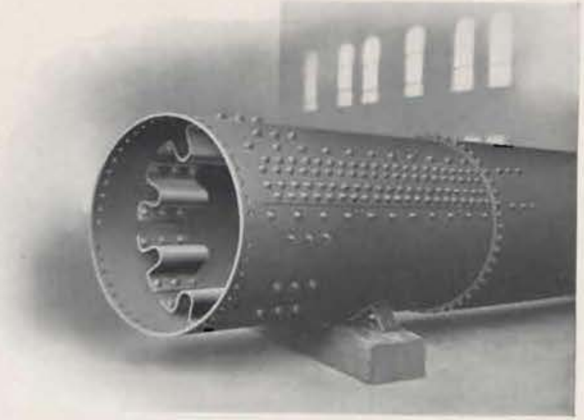
Another feature of boiler performance which must not be overlooked is quality of steam. Many official tests of Edge Moor boilers have shown that unusually dry steam is delivered—less than 1 per cent. of moisture being very common.

TABLE III—CAPACITY TESTS OF EDGE MOOR BOILERS

Name and location of plant	Date of test	Duration of test Hrs.	Rated capacity H. P.	H. P. developed	Per cent. of rating developed
Union Electric Light & Power Co., St. Louis, Mo.	1910	4	518	1265	244.2
Union Electric Light & Power Co., St. Louis, Mo.	1917	2	558	1834	328.6
Sanitary District of Chicago, Chicago, Ill.	1916	4	499	971	194.5
Consolidated Gas, El. Lt. & Pr. Co., Baltimore, Md.	1913	8	736	1829	248.5
Consolidated Gas, El. Lt. & Pr. Co., Baltimore, Md.	1913	2	736	2340	317.9
Consolidated Gas, El. Lt. & Pr. Co., Baltimore, Md.	1915	12	1047	2472	236.1
New York Steam Co., New York City	1917	240	1000	2070	207.0
New York Steam Co., New York City	1917	10	1000	2596	259.6

Materials and Workmanship

THE defects of an incorrect design can never be compensated for by workmanship or structural features, however good. But when it is recognized that the principles of design permit a realization of the best results, it is next in order to look into the various provisions for safety—the primary requirement, for accessibility for cleaning—which affects the efficiency and labor cost, and for conveniences for quickly taking a boiler out of service and putting it back—which affects the labor cost and the fixed charges.



Triple riveted, double butt strapped drum showing U-plates on the inside

Every drum is tested at the works with water under pressure to assure tightness of riveting before shipment

Copy of EDGE MOOR IRON CO.

Mill Tests of Material.

Made by

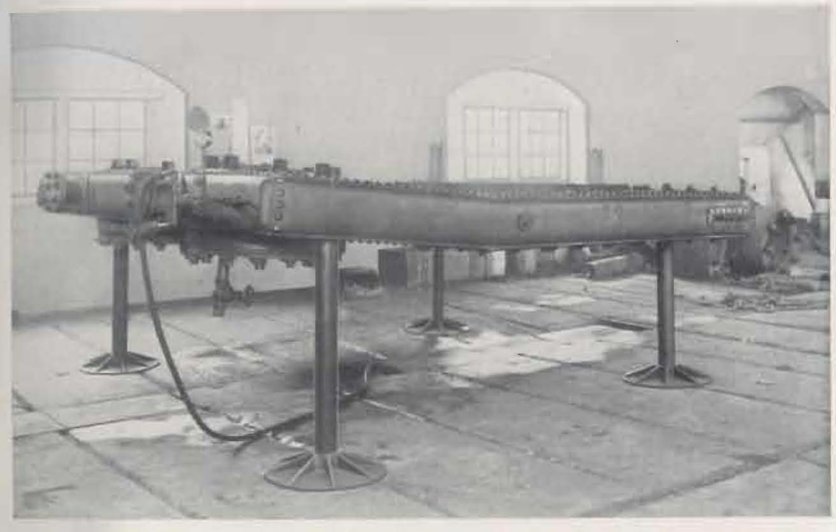
Boiler No. 1427 Order No. 1003 Date

HEAT NO.	MARKS.	SIZE.	Dimensions of Test Pieces: Width Inches	Tickness Inches	Area Square In.	Elastic Limit In. Lbs. Per Sq. In.	Breaking Strain In Lbs.	Ultimate Strength In Lbs. Per Sq. In.	Original Length Between Shoulders In.	Final Elongation Per Cent.	Reduction of Area in per cent of original Area	Carbon	Phosphorus	Manganese	Sulphur	Appearance of Fracture	PART OF BOILER USED FOR
						FRONT HEADER											
2443	2A1	15'-4¾"×59½×½	1.530	.509	779	36070		55840	8"	26.0	57.6	18	012	37	029		Bulge Plate
1081	D1	15'-5¼"×62×½	1.510	.509	769	33680		56440	"	29.0	59.9	18	020	30	033		Flange "
3537	2B1	15'-2¾"×87¾×7/16	1.500	.450	675	36000		56000	"	28.0	60.0	18	015	34	022		Hand Hole "
3538	2G2	15'-2¾"×87¾×½	1.545	.515	796	34420		58300	"	28.5	57.4	19	015	33	034		Tube "
4702	A1	16'-0¼"×17½×7/16	1.520	.447	679	35500		61860	"	27.5	52.1	19	021	34	029		Top Trough "
4702	A2	16'-0¼"×17½×7/16	1.520	.447	679	35500		61860	"	27.5	52.1	19	021	34	029		Btm. " "
4702	B1	11'-9¾"×21×7/16	1.525	.445	679	36080		61860	"	28.0	53.5	19	021	34	029		R.Side " "
1035	B2	11'-9¾"×21×7/16	1.570	.439	689	36000		57330	"	28.0	59.2	16	011	34	035		L.Side " "
						REAR HEADER											
4776	2A2	15'-4¾"×59½×½	1.475	.498	734	35430		55590	8"	30.0	59.9	17	016	38	039		Bulge Plate
3584	2D2	15'-5¼"×62×½	1.510	.513	775	37810		61940	"	28.0	57.0	20	016	43	035		Flange "
4740	3FX	15'-2¾"×87¾×7/16	1.505	.442	665	35190		59850	"	26.0	58.6	17	010	41	028		Hand Hole "
1035	2G1	15'-2¾"×87¾×½	1.530	.501	767	33900		55800	"	26.5	59.2	16	011	34	038		Tube "
4702	H1	15'-2¼"×22½×½	1.520	.510	775	38290		61930	"	29.5	57.4	19	021	34	029		F.Throat "
1039	2H1	15'-2¼"×22½×½	1.370	.502	688	35610		61770	"	28.5	52.6	17	017	41	036		B. " "
3544	A1	16'-0¼"×17½×7/16	1.525	.448	683	33090		55340	"	30.0	62.4	16	013	37	035		Top Trough "
4702	A4	16'-0¼"×17½×7/16	1.520	.447	679	35500		61860	"	27.5	52.1	19	021	34	029		Btm. " "
4702	C1	13'-4¼"×21¼×7/16	1.525	.445	679	36080		61860	"	28.0	53.5	19	021	34	029		R.Side " "
4702	C2	13'-4¼" 21¼×7/16	1.525	.445	679	36080		61860	"	28.0	53.5	19	021	34	029		L.Side " "

A first-class product must begin with carefully selected materials. Mill tests are required for every plate of an Edge Moor boiler

For safety, it is of the utmost importance that all materials shall be of homogeneous quality and of known strength and properties. The Edge Moor Iron Company requires tests of all plates and staybolt materials, and subjects such materials to critical inspection at its works before fabrication.

The Edge Moor boiler, exclusive of handhole plates, is strictly an *all steel* boiler, for not a particle of any such uncertain metal as cast iron



Every header is also tested at the works. Special testing equipment for both drums and headers are required for this purpose

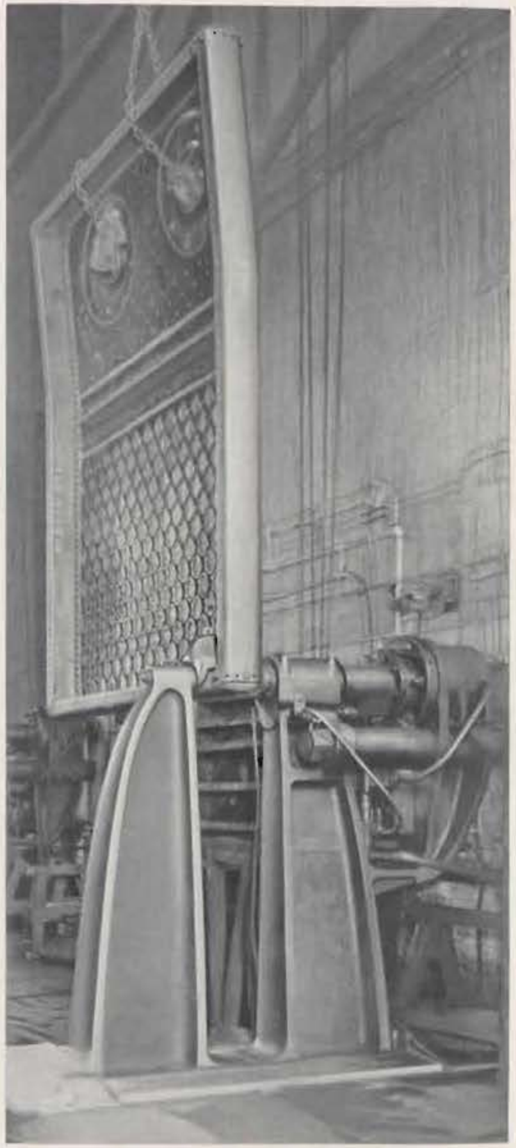
enters into its construction. Handhole plates, which are in compression, are furnished of either cast iron or forged steel, as the purchaser desires.

Two other primary structural factors are riveting and the staying of flat surfaces. With regard to riveting, it is a standard practice with the Edge Moor Iron Company to first punch guide holes for the drill, ¼ inch smaller than the finished rivet holes, in only one plate of a joint.

The plates are afterward bolted together, and the rivet holes are drilled through the lapped plates *at one operation*, assuring a perfect match of holes and thus eliminating the possible future use of the injurious drift pin. The plates are then taken apart, all burrs and chips are scraped off (only those who have seen the accumulations on the dismantled plates will appreciate the importance of this step) and the plates are reassembled for riveting.

All rivets are of standard soft steel, brought to the proper heat before riveting, driven by an hydraulic riveter wherever possible, or by a pneumatic hammer, and held until black. The tightness of all joints is proved in the final shop tests.

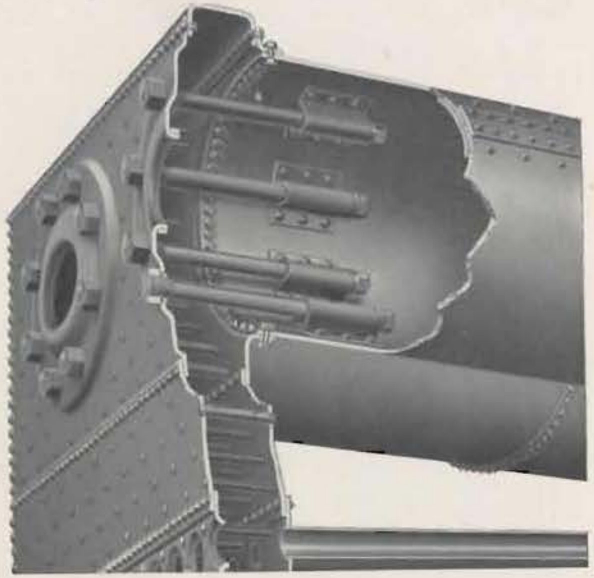
The accompanying engravings show clearly the manner of staying the headers. Just as for effective designs in building and bridge construction, it becomes necessary to make use of built-up girders instead of rolled beams, so in boiler construction it is necessary to resort to stayed surfaces when the space limitations of small containers, cylindrical and spherical walls, and the uncertainties attending their construction, stand in the way of carrying out a design that will give added strength and efficiency.



An example of high-class workmanship. The hydraulic riveter is used wherever possible

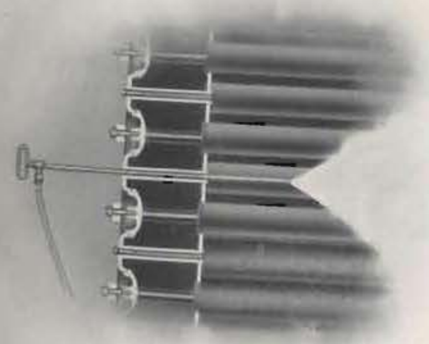
A cable built up of strands of small wire is far stronger and more reliable than a solid wire of the same cross-section, because of the greater certainty of the strength of all parts. The same is true for built-up boiler headers as against those cast or forged to a single piece. The statistics of the boiler insurance companies with regard to the causes of accidents fully substantiate this point.

The bulges opposite the drums of Edge Moor boilers are effectively stayed by eight steel bolts, $2\frac{1}{2}$ inches in diameter, anchored through steel U-plates riveted to the inside of the drum. The joint in the header plate is made permanently tight by the use of an annealed copper cone-nut which is drawn into the conical hole in the plate by screwing up on the outside nut before the staybolt is anchored.



Edge Moor headers are stayed in a most effective manner

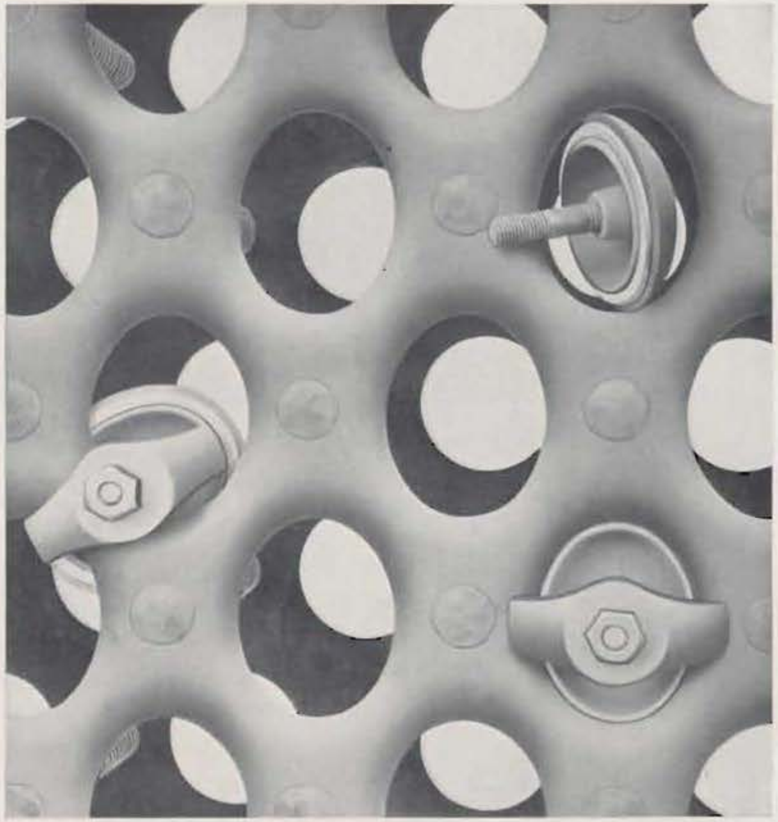
The other parts of the header are stayed by bolts of proper cross-section installed as follows: After the staybolt holes are drilled and the header plates are riveted together, the headers are set on edge, and opposite staybolt holes in both plates are first reamed and then tapped by the continuous travel of a special combined reamer and long tap which passes through the staybolt holes in both plates and thus threads the opposite plates as if they were in the same piece of metal, making it possible to screw in the staybolts without forcing. Staybolts cut to size and threaded throughout their length are then screwed in place and the projecting ends are riveted over and caulked to make the joints tight.



Hollow staybolts are used when the tubes are to be dusted from front or rear

The Handhole Plate

TOO often, boilers are bought "by the horsepower." Considerations other than the price and the heating surface are given scant thought,

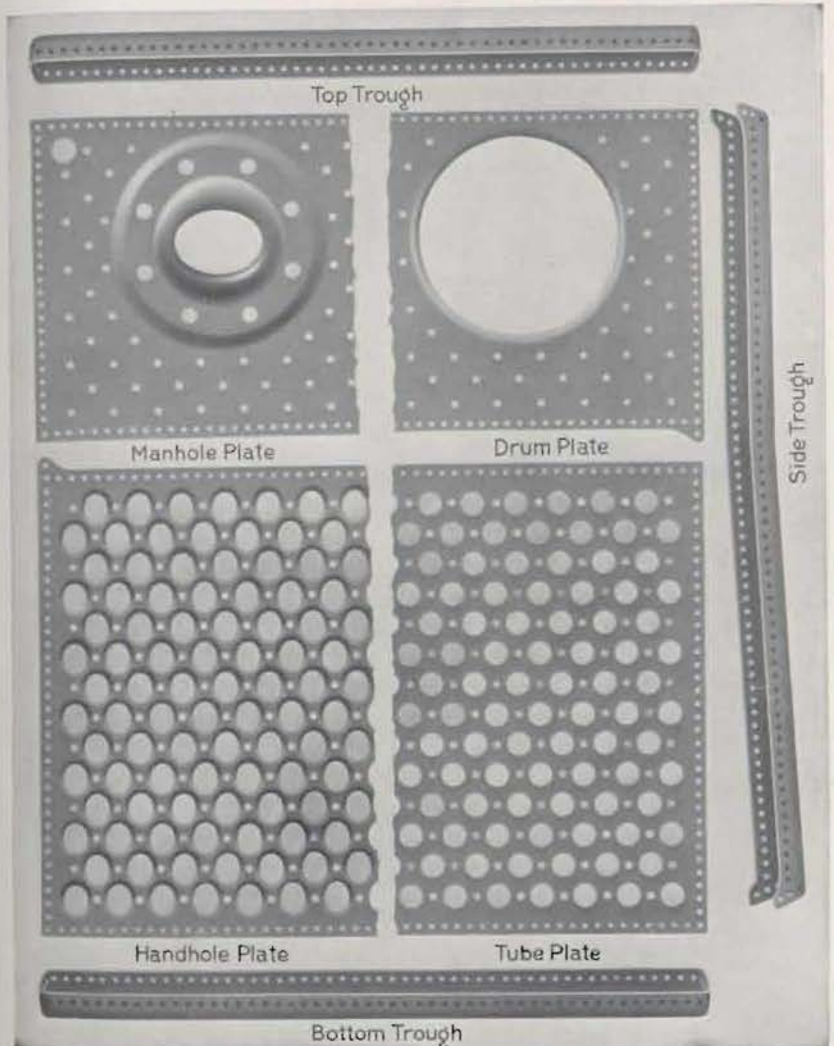


Elliptical handholes make it possible to remove any cover without disturbing any other cover resulting in a saving of time and gaskets

with the result that several times the additional cost of a superior boiler may be wasted annually for extra fuel and maintenance.

A feature of Edge Moor construction that affects maintenance, and one worthy of especial notice is the handhole plate. Every handhole is elliptical to make it possible to pass every cover through its own hand-

hole, instead of from one hole to another, as in those boilers where, for the sake of cheapening the cost of construction, most of the holes have

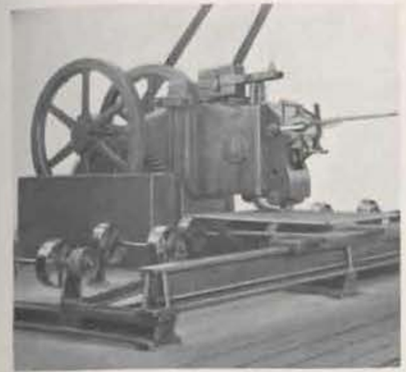


PARTS OF AN EDGE MOOR HEADER

Visitors at our shops are impressed with the workmanship that gives Edge Moor boilers distinction

been made circular with an elliptical or heart-shaped hole here and there to enable the covers to be removed. Such cheapened construction requires,

Every handhole plate is fabricated in three stages



Elliptical holes are first punched in the blank plate by means of a combined punch and spacing mechanism

of course, much extra labor to open and close up a boiler during the inspection and cleaning periods.

It will be noticed that the covers bear against the inside of the header plate which makes their factor of safety independent of the strength of the studs or dogs. Should, by accident, a stud break when being set up while a boiler is under pressure, the joint will still remain tight, for the cover is held against the plate by the internal pressure. No special make of gasket is required with Edge Moor boilers. The purchaser may use any satisfactory gasket, provided it is made to fit the cover.

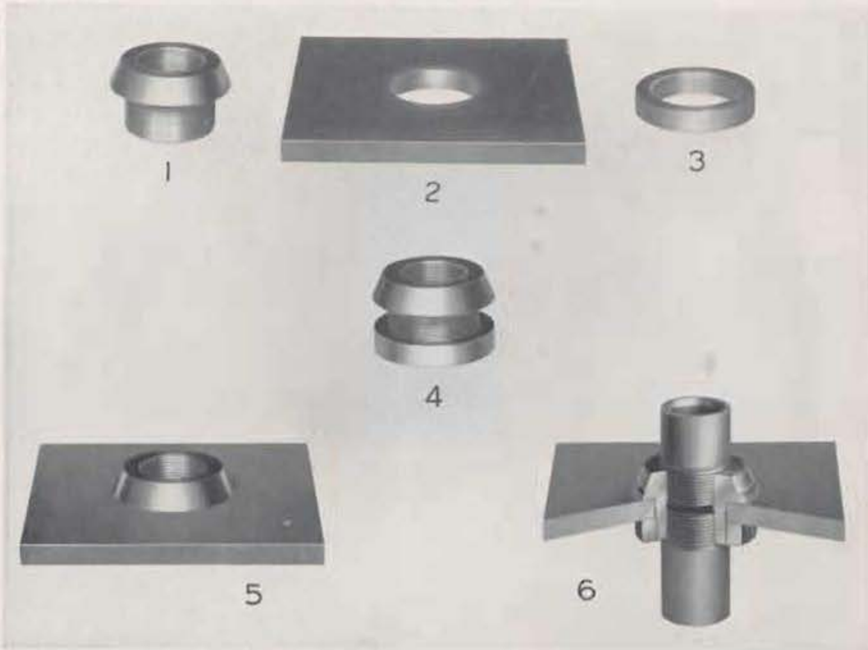
Returning to the construction of the handhole plate, it will be seen that the edges of the holes are flanged inward. This is done by means of dies after guide holes have been punched in the plate and it has been heated to the proper temperature for flanging. After the flanging, the plate is sent to a specially constructed multiple spindle machine which faces the upturned edges to smooth, plane surfaces. The flanging greatly stiffens the plate to resist the internal pressure of the water and to prevent the springing of the faces of the handholes while the plates are being set up against the gaskets—a workmanlike construction, assuring tight joints.

The plate is then heated to a cherry red and the holes are forged to shape between multiple dies

A multiple spindle machine faces the edges and automatically spaces and drills the holes for staybolts

Miscellaneous Details

ONE of the unique structural details of the Edge Moor boiler is the patented pipe connector. This takes the place of the commonly used reinforcing pad wherever there is not sufficient thickness of metal for

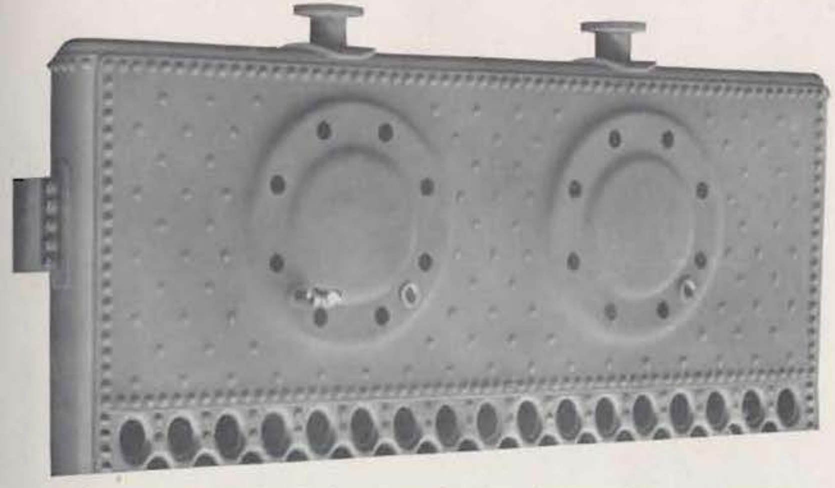


PATENTED EDGE MOOR PIPE CONNECTOR

1. Pipe connector 2. Plate to be reinforced 3. Lock nut 4. Lock nut on connector 5. Connector in place before caulking 6. Connector after caulking, showing pipes in place

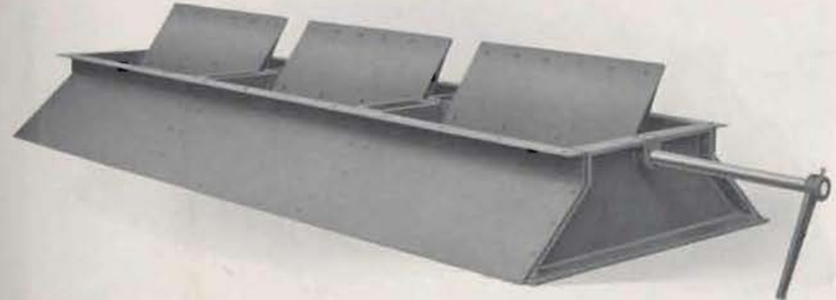
the larger pipe connections. For attaching the feed-water, water-column and surface blow-off piping, these connectors are ideal. They are made of steel, are very simple in construction and present a workmanlike appearance.

The method of installation is as follows: Referring to the engraving above, a straight circular hole *2* is first bored through the plate to be reinforced. The connector *1* is then passed through this hole, as at *5*, and locked in place by the nut *3*, as shown in *6*. This nut is threaded for an easy fit,



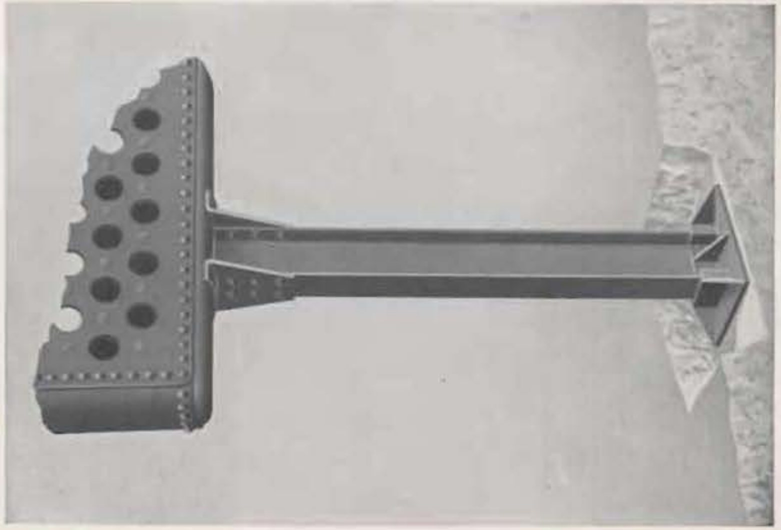
These connectors, for feed water and water column piping, are a decided improvement on the commonly used reinforcing pads

so it may be screwed up by hand. Finally, the bevelled edge of the connector is fullered and caulked against the plate to make a tight joint. The fullering causes the connector to fit snug against the plate and is equivalent to screwing up the lock nut with considerable force, so much so that the connector can only be removed by cutting the nut apart.

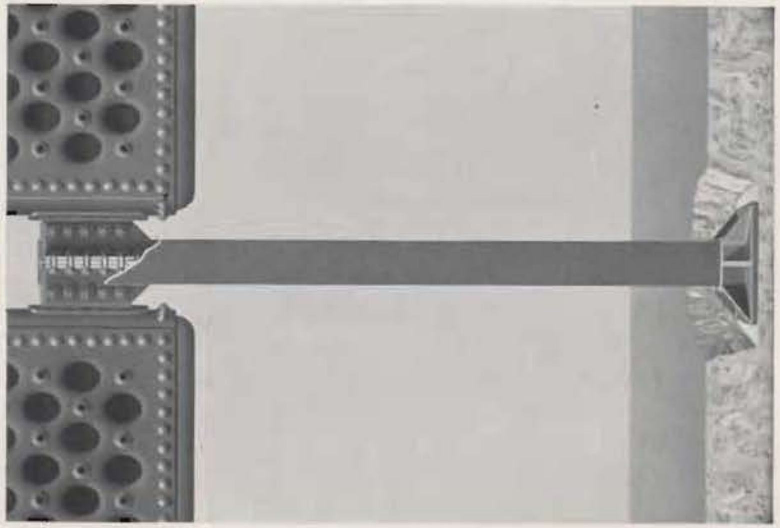


Uptake and damper furnished when the gases are to pass out of the top of the setting

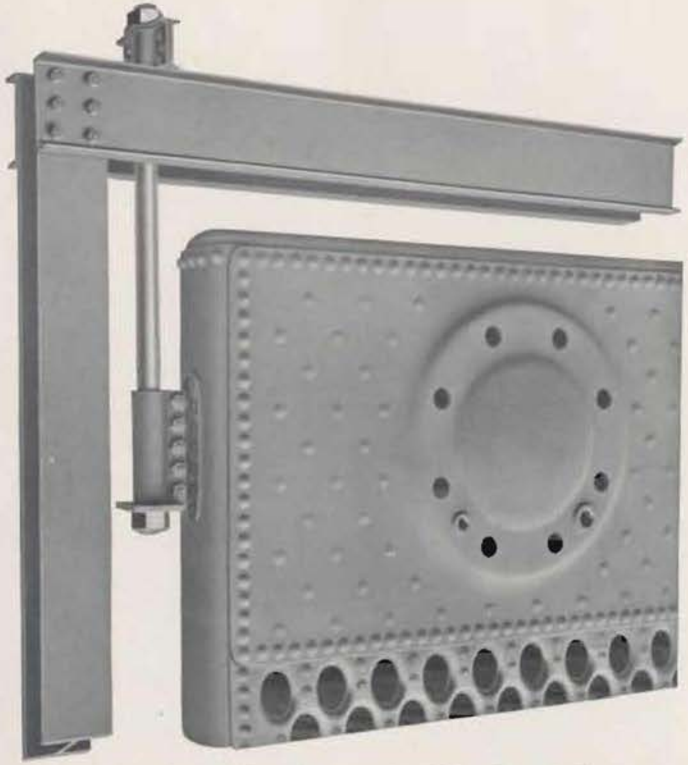
Owing to the ease with which connectors may be installed, they are especially suitable for any additional connections that may be desired during or after erection. They are to be found only on Edge Moor boilers as the patent is the exclusive property of the Edge Moor Iron Company.



Saddle type of support for rear headers



H-column support for battery of boilers

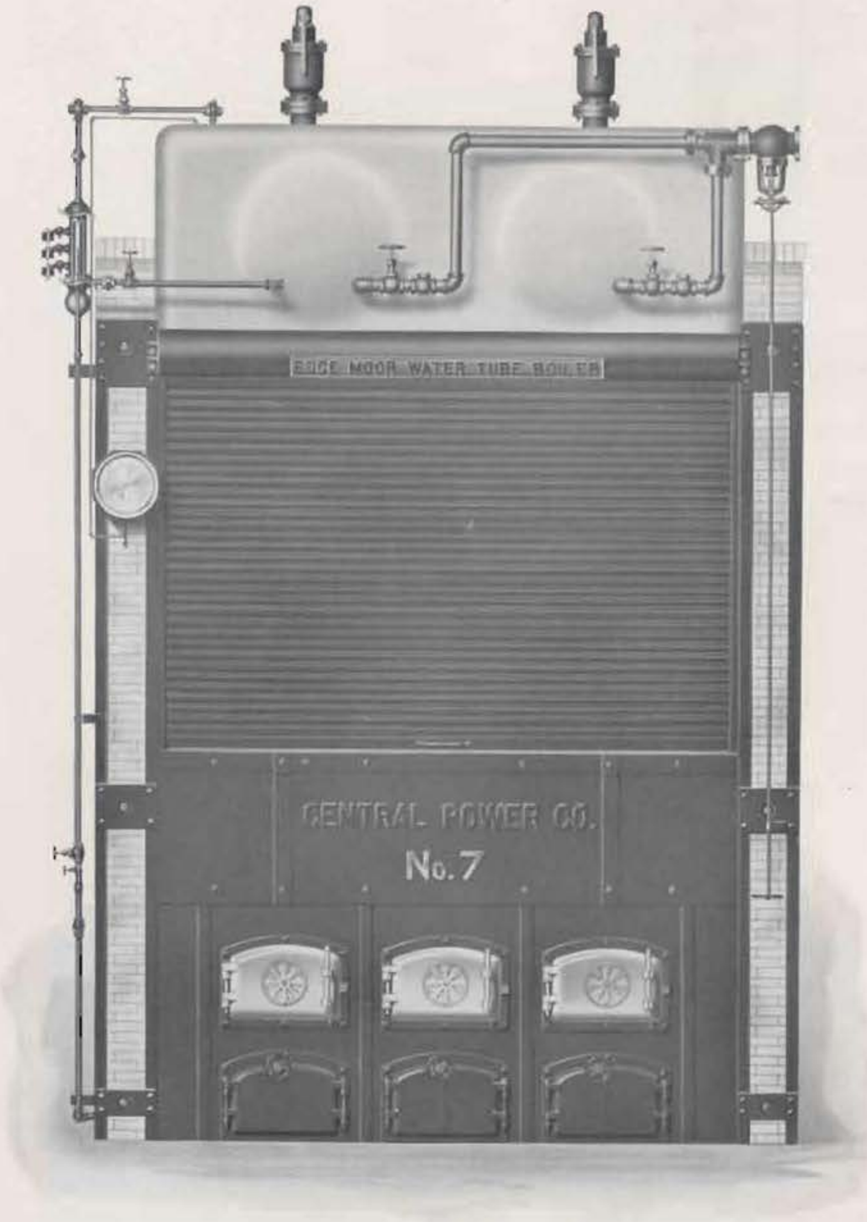


Standard method of suspending Edge Moor boilers

Edge Moor boilers are either supported by columns or hung from overhead beams. The method selected for an installation will depend on the special conditions to be met. In all methods the columns terminate in cast iron base plates set in the foundations and are not connected to, nor do they rest on, the brickwork of the setting.

When boilers are supported or hung from the sides, the initial connection is a specially constructed steel tee riveted to the side trough of the header. This is bolted to the connecting angles on the column supports or, in the suspended type, to the steel sleeve through which the hanger bolt passes. This bolt terminates at both ends in ball-faced nuts which fit into correspondingly recessed washers to facilitate readjustment when the boiler expands or contracts.

The design of other details such as front castings, manhole doors, tube dusting frames and parts, etc., conforms to the high character of the boiler proper. The customary fittings are of the best standard makes.



Standard front of an Edge Moor boiler

As these engravings show, the details affecting the external appearance of the Edge Moor boiler have been designed to combine strength with utility and pleasing appearance. The ends of the longitudinal walls terminate at both front and rear in pilasters built up of steel angles and plates. Tie rods connect front and rear pilasters to strengthen the wall against cracking.

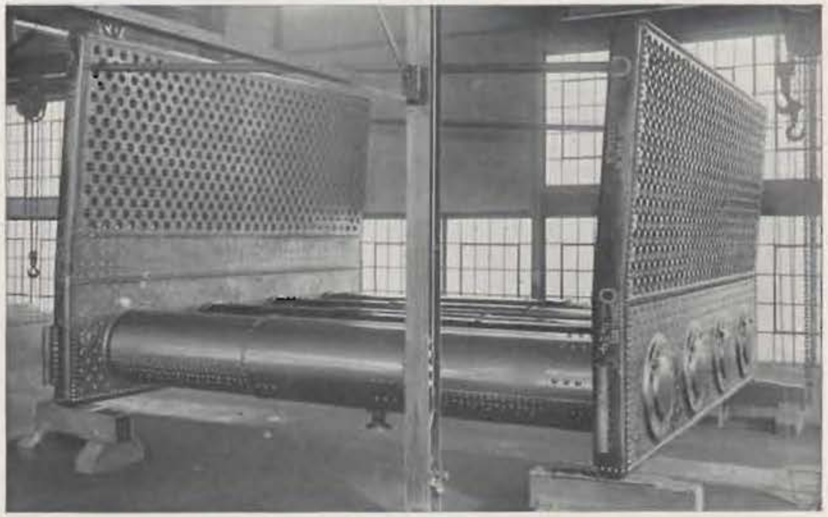
For insulation and appearance, and for quick access to all of the handholes of the front header, a strong and attractive metal rolling door, such as is often seen at entrances to warehouses and other fire-proof structures, is mounted between the front pilasters. The door rolls upward into a cylindrical shell and is therefore entirely out of the way when open.

Opposite the rear header sectional doors, built up of corrugated iron, are used. These are fitted with handles so they may be conveniently taken out and set to one side.

Rear view of a battery of boilers

The upper parts of the headers are usually covered with non-conducting covering, about two inches thick, neatly troweled to a hard finish. The spaces between headers and brickwork are packed with asbestos fibre to prevent leakage of air.

The complications that are apt to arise during erection are avoided as much as possible by fitting the different parts in the shop and reducing the field work to a minimum. As the illustration below shows, the headers and drums of each boiler (the one shown is a four-drum boiler having 10,490 square feet of water-heating surface) are put together in the assembling shop, accurately aligned, and then the holes for connecting the drums to the headers are drilled continuously through the lapped joints to assure a perfect match of holes. The headers and drums are afterward taken apart and prepared for shipment.

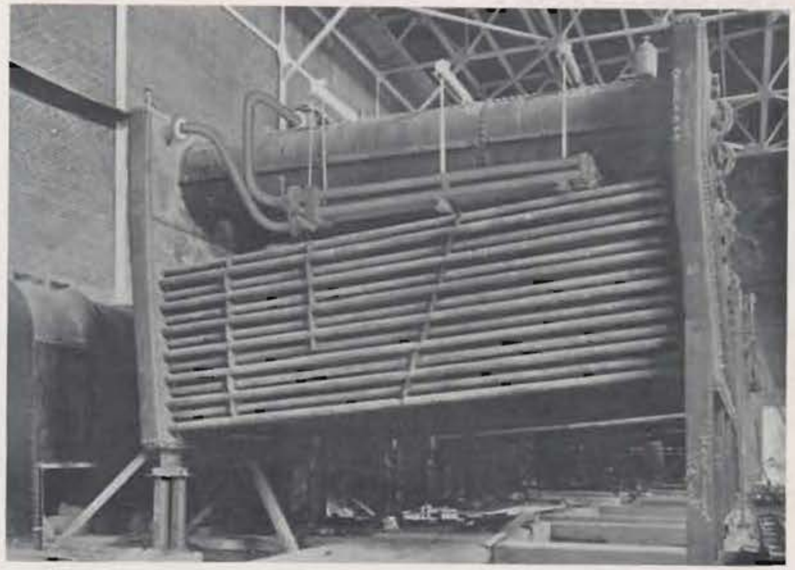


All headers and corresponding drums are invariably assembled in our shops. This is done upside down for convenience in drilling the holes through header flanges and drum ends

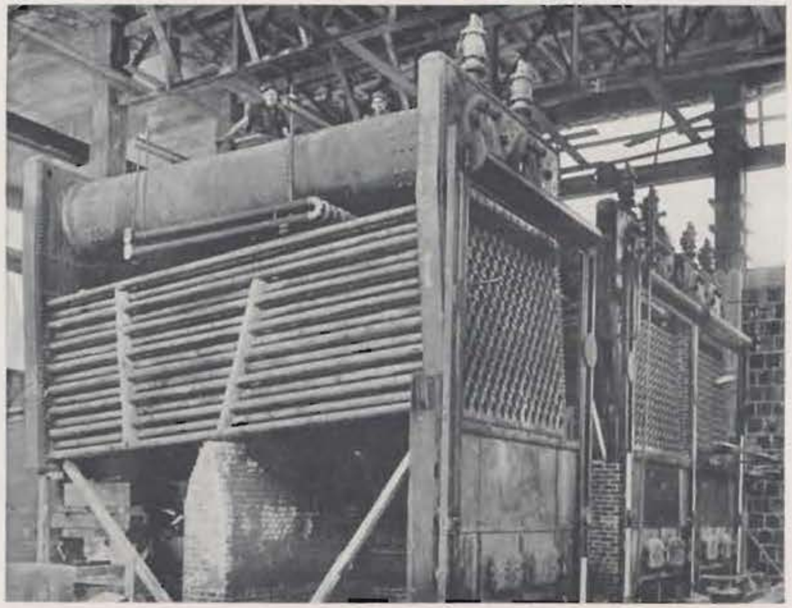
With the exception of the very smallest sizes, Edge Moor boilers are shipped from the works in "knocked-down" condition. Parts are of such size and weight that they can be easily removed from the cars and transported to the boiler foundations, whether in basement, at ground level or in upper stories. The field erection is simple, requires very little skilled labor and may be carried out with great expedition. By means of the method of connecting drums to headers, all riveting in the field is avoided and only a very little caulking is required.

Typical loading of large Edge Moor headers

Shipment of three 600 horsepower boilers leaving the works



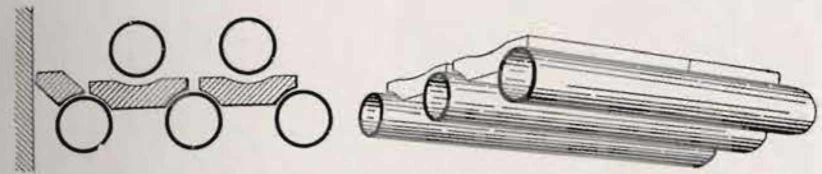
Showing bare baffle plates. Four-pass setting.
U. S. Navy Yard, Mare Island, California



Showing plastered baffle plates. Three-pass setting.
Maverick Mills, East Boston, Mass.

Baffling and Stokers

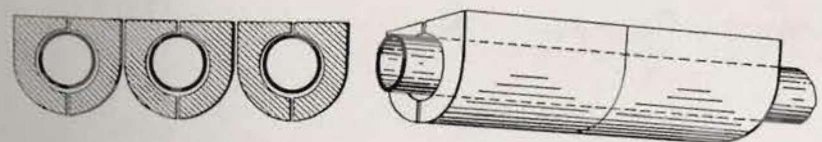
THE drawings which follow show a variety of combinations of differently baffled Edge Moor boilers set with some of the representative types of stoking and combustion devices now in use. The Edge Moor Iron Company does not build nor recommend any particular make of stoker but, since every stoking device usually requires some special modi-



D-Tile Used for Horizontal Baffles

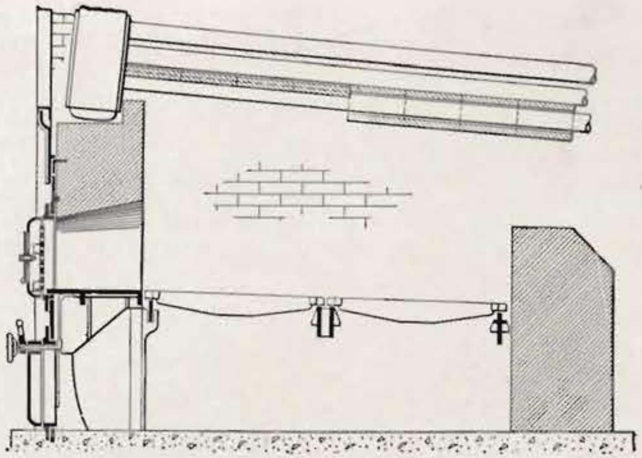
fications of the boiler setting for the best ultimate results, this company will gladly co-operate with builders of stokers and with prospective purchasers in jointly working out the most promising arrangement for every case.

The types of baffling and combinations shown are only a few of those that have given satisfaction. They are only intended to be suggestive and to show how easily Edge Moor boilers can be modified to meet local conditions.

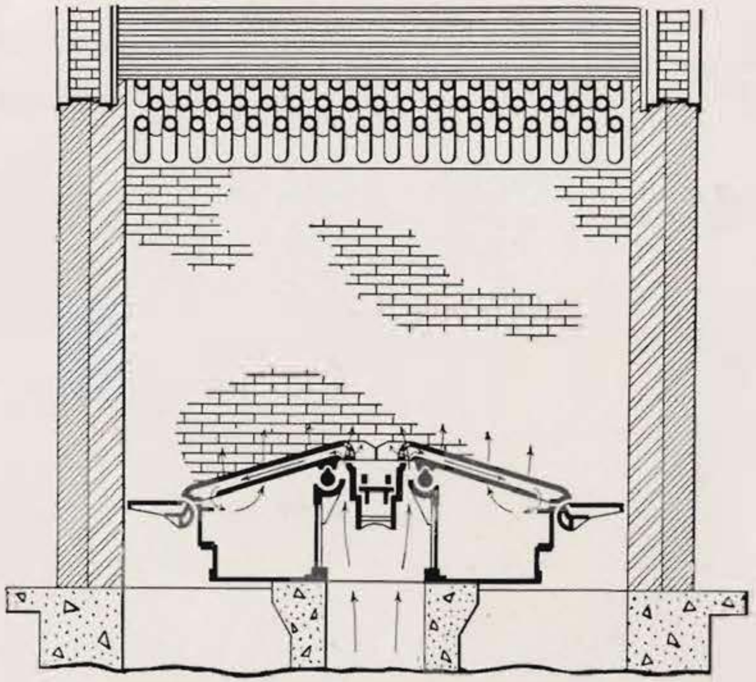


Encircling Tile for Flat Arches

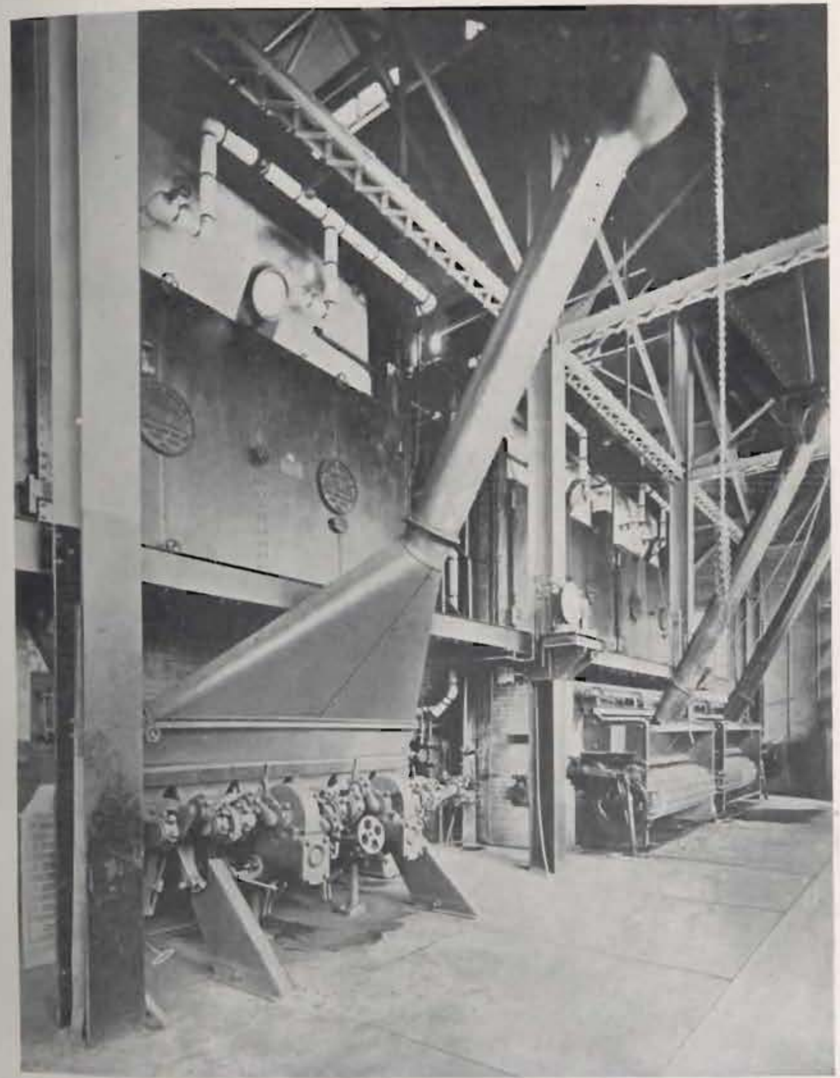
As shown in the illustrations, "horizontal baffles" and "flat arches" are built up of special tile which can be easily installed and replaced. The cross baffles, as shown on page 26, consist of sectional cast iron plates on both sides of which is plastered a high heat-resisting asbestos cement which hardens and clings to the plates. An advantage of this construction is that the baffles may be easily kept tight. The front face of the first baffle is lined with renewable tile made to fit around the tubes and lock in place.



Flat Arch of D and Encircling Tile for Smokeless Combustion of Bituminous Coal

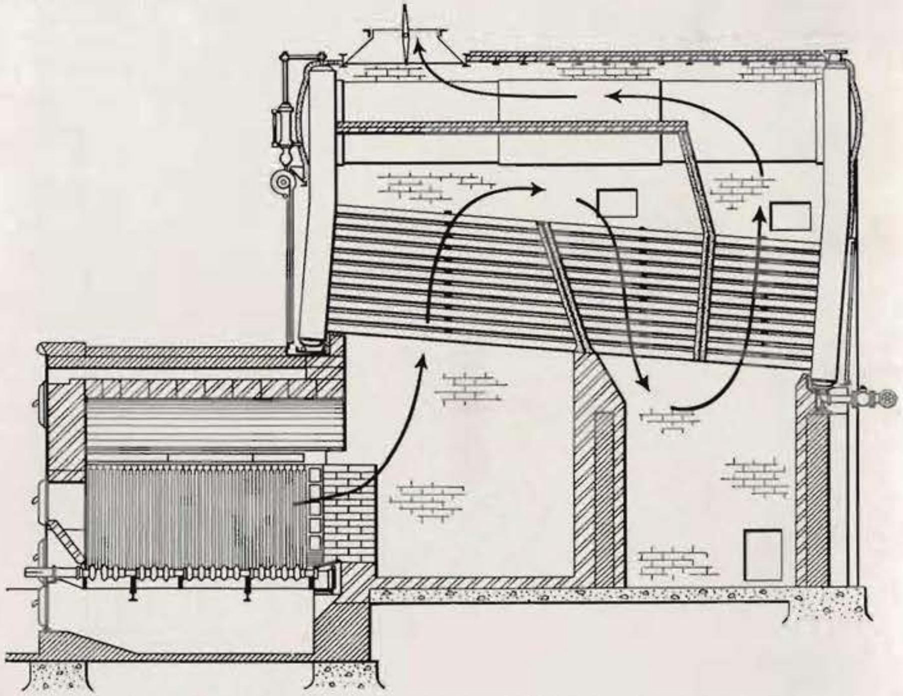


Front View of Furnace with Forced-Draft, Center-Retort, Underfeed Stoker



Forced-draft, front underfeed stoker and natural draft, chain grate stokers under Edge Moor boilers. Laclede Gas Light Co., St. Louis, Mo.

It will be noticed in the following drawings that the baffling can be arranged so that gases may pass out at the front of the top of the setting, or at the rear of the top of the setting, or at the rear of the bottom of the setting.

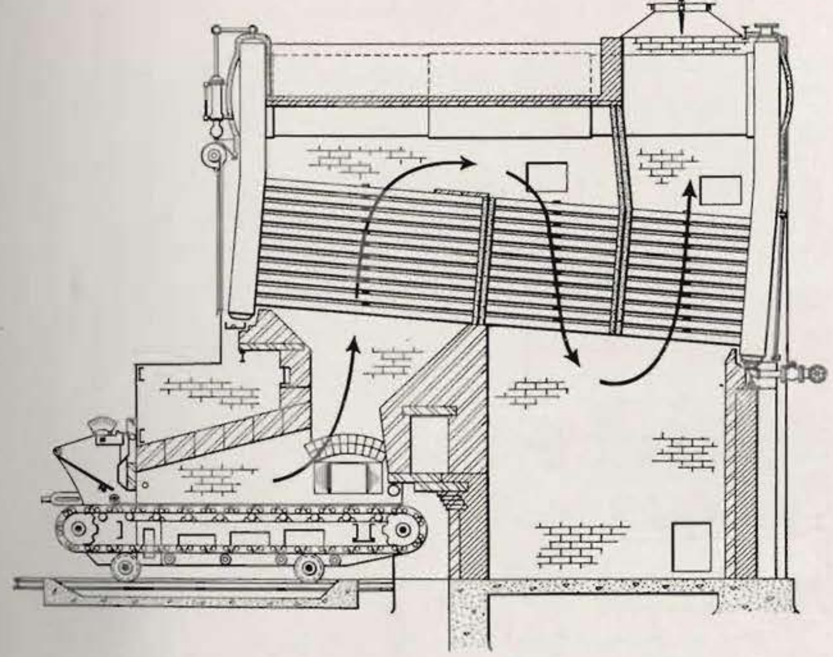


Three Cross-Pass Setting—Gases off at Front—Side Overfeed Stoker

No manufacturer of boilers can give the best service to boiler users by limiting himself to one or two "standard" types of baffling, because a type of baffling that will give good results with one kind of fuel or stoker may give poor results when these are different. As an example, the combination arch shown in the upper part of page 28 will give excellent results with soft coal but will decrease both efficiency and capacity when the coal is anthracite. On the other hand, the baffling shown in the lower part of the same page will give excellent efficiency and smokeless combustion when the coal is anthracite but will be very inefficient and a smoke nuisance when the coal is soft bituminous. Hence the baffling of a boiler must be carefully selected to fit each particular case.

It is sometimes supposed that the floor space required by boilers is modified by the horizontal center-to-center spacing of the tubes. That

this is not so when the fuel to be burned requires a grate is easily seen. A steam generator consists of two parts which have entirely different functions—the grate and furnace *evolve* the heat; the boiler *absorbs* it. It is therefore plain that the first step in the selection of a steam generator



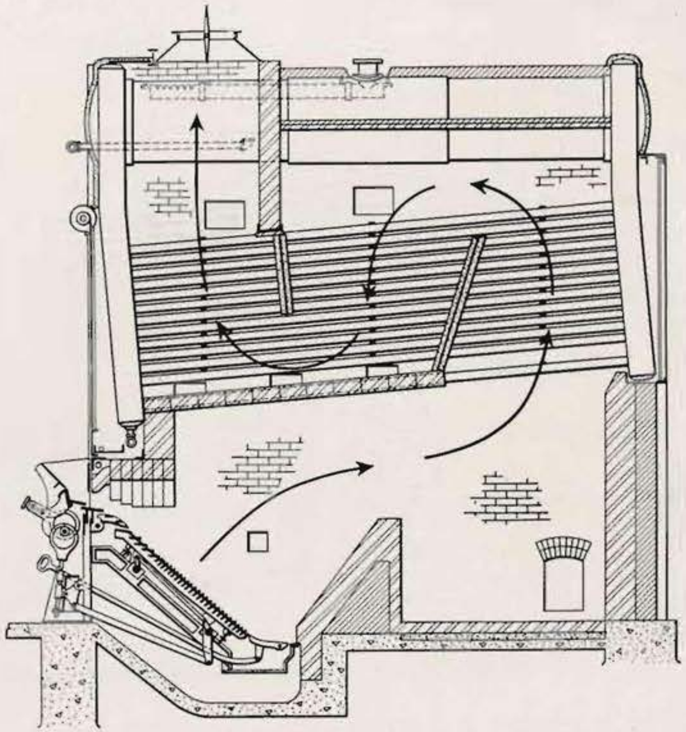
Three Cross-Pass Setting—Gases off at Rear—Chain Grate

is to determine the size of grate necessary for the proper combustion of the estimated amount of coal to be burned, and the second step is to choose a boiler that will fit that grate mechanically as well as thermally. As an example, suppose it is desired to select a boiler for the continuous delivery of steam equivalent to 250 boiler horsepower. Suppose, further, that the coal to be used will have a heat value of 14,200 B. T. U. per pound, and that the combined efficiency of the generator will be 72 per cent. Then the stoking device must be able to burn at least

$$\frac{250 \text{ H. P.} \times 34.5 \text{ lbs.} \times 970.4 \text{ B. T. U.}}{0.72 \times 14{,}200 \text{ B. T. U}}$$

or 816.6 pounds of coal per hour.

Now suppose that the type of stoking device to be used and the furnace draft (or ash-pit pressure) available will permit of the continuous combustion of 20 pounds of coal per square foot of grate surface per hour. Then the amount of grate surface required will be 818.6 ÷ 20 or 40.9 square feet.



THREE CROSS-PASS REVERSED SETTING—GASES OFF AT FRONT—FRONT OVERFEED STOKER

Since the length of the stoker or grate is determined by the design, or by the stoking conditions, and is independent of the boiler, it follows that as soon as the grate surface is determined the width of furnace is also determined, and this width, from the foregoing reasoning, is independent of any arrangement of boiler tubes. If, in the above example, the length of grate is taken as 6 feet, the furnace width will be 40.9 ÷ 6 or 6.8 feet; and the proper boiler for this installation must have an inside width of setting approximately equal to this. With the width of boiler fixed by the amount of coal to be burned and stoking device to be used, the advantage of one design of boiler over another as regards floor space,

must depend on the length of setting. Fortunately, the design of the Edge Moor boiler tends to make the length of setting a minimum.

It should not be supposed that for every Edge Moor boiler of a given rating there is but one arrangement of tubes and but one furnace width. The table given below illustrates the latitude of arrangement of tubes that is applicable to all ratings. It is seen that there are five sizes of boilers

Edge Moor boilers with natural draft, front overfeed stokers
Lardner's Point Pumping Station, City of Philadelphia

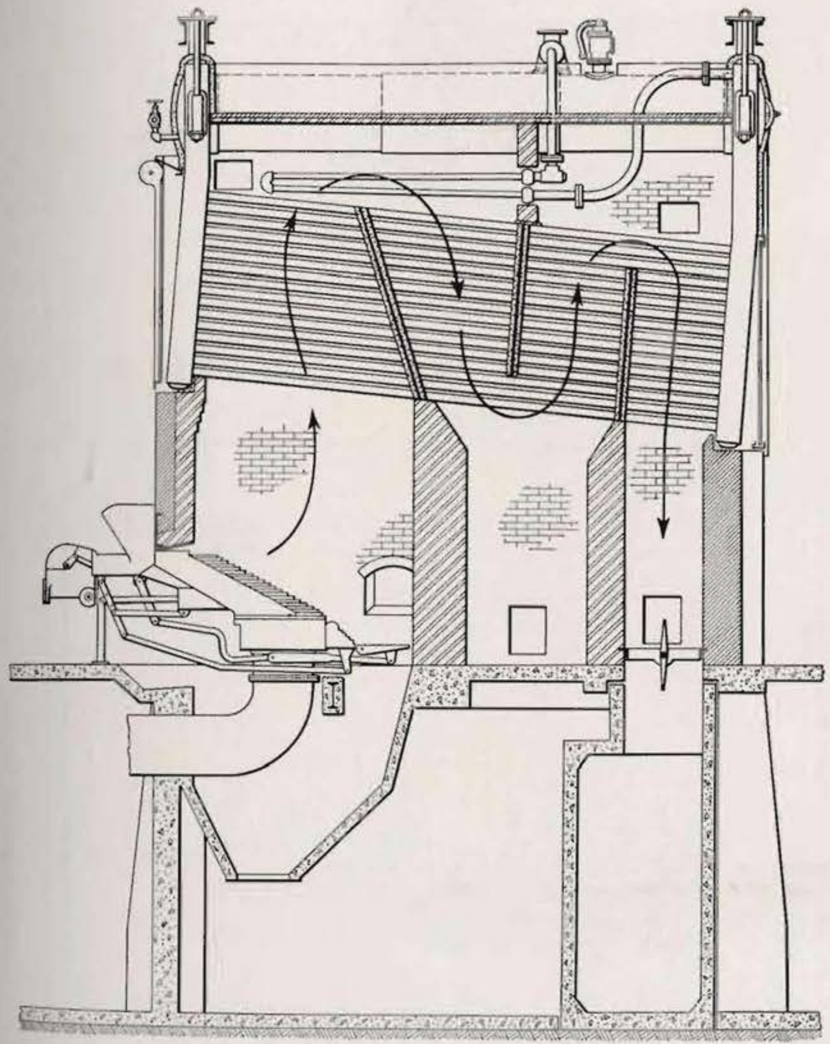
TABLE SHOWING FIVE STANDARD SIZES OF EDGE MOOR BOILERS FOR A NOMINAL RATING OF 400 HORSEPOWER. TUBES ARE 18 FT. LONG. LENGTH OF GRATE TAKEN AT 8 FT.

Tubes high	Tubes wide	Heating surface	Furnace width	Grate surface	Ratio of H.S. to G.S.	Floor space
		Sq. ft.		Sq. ft.		Sq. ft.
16	13	4008	8′ 3″	66.0	60.7	231.6
15	14	4069	8′ 10½″	71.2	57.1	244.5
14	15	4074	9′ 6½″	76.3	53.4	258.7
13	16	4060	10′ 2″	81.4	49.9	271.7
12	17	3988	10′ 9½″	86.4	46.2	284.7

each of which has approximately 4000 square feet of heating surface but with varying grate areas ranging from 66 to 86.4 square feet, and floor areas from 231.6 to 284.7 square feet.

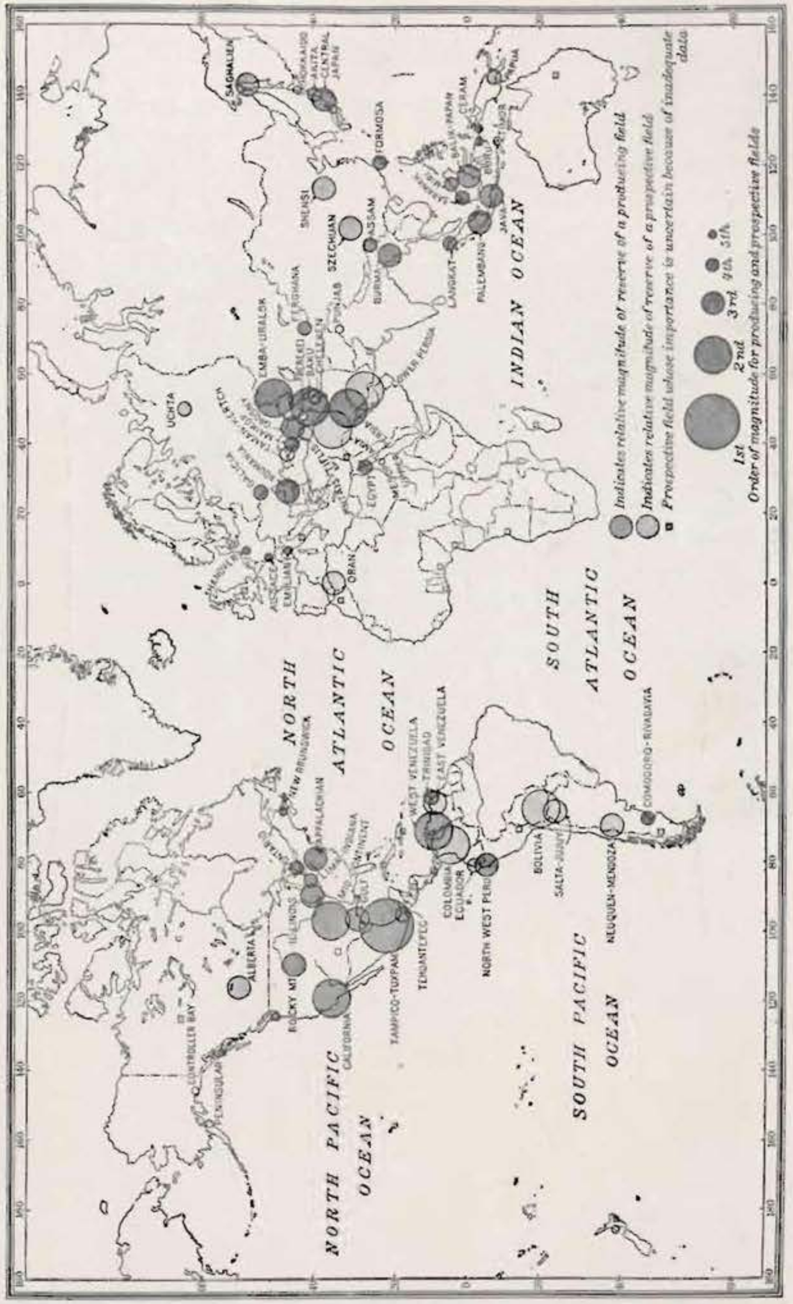
Typical installation of superheater in connection with a four cross-pass boiler

By having a variety of sizes for a given nominal rating it is possible to meet, efficiently, the different requirements of boiler users. The best size is generally determined by the kind of fuel to be burned. Thus, if the fuel is to be anthracite coal the best boiler to use is the one with a wide grate because it is possible to burn only a relatively small amount of this kind of coal per square foot of grate surface. On the other hand, if a high-grade semibituminous coal is to be used a boiler with a narrower grate will give the best results.



FOUR CROSS-PASS BOILER WITH SUPERHEATER AND FRONT UNDERFEED STOKER

Standard sizes of Edge Moor boilers have ratings from 75 to 1050 boiler horsepower. All tubes are four inches in diameter. The lengths of tubes most commonly used are 18 and 20 feet, but other lengths will be furnished when special conditions make this desirable.



THE WORLD'S OIL FIELDS (U. S. GEOLOGICAL SURVEY, 1918)

Firing with Oil

OIL has been frequently spoken of as "the ideal fuel." It has many advantages over coal: delivery and storage are greatly simplified; firing requires simple equipment and a minimum of labor; there are no ashes to remove; fuel waste is much more easily controlled and therefore greatly reduced; consumption of fuel during stand-by periods is unnecessary; upkeep is lower than in stoker-fired plants when design and operation have been given proper attention; smoke nuisances are avoided; and the boiler room may be kept as clean as the engine room.

Unfortunately, the demand for oil as compared with the supply is so great that this fuel is not available for general use. Even though oil costs considerably more than coal for the same number of heat units the differences in the costs of storing, firing, etc., may make oil the cheaper fuel in the end. For comparing the economic values of oil and coal, costs on a fuel basis alone are therefore misleading. A complete analysis is necessary, for which the following form is suggested.

SUMMARY OF COSTS FOR OIL VERSUS COAL

Estimated costs on annual basis	With oil	With coal
Cost of fuel, delivered at the plant site, consumed for production	$	$
Cost of fuel, delivered at the plant site, consumed during stand-by periods	$	$
Cost of fuel loss from storage	$	$
Cost of unloading, storing and delivering fuel to the firing equipment	$	$
Cost of firing labor	$	$
Cost of ash removal	....	$
Cost of replacements and repairs for fuel handling and firing equipment, and for furnaces	$	$
Charges for investment in storage equipment, firing equipment, etc.	$	$
Total	$	$

From the tabulated data below an approximate comparison of fuel costs may be obtained. It will be noticed that in each case the average *net* efficiency specified (the percentage of the calorific value of the fuel which enters the feed water to make useful steam) is about 5 per cent. less than would be expected from results obtained in tests. Some such allowance must be made, of course, to cover the difference between test conditions and average operating conditions throughout the year.

Fuel Required Per Hour Per Thousand Useful Boiler Horsepower

Plant A: Oil-burning plant (average net boiler-room efficiency 75 per cent., 18,500 B. T. U. per lb. oil, 8 lb. per gal., 336 lb. per bbl.) . . 301 gal. or 7.2 bbl.

Plant B: Oil-burning plant (average net boiler room efficiency 73 per cent., oil as above) . . . . 310 gal. or 7.4 bbl.

Plant C: Coal-burning plant, stoker-fired (average net boiler room efficiency 70 per cent., 13,500 B. T. U. per lb. coal, 2,240 lb. per ton) . . . . 1.6 tons.

Plant D: Coal-burning plant, hand-fired (average net boiler room efficiency 60 per cent., coal as above) . . . . 1.8 tons.

Comparative Costs for Plants *B* and *C*

Oil at	2 cents per gallon	is on a par with	coal at	$3.90	per ton.
"	3 "	"	"	5.85	"
"	4 "	"	"	7.80	"
"	5 "	"	"	9.75	"
Oil at	75 cents per barrel	is on a par with	coal at	$3.45	"
"	$1.00	"	"	4.60	"
"	1.50	"	"	6.90	"
"	2.00	"	"	9.25	"

As a rule, the calorific value of oils used for boiler firing, from whatever source, varies very little from 18,500 B. T. U. per pound. It is, of course, very different for coal. The calorific value of the coal commonly used may be anywhere between 10,000 and 14,500 B. T. U. per pound, while in certain localities the value may be outside of these limits. Also, firing efficiency must be considered. A hand-fired coal-burning plant is much less efficient than the average oil-fired plant, but a modern stoker-fired plant may have an all-over efficiency almost as good.

The oil used for firing boilers is either the natural liquid, petroleum, as it is taken from sand or rock strata in widely scattered regions of the earth, or it is the end-product of that liquid after certain components have been removed. Petroleum is a complex mixture of many different hydrocarbons. These may be separated in the refinery and are commercially known as gasoline, benzine, kerosene, lubricating oils, grease, paraffin or asphalt, etc. Generally the mixture contains small quantities of water, sulphur and sand. Its specific gravity may be between 10° and 50° Beaumé (1.000 to 0.785 as compared with water); its color may vary from a pale yellow to a reddish or blackish brown; its mobility from that of a light oil to that of grease.

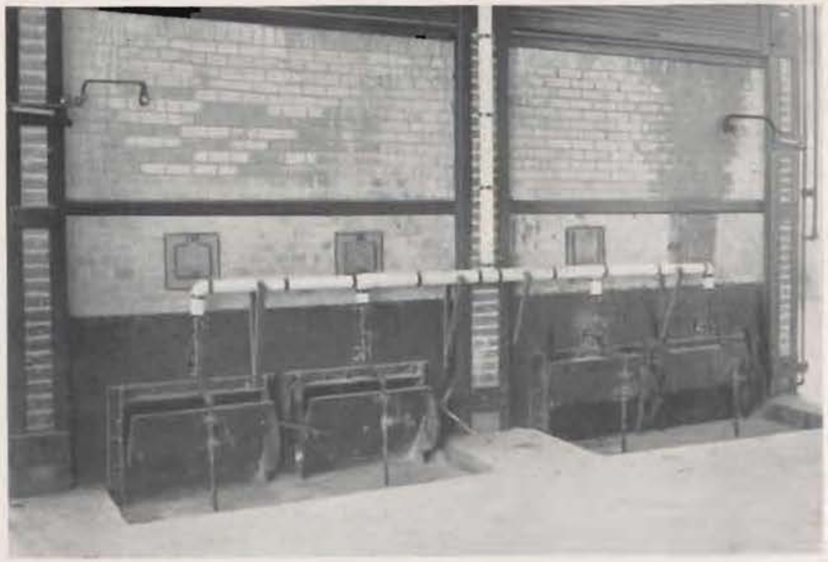
Reduction Table for Oil Fuel

Degrees Beaumé	10	11	12	13	14	15	16	17	18	19	20
Lbs. per gal.	8.33	8.27	8.21	8.16	8.10	8.05	8.00	7.94	7.89	7.83	7.78
Lbs. per cu. ft.	62.3	61.9	61.4	61.0	60.6	60.2	59.8	59.4	59.0	58.6	58.2
Lbs. per bbl.	350	347	345	343	340	338	336	333	331	329	327

One barrel = 42 U. S. gallons.

A petroleum may be so poor in the valuable hydrocarbons as not to warrant refining, and is then sold for firing boilers, etc. On the other hand, some petroleums are so rich in the valuable hydrocarbons that refining is carried to a point where no residue remains suitable for fuel. An untreated petroleum is commonly designated "crude oil." When the lighter hydrocarbons are removed from a petroleum and the residue is suitable for fuel this residue is variously known as "residuum oil," "topped oil" or "treated oil." The term "fuel oil" is sometimes used to designate the distillates of petroleum between the lighter illuminating oils and the heavier lubricants. Its gravity may be between 25° and 30° Beaumé. 'Fuel oil' is commonly used for firing metal treating furnaces.

Some petroleums are asphalt base, some are paraffine base and some contain both asphalt and paraffine. The B. T. U. per pound may be between 17,500 and 22,000. But these variations need not be considered in ordinary boiler-room practice. Paraffine and asphalt base oils burn about equally well. The petroleums high in B. T. U. are generally least suited for boiler-room fuel on account of the low flash point and more valuable for refining. These are commonly reduced to a residuum oil of gravity between 14° and 15° Beaumé, which is sold for steam generation. Residuum oils do not vary considerably from 18,500 B. T. U. per pound. This is also true of the crude oils sold for fuel. Hence for ordinary boiler-room calculations the estimator may assume 18,500 B. T. U. per pound.



Oil fired fronts of Edge Moor boilers.
Miami Beach Electric Co., Miami, Florida.

There are three substances in oil which may occur in such quantities as to cause considerable trouble. These are sulphur, water and "foreign matter." The sulphur content burns to sulphur dioxide which combines with moisture, forming a corrosive acid. Ordinarily the quantity of sulphur present is too small to produce harmful effects. The water content does not generally exceed 1 per cent. but in exceptional cases may run as high as 30 per cent. from seepage into the wells or into the storage reservoirs. The term "foreign matter" includes sand and other solids.

The tables on the opposite page show average properties and composition of California crude oils. The yield from other fields in the United States is mostly lighter. The heaviest oils come from the Mexican fields, are of asphalt base and run as low as 10° Beaumé.

Residuum oils are generally better for fuel than crude oils because in the process of refining nearly all of the associated water passes off with the distillates and settling removes most of the foreign matter. The gross calorific values of both classes of oils are about the same while the effective values may be higher for the residuum oils because of a lower hydrogen content. Heavy oils generally have a somewhat lower calorific

PROPERTIES OF CALIFORNIA CRUDE OILS[1]

Name of oil field	Specific gravity at 15° C.	Degrees Baumé at 60° F.	Heat value per lb. B. T. U.	Weight per gallon Lbs.
Kern River				
Average of 40 samples	0.9645	15.16	18,553	8.03
Composite sample[2]	.9670	14.78	18,562	8.06
Coalinga				
Average of 62 samples	.9498	17.52	18,727	7.91
Composite sample	.9505	17.29	18,720	7.92
McKittrick				
Average of 26 samples	.9566	16.37	18,508	8.01
Composite sample	.9600	15.83	18,335	8.00
Midway				
Average of 29 samples	.9570	16.34	18,613	7.97
Composite sample	.9580	16.14	18,565	7.98
Sunset				
Average of 25 samples	.9701	14.37	18,478	8.08
Composite sample	.9705	14.26	18,419	8.09

COMPOSITION OF CALIFORNIA CRUDE OILS[1]

Name of oil field	Specific gravity at 15° C.	Hydrogen Per cent.	Carbon Per cent.	Nitrogen Per cent.	Sulphur Per cent.	Undetermined Per cent.
Kern River composite	0.9670	11.27	86.36	0.74	0.89	0.74
Coalinga	.9505	11.30	86.37	1.14	.60	.59
McKittrick	.9600	11.41	86.51	.58	.74	.76
Midway	.9580	11.61	86.58	.74	.82	.25
Sunset	.9705	11.37	85.64	.84	1.06	1.09

[1] From Bulletin 19, 1911, Bureau of Mines.
[2] A composite sample is a mixture of several samples as received.

value per pound than light oils, though not always, but as there are more pounds in a gallon or barrel of heavy oil—the units by which oil is sold—the heavier oils generally have a higher B. T. U. value per gallon or per barrel.

In all methods used at present for boiler-room firing the oil is passed through strainers to remove foreign matter and raised to a pressure and temperature best suited for atomization—that is, for discharging the oil into the furnace in finely divided particles. In the "mechanical system" atomization is produced by giving the oil a whirling motion in the burner tip and discharging it into the furnace through a small orifice, without the aid of any atomizing agent. In the "steam-atomizing system" and in the "air-atomizing system," which are essentially the same in principle, the oil is broken up by a continuous discharge of steam or air under pressure within the burner or at the tip outlet. For stationary plants air has been found to have no advantage over steam as an atomizing agent and has gone out of use except for firing small house-heating boilers or where water is scarce.

The mechanical system has an advantage over the steam-atomizing system in that the steam required to operate the complete oil-burning system is several per cent. less, but the steam-atomizing system is considered to be better suited for regulation under the variable load conditions which obtain in most stationary plants and has other advantages that tend to more than compensate for the steam used for atomization. As a consequence, most of the stationary plants are equipped with the steam-atomizing system.

Both systems require certain auxiliaries besides the storage and suction tanks. There should be a steam coil in the suction tank to heat the oil when it does not flow freely to the pumps; a coarse-mesh strainer in the pump suction and a fine-mesh strainer in the discharge between heater and burners to remove foreign matter; two suitable pressure pumps (one for stand-by) to raise the oil to the required pressure; and one or more heaters to raise the oil to the required temperature. Except for small installations, it is generally preferable to heat the oil with live steam. The amount of live steam required for heating is very small and better temperature regulation is obtained, as a rule, with live steam than with exhaust steam. The speed of the pump should be controlled by an automatic governor to maintain a uniform pressure of oil irrespective of the demand; there should be a relief valve on the discharge to release excess oil; an air chamber to neutralize the pulsations of the pump; and a pressure gauge

and thermometer to indicate the pressure and temperature of the oil passing to the burner piping. In and near cities and towns the manner of installing tanks and firing equipment is prescribed by underwriters' rules and building laws to minimize danger from fire and accidents.

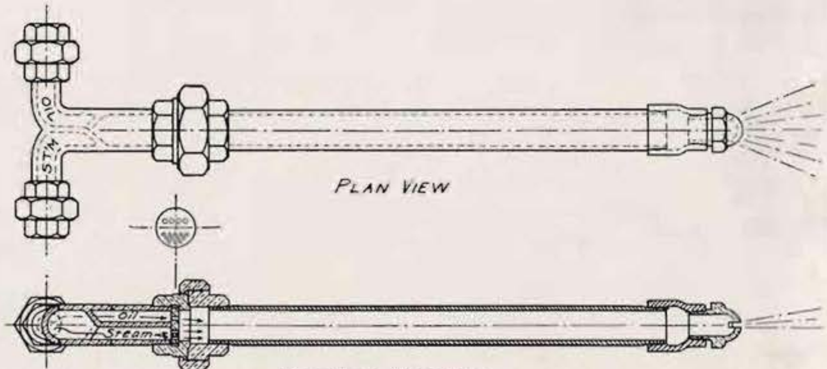
There are some details in the installation of oil-burning equipment which are not infrequently overlooked. The steam for the burners should be taken from a point where the steam will contain the least amount of moisture and the piping should be installed so as to avoid pockets where condensed steam may accumulate. It is preferable to run a steam line direct to the burners from each boiler outlet (or superheater outlet, if the boiler has a superheater) with an auxiliary connection to a header, the auxiliary connection to be used for firing up the boiler, and the boiler-outlet connection for operation. All steam piping should be lagged.

On account of the tendency of oil and oil vapor to leak through pipe joints, the threads should be cut with great care and the joints made up either with shellac or *freshly mixed* litharge and glycerine. Screwed unions should be of the ground joint type with either brass to iron or brass to brass seats. No. 1 canvas shellaced or coated with litharge and glycerine on both sides makes an excellent gasket for flanged joints.

Before installing the burners both steam and oil piping should be lightly rapped and thoroughly blown out with steam or air. This will eliminate most of the trouble from clogging of burners when the installation is put into service.

The temperature to which the oil should be heated is of great importance. No specific information can be given on this point because the viscosity of different oils varies greatly. The temperature for steam-atomizing burners will usually be between 100° and 160° F. but the operating temperature should be determined by trial with the oil supplied. If the oil is too hot, the burners will puff; if too cold, a dull smoky flame will indicate improper atomization. (Water in the steam or oil causes a sputtering action.) A good way to determine the best temperature for the oil is to first heat up the furnace walls of a boiler and then gradually alter the steam supply to the heater until clear and steady flames are produced by the burners assuming, of course, that the supply of air is ample. The temperature at which this takes place should be noted and maintained. For the guidance of the fireman a thermometer in the oil supply pipe, conveniently located in the fireroom, is indispensable. Certain of the Mexican oils require heating to between 80° and 90° F. in the suction tank to produce a free flow to the pump.

The proper oil pressure at the pump discharge is principally dependent on the construction of the burner used, but the maximum horsepower to be developed per burner, the restrictions in the heater and piping and the viscosity of the oil are modifying factors.



THE OWENS STEAM-ATOMIZING OIL BURNER—PATENTED

Steam-atomizing burners are classed as "inside-mixers" or "outside-mixers" depending on whether the steam and oil are brought together inside of the burner or just outside of the tip. But this classification has a doubtful value in practice. In the selection of a burner it is important to know if the burner is of the "long-flame" or "short-flame" type. The discharge of a mixture of oil and steam has more or less momentum which depends on the burner design, other factors remaining the same. If the burner makes a long flame and the furnace is relatively short the flame will strike the opposite furnace wall and be reflected to the tubes, producing a blow-pipe action on both wall and tubes which is highly destructive. Such a "misfit" of burner to furnace is a common cause of the furnace and tube troubles experienced in oil-fired plants. The discharge openings in the burner tip should be cut with great care, both as to size and finish. As a rule, after two to three months' service the openings become worn too large for good atomization. The tip should then be renewed.

The illustration above shows a steam-atomizing oil burner of the short-flame type which has proved highly efficient and reliable. The oil enters through one of the connections and flows along the upper half of the burner body. The steam enters through the other connection and flows along the lower half of the body. At the end of the body is a flat disc or baffle which contains a few holes for the discharge of oil and a larger number for the discharge of steam. The streams of oil flow into the jets of steam issuing through the lower part of the baffle, the mixture is carried along a one-inch pipe (which may be of any length) and discharged through a slot in the tip cut to give a fan-shaped flame of the desired width. The retardation in the pipe-mixer produces a soft flame, several feet shorter than flames from burners in which the steam and oil come together inside of the tip or just beyond it; also, the temperature of the oil is raised considerably by the steam before passage through the tip. This additional heating facilitates the combustion of very heavy oils. The burner is rugged and simple in construction and the only part which requires renewal is the inexpensive tip.

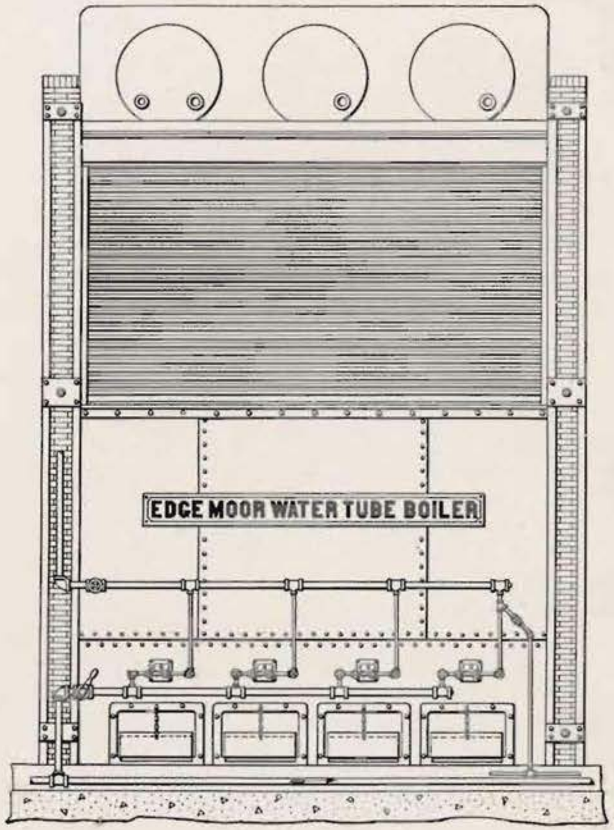
In the early development of oil firing undue attention was given to the burner details and too little attention was given to the furnace design. The function of the burner is to atomize the oil properly and produce a flame of the desired shape, width and length. But a good burner will give unsatisfactory results if the furnace is not properly proportioned. The furnace should be of such length that the discharge from the burners will not strike the opposite wall; the height should be such that the gases are well mixed and the temperature lowered by radiation before the gases strike the boiler tubes. When oil burns in the presence of but little excess air the temperature is close to 3000° F. and if combustion takes place close to the boiler tubes blistering and burning will result. Since combustion cannot be uniform in the furnace, the furnace volume should be ample for good diffusion of the gases.

On account of the high temperatures in an oil furnace the lining should be of first quality firebrick throughout. It has been found that firebrick arches and deflecting walls are unnecessary in a well designed furnace as an aid to combustion. Also, they are objectionable because they will melt or burn down rapidly at the high temperatures developed.

For steam-atomizing burners the air is admitted through ports in the furnace floor directly under the burner discharge. The size and location of these ports is of very great importance. The arrangement of ports should follow a plan which has been carefully checked throughout the working range of the burners by gas analysis. The air ports not only affect the quality of combustion but also the shape of the burner flame.

Firemen sometimes change the arrangement of the air ports because they have trouble in lighting the burners or in keeping them going due to the inrush of cold air. When this occurs the air supply should be decreased by manipulating the air admission doors.

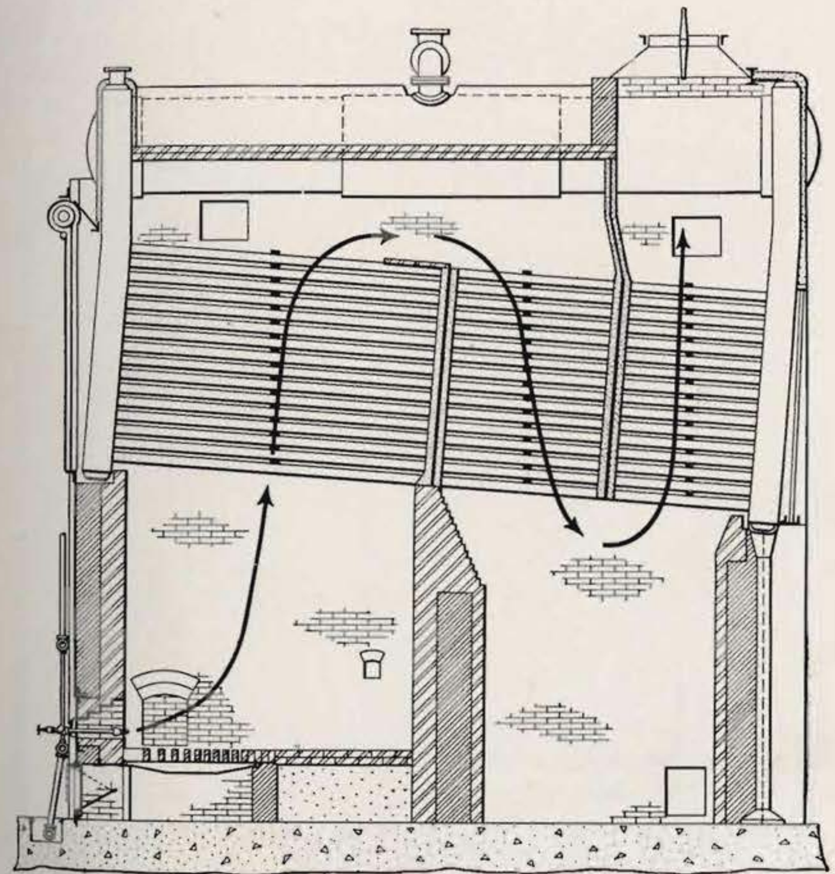
The two following illustrations show an oil-fired front and a side view of an Edge Moor boiler equipped with an oil furnace. The burners enter the furnace through small framed openings in the front. These openings are of ample size for lighting the burners and observing the flames, and are fitted with doors especially designed for the convenience of the operator.



OIL FIRED FRONT AND BURNER PIPING

The steam manifold is above the burners and the oil manifold below. A globe valve controls the steam supply to each burner and a standard needle valve controls the oil supply. In addition, both steam and oil manifolds include master valves for shutting off and regulating the supply of steam and oil to all burners of a boiler. Both valves are of the standard globe pattern but the master oil valve is fitted with a lever for making adjust-

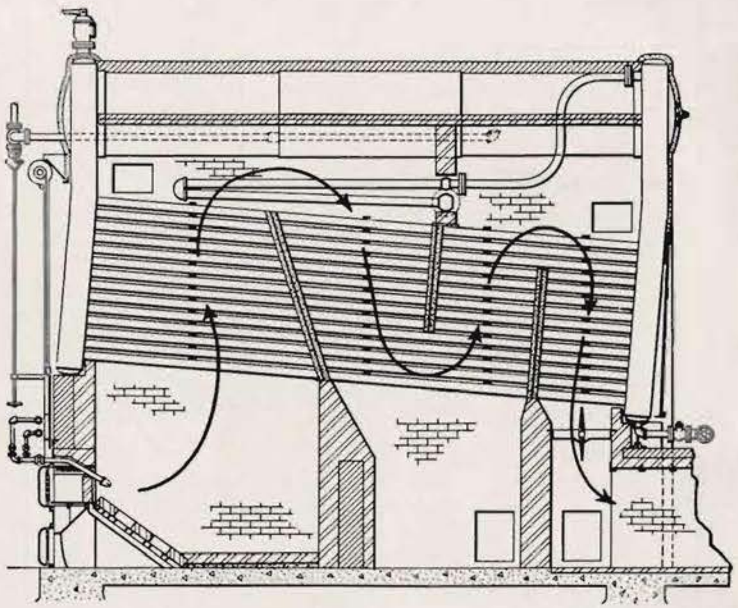
ments conveniently to produce an increase or decrease of the fire as desired. The steam piping is fitted with a drain and is especially designed to prevent accumulations of condensed steam.



SECTIONAL ELEVATION OF AN EDGE MOOR BOILER
FITTED WITH AN OIL FURNACE

The furnace includes an access door in one of the sidewalls. This is protected with loose firebrick laid up in the opening. A small inspection door is placed forward of the bridgewall for observing the ends of the flames. The front part of the furnace floor is supported by cast iron bars; the rear part by an earth fill. The floor is of first quality firebrick and contains air admission openings laid out according to a plan determined experimentally for obtaining the most satisfactory mixtures for combustion.

The air supply is regulated by a large door under each burner hinged at the bottom. An advantage of this type of door is that the air is deflected to the front air spaces when the door is only partly open. This produces more efficient combustion during light firing. The doors may be separately adjustable or connected to a common shaft for central control.



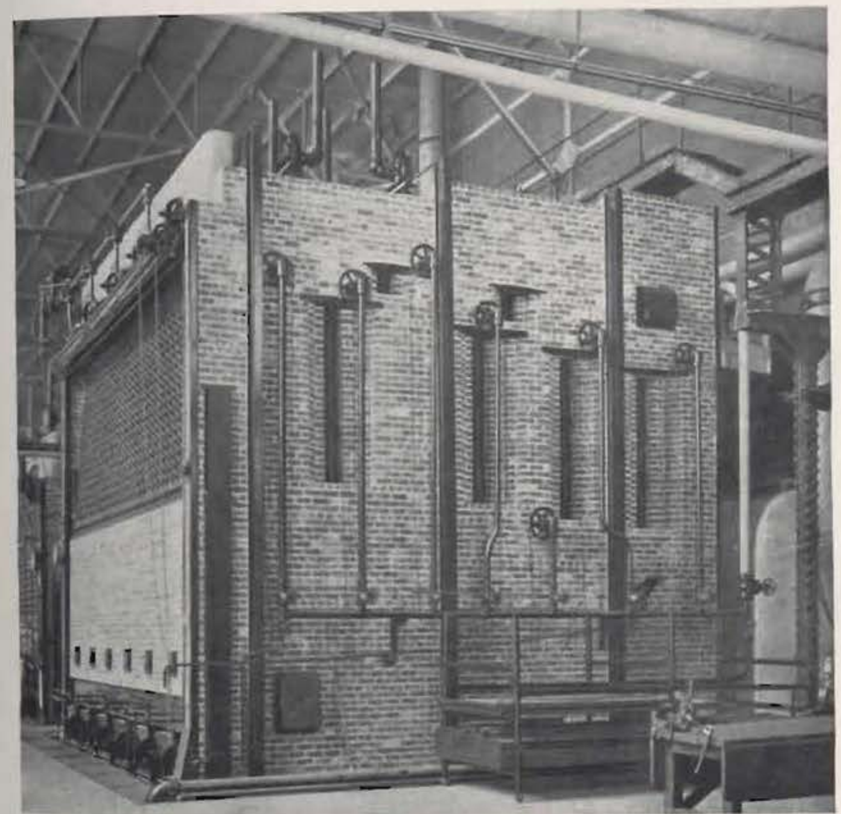
Edge Moor Boiler with Oil Furnace for a Low Setting

The illustration above shows a modification of the furnace previously described which is especially suitable for low settings, though it lacks some of the advantages of a high setting and a horizontal floor.

For economical use of steam for atomization the master valve of the steam manifold should be opened just enough to pass the required amount of steam. Throttling through this valve is desirable as lower steam pressures at the burners produce softer flames. The steam burner valves should be opened just enough to produce good atomization. The fireman can waste considerable steam through the burners by neglecting these adjustments.

To start a burner, open the damper if it is not already open, then open the burner steam valve about a quarter turn, insert a lighted torch and open the oil valve just enough to produce a short flame. When starting a

fire in a cold furnace the torch should be left in the furnace until the flame burns steadily. If a burner stops firing even when the furnace walls are very hot, the oil valve should be shut immediately and not re-opened until a lighted torch is inserted, unless other burners are in service. Bad flarebacks or even explosions of sufficient force to blow out part of the sidewalls not infrequently happen when the fireman disregards this precaution.



A 1000 H.P. Edge Moor boiler equipped with oil burners.
U.S. Navy Yard, Mare Island, California

In a properly equipped plant, an attentive operator who fires "by eye" can maintain a very high boiler-room efficiency without the guidance of instruments other than a pressure gauge and a thermometer on the oil supply to the burners, though a differential draft gauge connected to each furnace is very helpful. With oil the greatest waste results from excess air admitted into the furnace as a consequence of neglect to adjust the damper and air doors to correspond with the quantity of oil burned. This is clearly shown by the table on the opposite page.

As an example, for 13 per cent. CO_2 the excess air is 19 per cent. and the chimney loss, for a chimney temperature of 450° above external air temperature, is 9.50 per cent. For 8 per cent. CO_2 the excess air is 89 per cent. and the chimney loss is 15.21 per cent. The heating of the unnecessary air therefore represents a waste of 15.21 minus 9.50 or 5.71 per cent. of fuel.

The operator should aim to maintain the CO_2 between 13 and 14 per cent. at the boiler damper. Adjustments to obtain a higher CO_2 are so delicate that the formation of considerable monoxide will probably result, which increases the chimney loss. It should be noted that a given percentage of CO_2 indicates a very different percentage of excess air if the fuel is coal, due to the lesser hydrogen content of coal. This is shown in the following table.

Table Showing Relation Between CO_2 and Excess Air for Average Coal and Oil

Per cent. CO_2 in dry gases by volume	18.7	18.0	17.0	16.0	15.6	15.0	14.0	13.0
Per cent. excess air for average coal	0	4	10	17	..	24	33	43
Per cent. excess air for average oil	..	..	..	..	0	4	11	19

The calculations for oil given above are based on a composition of 85 per cent. carbon, 12 per cent. available hydrogen (H– O/8) and 1 per cent. sulphur; calorific value 18,500 B. T. U. per pound. The ratio of carbon to available hydrogen in average coal is about 80 per cent. carbon to 4 per cent. available hydrogen. One pound of oil as above requires 14.0 pounds of moisture-free air for complete combustion without excess oxygen.

When the oil pressure, oil temperature and air spacing in the furnace floor are properly maintained it is possible to burn oil completely with but little excess air, firing "by eye." The color of the most efficient oil flame, as it approaches the boiler tubes, is an almost clear

orange. With such a flame a slight haze will be visible at the top of the chimney. A dazzling white flame indicates considerable excess air while a reddish smoky flame indicates too little air. Light starring in the furnace indicates the combustion of finely divided particles of carbon which

Excess Air and Chimney Losses for Different Percentages of CO_2

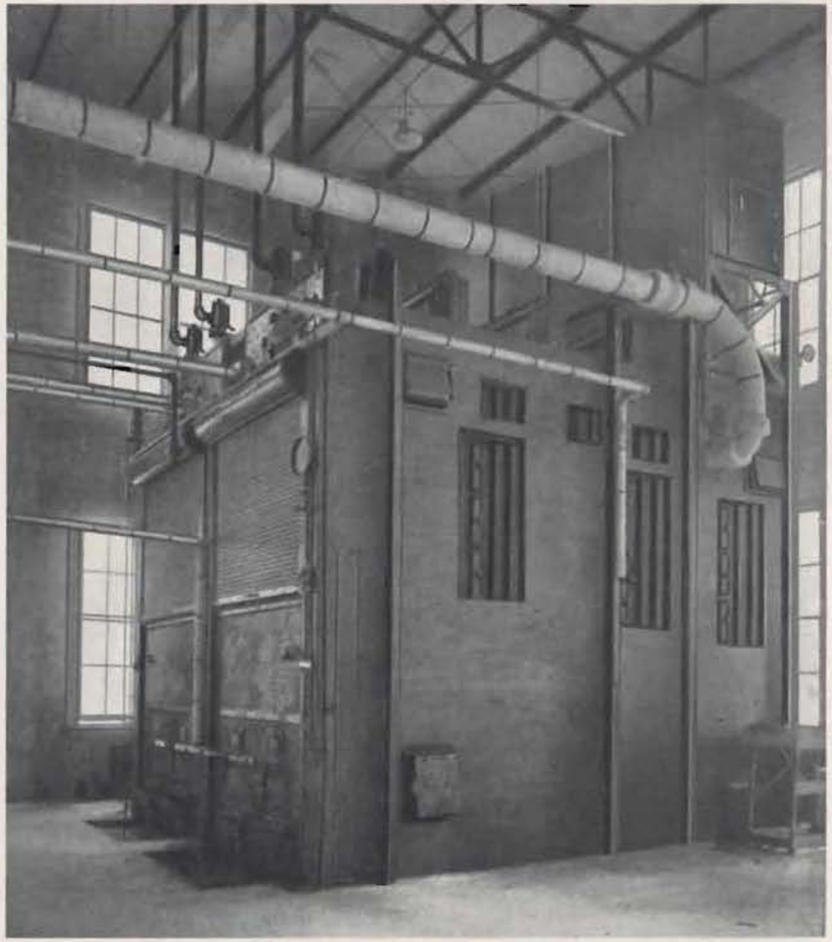
Per cent. CO_2 in dry gases by volume	15.6	15.0	14.0	13.0	12.0	11.0
Excess air in per cent. of theoretical minimum .	0	4	11	19	28	39
Weight of dry gas per lb. oil in lbs.	13.9	14.4	15.4	16.5	17.8	19.4
[1] Chimney loss per 100° F. in per cent. of the calorific value of the oil . . .	1.78	1.85	1.97	2.11	2.28	2.48
[1] Chimney loss per 450° F. in per cent.	8.01	8.32	8.86	9.50	10.26	11.16

Excess Air and Chimney Losses—Continued

Per cent. CO_2 in dry gases by volume	10.0	9.0	8.0	7.0	6.0	5.0
Excess air in per cent. of theoretical minimum .	53	69	89	115	150	199
Weight of dry gas per lb. oil in lbs.	21.3	23.6	26.4	30.1	34.9	41.8
[1] Chimney loss per 100° F. in per cent. of the calorific value of the oil . . .	2.73	3.02	3.38	3.86	4.47	5.35
[1] Chimney loss per 450° F. in per cent.	12.28	13.59	15.21	17.37	20.11	24.08

[1] Based on dry-gas weights and therefore do not include heat carried away by steam formed from combustion of hydrogen, by steam for atomization and by moisture in air.

does no harm if the particles are completely burned before they strike the brickwork or tubes. (Soot is deposited if they impinge on any solid substance.) But heavy smoky sparks are large globules of oil, indicating imperfect atomization If additional steam does not correct this it is likely that



Battery of boilers in the plant of the Miami Beach Electric Co., Miami, Fla.

the slot in the burner tip is poorly cut or badly worn. As stated above, water injected with the oil causes the flame to sputter. This may come from accumulations in the steam piping or from the settling chamber in the oil heater. The latter should be drained at regular intervals.

For oil fuel, chimneys much higher than necessary are very objectionable. It is not desirable to throttle the boiler dampers too much as flarebacks may result. Hence with an excessively high chimney air regulation is much more difficult and the induction of excess air is greatly increased, resulting in a corresponding waste of fuel.

The furnace draft required for the burner and furnaces illustrated above is considerably less than for natural-draft coal-burning installations but, in general, this will not be true for burners of the mechanical-atomizing type. Also, provision for excess air under abnormal conditions need be very little for oil. Chimneys suitable for natural-draft coal-burning installations will, as a rule, be much too high for efficient combustion of oil (employing steam-atomizing burners) but chimneys for forced-draft installations will, generally speaking, be satisfactory since, in the latter, the allowance for furnace draft and excess air is much reduced and also because the gas volume per 10,000 B. T. U. in the fuel is about the same for oil and coal, for equal percentages of excess air.

Mill No. 6 of the Alpha Portland Cement Company at Alsen, N. Y., where the first Edge Moor waste heat plant was installed

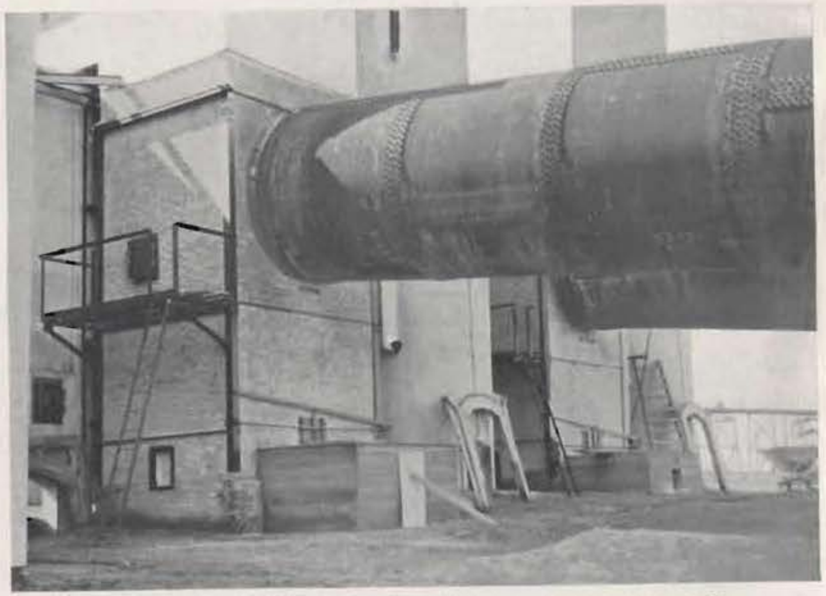
Factors in the Recovery of Waste Heat

IN the manufacture of certain products, especially steel and cement, millions of dollars' worth of fuels are annually converted into gases which leave the manufacturing equipment at a temperature between 1000 and 1500 deg. F. and are discharged into the atmosphere. The possibility of recovering a large part of the heat thus wasted has long been realized but the development necessary for a high economic return has been reached only in recent years.

As an example of what may be expected, the approximate recovery per hundred pounds of 13,500 B.T.U. coal, burned in an efficiently operated cement kiln employing the dry process, is here calculated. To simplify the problem it will be assumed that no carbon monoxide is present. The production of gas per hundred pounds of coal is about 1400 pounds. The gas leaves the kiln at about 1500 deg. F. An equipment which would reduce the temperature from 1500 to 350 deg. F., with an allowance of 40 per cent. air leakage and mean specific heat of gas at 0.26, would recover about 379,000 B.T.U. for each hundred pounds of coal burned.

If this recovery is in the form of steam, generated from feed water at 200 deg. F. to a pressure of 200 lb. per sq. in. gauge and superheat of 100 deg. F., the intake of heat per pound of steam is 1091 B.T.U. Therefore, the heat recovery per hundred pounds of coal would yield 350 pounds of steam. If this is delivered to a turbine plant which consumes 17½ pounds of steam per kilowatt-hour at the switchboard, the power yield would be 20 kilowatt-hours; that is, for each one hundred pounds of coal burned in the kiln 350 pounds of steam or 20 kilowatt-hours would be obtained without any expenditure for fuel whatever. In some industries the recovery is itself sufficient to generate all the steam and power required.

The recovery of heat from kiln gas has sometimes been greatly underestimated because the temperature was measured either in the kiln housings or in the stacks. In the average mill, the leakage of cold air into the housings, around the kilns and through openings in the housings, may amount to from 200 to 300 per cent. of the weight of kiln gas. The mixing of this cold air with the kiln gas produces, of course, a much lower average temperature. With well constructed kiln seals and housings this leakage may be almost entirely prevented; hence for estimates for a waste-heat plant the temperature should be taken at a point where the gas is not affected by air leakage. In practice it has been found desirable to measure the temperature and take samples of the gas inside of the kilns, two feet from the end at about the center.



Kilns, kiln seals, and housings. Mill of the International Portland Cement Company at Sierras Bayas, Argentine Republic

Generally speaking, with Edge Moor equipment the reduction in cost of product will pay for a waste-heat installation in from two to three years. In cement mills usually from 30 to 50 boiler horsepower is available from the kiln gas per 100-barrel capacity per day, and the credit will amount to from eight to twelve cents per barrel of cement made. The recovery from open-hearth furnaces is from four to six boiler horsepower per ton of ingots per heat; that is, a 50-ton furnace will average from 200 to 300 boiler horsepower. The credit given the open-hearth plant will vary from thirty to sixty cents per ton of ingots.

In soaking pits and regenerative heating furnaces the recovery is usually about one boiler horsepower per ten pounds of coal burned in the producers per hour; from a heating furnace of the non-regenerative type, about twice as much heat is recovered. In these latter instances, the cost of the installation is usually paid for in the first year's operation.

The early installations of waste-heat boilers were very crude because certain laws of heat transmission were not understood and insufficient

attention was given to important details. The design of an efficient direct-fired boiler plant of the ordinary type and the design of an efficient waste-heat boiler plant are and should be very different. In the former, the gas approaches the boiler at a temperature which may be as high as 3000 deg. F. while in the latter the gas enters at a temperature between 1500 and 1000 deg. F. As a result, the average heat transmission per square foot of boiler heating surface is much greater in the former than in the latter. If boilers of the same design, similarly baffled, are used for both plants, as has been done, the boilers for the waste-heat plant will have to be very much larger for the same horsepower to be developed.

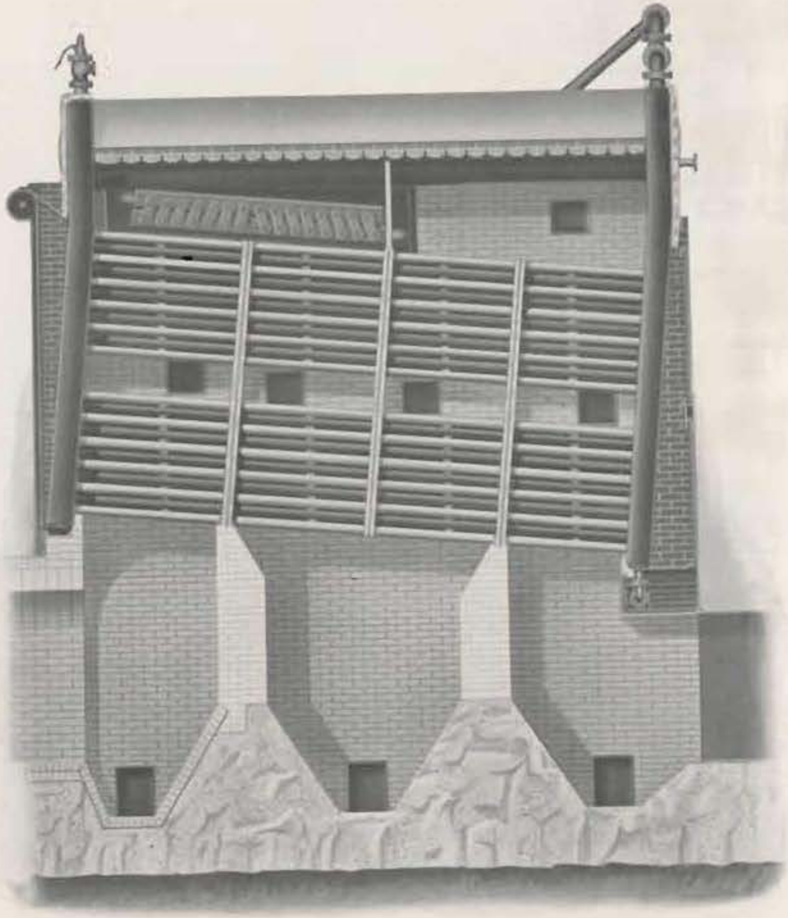
In earlier installations it was common practice to allow about 20 square feet of heating surface per boiler horsepower. As a result boilers were relatively very large, had relatively large settings which increased the associated losses, and consequently produced a small net gain.

Since then the laws of heat transmission are better understood. It has been found that the heat transmitted per square foot of boiler surface can be greatly increased by increasing the gas velocity across the surface. Roughly speaking, if the velocity can be increased three times the heating surface can be reduced one-half. Also, by making the gas passage longer the amount of heat abstracted is likewise increased.

Increasing the gas velocity as above outlined increases the frictional resistance opposing the passage of the gas through the boiler. This makes it necessary to include an induced draft fan as part of the equipment, the increased draft required being too great to be produced by a chimney.

For a given volume of gas transmitted the frictional resistance varies considerably in boilers of different construction and arrangement of baffling. The Edge Moor boiler, with its wide tube spacing and parallel baffles, offers minimum resistance to the flow of gas. This has a bearing on the over-all efficiency, since the greater the frictional resistance the greater will be the power consumed by the fan.

A factor of primary importance which affects the over-all efficiency is the infiltration of cold air into the flues and settings. This is detrimental in four ways. First, air coming into contact with very hot, incompletely burned gas tends to produce explosions under certain conditions. Second, the mixing of the air with the hot gas lowers the temperature of the gas and this lowers the rate of heat transfer into the boiler. Third, the frictional resistance in the gas passages is increased causing an increase in the power consumption of the fan. Fourth, heat is carried into the chimney which could otherwise be absorbed by the boiler.



Edge Moor waste heat boiler equipped with superheater. The passes are proportioned for a high gas velocity

The detrimental effects of air leakage are much greater in waste-heat plants than in direct-fired plants because much more air is drawn through cracks or openings of the same size, due to the higher internal draft. This leakage is not so much through the brickwork as it is through the joints and around the frames of access doors, and generally along the contact faces between the brickwork and metal parts. Consequently, casing the boilers in sheet steel is of little benefit. It is necessary to reduce the number of openings to a minimum and to have few surfaces of contact between the brickwork or filling and the metal parts. In this connection, the box-header construction of the Edge Moor boiler is a manifest advantage.

A considerable amount of carbon monoxide, without excess air, is often present in the hot gases. When the temperature is above 1200 deg. F., the approximate ignition temperature of carbon monoxide, and air is introduced, further combustion takes place and releases additional heat for absorption by the boiler. But with open-hearth furnaces, or others of the reversing, regenerative type, the suction of considerable air at certain points promotes gas explosions which, while not of a serious character, strain the setting and increase the general leakage.

In a plant poorly designed or maintained the aggregate loss resulting from air leakage may almost if not entirely negative any economic benefit from the installation.

Another important factor is the maintained cleanliness of the heating surface. In a waste-heat boiler the loss from fouled surface is two to three times as much as in a direct-fired boiler. In the former, if due to fouled heating surface the average flue-gas temperature is raised 75 to 100 deg. F. the loss in evaporation will amount to from 10 to 15 per cent.

The quantity of deposits on the exterior heating surface is reduced in boilers designed for a high gas velocity. Where the water forms considerable scale, the deposits on the interior surfaces may be reduced or eliminated by chemical treatment of the water, but this is seldom necessary in a waste-heat plant. Deposits which do accumulate should be removed at regular intervals if the maximum return on the investment is desired. This brings into prominence the provisions in the design for both external and internal cleaning.

Until recent years cement mills have offered a difficult problem on account of the high dust content of the kiln gas. As an example of how much dust is carried along with the gas, in one plant it was found that this amounted to 44 tons daily for a production of 2900 barrels of cement, or about 30 pounds of dust per barrel of clinker burned. The dust problem has been successfully solved in the Edge Moor System not only by special design of the boiler, superheater, economizer and fan, but also of the flues, which are of equal importance—to facilitate and permit removal of dust without interfering with the continuous operation of the plant.

From what has been stated above it will be inferred that the design of a successful waste-heat plant involves many complex problems. In this connection, the following formulæ may be of interest:

Specific Heat of Gases.—The general formula for the instantaneous specific heat of a gas at temperature T in degrees F. is

$$C_p = a + bT + cT^2$$

where a, b and c are empirical coefficients.[1]

The mean specific heat between temperatures T_1 and T_2 is then,

$$C = a + b\,\frac{T_1 + T_2}{2} + c\,\frac{(T_1 + T_2)^2 - T_1T_2}{3}$$

For carbon dioxide (CO_2),

$$C_p = 0.1983 + 835 \times 10^{-7}T - 16.7 \times 10^{-9}T^2$$

For oxygen (O_2),

$$C_p = 0.2154 + 0.000019\,T$$

For nitrogen and carbon monoxide (N_2 and CO),

$$C_p = 0.2343 + 0.000021\,T$$

For water vapor at atmospheric pressure,

$$C_p = 0.465$$

Miscellaneous Formulæ:—

Let—

S = heating surface of boiler in square feet.
T_1 = temperature of gases entering boiler in degrees F.
T_2 = temperature of gases leaving boiler in degrees F.
T_a = temperature of the atmosphere in degrees F.
t = temperature of saturated steam in degrees F.

[1] The values given below are according to Holborn and Henning, Annalen der Physic, 1907, and are now accepted in scientific work as authoritative.

W = weight of gases entering boiler in pounds per hour.
aW = weight of air leakage through setting in pounds per hour.
a = per cent. air leakage through boiler setting.
C_1 = mean specific heat of gases between T_1 and T_2.
C_2 = mean specific heat of gases between T_2 and T_a.
C_o = mean specific heat of gases between T_1 and T_a.
D = distance between boiler sidewalls in feet.
e = base of Naperian logarithms = 2.7183.
E = heat absorbed by boiler in B. T. U. per hour.
L = length of tubes in feet.
N = number of gas passes in boiler.
R = heat transfer rate in B. T. U. per hour per sq. ft. of heating surface per degree F. difference in temperature.

The mean heat transfer rates for the mean temperature differences noted between gas and tube surface for 4-inch staggered tubes in cross-pass boilers are,

For mean temp. diff. = 1000° F., $R = 2.0 + 0.0038\,\frac{W\,N}{L\,D}$
" " " " = 500° F., $R = 2.0 + 0.0031\,\frac{W\,N}{L\,D}$
" " " " = 200° F., $R = 2.0 + 0.0027\,\frac{W\,N}{L\,D}$

The draft loss through the boiler in inches of water is,

$$\text{Draft loss} = 0.65\left(\frac{W\,N}{1000\,L\,D}\right)^2$$

Case I.—When leakage through setting is neglected.—

Heat absorbed by boiler.

$$E = (T_1 - T_2)\,C_1\,W$$

Equivalent horsepower

$$B.\,H.\,P. = \frac{E}{33480} = \frac{(T_1 - T_2)\,C_1\,W}{33480}$$

Weight of gases passing through boiler

$$W = \frac{E}{(T_1 - T_2)\,C_1}$$

Temperature of gases leaving boiler

$$T_2 = t + (T_1 - t)\, e^{-\frac{RS}{WC_2}}$$

Heating surface of boiler

$$S = \frac{W\,C_1}{R} \log_e \left(\frac{T_1 - t}{T_2 - t}\right)$$

Heat transfer rate of boiler

$$R = \frac{W\,C_1}{S} \log_e \left(\frac{T_1 - t}{T_2 - t}\right)$$

For tables of Naperian logarithms (base e) see Kent's *Handbook*, page 156 (1906 ed.), Marks and Davis' *Steam Tables*, page 76 (1912 ed.), or *Smithsonian Mathematical Tables* (1909), Table V, p. 263. For the values of the exponential functions see *Smithsonian Tables*, Table IV, p. 225.

Case II.—When leakage through setting is considered.—

Heat absorbed by boiler

$$E = W\,[C_o(T_1 - T_a) - (1 + a)\,C_2\,(T_2 - T_a)]$$

Equivalent horsepower

$$B.H.P. = \frac{E}{33480} = \frac{W\,[C_o\,(T_1 - T_a) - (1 + a)\,C_2\,(T_2 - T_a)]}{33480}$$

Weight of gases entering boiler

$$W = \frac{E}{C_o\,(T_1 - T_a) - (1 + a)\,C_2\,(T_2 - T_a)}$$

Weight of gases leaving boiler

$$W\,(1 + a) = W + Wa$$

Per cent. air leakage

$$a = \frac{WC_o\,(T_1 - T_a) - E}{WC_2\,(T_2 - T_a)} - 1$$

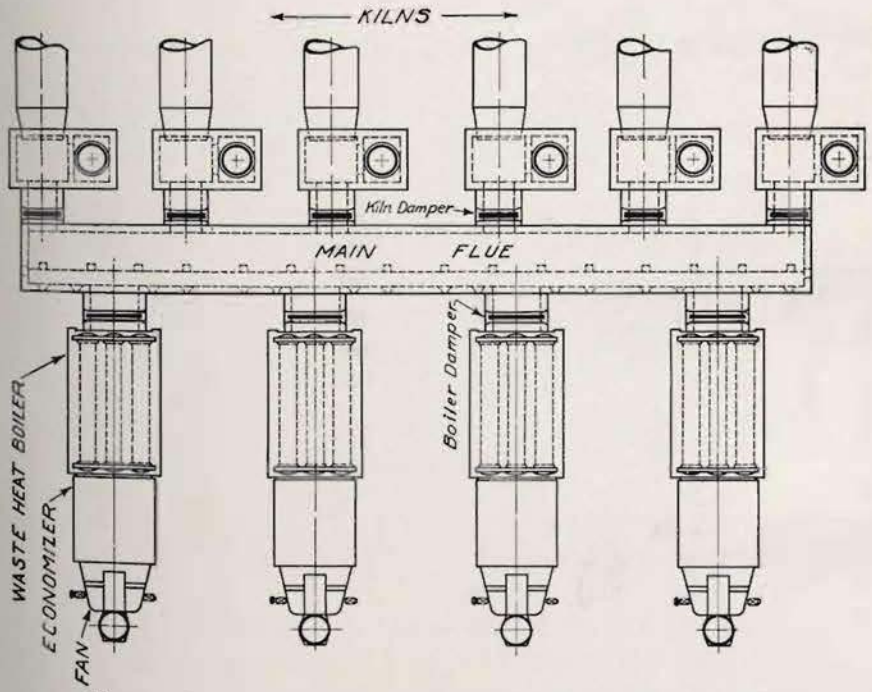
Temperature of gases leaving boiler

$$T_2 = \frac{SRt + WaC_2T_a}{SR + WaC_2} + \left(T_1 - \frac{SRt + WaC_2T_a}{SR + WaC_2}\right)(1 + a)^{-\frac{SR + WaC_2}{WaC_2}}$$

Waste Heat Equipment for Metal and Cement Mills

THE primary factors which enter into the construction and maintenance of a successful waste-heat installation, whether for smelters, steel mills or cement mills, have been discussed in the preceding pages. Proportions, flue construction, details and arrangement will vary, of course, according to local conditions but, in general, the principal components will be similar.

In earlier waste-heat practice it was considered best to have a separate boiler for each furnace or kiln. Later analysis has shown that this is disadvantageous in many ways. By having fewer and larger boilers the investment is decreased, the floor space is decreased, the number of openings permitting air leakage is decreased and other desirable results are obtained.



TYPICAL ARRANGEMENT OF AN EDGE MOOR WASTE HEAT PLANT FOR A CEMENT MILL

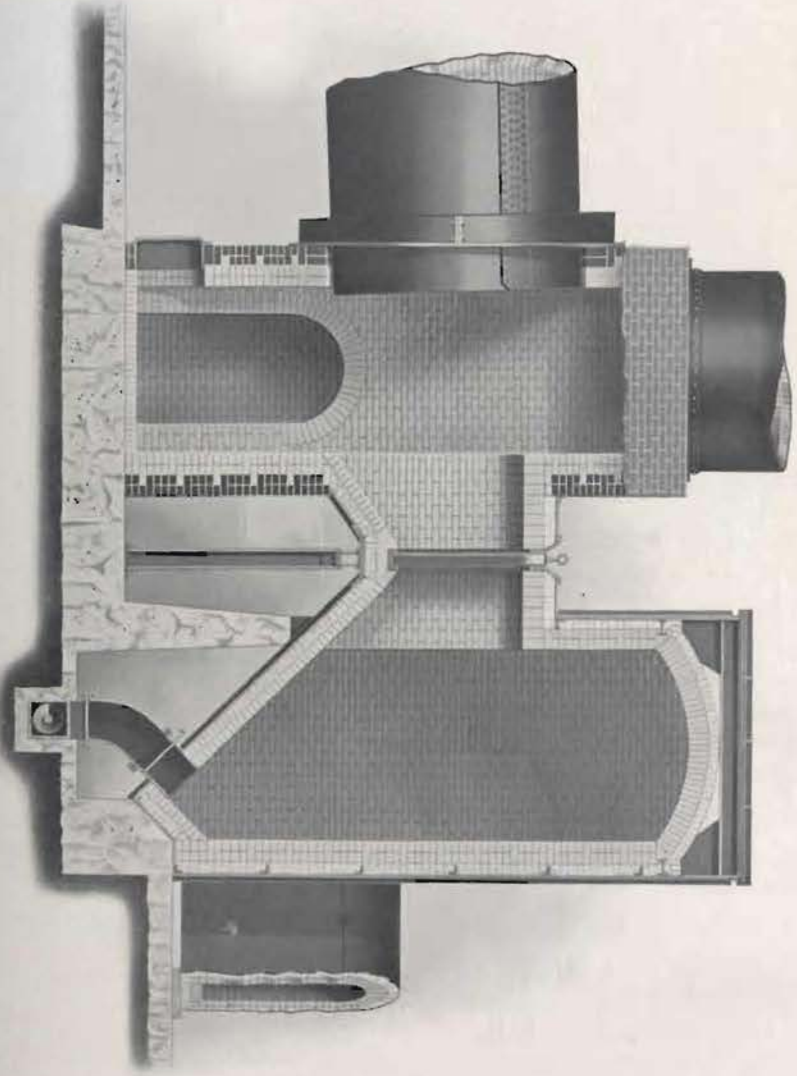
The use of a single collecting flue, which receives the gas from all furnaces or kilns, and distributes it to the waste-heat units, is a distinctive feature of the Edge Moor System. The drawing on the preceding page shows a typical layout for a cement mill. The location of the main flue and waste-heat units is varied, of course, to suit the available space. The arrangement is such that any combination of kilns may be used with any or all of the waste-heat units by means of the dampers.

Gas from dry-process kilns usually contains from 1 to 3 per cent. of carbon monoxide without any free oxygen. The temperature is usually above the ignition temperature of the monoxide, hence the air drawn in through the kiln seals produces further combustion and changes in temperature. The main collecting flue therefore acts as a chamber where the gas from the different kilns is thoroughly mixed. But its most important function is to assist in the removal of a large part of the dust from the gas, especially the heavier particles which cause incrustation, before the gas reaches the boilers.

As is shown in the illustration on the opposite page, each small flue between a kiln housing and the main flue includes a throttled area to speed up the gas, as in a Venturi tube. The velocity changes cause a large part of the dust to drop to the bottom of the main flue. The floor of the latter is trough-shaped and sloped to carry the dust to a series of spouts, through which it passes to a conveyor box and is carried away.

For long life and maintained high efficiency special construction of the main flue is of primary importance. In the Edge Moor design there is an outer casing of concrete, or of sheet steel reinforced with stiffening angles. Next to the casing is a course of special brick which has a high heat-insulating value; and next to this is the firebrick lining. Large flues having arched roofs not infrequently fail due to the settling of the arch. This weakness has been entirely overcome in the Edge Moor design. Spaced along the top of the flue is a series of strongbacks built up of steel channels with knee bracing at the corners. Connected to these, and running longitudinally, are I-beams which counteract the thrust of the arch and effectively prevent any settling.

When several kilns are connected to a single flue, velocity changes and friction along the flue will give different drafts at the kilns unless some equalizing means is provided. Also, in some plants kilns of different sizes may require different drafts. Regulating dampers may be used for these purposes but they produce objectionable effects on the kiln output which, for a maximum, requires a steady draft pull.



Kiln housing, connecting and main flue, showing provision for dust separation and removal, and equalizing of draft

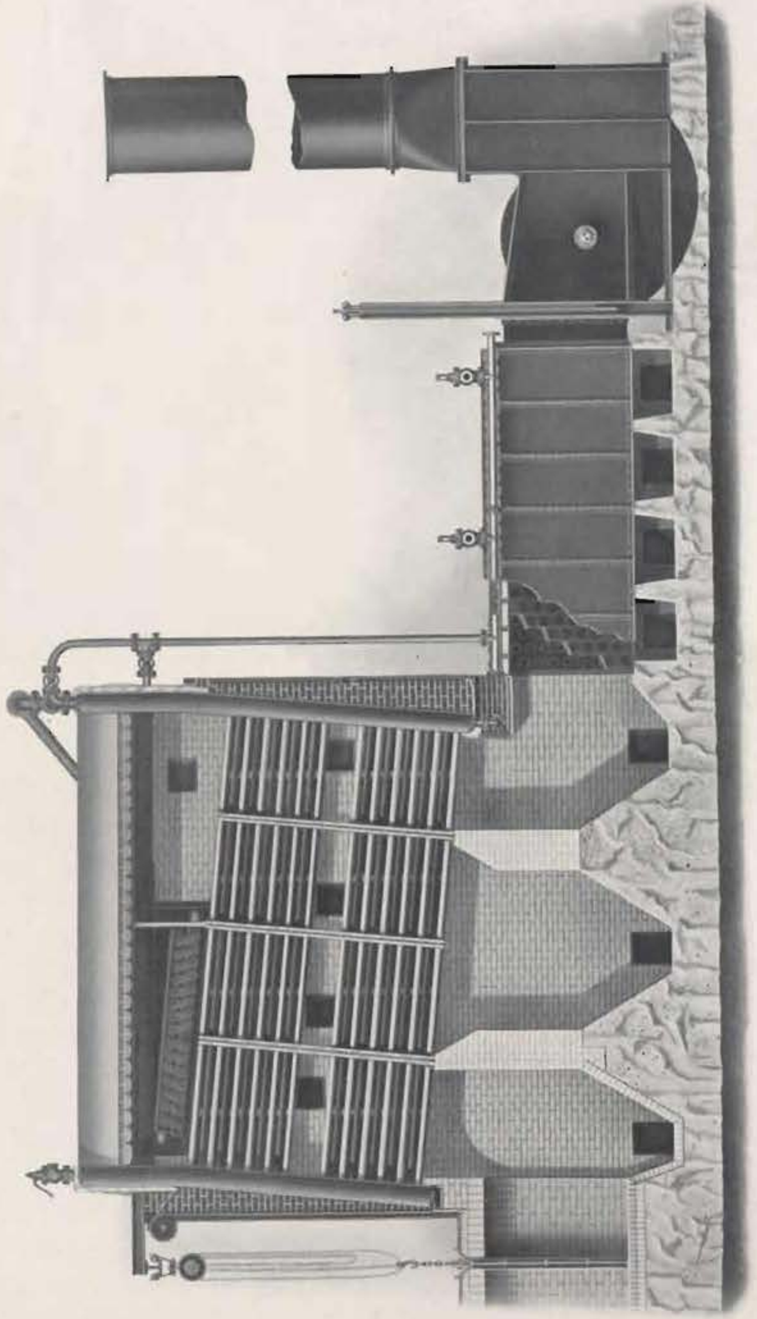
Waste heat equipment in course of erection. Marquette Cement Mfg. Co., Oglesby, Ill.

Foundation for waste heat equipment. Marquette Cement Mfg. Co., Oglesby, Ill.

Far more satisfactory results are obtained in the Edge Moor design by introducing the restricted openings in the connection between each kiln and the main flue previously referred to. These act to produce a uniformity of draft in all the kilns, counteracting the effect of flue resistance much in the same way as cores in superheater tubes cause an equal distribution of steam to all tubes. The dampers used in these flues are a distinctive part of the Edge Moor design and have proved very serviceable.

In mills where, at times, it is desired to operate the kilns without the waste-heat equipment, the kiln stacks are retained and special stack shut-offs are provided.

On account of the special problems and the interdependence of all parts for efficient performance, the Edge Moor System for waste-heat recovery embraces the complete installation, from the ends of the kilns to the fan outlets. Special designs have been developed to overcome the highly detrimental effects of air leakage and dust. Patents covering certain of these designs limit their use to the Edge Moor System.



An Edge Moor waste heat unit, including boiler, superheater, economizer, fan and shut-off damp

From the main flue, the gas is distributed to the waste-heat units through short brick-lined flues. Each unit includes—

An Edge Moor waste-heat boiler.
A superheater, if superheated steam is desired.
An economizer, if maximum recovery is desired.
A fan to produce the required draft, and a low chimney.

The structural features of the Edge Moor boiler make it especially suitable for waste-heat recovery. Excepting certain necessary modifications, the parts are of the same standard design as for the direct-fired Edge Moor boilers commonly used in power plants.

The design differs for waste heat in that headers are built much higher and relatively narrower, and tubes are longer, to obtain by suitable baffles the high gas velocity and long gas path necessary for a high heat transfer.

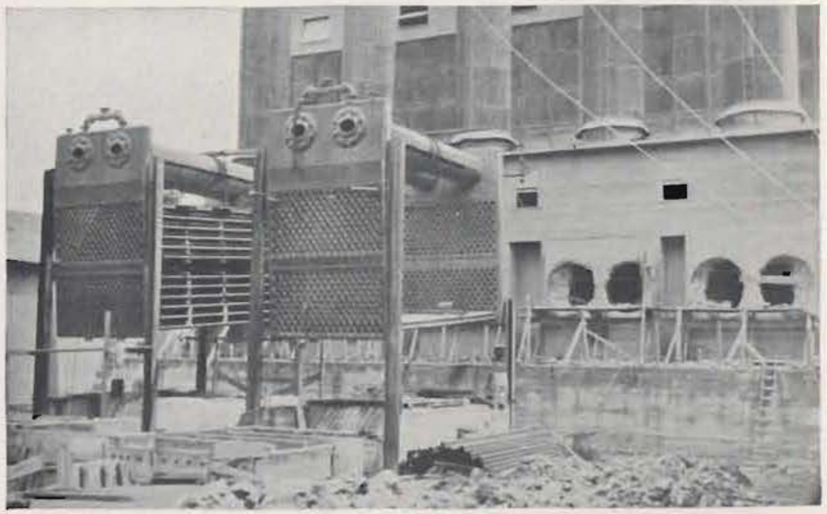
Headers are continuous throughout their entire height and width and therefore have no packed joints in their faces through which cold air may pass into the setting.

The baffles are easily installed and kept tight to prevent short-circuiting of gas. Baffles are straight, almost vertical, and the bottom of each pass is a clear opening through which deposits drop or are forced by the high gas velocity to the deep pits below. Also, there are no ledges or pockets where deposits may accumulate.

The setting is such that equipment for hand or mechanical blowing may be installed for maximum efficiency and convenience of the operator. The provisions for internal cleaning are likewise favorable. Tubes straight throughout their entire length and handhole plates individually removable make internal cleaning convenient and efficient.

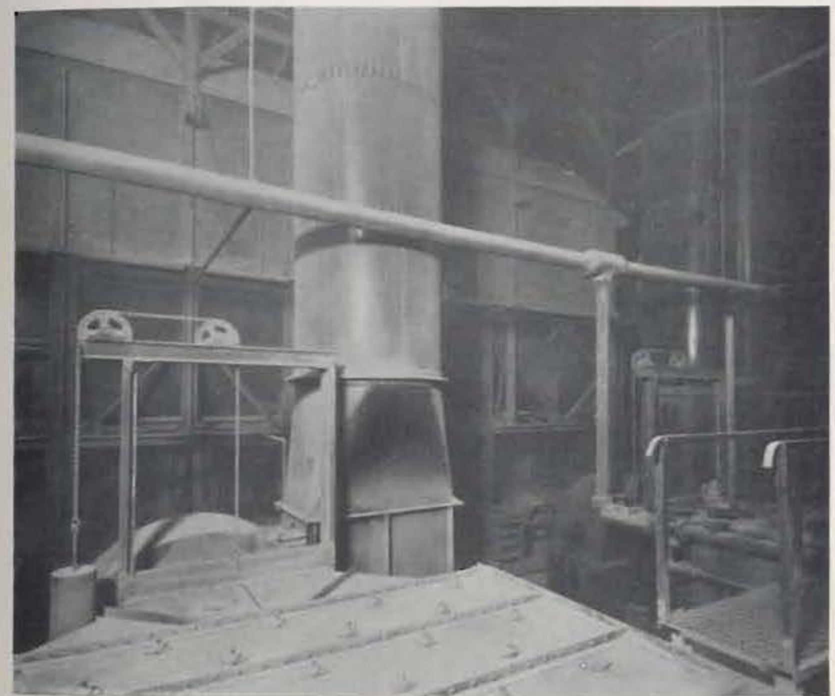
An important advantage of the general design of the Edge Moor boiler is that all parts may be readily inspected to see the actual condition instead of "guessing" at it. This is highly important for proper maintenance of plant. The diagonal rows of tubes are parallel, with clear spaces between them; hence the inspector may see all of the exterior heating surface. Also, he can conveniently see both sides of the baffles as well as the junctions between the baffles and the bridge and sidewalls. Unless baffles and junctions in a boiler are kept tight the gas will short-circuit through the boiler with consequent decrease in the steam production. The inner surface of the tubes is also easily inspected. By having a light at one end of a tube and looking through the other, all tubes being straight, the internal condition of the tubes may be positively known.

Concrete main flue in the center. Plant of the International Portland Cement Company, Sierras Bayas, Argentine Republic



Waste heat boilers in course of erection. Alpha Portland Cement Company, Alsen, N. Y.

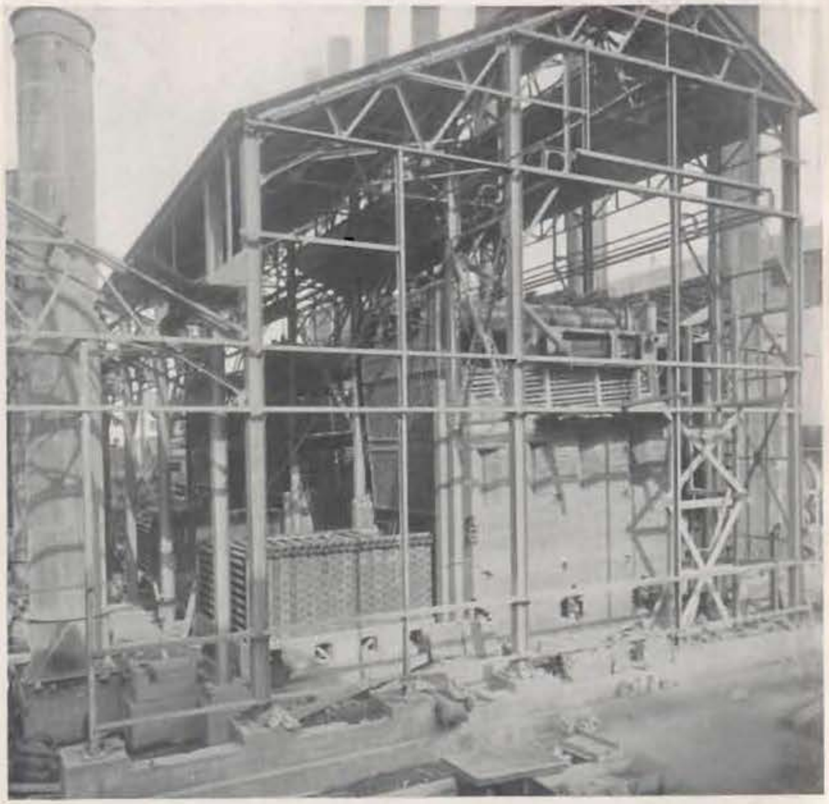
The dust in the gas has made it necessary to employ a superheater of special design. Superheater tubes are surrounded by cast iron rings of relatively large diameter which taper outward to an edge leaving deep V-shaped spaces between rings. The superheater is placed above the first and second passes of the boiler with the tubes at right angles to the boiler tubes so that the gas, coming out of the first pass at a high velocity, sweeps through the V-spaces and prevents the accumulation of any con-



Showing dampers, in shut and open positions, between economizers and fans. Knickerbocker Portland Cement Company, Hudson, N. Y.

siderable amount of dust. A large part of the ring surface is therefore kept clean even when dusting by a hand lance or mechanical blower is not more frequent than once every eight hours. In practice 80 to 100 deg. of superheat has been obtained continuously under these conditions.

The superheater headers are set in cast iron boxes built into the side-wall. The space between headers and boxes is packed with a suitable filler, and the boxes are closed on the outside by doors, making the construction air-tight.



Typical arrangement of boiler, superheater and economizer.
Marquette Cement Mfg. Co., Oglesby, Ill.

An economizer of the design used in direct-fired plants is unsuitable for the gas from cement kilns. With headers at the top and bottom the economizer would soon become choked with dust. Scrapers are unnecessary and objectionable and the openings for the chains would permit the inflow of an excessive amount of cold air.

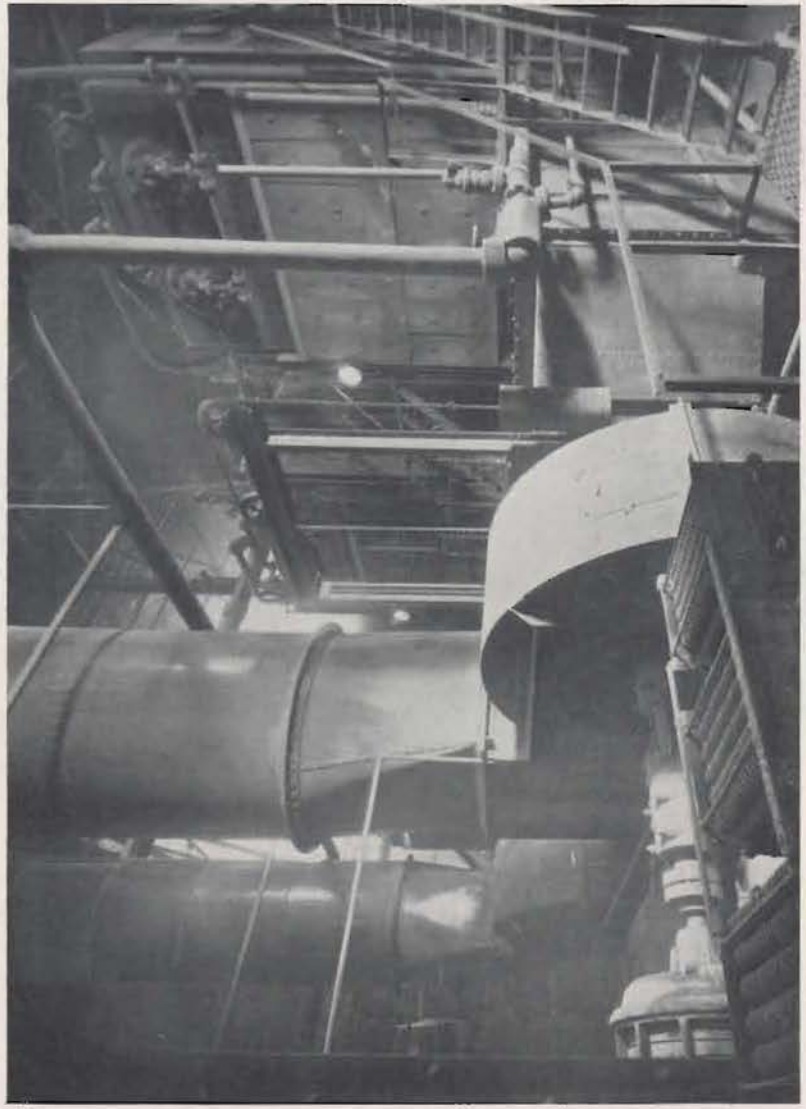
The economizer used in the Edge Moor System is therefore also special. The tubes are horizontal and staggered, terminating in vertical headers. The sides of the headers are machined to form tight sidewalls when in place. The roof of the economizer is built up of two steel plates with an insulating filler between. For dusting the tubes, cast iron bushings are set in the roof at proper intervals and closed by plugs, contact faces being machined.

Boilers and economizers, showing dusting plugs for economizer tubes.
Knickerbocker Portland Cement Company, Hudson, N. Y.

Radiation from the exposed surfaces of the headers is reduced by removable side casings. Beneath the economizer are dust pits provided with tight fitting clean-out doors.

An economizer of this design may be set very close to the boiler, resulting in a very compact installation. To provide against water hammers the connection between economizer and boiler consists of a large vertical riser which opens to both the steam and the water space of the boiler. Any air or steam in the economizer is therefore immediately freed to the top of the boiler.

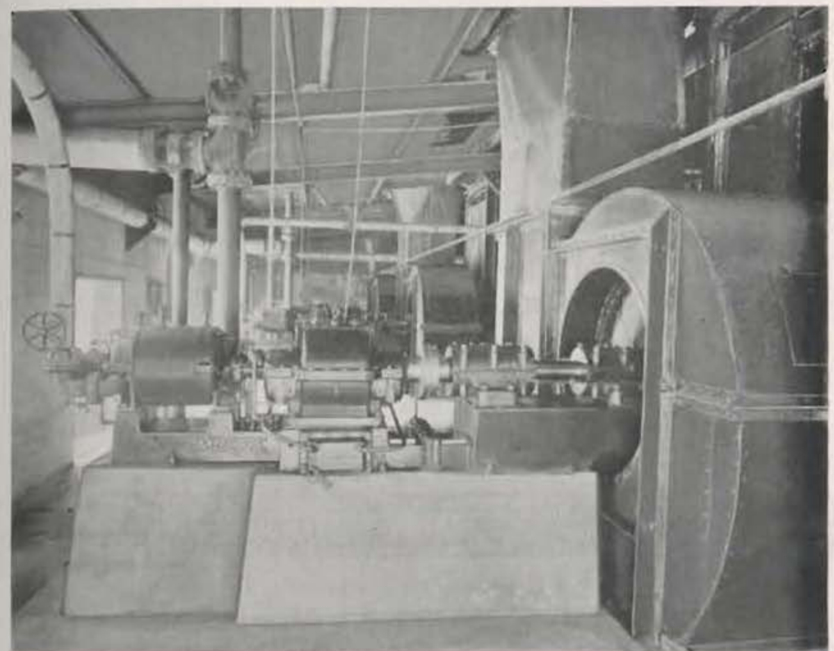
In cement plants a fan of the ordinary type will not give satisfactory results. In such a fan dust will accumulate so rapidly that it



Edge Moor waste heat units with motor-driven fans. Knickerbocker Portland Cement Company, Hudson, N. Y.

will be necessary to shut down the fan at frequent intervals for cleaning. Also, the erosion from the dust will soon wear away blades of the common designs. The fan used in the Edge Moor System has been developed to overcome these difficulties. The blades are so shaped that practically no dust accumulates. With this and other modifications fans may be kept in service continuously and at a high efficiency.

Fans are driven either by small steam turbines or by electric motors. When the temperature of the available feed water is low, it is more economical to employ turbines exhausting to a feed water heater. But when the



Turbine-driven fan with reduction gear. Alpha Portland Cement Company, Martins Creek, Pa.

feed water can be heated to a temperature of about 200 deg. F. by the exhaust from other equipment the electric motor is preferable, unless the exhaust from fan turbines can be utilized in a mixed or low-pressure power turbine.

It is sometimes supposed that waste-heat equipment will reduce the normal cement production of the mill. On the contrary, a properly designed waste-heat installation tends to increase it because, with fans, the kiln draft may be easily maintained to that required for maximum output of clinker.

Summarizing, special design of the flues causes a large part of the dust to drop out of the gas before it reaches the boilers; the design of boilers, superheater, economizers and fans avoids construction which would permit heavy accumulations of dust at objectionable points. The cross-section of passes in boilers and economizers is such as to produce a high gas velocity, which tends to keep the heating surface clean. The small amount of dust which collects on the heating surface may be removed at regular intervals with a hand lance or mechanical soot-blower, but this is done more to prevent the dust from "building up" than to keep the surface entirely clean. The amount of dust which collects on the boiler, superheater and econmizer tubes in a day does not seriously interfere with the steam production. As evidence of this, the performance of one of the first Edge Moor installations is here given. The tubes were dusted with a hand lance only once in twenty-four hours. The results are the averages of observations for eight days.

Average steam production	1666 boiler horsepower.
Average steam pressure, gauge	160 lb. per sq. in.
Average superheat	69 deg. F.
Average rise of water temperature in economizers	85 deg. F.
Average temperature of water entering economizers	190 deg. F.

In another mill the steam produced continuously by the waste-heat equipment was found to be sufficient to generate the total power required, which averaged 2200 kilowatts. Before this equipment was installed the average coal consumption per barrel of cement was 96 pounds in the kilns and 61 pounds in the power house; afterward, the average for the year following was 96 pounds in the kilns and 6 pounds in the power house, the latter for heating, fire pumps, etc., when the mill was shut down. The net saving, due to the waste heat equipment, is therefore 56 pounds of coal per barrel of cement manufactured.

In wet-process mills, the water in the slurry makes the weight of kiln gas per barrel of cement manufactured very much greater than in dry-process mills. Also, the specific heat of the gas is higher. But, counteracting these differences, the temperature of escaping gases in dry-process mills is generally several hundred degrees higher and the gas usually contains carbon monoxide which yields additional heat. As a consequence, the reclamation of waste heat per barrel of cement manufactured should be about the same for both types of mills.

Mill of the International Portland Cement Company, at Sierras Bayas, Argentine Republic, where steam is generated with Edge Moor waste heat equipment

The importance of waste-heat equipment in conserving fuel resources is indicated by the following calculation for a single cement mill of average size. The estimated net steam production from waste heat in a 4000-barrel mill is about 53,000 pounds per hour, from a feed water temperature of 200 deg. F. to a pressure of 200 lb. per sq. in., gauge, and 100 deg. of superheat. This is exclusive of the steam consumed by the fans, and is therefore available for power.

A modern stoker-fired boiler plant without economizers will consume about 115 pounds of 13,500 B.T.U. coal per 1000 pounds of steam generated, or 2.7 long tons per hour for an hourly net steam production of 53,000 pounds. Hence if the steam required for power is generated from waste heat instead of by a modern stoker-fired boiler plant the saving of fuel for the 4000-barrel mill should be as follows:

Estimated saving of coal per 24-hour day	65 long tons
Saving per 300-day year	19,500 long tons

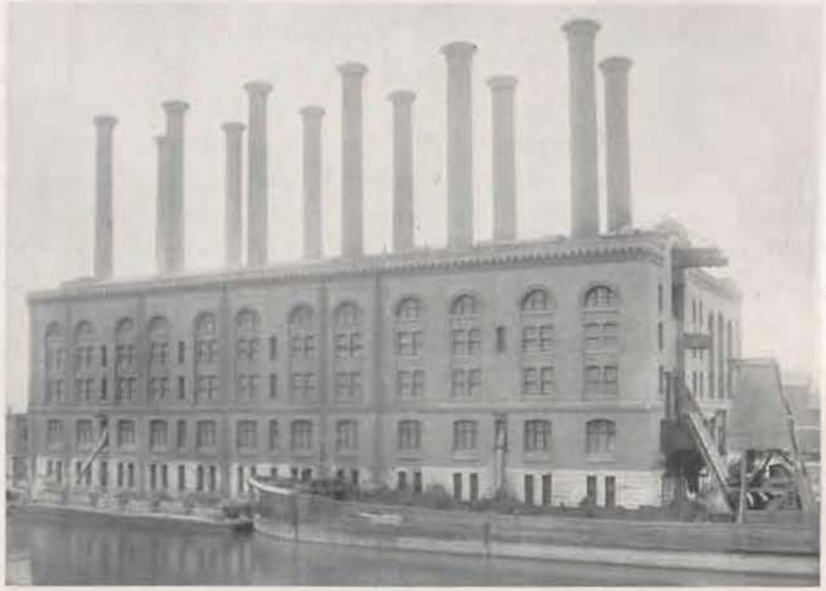
It has been estimated that the cement industry in the United States consumes over two and one-half million tons of fuel for power purposes only. Since all or nearly all the power required by cement mills can be generated from the waste heat in the kiln gas, the two estimates given above show that extensive use of waste-heat equipment will go a long way toward solving problems of fuel shortage and conservation, besides producing a considerable reduction in the cost of the manufactured product.

Flue from fans, in the low building, to a Cottrell dust separator. Alpha Portland Cement Company, Alsen, N. Y.

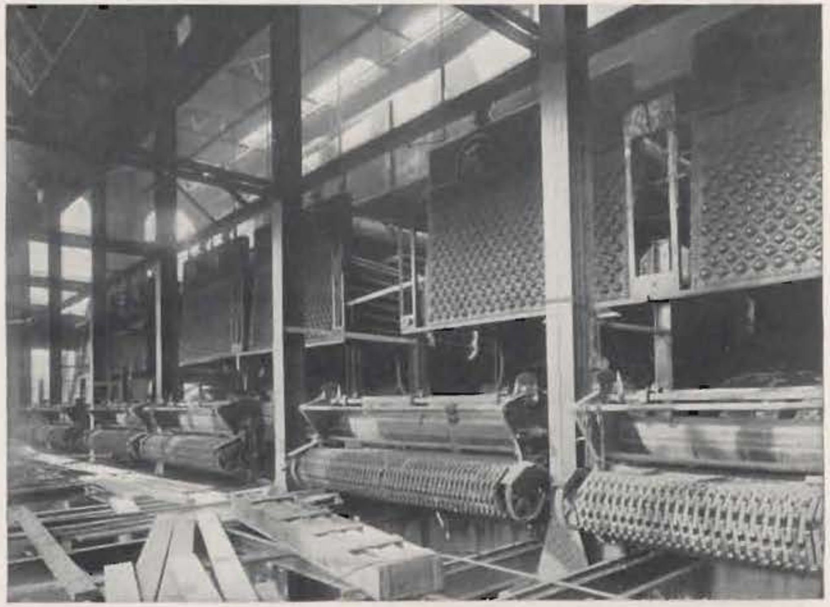
Representative Installations

IN every critical investigation of a product it is not alone sufficient to satisfy oneself that the design is theoretically correct and practical, that the materials and workmanship are first class, and that the performance in authoritative tests compares favorably with that of the best of other makes of the same kind of product. The most convincing tests are after all, represented by the questions: Who have bought this product?

And have these purchasers shown their satisfaction by placing additional orders? The pages which follow give the answers to these questions. It will be seen that almost all classes of industries are represented in this partial list of users of Edge Moor boilers and that the largest and most critical buyers are included.



Commerce Street Station of the Milwaukee Electric Railway and Light Company



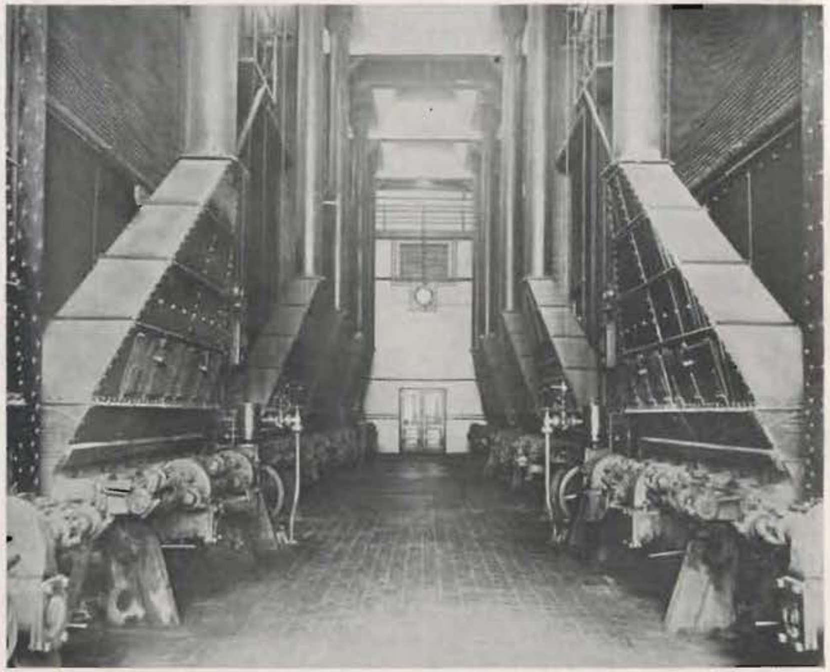
Edge Moor boilers set with chain grate stokers. Fort Worth Power and Light Company, Fort Worth, Texas

CENTRAL POWER STATIONS Arkansas Valley Railway, Light & Power Company.......Pueblo, Col.
Beloit Water, Gas & Electric Company, four orders.......Beloit, Wis.
Burlington Light & Power Company................Burlington, Vt.
Charleston Industrial Corporation..............................Nitro, W. Va.
Consolidated Gas, Electric Light & Power Company, seven orders..Baltimore, Md.
Desert Power & Water Company, three orders..................Kingman, Ariz.
Dominion Power & Transmission Company, Ltd...........Hamilton, Ont., Can.

Erection of one-thousand horsepower units for the Consolidated Gas, Electric Light and Power Company, Baltimore

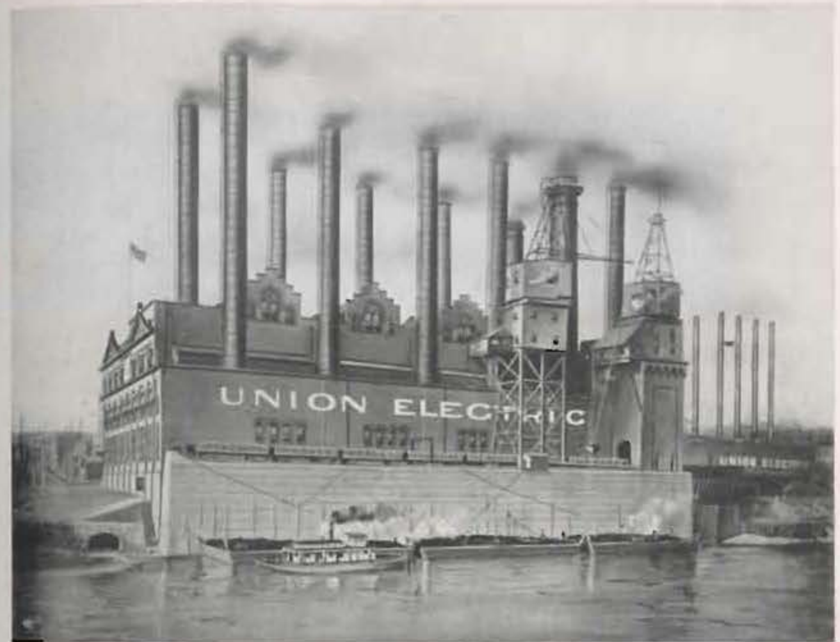
Edison Electric Illuminating Company of Brockton, three orders...............
....E. Bridgewater, Mass.
Fort Worth Power & Light Company, five orders..............Fort Worth, Tex.
Interstate Light & Power Company, three orders...................Galena, Ill.
Iowa Railway & Light Company, seventeen orders..........................
.............Boone, Cedar Rapids, Iowa Falls, Marshalltown, and Perry, Iowa.
Laclede Gas Light Company, three orders.......................St. Louis, Mo.
Logan County Light & Power Company, four orders.............Logan, W. Va.
Metropolitan Edison Company, three orders......................Reading, Pa.
Miami Beach Electric Company...............................Miami, Fla.
Milwaukee Elec. Ry. & Lt. Company, twenty-six orders......................
....Milwaukee and Racine, Wis.

Northern States Power Company, seven orders.................................
..........................St. Paul, Minn., Fargo, N. D., and Sioux Falls, S. D.
Oshkosh Gas Light Company.................................Oshkosh, Wis.
Ottertail Power Company...............................Fergus Falls, Minn.
Penn Central Light & Power Company, six orders...........................
..............................Altoona, Warrior Ridge, and Williamsburg, Pa.
Pennsylvania Utilities Company, two orders.......................Easton, Pa.

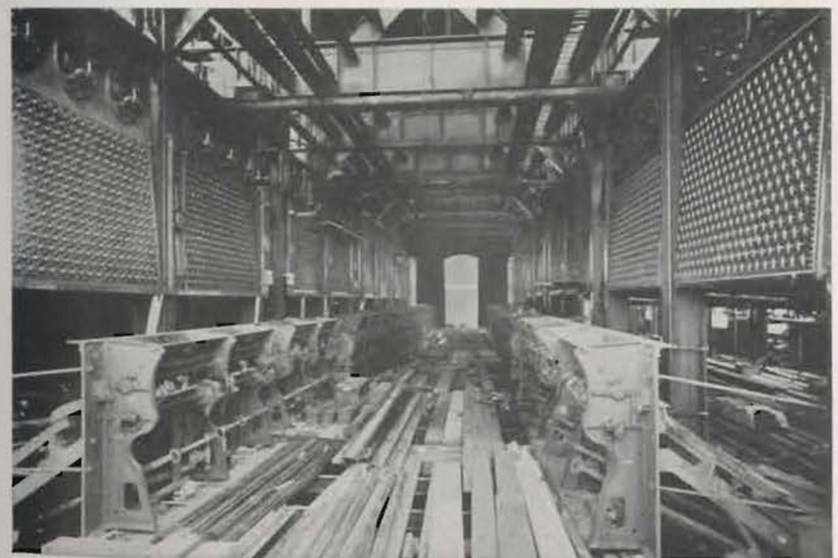


Edge Moor boilers with forced-draft stokers
United Electric Light Co., Springfield, Mass.

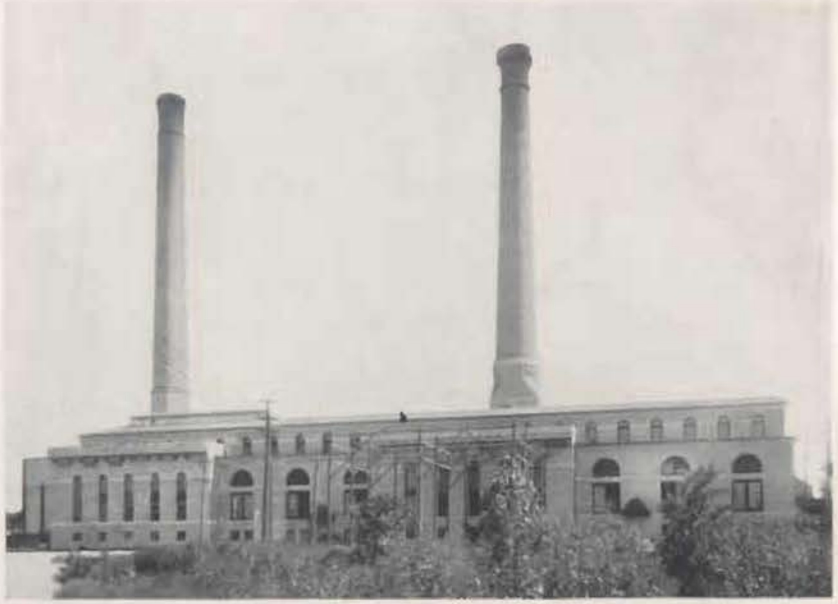
Philadelphia Electric Company, eleven orders, Chester, Philadelphia, and Tacony, Pa.
Public Service Electric Company, three orders...............................
..................................Burlington, Camden, and Cranford, N. J.
Rockland Light & Power Company, two orders..................Hillburn, N. Y.
Society for Establishing Useful Manufactures..................Paterson, N. J.
Southern Power Company...................................University, N. C.
Turners Falls Power & Electric Company..................Chicopee Jct., Mass.
Union Electric Light & Power Company, three orders............St. Louis, Mo.
United Electric Light Company............................Springfield, Mass.
United Water, Gas & Electric Company...................Hutchinson, Kansas.
Wichita Falls Electric Company, two orders...............Wichita Falls, Texas.
Worcester Suburban Electric Company, three orders............Uxbridge, Mass.



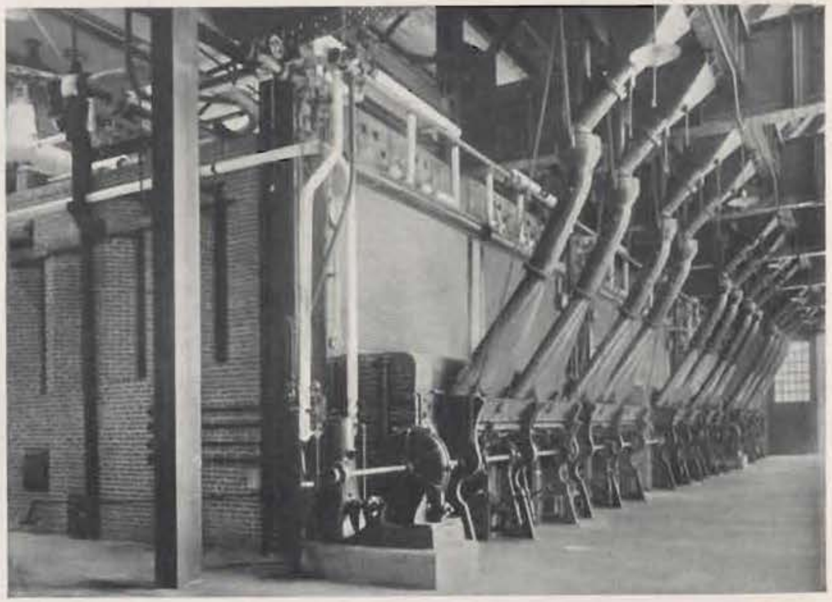
Plant of the Union Electric Light and Power Company, St. Louis



Sixteen boilers in course of erection at the plant of the Metropolitan Edison Company, Reading, Pa.



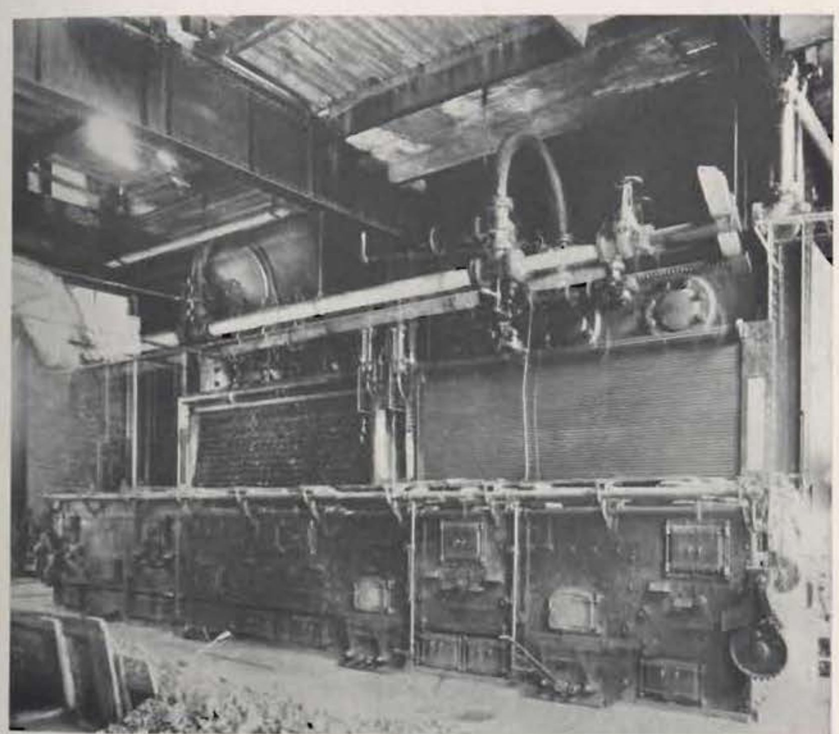
Generating Station at Batavia, Ill. Aurora, Elgin and Chicago Railroad



One of the installations of the Wilmington and Philadelphia Traction Company, Wilmington, Del.

CENTRAL HEATING PLANTS
Germantown Steam Company, two orders.........Germantown, Pa.
New York Steam Company, three orders...........New York City.
Overbrook Steam Heat Company, four orders........Overbrook, Pa.

ELECTRIC RAILROADS
Aurora, Elgin & Chicago Railroad, six orders.........Batavia, Ill.
Bay State Street Railway Company................Salem, Mass.
Connecticut Company, The.................................Hartford, Conn.
Cortland County Traction Company, two orders...............Cortland, N. Y.



Partial view—Consumers Light and Power Company, St. Paul. Owned and operated by H. M. Byllesby Company

Lexington Utilities Corporation, two orders.....................Lexington, Ky.
Lincoln Traction Company.....................................Lincoln, Neb.
Philadelphia & West Chester Traction Company, four orders.....................
....Llanerch and Ridley Creek, Pa.
Shore Line Electric Railway Company.........................Norwich, Conn.
Trenton & Mercer County Traction Corporation, two orders.......Trenton, N. J.
Wilmington & Philadelphia Traction Company, six orders.......Wilmington, Del.
Worcester Consolidated Street Railway Company...............Millbury, Mass.

STEAM RAILROADS Boston & Maine Railroad........................Boston, Mass.
Fort Dodge, DesMoines & Southern Railroad Company, five orders ....Fraser, Iowa.
Great Northern Railway Company, seven orders ....St. Paul, Minn., Allouez and West Superior, Wis.
Minneapolis, St. Paul & Sault Ste. Marie Railway, five orders...Minneapolis, Minn.
New York Central & Hudson River Railroad Company, two orders ....Albany, N. Y. and Avis, Pa.
Oregon Railroad & Navigation Company........................Portland, Oregon.
Philadelphia & Reading Railway Company........................Philadelphia, Pa.
Pennsylvania Railroad Company, five orders. Baltimore, Md., and Wilmington, Del.
Union Depot Company, two orders........................Columbus, Ohio.

Passenger Station of the Great Northern Railway, Minneapolis

EDUCATIONAL INSTITUTIONS Drexel Institute, two orders........................Philadelphia, Pa.
Haverford College........................Haverford, Pa.
Jefferson Medical College........................Philadelphia, Pa.
West Chester State Normal School........................West Chester, Pa.

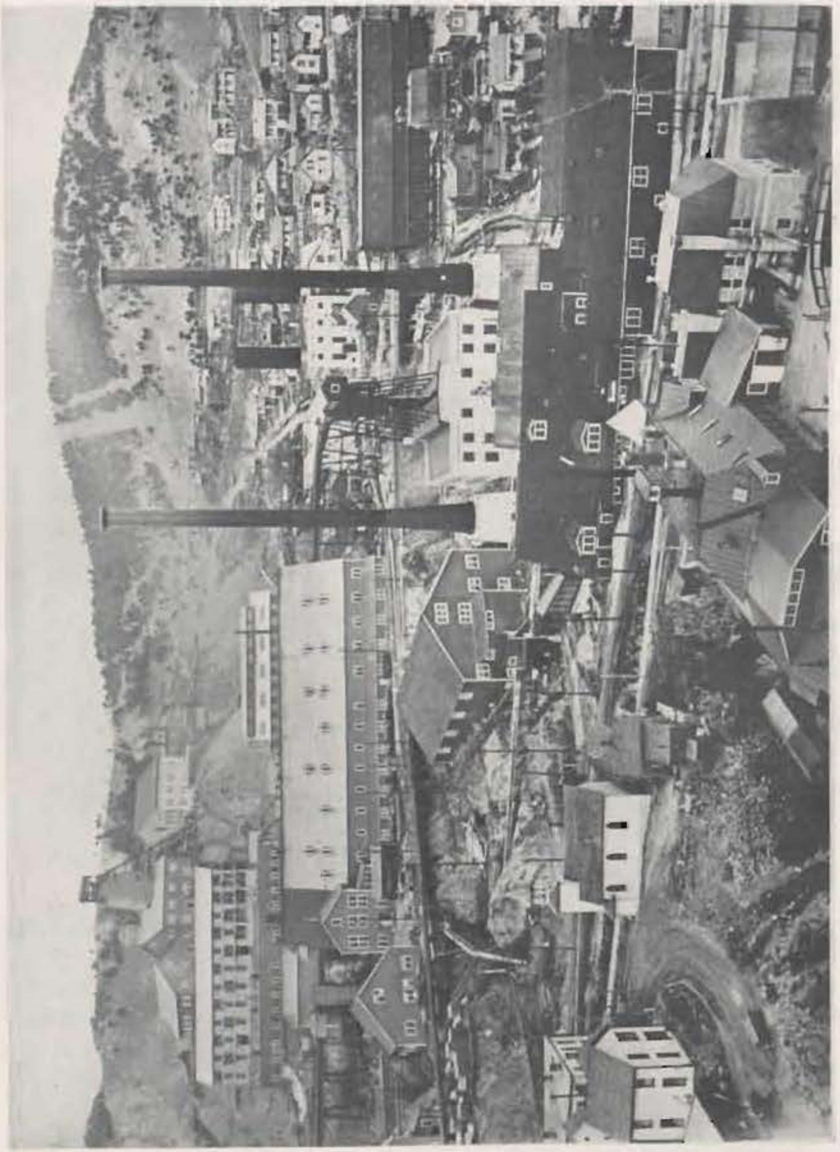
U. S. GOV'T PLANTS Naval Aircraft Factory, two orders, League Island, Philadelphia, Pa.
United States Naval Operating Base........Hampton Roads, Va.
United States Navy Yard........................Brooklyn, New York.
United States Navy Yard, three orders..........League Island, Philadelphia, Pa.
United States Navy Yard, two orders........................Mare Island, Cal.
United States Navy Yard, two orders........................Norfolk, Va.
United States Soldiers' Home, two orders........................Washington, D. C.

MUNICIPAL PLANTS Baltimore, City of, two orders ....High Pressure Pumping Station, Baltimore, Md.
Chicago, City of, eight orders...Lawrence Ave.; 95th St.; Roseland; Central Park Ave.; 39th St.; Mayfair; Springfield Ave.; and Lakeview Pumping Stations.
Holyoke, City of........................Holyoke, Mass.
Minneapolis, City of, Northeast Pumping Station............Minneapolis, Minn.
Montclair Water Company........................Little Falls, N. J.

The Roseland Pumping Station, City of Chicago

Philadelphia, City of, Water Department, three orders ....Lardner's Point and Roxboro Stations, Philadelphia, Pa.
Rahway Water Works, two orders........................Rahway, N. J.
Sumter, City of, two orders........................Sumter, S. C.
Wilmington Water Department, two orders..................Wilmington, Del.

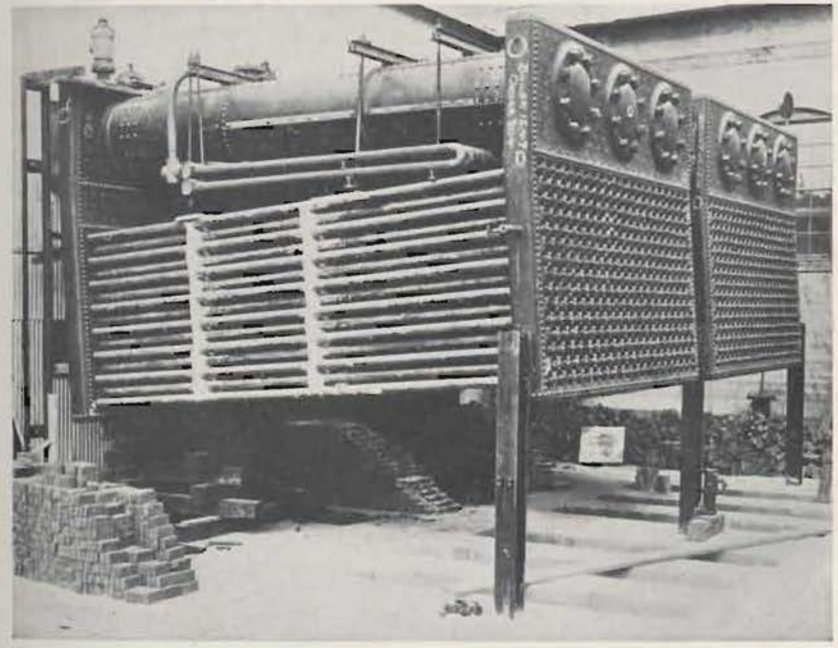
HOSPITALS Cook County Hospital........................Chicago, Ill.
Eastern Shore Hospital........................Cambridge, Md.
Hahnemann Hospital, two orders........................Philadelphia, Pa.
Sheppard & Enoch Pratt Hospital........................Towson, Md.
Springfield State Hospital, two orders........................Sykesville, Md.
St. Luke's Hospital........................Chicago, Ill.
State Asylum for the Chronic Insane........................Wernersville, Pa.



Works of the Homestake Mining Company, Lead, S. D. Operated with Edge Moor boilers

MINES AND SMELTERS

Blackwood Coal & Coke Company.....Pardee, Wise County, Va.
Charleston Mining & Manufacturing Company...Fort Meade, Fla.
Elkhorn Piney Coal Mining Company........................Weeksbury, Ky.
Florida Phosphate Mining Corporation..........................Royster, Fla.
Homestake Mining Company....................................Lead, S. D.
New Jersey Zinc Company......................................Hazard, Pa.
Newport Mining Company...................................Bessemer, Mich.
Phosphor Bronze Smelting Company, two orders..............Philadelphia, Pa.
Southern Phosphate Corporation..............................Tancrede, Fla.
Susquehanna Collieries Company, two orders....Lykens, Pa., and Shamokin, Pa.
United States Metals Refining Company....................East Chicago, Ind.

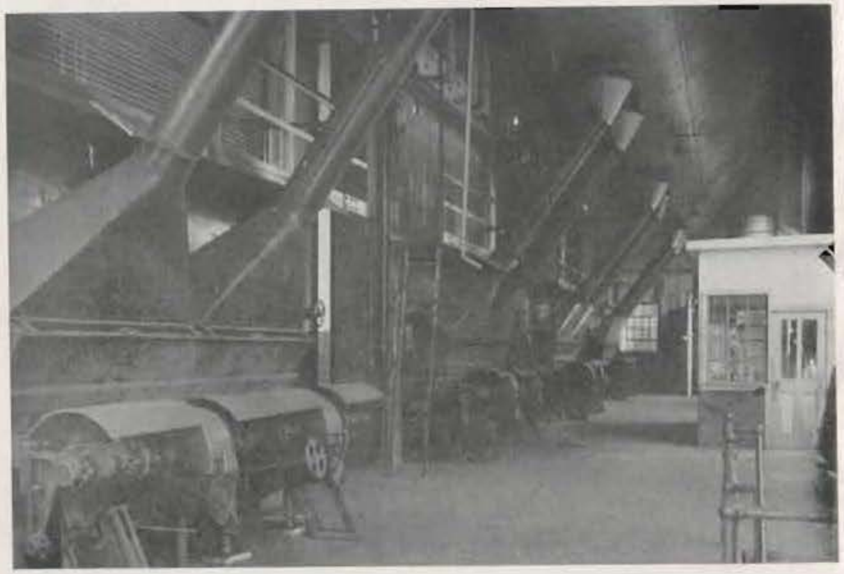


An Arizona installation. Desert Power and Water Company, Kingman, Ariz.

CEMENT PLANTS

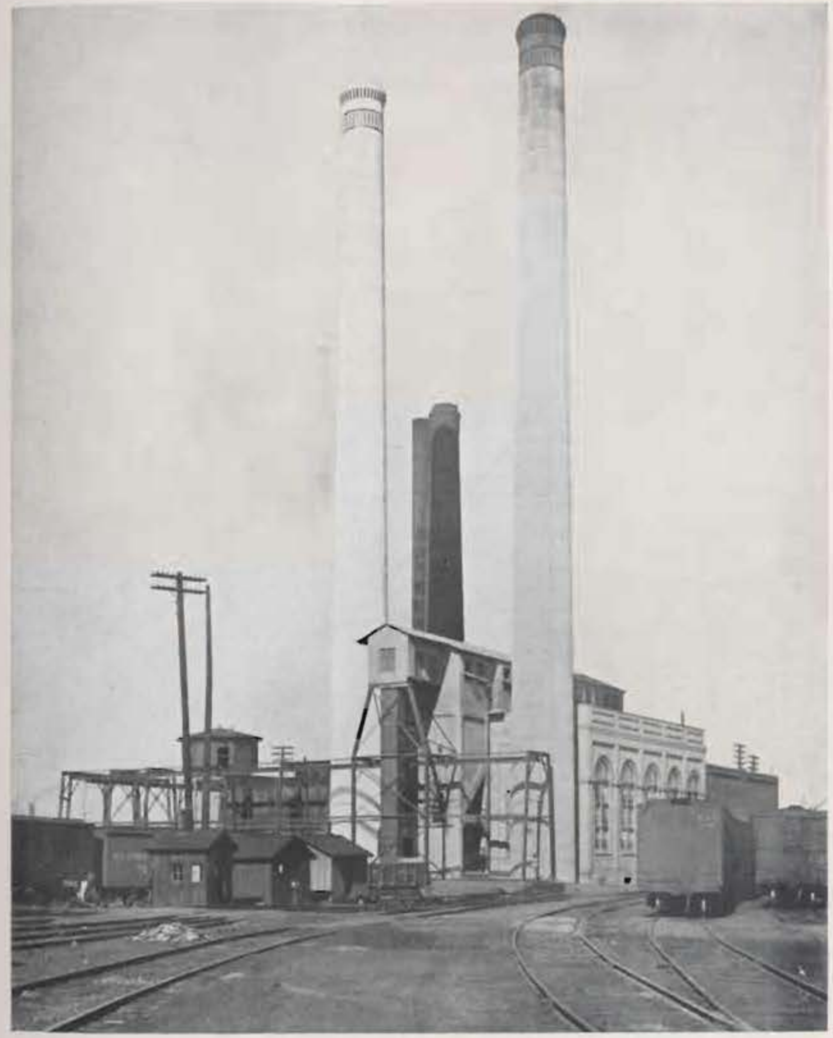
Alpha Portland Cement Company, four orders......................
..........Alsen, N. Y.; Manheim, West Va.; and Martins Creek, Pa.
Asano Portland Cement Company...................two plants, Tokyo, Japan.
Clinchfield Portland Cement Company......................Kingsport, Tenn.
Crescent Portland Cement Company..........................Wampum, Pa.
Dewey Portland Cement Company........................Dewey, Oklahoma.
Dexter Portland Cement Company...........................Nazareth, Pa.
Hokoku Cement Company....................................Kobe, Japan.
Huron Portland Cement Company............................Alpena, Mich.

International Portland Cement Company..............Sierras Bayas, Argentine.
Knickerbocker Portland Cement Company..................Hudson, New York.
Lehigh Portland Cement Company................................Oglesby, Ill.
Marquette Cement Manufacturing Company.......................Oglesby, Ill.
Northwestern States Portland Cement Company.............Mason City, Iowa.
Petoskey Portland Cement Company...........................Petoskey, Mich.
Trinity Portland Cement Company..........................Eagle Ford, Texas.
Western States Portland Cement Company..............Independence, Kansas.



At the Kewanee Works of the Walworth Manufacturing Company, Kewanee, Ill.

IRON AND STEEL WORKS American Steel & Wire Company............Worcester, Mass.
Bethlehem Steel Company, three orders......S. Bethlehem, Pa.
Birdsboro Steel Foundry & Machine Company, three orders.......Birdsboro, Pa.
Eastern Car Company, Limited, two orders................New Glasgow, N. S.
International Harvester Company, ten orders..Chicago, Ill., and Milwaukee, Wis.
Jones & Laughlin...Pittsburgh, Pa.
Lobdell Car Wheel Company, two orders....................Wilmington, Del.
Meadville Malleable Iron Company..........................Meadville, Pa.
Mesabi Iron Company.......................................Babbitt, Minn.
Oliver Chilled Plow Company..............................South Bend, Ind.
Walworth Manufacturing Company............................Kewanee, Ill.
Wisconsin Steel Company...................................Chicago, Ill.
Worth Steel Company, two orders...........................Claymont, Del.



Cedar Rapids plant of the Iowa Railway and Light Company

MACHINE SHOPS AND FOUNDRIES Allis Chalmers Company, five orders.........W. Allis, Wis.
American Pulley Company, two orders....Philadelphia, Pa.
Camden Forge Company, two orders..........................Camden, N. J.
Landis Tool Company..Geiser, Pa.
Lanston Monotype Machine Company.......................Philadelphia, Pa.
Pusey & Jones Company, two orders.......................Wilmington, Del.
Sellers & Company, Wm., Inc., two orders...................Philadelphia, Pa.

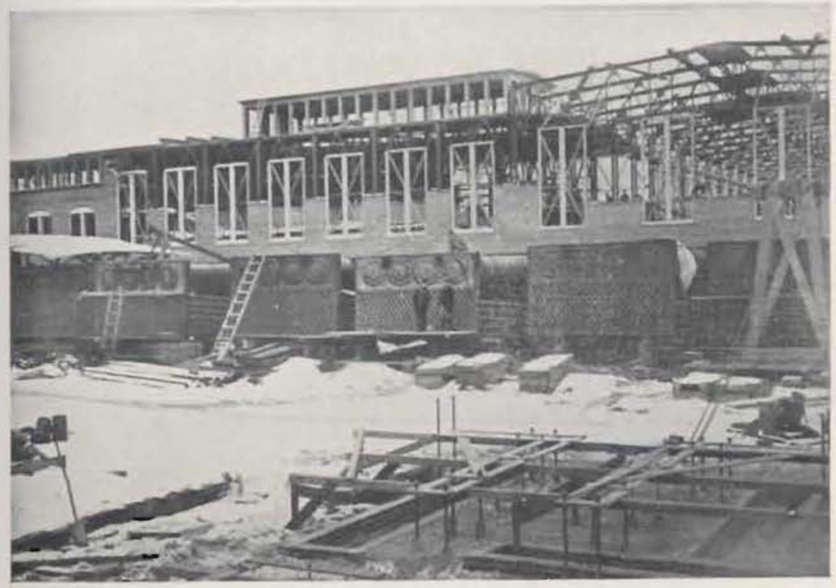
TEXTILE MILLS Aberfoyle Manufacturing Company, three orders........Chester, Pa.
American Printing Company, three orders..........Fall River, Mass.
American Thread Company..........Fall River, Mass.
Bancroft & Sons Company, Joseph, four orders..........Wilmington, Del.
Dobson, John & James, Inc., two orders..........Philadelphia, Pa.
Erlanger Underwear Manufacturing Company..........Baltimore, Md.
Fleisher, S. B. & B. W., Inc., four orders..........Philadelphia, Pa.
Franklinsville Manufacturing Company..........Franklinsville, N. C.
Gera Mills, two orders..........Passaic, N. J.
Harmony Mills..........Cohoes, N. Y.
Highland Worsted Mills..........Camden, N. J.
Lewiston Bleachery & Dye Works..........Lewiston, Maine.

Riverside and Dan River Cotton Mills, Danville, Va.

Ludlow Manufacturing Associates, two orders..Calcutta, India, and Ludlow, Mass.
Maverick Mills..........East Boston, Mass.
National Knitting Company..........Milwaukee, Wis.
Riverside & Dan River Cotton Mills, five orders..........Danville, Va.
Viscose Company, six orders....Roanoke, Va.; Marcus Hook and Lewistown, Pa.
Wolstenholme & Son, Inc., Alfred, two orders..........Philadelphia, Pa.
Wolstenholme & Sons Company, Thomas..........Philadelphia, Pa.

CHEMICAL AND DYE WORKS American Agricultural Chemical Company..........Pierce, Fla.
Crescent Chemical Manufacturing Company, three orders..........Brooklyn, N. Y.
Curtis Bay Chemical Company, two orders..........Curtis Bay, Md.
Krebs Pigment & Chemical Company..........Newport, Del.
Liquid Carbonic Company..........Chicago, Ill.
Monsanto Chemical Works..........St. Louis, Mo.
Nichols Copper Company, two orders..........Laurel Hill, N. Y.
Perth Amboy Chemical Works, two orders..........Perth Amboy, N. J.
Philadelphia Dye Works..........Philadelphia, Pa.

PAPER MILLS American Writing Paper Company..........Holyoke, Mass.
Bird & Son, F. W..........East Walpole, Mass.
Dill & Collins Company, four orders..........Philadelphia, Pa.
Glatfelter Company, P. H., two orders..........Spring Grove, Pa.
Great Northern Paper Company..........E. Millinocket, Maine.
Hammermill Paper Company, two orders..........Erie, Pa.

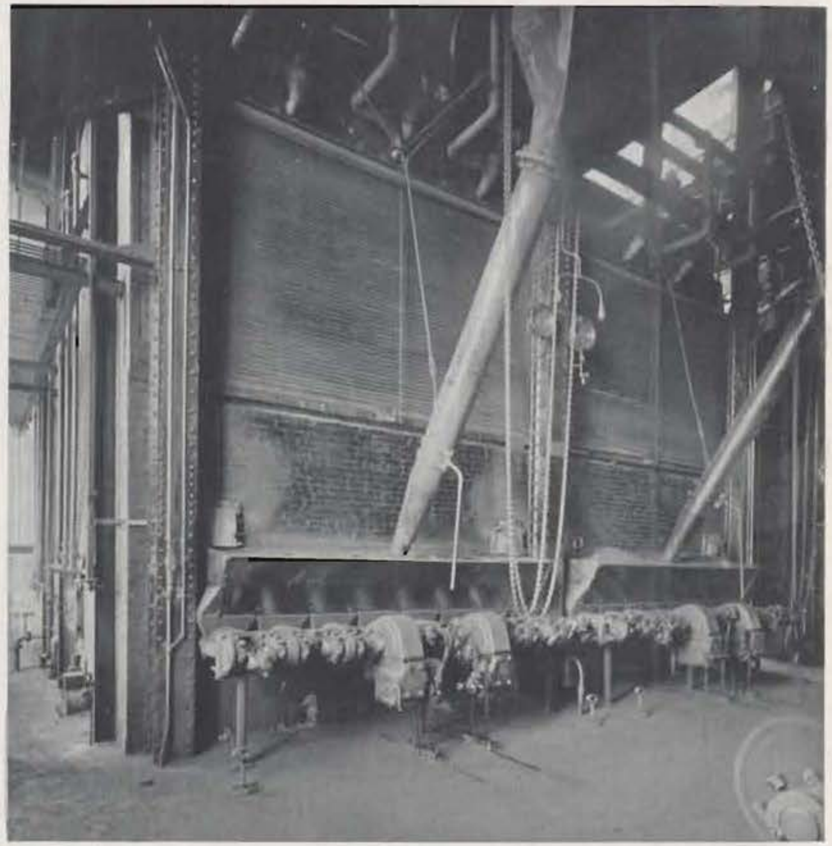


Boilers in course of erection at the Covington, Va., plant of the West Virginia Pulp and Paper Company

Kimberly Clark Company..........Kimberly, Wis.
Lawless Bros. Company..........East Rochester, N. Y.
Megargee Paper Mills, three orders..........Modena, Pa.
New York & Pennsylvania Company.....Willsboro, N. Y., and Johnsonburg, Pa.
Port Huron Sulphite & Paper Company, two orders..........Port Huron, Mich.
Sorg Paper Company, Paul A., two orders..........Middletown, O.
St. Lawrence Pulp & Lumber Corporation, two orders....Chandler, Quebec, Can.
Warren Manufacturing Company, five orders..........Milford, Warren and Hughesville, N. J.
West Virginia Pulp & Paper Company, fourteen orders..........Mechanicsville, N. Y.; Tyrone, Pa.; Covington, Va.; and Piedmont, W. Va.

FIBRE MILLS Continental Fibre Company, four orders..........Newark, Del.
Diamond State Fibre Company, two orders..........Bridgeport, Pa.

OIL PUMPING PLANTS AND REFINERIES American Cotton Oil Company............Guttenberg, N. J.
Associated Pipe Line Company, two orders..San Francisco, Cal.
Beacon Oil Company........................Everett, Mass.
Crew-Levick Company, Seaboard Oil Plant......................Chester, Pa.
International Oil & Gas Corporation.........................Shreveport, La.
Sinclair Refining Company, two orders.....Coffeyville and Kansas City, Kansas.

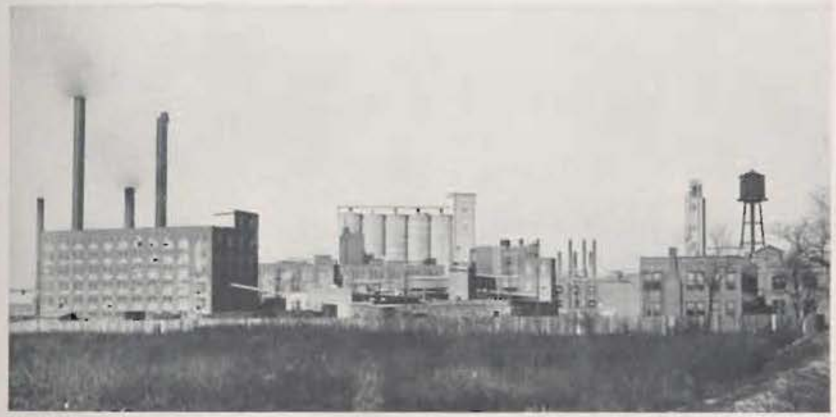


Edge Moor boilers with forced draft, underfeed stokers. Worcester Electric Light Company, Worcester, Mass.

RUBBER AND TIRE FACTORIES Electric Hose & Rubber Company, two orders.....Wilmington, Del.
Essex Rubber Company, two orders...............Trenton, N. J.
Fisk Rubber Company, two orders..........Chicopee Falls, Mass.
Hood Rubber Company, two orders.....................E. Watertown, Mass.
Quaker City Rubber Company............................Philadelphia, Pa.
Revere Rubber Company, two orders........................Providence, R. I.

ICE PLANTS American Ice Company, four orders, three plants, Philadelphia, Pa.
Bee Hive Hygienic Ice Company...........................Brooklyn, N. Y.
Delaware Storage & Freezing Company......................Philadelphia, Pa.
New York Ice Company...................................New York City.
Terminal Freezing & Heating Company.......................Baltimore, Md.

PACKING HOUSES Armour Packing Company.....................Kansas City, Mo.
Gobel, Adolf.......................................Brooklyn, N. Y.
Morris & Company, fourteen orders..........Chicago, Ill.; East St. Louis, Ill.; Kansas City, Kan.; St. Joseph, Mo.; Oklahoma City, Okla.; Montevideo, S. A.
North Packing & Provision Company, two orders............Somerville, Mass.
Richardson & Robbins.......................................Dover, Del.

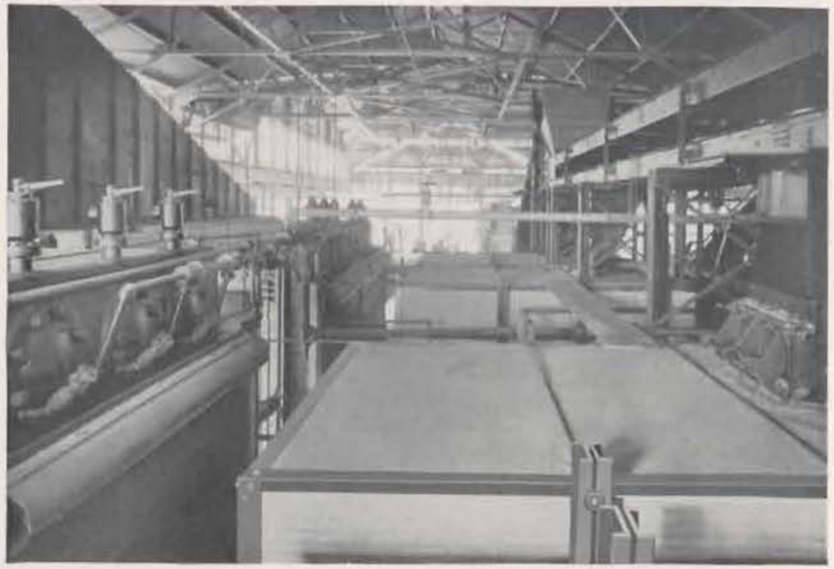


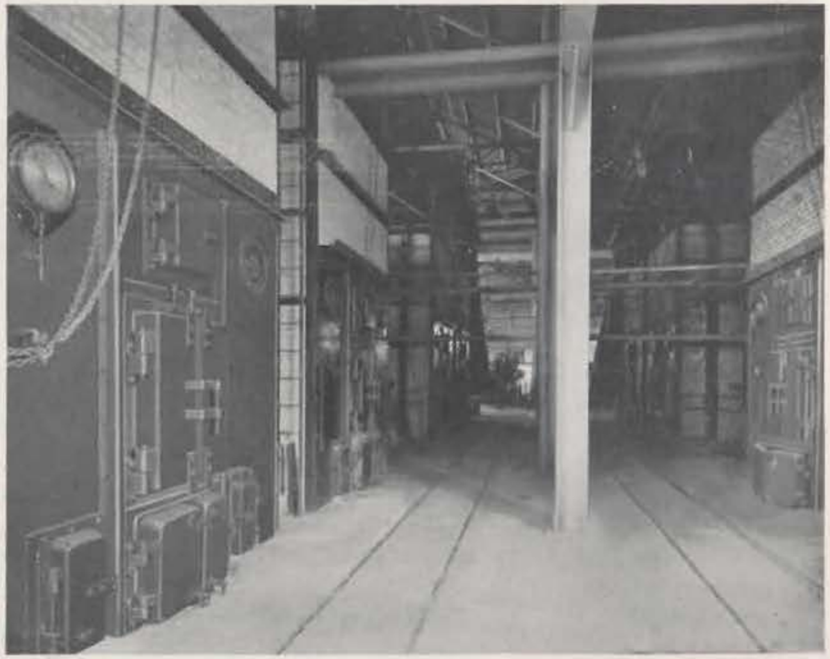
Plant of A. E. Staley Manufacturing Company, Decatur, Ill.

TANNERIES AND GLUE FACTORIES Foerderer Company, Robert H., three orders......................Bridesburg and Frankford Junction, Pa.
Pfister & Vogel Leather Company, nine orders..............................three plants, Milwaukee, Wis.
Trostel & Sons Company, Albert, two orders.................Milwaukee, Wis.
United States Glue Company, six orders.....................Carrollville, Wis.

SOAP AND STARCH FACTORIES Fels & Company, two orders..................Philadelphia, Pa.
Larkin Company..............................Buffalo, N. Y.
Lever Bros.................................Cambridge, Mass.
National Starch Company.................................Oswego, N. Y.
Staley Manufacturing Company, A. E., four orders................Decatur, Ill.

POWDER PLANTS E. I. duPont de Nemours Powder Company.........Barkesdale, Wis.; Wilmington, Del.; Repauno, N. J.; Carney's Point, N. J.; Hopewell, Va.
Hercules Powder Company, two orders......................San Diego, Cal.





Edge Moor boilers set with bagasse furnaces.
Central Agramonte, Camaguey, Cuba

GRAIN AND FLOUR MILLS Commercial Milling Company.................Detroit, Mich.
Gambrill Manufacturing Company, C. A......Ellicott City, Md.
Millbourne Mills Company, two orders.....................Philadelphia, Pa.
Philadelphia Grain Elevator Company.....................Philadelphia, Pa.
Washburn-Crosby Company.................................Buffalo, N. Y.

Commercial Milling Company, Detroit, Mich.

SUGAR MILLS E. Atkins & Company, three orders........................
......Central Florida, Camaguey, Cuba; and Central Soledad, Cienfuegos, Cuba.
Cape Cruz Company..............................Esenada de Mora, Cuba.
Central Santa Ana..................................Auza, Oriente, Cuba.
Compania Azucarera Vertientes, three orders..............................
......................Centrals Agramonte and Vertientes, Camaguey, Cuba.
Cuba Cane Sugar Corporation.........................Central Stewart, Cuba.
Czarnikow Rionda Company.........................Central Francisco, Cuba.
Hershey Corporation, two orders..............Central Hershey, Bainoa, Cuba.
Honolulu Iron Works......................................Central Fe, Cuba.
Manati Sugar Company........................Central Manati, Oriente, Cuba.
Miranda Sugar Company....................Central Miranda, Oriente, Cuba.
United Fruit Company............................Bocas del Toro, Panama.

CANDY FACTORIES American Chicle Company..............Long Island City, N. Y.
Hershey Chocolate Company, four orders...........Hershey, Pa.
Wilbur & Son, H. O., two orders..........................Philadelphia, Pa.

DEPARTMENT STORES AND WAREHOUSES

Baltimore Bargain House, three orders.........Baltimore, Md.
Filene Sons Company, Wm., two orders.........Boston, Mass.
Gimbel Brothers.........................Philadelphia, Pa.
Mandel Brothers, two orders.........................Chicago, Ill.
Montgomery Ward & Company, four orders....Chicago, Ill., and St. Paul, Minn.
Rhodes Brothers Department Store.........................Tacoma, Wash.
Rice Stix Dry Goods Company, two orders.........................St. Louis, Mo.
Rosenburg Brothers & Company.........................Rochester, N. Y.
Zangerle & Peterson.........................Chicago, Ill.

Filene's—Boston's finest department store

OFFICE BUILDINGS

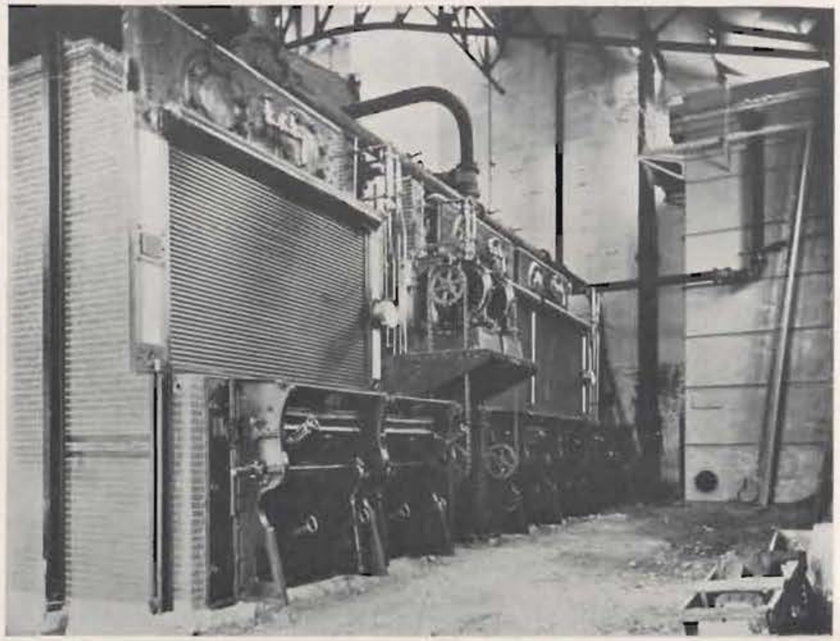
Chicago Title & Trust Company.........................Chicago, Ill.
Cincinnati & Suburban Bell Telephone Building.....Cincinnati, O.
Drexel Building, two orders.........................Philadelphia, Pa.
DuPont Building, four orders.........................Wilmington, Del.
Fidelity Building.........................Baltimore, Md.
Fire Association Building.........................Philadelphia, Pa.
First National—Soo Line Building.........................Minneapolis, Minn.
Girard Building, two orders.........................Philadelphia, Pa.
Hudson Building.........................New York City.
Merchants' National Bank Building.........................St. Paul, Minn.

Minahan Building.........................Green Bay, Wis.
New York Life Building, two orders.........................Chicago, Ill.
North American Building.........................Chicago, Ill.

Just below Independence Hall, Philadelphia, is the Drexel Building equipped with five Edge Moor boilers

North American Building.........................Philadelphia, Pa.
Otis Building.........................Chicago, Ill.
Pacific Electric Building.........................Los Angeles, Cal.
Public Service Building.........................Milwaukee, Wis.

HOTELS AND CLUBS Belvidere Hotel.................................Baltimore, Md.
Illinois Athletic Club.................................Chicago, Ill.
Manufacturer's Club, two orders..................Philadelphia, Pa.
Morrison Hotel.................................Chicago, Ill.
Rennert Hotel.................................Baltimore, Md.
Union League Club, two orders.........................Philadelphia, Pa.

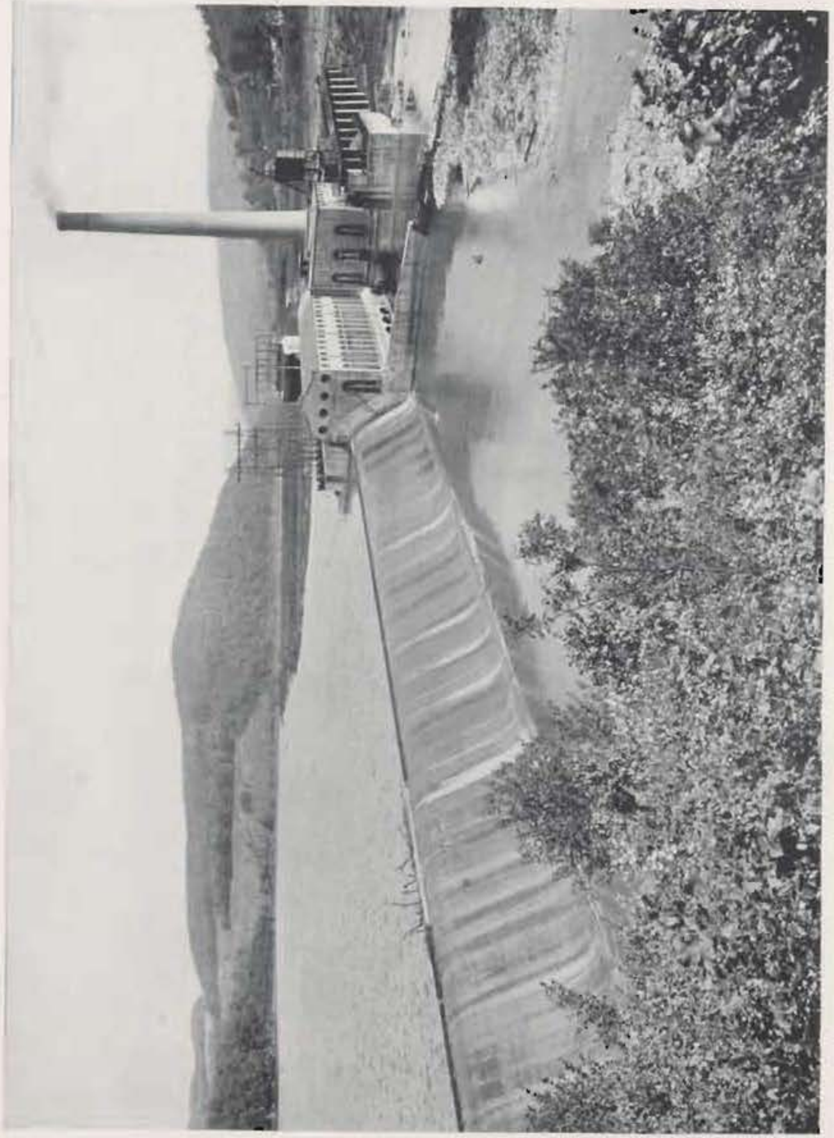


At United States Soldiers' Home, Washington, D. C. The U. S. Government has also purchased Edge Moor boilers for the Brooklyn, Mare Island, Norfolk and Philadelphia Navy Yards

MISCELLANEOUS Auto Car Company.........................Ardmore, Pa.
Cleveland Sarnia Saw Mills Company, Ltd., two orders........Sarnia, Ont., Can.
Clinton Wire Cloth Company.................................Clinton, Mass.
Columbia Box Company.................................St. Louis, Mo.
Corning Glass Works.................................Corning, N. Y.
Delaware River Cordage Company, two orders................Philadelphia, Pa.
Destructor Company, The, four orders.................................
................Brooklyn, N. Y.; Atlanta, Ga.; Paterson, N. J.; Havana, Cuba.
Farr & Bailey Manufacturing Company.........................Camden, N. J.
H. H. Franklin Manufacturing Company, two orders............Syracuse, N. Y.
Hamilton Brown Shoe Company.........................St. Louis, Mo.
MacAndrews & Forbes, four orders.........................Camden, N. J.

One of the many office buildings equipped with Edge Moor boilers North American Building, Chicago

New York Consolidated Card Company, The...........Long Island City, N. Y.
Remington Salt Company.................................Ithaca, New York.
Townsend Grace Company.................................Baltimore, Md.
Victor Talking Machine Company, seven orders.......two plants, Camden, N. J.
Waldorf Box Board Company, two orders.......................St. Paul, Minn.



Plant of the Penn Central Power and Transmission Company, Warrior Ridge, Penna.

ENGINEERING DATA

Fuel

THE many kinds of fuel used for the generation of steam may be divided into three classes: natural fuels, prepared fuels, and the by-products and end-products from industries. To the first class belong wood, coal, crude petroleum and natural gas; to the second powdered coal and briquettes; and to the third bagasse, tan bark, blast-furnace gas, coke-oven gas, waste gases from cement kilns, open-hearth furnaces, etc. Of these fuels, the most widely distributed, and therefore most commonly used, is coal.

Classification of Coal.—The very great variation in the composition of coal found in different localities has made it desirable, for technical purposes, to classify coal into various grades based on some relation between the volatile matter and either the fixed carbon or total combustible present. In the language of the chemist, that part of coal, moisture excepted, which is driven off when a sample is subjected to a temperature up to about 1750° F. is the "volatile matter"; the solid carbon is the "fixed carbon"; the sum of volatile matter and fixed carbon is the "total combustible"; and the part that does not burn is "ash".

CLASSIFICATION OF AMERICAN COALS[1]

Class	Volatile matter Per cent. of combustible	Oxygen in combustible Per cent.	B. T. U. per lb. combustible
I. Anthracite	Less than 10	1 to 4	14,800 to 15,400
II. Semi-anthracite	10 to 15	1 to 5	15,400 to 15,500
III. Semi-bituminous . . .	15 to 30	1 to 6	15,400 to 16,050
IV. Eastern cannel	45 to 60	5 to 8	15,700 to 16,200
V. Bituminous, high grade .	30 to 45	5 to 14	14,800 to 15,600
VI. Bituminous, medium grade	32 to 50	6 to 14	13,800 to 15,100
VII. Bituminous, low grade . .	32 to 50	7 to 14	12,400 to 14,600
VIII. Sub-bituminous and lignite	27 to 60	10 to 33	9,600 to 13,250

[1] From table by William Kent in Journal A. S. M. E., vol. 36, p. 437, 1914.

Sizes of Coal.—Coal as taken from the mine varies in size from large lumps to a fine dust. In general, the smaller the size the greater is the amount of impurities present, the heat value is lower, more coal sifts through the grate, and other objectionable results are increased. As a consequence, the larger sizes usually command higher prices, especially for anthracite.

Coal is graded into sizes by screening through standard openings which, however, differ somewhat both as to size and shape in different localities. The preliminary report of the Committee on Power Tests of the American Society of Mechanical Engineers (1912) recommends the grading of coal as follows:

SIZES OF ANTHRACITE COAL

Size	Diameter of opening through or over which coal will pass, inches	
	Through	Over
Broken	$4\frac{1}{2}$	$3\frac{1}{4}$
Egg	$3\frac{1}{4}$	$2\frac{5}{16}$
Stove	$2\frac{5}{16}$	$1\frac{5}{8}$
Chestnut	$1\frac{5}{8}$	$\frac{7}{8}$
Pea	$\frac{7}{8}$	$\frac{9}{16}$
No. 1 Buckwheat	$\frac{9}{16}$	$\frac{5}{16}$
No. 2 Buckwheat	$\frac{5}{16}$	$\frac{3}{16}$
No. 3 Buckwheat	$\frac{3}{16}$	$\frac{3}{32}$
Culm	$\frac{3}{32}$	...

SIZES OF BITUMINOUS COAL—EASTERN STATES

Run of mine coal—The unscreened coal taken from the mine.

Lump coal—That which passes over a bar-screen with openings $1\frac{1}{4}$ inches wide.

Nut coal—That which passes through a bar-screen with $1\frac{1}{4}$-inch openings and over one with $\frac{3}{4}$-inch openings.

Slack coal—That which passes through a bar-screen with $\frac{3}{4}$-inch openings.

SIZES OF BITUMINOUS COAL—WESTERN STATES

Run of mine coal—The unscreened coal taken from mine.

Lump coal—Divided into 6-inch, 3-inch and $1\frac{1}{4}$-inch lump according to the diameter of the circular openings over which the respective grades pass; also into 6 x 3 lump and 3 x $1\frac{1}{4}$ lump according as the coal passes through a circular opening of the larger diameter and over one of the smaller diameter.

Nut coal—Divided into 3-inch steam nut, which passes through a 3-inch circular opening and over a $1\frac{1}{4}$-inch; $1\frac{1}{4}$-inch nut, which passes through a $1\frac{1}{4}$-inch circular opening and over a $\frac{3}{4}$-inch; and $\frac{3}{4}$-inch nut, which passes through a $\frac{3}{4}$-inch circular opening and over a $\frac{5}{8}$-inch.

Screenings—That which passes through a $1\frac{1}{4}$-inch opening.

Variation in Calorific Value.—The calorific value of the principal fuels per pound as received varies about as follows:

Air-dried wood	6,000 to 7,500	B. T. U.
Air-dried peat	about 7,500	"
Lignite	5,200 to 7,500	"
Sub-bituminous coal	5,500 to 11,500	"
Bituminous coal	10,000 to 14,500	"
Semi-bituminous coal	13,500 to 14,900	"
Anthracite coal	11,000 to 13,800	"
California crude oil	17,000 to 19,300	"
Penn. heavy crude oil	about 20,700	"

COMPOSITION AND CALORIFIC VALUES OF FUEL GASES[1]

	Natural gas	Coal gas	Water gas	Producer gas	
				Anthra.	Bitumin.
CO	0.50	6.0	45.0	27.0	27.0
H	2.18	46.0	45.0	12.0	12.0
CH_4	92.6	40.0	2.0	1.2	2.5
C_2H_4	0.31	4.0	....	....	0.4
CO_2	0.26	0.5	4.0	2.5	2.5
N	3.61	1.5	2.0	57.0	56.2
O	0.34	0.5	0.5	0.3	0.3
Vapor	....	1.5	1.5	...	....
Pounds per 1000 cu. ft.	45.6	32.0	45.6	65.6	65.9
B. T. U. per 1000 cu. ft.	1,100,000	735,000	322,000	137,455	156,917

[1] W. J. Taylor, Trans. A. S. M. E., vol. xviii, p. 205.

Properties of American Coals.—The data in the six pages following were selected from *Professional Paper 48*, 1906, Bureau of Mines; *Bulletin 85*, 1914, Bureau of Mines; and *The Chemical and Heat-Producing Properties of Maryland Coal*, 1905, by W. B. D. Penniman and Arthur L. Browne, Maryland Geological Survey.

PROPERTIES OF REPRESENTATIVE AMERICAN COALS AS RECEIVED[1]

Locality and designation	Proximate analysis in per cent.				Ultimate analysis in per cent.—moisture included					Heat value per lb. B. T. U.
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
ALABAMA										
Jefferson County	2.53	26.94	59.48	11.05	0.79	4.80	74.44	1.59	7.33	13,286
"	1.95	30.66	60.04	7.35	2.75	4.93	77.71	1.70	5.56	13,963
St. Clair County	2.38	33.31	60.00	4.31	1.07	5.27	81.85	1.46	6.04	14,648
Shelby County	3.06	35.64	53.33	7.97	.59	....	.....	....	.....	13,172
Tuscaloosa County	2.62	24.18	64.11	9.09	.64	4.72	77.52	1.48	6.55	13,729
ALASKA										
Alaska Peninsula	2.33	34.82	46.75	16.10	.65	4.82	66.58	.81	11.04	11,928
Bering River	3.63	15.37	73.95	7.05	1.18	3.84	77.85	1.64	8.44	13,116
"	1.65	10.87	29.48	58.00	.33	2.20	31.93	.92	6.62	5,496
"	2.68	7.37	88.37	1.58	.54	3.09	89.96	1.26	3.57	14,708
Matanuska	3.59	6.83	64.29	25.29	.19	2.03	65.91	.59	5.99	10,268
"	2.85	7.75	77.34	12.06	.61	2.66	78.35	1.25	5.07	12,732
"	.74	21.81	70.45	7.00	.44	4.59	81.93	1.41	4.63	14,317
COLORADO										
Adams County	35.00	27.39	30.23	7.38	.31	6.56	41.71	.74	43.30	6,982
Boulder County	20.71	31.82	43.98	3.49	.45	6.04	57.80	1.20	31.02	9,941
El Paso County	33.13	25.95	27.03	13.89	.30	6.48	37.25	.68	41.40	6,199
Gunnison County	5.61	37.60	47.57	9.22	.43	5.31	69.68	1.40	13.96	12 434
Las Animas County	1.42	32.31	53.33	12.94	.50	5.04	73.46	1.71	6.35	13,081
Montezuma County	8.05	32.27	45.50	14.18	.57	4.72	60.29	1.01	19.23	10,439
Rio Blanco	11.02	38.53	44.25	6.20	.85	5.80	64.20	1.32	21.63	11,365
IDAHO										
Boise County	10.11	38.24	36.07	15.58	.51	....	.....	....	.....	10,435
Cassia County	34.46	26.41	21.08	18.05	.63	....	.....	....	.....	5,812
Fremont County	11.45	37.24	47.01	4.30	.54	5.94	68.09	1.40	19.73	12,094

[1] See page 105

PROPERTIES OF REPRESENTATIVE AMERICAN COALS AS RECEIVED—Continued

Locality and designation	Proximate analysis in per cent.				Ultimate analysis in per cent.—moisture included					Heat value per lb. B. T. U.
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
ILLINOIS										
Madison and St. Clair Counties	9.69	36.91	38.21	15.19	4.40	....	.....	....	.....	10,706
Madison	12.94	35.76	41.92	9.38	3.65	....	.....	....	.....	10,973
"	12.31	37.57	41.09	9.03	3.58	....	.....	....	.....	11,115
Montgomery County	13.31	33.62	41.34	11.73	3.75	5.19	59.07	.95	19.31	10,548
Williamson County	8.51	31.19	48.75	11.55	1.50	....	.....	....	.....	11,763
Saline County	7.12	34.55	50.68	7.65	2.23	....	.....	....	.....	12,481
Vermillion County	16.16	34.09	39.19	10.56	1.74	5.71	58.38	1.25	22.36	10,433
INDIANA										
Sullivan County	13.05	34.30	47.61	5.04	.82	6.07	67.34	1.44	19.29	12,022
Warrick County	9.69	38.59	41.04	10.68	4.79	5.39	62.36	1.28	15.50	11,412
INDIAN TERRITORY										
Henryetta	7.65	33.96	46.30	12.09	1.80	....	.....	....	.....	11,852
Hartshorne	3.71	36.21	50.31	9.77	1.39	....	.....	....	.....	12,916
Lehigh	6.24	35.44	45.33	12.99	3.86	....	.....	....	.....	11,276
IOWA										
Marion County	14.88	35.35	33.73	16.04	4.73	....	.....	....	.....	9,786
Wapello County	8.69	33.08	39.89	18.34	6.39	....	.....	....	.....	10,449
KANSAS										
Crawford County	4.85	33.53	52.52	9.10	4.95	5.08	71.20	1.24	8.43	12,942
Leavenworth County	11.10	35.51	40.69	12.70	3.99	5.30	60.72	1.13	16.16	11,065
"	12.06	35.42	36.45	16.07	4.77	5.16	56.54	1.07	16.39	10,215
KENTUCKY										
Muhlenberg County	8.73	37.76	45.93	7.58	2.65	5.52	67.65	1.42	15.18	12,208
Ohio County	9.89	35.94	43 36	10.81	3.64	5.37	62.27	1.33	16.58	11,392
Pike County	1.94	35.48	59.88	2.70	.57	5.38	81.37	1.42	8.56	14,693

PROPERTIES OF REPRESENTATIVE AMERICAN COALS AS RECEIVED—Continued

Locality and designation	Proximate analysis in per cent.				Ultimate analysis in per cent.—moisture included					Heat value per lb. B. T. U.
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
MARYLAND										
Georges Creek	0.56	20.07	63.93	15.44	1.01	....	.....	....	.....	13,068
"	.94	18.34	76.50	4.22	.95	....	.....	....	.....	14,908
"	.79	15.84	70.88	12.49	2.61	....	.....	....	.....	13,433
"	.60	17.71	72.93	8.76	.59	....	.....	....	.....	14,288
Potomac Basin	3.32	22.43	63.18	11.07	.49	....	.....	....	.....	13,104
"	.29	16.93	73.07	9.71	1.14	....	.....	....	.....	14,161
Castleman Basin	1.96	21.31	63.67	13.06	4.49	....	.....	....	.....	13,230
"	1.64	21.25	71.49	5.62	1.62	....	.....	....	.....	14,477
Lower Youghiogheny	1.21	23.56	68.02	7.21	2.81	....	.....	....	.....	13,894
"	1.86	22.81	62.74	12.59	.89	....	.....	....	.....	13,127
Upper Youghiogheny	4.47	22.74	53.72	19.07	3.27	....	.....	....	.....	12,042
"	1.13	25.43	65.66	7.78	1.15	....	.....	....	.....	14,051
MISSOURI										
Bates County	12.27	30.36	46.68	10.69	2.08	5.50	63.26	1.20	17.27	11,295
Henry County	9.90	35.03	43.31	11.76	5.38	5.39	61.99	1.06	14.42	11,441
Putnam County	18.45	32.62	39.03	9.90	4.09	5.76	55.71	.91	23.63	10,040
Randolph County	13.23	34.99	41.53	10.25	5.19	5.58	60.25	.92	17.81	10,982
Vernon County	6.50	32.61	50.83	10.06	4.95	5.21	67.97	1.09	10.72	12,458
MONTANA										
Blaine County	18.77	31.48	40.40	9.35	.73	....	.....	....	.....	9,135
Custer County	38.67	27.02	25.10	9.21	.30	....	.....	....	.....	6,021
Valley County	40.41	24.50	27.58	7.51	.39	6.94	35.15	.57	49.44	5,830
NEVADA										
Esmeralda County	1.89	26.74	27.42	43.95	.60	....	.....	....	.....	8,098
"	1.61	39.18	43.79	15.42	6.64	....	.....	....	.....	12,917

PROPERTIES OF REPRESENTATIVE AMERICAN COALS AS RECEIVED—Continued

Locality and designation	Proximate analysis in per cent.				Ultimate analysis in per cent.—moisture included					Heat value per lb. B. T. U.
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
NEW MEXICO										
Bernalillo County	1.61	31.11	36.14	31.14	3.24	....	.....	....	.....	10,046
Santa Fe County	3.65	35.05	49.47	11.83	.96	5.04	69.89	1.29	10.99	12,353
NORTH DAKOTA										
Morton County	36.18	29.77	25.35	8.70	.68	6.76	39.45	.59	43.82	6,700
Williams	43.87	24.88	25.43	5.82	.49	....	.....	....	.....	5,938
OHIO										
Jefferson County	3.50	37.98	51.08	7.44	3.09	5.43	73.39	1.46	9.19	13,286
Noble County	5.15	37.34	49.00	8.51	2.94	5.42	70.51	1.50	11.12	12,733
OKLAHOMA										
Haskell County	2.70	21.07	69.88	6.35	.77	4.46	81.33	1.67	5.42	14,098
Pittsburg County	4.83	35.76	55.55	3.86	1.34	5.57	77.08	1.97	10.18	13,829
OREGON										
Coos County	10.13	31.31	24.91	33.65	1.11	....	.....	....	.....	7,466
"	9.97	38.45	36.35	15.23	.63	....	.....	....	.....	10,528
Malheur County	30.31	19.03	18.86	31.80	2.66	....	.....	....	.....	4,376
PENNSYLVANIA										
Allegheny County	2.73	36.03	54.98	6.26	1.39	5.26	76.82	1.46	8.81	13,815
Cambria County	1.75	21.70	69.13	7.42	1.81	4.69	80.33	1.38	4.37	14,227
"	1.83	16.82	75.34	6.01	.84	4.56	83.43	1.28	3.88	14,544
"	1.32	20.33	73.01	5.34	1.39	4.66	83.45	1.33	3.83	14,762
Center County	3.04	22.92	67.32	6.72	1.54	4.95	79.49	1.33	5.97	14,132
Clearfield County	2.95	21.29	66.92	8.84	1.35	4.74	78.51	1.19	5.37	13,901
"	.82	20.40	67.86	10.92	3.08	4.34	77.62	1.08	2.96	13,734
"	2.83	20.30	66.91	9.96	1.32	4.67	77.05	1.25	5.75	13,644
Huntingdon County	2.14	15.47	75.96	6.43	1.05	4.44	82.83	1.27	3.98	14,470

Properties of Representative American Coals as Received—Continued

Locality and designation	Proximate analysis in per cent.				Ultimate analysis in per cent.—moisture included					Heat value per lb. B. T. U.
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Pennsylvania—Continued										
Indiana County	1.30	26.70	64.40	7.60	2.03	5.02	80.35	1.36	3.64	14,315
Jefferson County	2.44	28.44	60.68	8.44	1.32	5.07	76.91	1.31	6.95	13,732
Lackawanna County	3.43	6.79	78.25	11.53	.46	2.52	78.85	.77	5.87	12,782
Luzerne County	2.19	5.67	86.24	5.90	.57	2.70	86.37	.91	3.55	13,828
Somerset County	1.20	15.65	74.18	8.97	1.39	4.31	80.74	1.36	3.23	14,096
"	1.44	18.56	68.44	11.56	1.88	4.39	77.31	1.64	3.22	13,604
"	1.52	15.78	74.93	7.77	.66	4.36	82.09	1.43	3.69	14,285
Washington County	4.31	37.00	52.85	5.84	1.90	5.31	74.14	1.53	11.28	13,304
Westmoreland County	2.14	30.02	58.81	9.03	1.17	5.03	76.33	1.56	6.88	13,662
"	2.71	35.72	50.87	10.70	3.11	5.00	72.08	1.24	7.87	13,104
South Dakota										
Harding County	41.49	24.00	24.35	10.16	.55	....	.....	....	.....	5,652
Perkins County	39.16	24.68	27.81	8.35	2.22	6.60	38.02	.53	44.28	6,307
Tennessee										
Anderson County	1.47	35.93	53.39	9.21	1.03	5.13	75.03	1.84	7.76	13,615
Bledsoe County	3.33	27.89	63.17	5.61	1.88	....	.....	....	.....	14,130
Rhea County	1.91	29.67	54.39	14.03	1.43	4.71	71.50	1.41	6.92	12,796
Utah										
Carbon County	7.49	39.72	47.17	5.62	.64	6.09	69.12	1.35	17.18	12,521
Emery County	3.93	40.92	49.22	5.93	.39	5.52	73.02	1.25	13.89	12,965
Summit County	13.61	41.28	41.03	4.08	1.37	5.84	62.11	1.06	25.54	10,980
Virginia										
Henrico County	2.81	25.70	62.47	9.02	1.43	4.90	76.55	1.81	6.29	13,493
Russell County	2.76	34.96	56.51	5.77	.59	5.32	80.13	1.43	6.76	14,148
Wise County	3.26	31.30	59.07	6.37	.87	5.27	78.02	1.65	7.82	13,910

Properties of Representative American Coals as Received—Continued

Locality and designation	Proximate analysis in per cent.				Ultimate analysis in per cent.—moisture included					Heat value per lb. B. T. U.
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Washington										
King County	16.45	34.63	36.38	12.54	0.38	....	.....	....	.....	9,581
Lewis County	7.88	61.57	15.11	15.44	.29	6.73	58.92	.50	18.12	11,920
Pierce County	1.91	35.13	53.08	9.88	.86	5.72	75.10	2.19	6.25	13,588
West Virginia										
Brooke County	4.58	35.36	54.05	6.01	1.28	5.28	73.81	1.55	12.07	13,234
Fayette County	2.89	25.61	69.18	2.32	.55	4.99	84.11	1.64	6.39	14,796
"	3.17	18.46	70.86	7.51	1.07	4.84	79.07	1.56	5.95	13,995
M'Dowell County	3.10	17.91	75.26	3.73	.55	4.50	84.02	1.17	6.03	14,724
"	2.32	16.76	69.80	11.12	1.78	4.35	77.46	1.27	4.02	13,514
"	2.18	16.36	73.02	8.44	.69	4.20	80.70	1.44	4.53	14,006
Marion County	2.95	35.01	56.44	5.60	.67	5.33	77.89	1.38	9.13	13,862
"	2.60	35.88	52.83	8.69	2.03	5.22	74.69	1.25	8.12	13,513
Mercer County	3.16	16.98	76.21	3.65	.71	4.64	84.79	1.15	5.06	14,729
"	3.61	17.41	74.84	4.14	.76	4.57	83.68	1.12	5.73	14,587
Monongalia County	1.63	28.42	62.01	7.94	.96	5.00	78.24	1.28	6.58	13,937
Preston County	1.40	26.40	62.92	9.28	1.50	4.83	77.92	1.43	5.04	13,808
Raleigh County	4.93	19.96	72.38	2.73	.58	4.77	81.61	1.58	8.73	14,170
"	2.45	17.52	76.67	3.36	.48	4.56	85.51	1.51	4.58	14,789
"	2.17	17.39	77.77	2.67	.50	4.69	86.28	1.51	4.35	14,987
Randolph County	2.72	28.71	55.10	13.47	.96	4.74	73.22	1.09	6.52	12,946
Wyoming										
Converse County	27.91	27.07	36.73	8.29	.89	6.25	47.47	.80	36.30	7,927
Fremont County	23.07	33.07	39.66	4.20	.69	6.22	55.13	1.40	32.36	9,509
Hot Springs County	16.48	32.91	45.83	4.78	.58	5.97	61.08	1.35	26.24	10,750
Sheridan County	22.57	32.53	40.36	4.55	.30	6.30	53.43	1.09	34.33	9,218
Uinta County	5.18	38.73	47.54	8.55	1.40	5.53	68.08	1.10	15.34	12,209

Central Agramonte, Camaguey, Cuba.
Operated with Edge Moor boilers and bagasse furnaces.

Fuel Value of Bagasse. The refuse of sugar cane, known as bagasse, when burned in properly constructed furnaces is capable of generating most if not all of the steam required by a modern sugar factory. Bagasse consists of woody fibre, sucrose, glucose, very small quantities of other solids including ash and considerable moisture. Proportions depend not only on the processes employed in milling but also on the quality of the cane as determined by the locality where the cane is grown and its age at the time of cutting.

ASH AND CALORIFIC VALUE[1]

Source	Per cent. ash in dry bagasse	Gross B. T. U. per lb. dry bagasse[2]
Louisiana	1.19	8396
"	1.26	8431
"	1.11	8427
"	1.21	8340
"	.96	8350
"	1.40	8283
"	1.44	8357
"	.86	8318
"	.85	8409
Cuba	.75	8431
"	.76	8400
"	.83	8435
"	.87	8650
"	.78	8300
"	.76	8380

Wet bagasse contains from 30 to 50 per cent. of fibre (to which most of the heat of combustion is due) and less than 10 per cent. of sucrose, glucose and other organic solids. The amount of moisture varies from about 40 to 60 per cent. As a rule, the ash in dry bagasse does not exceed $1\frac{1}{2}$ per cent.

On account of the high moisture content of bagasse a much smaller proportion of the gross calorific value is available for the generation of steam than when the fuel is coal or oil. The practical fuel value is best determined by calculating the various losses and subtracting these from the gross calorific value.

Assuming 80° F. as the temperature of bagasse as received, the same temperature for the air supplied for combustion, 500° F. as the temperature of escaping gases and .237 as the specific heat of dry gases, the heat carried away per lb. of dry gases is .237 (500–80), or 99.5 B. T. U. The loss of heat per pound of moisture, for .47 as the specific heat of steam, is 1237.8 B. T. U. as shown below.

Heating water to 212° requires 212–80, or	132.0 B. T. U.
Evaporating water into steam at 212° requires	970.4 "
Superheating steam from 212° to 500° requires .47 (500–212), or	135.4 "
Total heat loss per lb. moisture	1237.8 "

[1] Prof. E. W. Kerr, Louisiana Bulletin No. 117, Agricultural Experiment Stations.
[2] By calorimeter.

Assuming dry bagasse composed of 44.5 per cent. carbon, 6 per cent. hydrogen, 48 per cent. oxygen and 1.5 per cent. ash, the gases to the chimney for different percentages of excess air, assuming complete combustion, will be as follows:

TABLE SHOWING WEIGHT OF GASES PER LB. DRY BAGASSE

Per cent. excess air	0	50	100
Carbon dioxide	1.63 lb.	1.63 lb.	1.63 lb.
Free oxygen	.00 "	.59 "	1.19 "
Nitrogen	3.94 "	5.91 "	7.88 "
Total dry gases	5.57 lb.	8.13 lb.	10.70 lb.
Water of formation from hydrogen	.54 "	.54 "	.54 "
Total gases per lb. dry bagasse	6.11 lb.	8.67 lb.	11.24 lb.

For the above conditions, 50 per cent. excess air and a gross calorific value of 8350 B. T. U. per lb. of dry bagasse the net heat convertible into steam per lb. of bagasse containing 50 per cent. moisture is determined by the following calculations.

		B. T. U.	Per cent.
Gross calorific value per lb. wet bagasse equals 50 × 8350, or		4175	100.0
Dry gases per lb. wet bagasse equals .50 × 8.13, or 4.06 lb. Heat carried away by dry gases equals 4.06 × 99.5, or		404	9.7
Moisture of formation from hydrogen equals .50 × .54, or	.27 lb.		
Free moisture in bagasse	.50 "		
Total moisture per lb. bagasse	.77 lb.		
Heat carried away by moisture equals .77 × 1237.8, or		953	22.8
Heat lost from radiation, combustible in ash and incomplete combustion of gases (assumed as 10 per cent. of the gross calorific value)		418	10.0
Total losses		1775	42.5
Heat remaining for absorption by boiler		2400	57.5

The results in the following tables were obtained by similar calculations and by converting the heat remaining for absorption by the boiler into pounds of equivalent evaporation and pounds of bagasse per boiler horsepower.

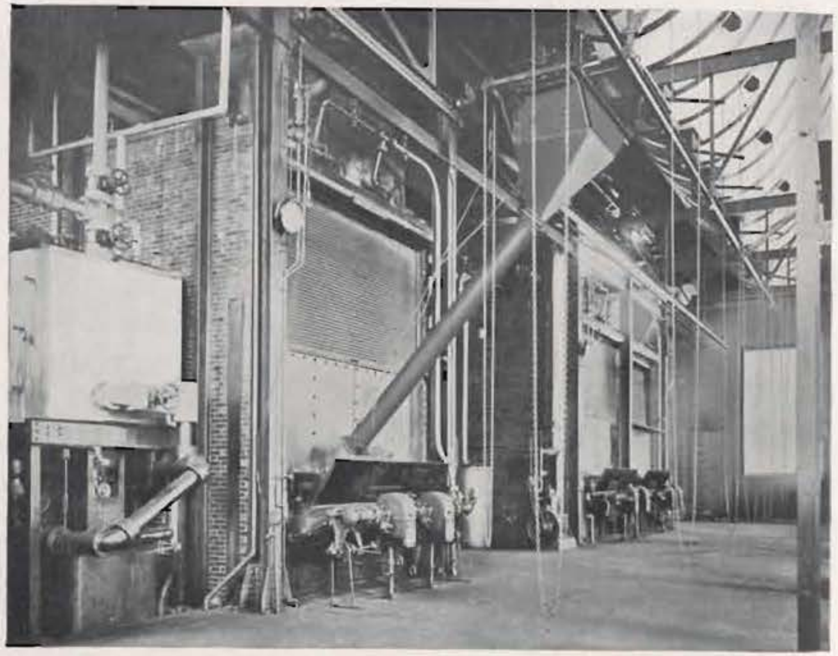
For large boilers and efficient furnaces the loss of heat from radiation and incomplete combustion may be as low as 5 per cent. of the gross calorific value instead of 10 per cent. as allowed, but the latter more nearly represents this loss for average operating conditions. The percentage of excess air will vary from 50 to 100 per cent. when furnaces are properly designed and given reasonably good attention.

EQUIVALENT EVAPORATION AND BAGASSE PER BOILER HORSEPOWER FOR 50 PER CENT. EXCESS AIR

Per cent. moisture in bagasse	25	30	35	40	45	50	55	60
Equiv. evap. from and at 212° per lb. wet bagasse, in lbs.	4.35	3.97	3.60	3.23	2.85	2.47	2.09	1.72
Wet bagasse per boiler horsepower, in lbs.	7.9	8.7	9.6	10.7	12.1	14.0	16.5	20.1

EQUIVALENT EVAPORATION AND BAGASSE PER BOILER HORSEPOWER FOR 100 PER CENT. EXCESS AIR

Per cent. moisture in bagasse	25	30	35	40	45	50	55	60
Equiv. evap. from and at 212° per lb. wet bagasse, in lbs.	4.16	3.79	3.43	3.07	2.70	2.34	1.97	1.61
Wet bagasse per boiler horsepower, in lbs.	8.3	9.1	10.1	11.2	12.8	14.7	17.5	21.4



Edge Moor boilers in the plant of the Society for Establishing Useful Manufactures, Paterson, N. J.

Combustion

ACCORDING to a well-established law of chemistry, there is a fixed and definite relation between the weight of a combustible and the weight of oxygen with which it unites during combustion.

Composition of Air.—In boiler practice the oxygen required for combustion is taken from the air. Besides those negligible substances such as ammonia, oxides of nitrogen, etc., there are present in air varying amounts, usually small, of carbon dioxide and water vapor. In the eastern states where the humidity often exceeds 75 per cent. at summer temperatures the percentage of water vapor may be as high as two per cent. Average proportions of oxygen and nitrogen in pure air free from moisture, as commonly given, are 20.91 parts oxygen to 79.09 parts nitrogen by volume, and 23.15 parts oxygen and 76.85 parts nitrogen by weight. The latter is equivalent to one pound of oxygen in 4.32 pounds of moisture-free air.

Air Required for Combustion.—The only elementary combustibles in fuels that need be considered in boiler practice are carbon, hydrogen and sulphur. The oxygen and air required for their combustion is given in the following table:

Oxygen and Air Theoretically Required for Complete Combustion

Combustible	Product of combustion	Oxygen required per pound of combustible	Moisture-free air per pound of combustible
Carbon	Carbon dioxide	2.66+ lbs.	11.5 lbs.
Hydrogen	Water	8.00 "	34.6 "
Sulphur	Sulphur dioxide	1.00 "	4.3 "

Air for Different Fuels.—If X represents the minimum weight of oxygen required for combustion in pounds per pound of fuel then

$$X = \frac{8}{3}C + 8\left(H - \frac{O}{8}\right) + S$$

where C, H, O and S represent the respective weights of carbon, hydrogen, oxygen and sulphur in a pound of fuel. The accompanying weight of nitrogen will be 3.32 X; and the weight of air, allowing 1 per cent. of water vapor, will be 4.36 X.

The proportions of these elementary combustibles in the common fuels vary considerably. Some analyses are given below.

VARIABLE COMPOSITION OF COMMON FUELS

Fuel	Composition—moisture included					Moisture per lb. fuel	B. T. U. per lb. as received
	Carbon	Hydrogen	Oxygen	Sulphur	Ash, etc.		
North Dakota lignite	0.394	0.068	0.438	0.007	0.093	0.362	6,700
Colorado lignite	.578	.060	.310	.004	.048	.207	9,941
Illinois bituminous	.609	.058	.192	.037	.104	.127	10,989
Ohio bituminous	.705	.054	.112	.029	.100	.052	12,733
Pennsylvania bituminous	.757	.054	.103	.012	.074	.035	13,700
Pennsylvania semi-bituminous	.807	.043	.032	.014	.104	.012	14,096
West Virginia semi-bituminous	.843	.047	.052	.007	.051	.031	14,688
Pennsylvania anthracite	.752	.028	.041	.008	.171	.021	12,472
California crude oil	.866	.116	.000	.008	.010	.000	18,565

By means of the formula and air ratio given above the air for each of these fuels was calculated, as follows:

MINIMUM WEIGHT OF AIR REQUIRED FOR DIFFERENT FUELS

Fuel	Air per lb. fuel Lbs.	Air per lb. combustible Lbs.	Air per 10,000 B. T. U. in fuel Lbs.
North Dakota lignite	5.0	9.2	7.54
Colorado lignite	7.5	9.9	7.53
Illinois bituminous	8.4	10.8	7.66
Ohio bituminous	9.7	11.2	7.63
Pennsylvania bituminous	10.3	11.3	7.50
Pennsylvania semi-bituminous	10.8	12.0	7.65
West Virginia semi-bituminous	11.2	12.1	7.65
Pennsylvania anthracite	9.6	11.9	7.66
California crude oil	14.1	14.2	7.59

It is seen that there is a wide variation in the air required per pound of fuel. The air per pound of combustible is more uniform and the air per 10,000 B. T. U. is almost the same throughout.

Heat of Combustion.—According to another law of chemical action, a definite amount of heat is evolved when a unit weight of combustible undergoes oxidation, that is, is burned. This heat of combustion, usually called "calorific value" varies somewhat under different physical conditions, which accounts for the variations in the values obtained by different investigators and given in the text-books.

APPROXIMATE CALORIFIC VALUES OF THE COMMON COMBUSTIBLES

Combustible	Product of combustion	Heat evolved per pound of combustible
Carbon (C)	Carbon monoxide (CO)	4,450 B. T. U.
Carbon (C)	Carbon dioxide (CO_2)	14,540 "
Hydrogen (H)	Water (H_2O)	62,030 "
Sulphur (S)	Sulphur dioxide (SO_2)	4,050 "
Carbon monoxide (CO)	Carbon dioxide (CO_2)	4,300 "
Ethylene (C_2H_4)	Carbon dioxide (CO_2) and water (H_2O)	21,500 "
Methane (CH_4)	Carbon dioxide (CO_2) and water (H_2O)	23,550 "

Calculating Calorific Values.—It has been established (see *Technical Paper 76*, 1914, Bureau of Mines, p. 43) that the calorific value of anthracite, semibituminous and bituminous coals can be calculated from an ultimate analysis to an accuracy of about $1\frac{1}{2}$ per cent. by means of Dulong's formula, as follows:

$$\text{B. T. U. per pound} = 14{,}540\,C + 62{,}030\left(H - \frac{O}{8}\right) + 4050\,S$$

where C, H, O and S are, as before, the weights of carbon, hydrogen, oxygen and sulphur in a pound of fuel. The constants used in the above formula are equivalent to those recommended by a committee of the American Chemical Society (*Jour. Am. Chem. Soc.*, vol. 21, p. 1130). The accuracy mentioned above is with reference to the calorific value obtained with a bomb calorimeter. This formula will not give such accurate results when applied to fuels rich in volatile matter as peat, lignite and crude oil.

Importance of Ignition Temperatures.—No matter how much oxygen is brought in contact with a combustible it will not "catch fire" unless it is at or above a certain temperature. This temperature of ignition varies for different substances and, to a lesser extent, for the same substance under different physical conditions. This accounts for the variation in ignition temperatures given in different text-books. The following are the Fahrenheit equivalents of those given in *Fuel*, by J. S. S. Brame.

Combustible	Temperature of ignition
Hydrogen	1070 to 1090 degrees F.
Carbon monoxide	1191 to 1216 "
Methane	1200 to 1240 "
Acetylene	760 to 825 "
Bituminous coal	750 to 800 "
Anthracite coal	Appr. 925 "

Every experienced fireman is aware of the difficulty of trying "to make steam" when the furnace walls are cold or when the fuel bed is in such bad condition that a large amount of excess air enters the furnace and chills the fire. The object of keeping the furnace hot is, of course, to keep the temperature well above the ignition temperatures of the solid fuel and volatiles. If carbon monoxide is not burned before the temperature falls below about 1200° F. then further combustion will not take place no matter how much excess air is present. The result is "the loss due to carbon monoxide."

Reducing Fuel to Equivalent Gases.—In boiler and chimney calculations it is often desirable to determine the weight and volume of gases involved. Practically, the true combustibles in the bituminous, semi-bituminous and anthracite coals are total carbon, available hydrogen $(H-\frac{O}{8})$ and sulphur. The proportion of available hydrogen to total carbon in coal is somewhere near one part available hydrogen to twenty parts carbon. On the assumptions that this proportion will be representative for the average coal, that the sulphur can be neglected, and that all carbon is burned to CO_2, the data in the next following table were calculated.

Weight and Volume of Gas per Horsepower.—The weight of gas per boiler horsepower can be determined approximately by the formula

$$W = \frac{33480\, w}{10000\, E}$$

where W is the weight of gas in pounds per hour per boiler horsepower, w is the weight of gas corresponding to an assumed CO_2 from the table following and E is the efficiency of boiler and furnace.

The total water vapor in the gases, including moisture in coal and air and that formed from the combustion of hydrogen, amounts to only a few per cent. of the total weight except in extreme cases, and therefore may be neglected.

WEIGHT OF GAS AND CHIMNEY LOSSES FOR DIFFERENT PERCENTAGES OF CO_2

Per cent. CO_2 in dry gases by volume	18.7	18.0	17.0	16.0	15.0	14.0	13.0	12.0
Excess air in per cent. of theoretical minimum	0	4	10	17	24	33	43	54
Weight of dry gas per 10,000 B. T. U. in the coal in lbs.	7.8	8.1	8.6	9.1	9.6	10.3	11.0	11.9
Chimney loss per 100° F. in per cent. of the calorific value of the coal	1.85	1.92	2.04	2.16	2.28	2.44	2.61	2.82
Chimney loss per 500° F. in per cent.	9.25	9.60	10.20	10.80	11.40	12.20	13.05	14.10

WEIGHT OF GAS AND CHIMNEY LOSSES—Continued

Per cent. CO_2 in dry gases by volume	11.0	10.0	9.0	8.0	7.0	6.0	5.0
Excess air in per cent. of theoretical minimum	68	85	105	130	162	206	267
Weight of dry gas per 10,000 B. T. U. in the coal in lbs.	12.9	14.2	15.7	17.6	20.0	23.3	27.8
Chimney loss per 100° F. in per cent. of the calorific value of the coal	3.06	3.37	3.72	4.17	4.74	5.52	6.59
Chimney loss per 500° F. in per cent.	15.30	16.85	18.60	20.85	23.70	27.60	32.95

The volume may be calculated from the formula

$$Q = \frac{6.73\,(t + 459.6)}{1{,}000{,}000}\, W$$

where Q is the volume of gas in cubic feet per second per boiler horsepower, t is the temperature of the gases in degrees Fah. and W is the weight of gases in pounds per hour per boiler horsepower.

Effect of Excess Air on Boiler Efficiency.—Referring to the percentages of chimney losses given in the table above it is seen that the loss per 500 degrees for 13 per cent. CO_2, which may be taken as representative of good furnace conditions, is 13.05 per cent., while for 7 per cent. CO_2 it is 23.7 per cent., or a decrease in efficiency of 10.65 per cent. Actually, the decrease is greater because, in general, the flue temperature rises when the excess air in the furnace is increased, the rate of steaming remaining the same. Another detrimental effect of excess air is reduction of available draft because of the increased volume of gas passing through fuel bed, boiler, breeching, and chimney.

The Three Factors of Efficiency.—Figuratively, the boiler is that part of the power plant where *money is burned* to make power. From an economic standpoint it is therefore the place where the greatest saving can be effected and where the greatest waste is possible. The efficiency of the boiler room may be represented by the formula

$$E = S \times B \times O$$

where E is the all-over efficiency of the boiler room; S is the stoker efficiency including grate, stoker proper and furnace, and adaptability of the stoker to the fuel burned; B is the boiler efficiency including boiler and setting; and O is the operating efficiency including both firing and maintenance labor. If any one of these factors is low the all-over efficiency must be correspondingly low. A high all-over efficiency requires high individual efficiencies for each of the three factors involved.

Water and Steam

WHERE heat is to be evolved in one place, transported and used in another, as in the steam plant, some carrier for the heat must be employed, since heat is transportable only when associated with matter. Of the substances that have been tried for this purpose water has proved to be preëminent because of its thermal properties, its fluidity, its abundance, and its low chemical activity. But water is not found in nature in the pure state, hence arise those complications for eliminating or neutralizing the impurities which come under "feed water treatment".

Effects of Impurities.—The objectionable effects of impurities depend on the relative amounts of each present, on the aggregate of all impurities and on the chemical or physical effects that one impurity has on another under the conditions that exist within a boiler. Impurities are usually reported in "grains per gallon", or "parts per million" by weight.

Corrosion.—The term "corrosion" as used in boiler practice means the eating away of metal by chemical action. When the metal is attacked only in spots, it is said to be pitted, when the action is the result of moisture in contact with exterior parts of the boiler, the metal is said to be "rusted". The most common causes of internal corrosion are acids, dissolved carbon dioxide, air in solution or sucked in by the feed pump, chloride and sulphate of magnesium, sea water, grease, and sewage.

Priming.—Since steam is generated in the midst of water, there is a tendency for particles of water to cling to the bubbles of steam. The carrying over of water with steam is called "priming". In properly designed boilers using fairly good feed water the amount of water carried over with the steam will ordinarily not exceed one and one-half parts in a hundred by weight, or (roughly) one part in about 10,000 by volume. The steam is then said to be "dry". When the percentage of moisture by weight exceeds two or three per cent. the steam is said to be "wet" and the boiler is said to "prime". The water may go over as a spray, in "slugs", or in a continuous stream. When there are sudden fluctuations of the water level in the gauge glass, indicating violent disturbances of the surface of the water, "foaming" is said to take place. Usually, foaming is accompanied by heavy priming. When the design of the boiler is not at fault, priming alone results from high concentrations of the readily soluble salts such as sodium chloride (common salt), sodium carbonate (soda ash), and sodium sulphate. Foaming is caused by accumulations of scummy matter at the water level, usually either from grease, sewage and other organic matter, or through the cementing action of the carbonates of calcium and magnesium on the solid particles in the water.

Incrustation.—The impurities in water are either dissolved or held in suspension. When ordinary water passes into a boiler, the pure water is driven off and removed as steam, while the impurities, both dissolved and suspended, are left behind. Since there is a limit to the solubility of every substance, the excess of the soluble matter will be thrown down as "precipitates" which, together with the solid matter in suspension, will accumulate in different parts of the boiler as "incrustations".

Certain substances, like the readily soluble salts are deposited as a sludge; others, like calcium carbonate, form a soft porous scale; while others, like the sulphate of calcium alone or in admixture with mud, oxide of silica, etc., bake on the boiler surface into a flinty scale which is very difficult and expensive to remove.

Tube Failures.—Tubes sometimes fail from pitting or general corrosion, but most often from overheating. The grades of steel used in the manufacture of tubes are excellent conductors of heat, but when these become coated with substances that offer a high resistance to the passage of heat, such as hard scale or oil, the cooling effect of the water and steam on the inside of the tubes is greatly diminished and the metal becomes overheated. This results in two kinds of destructive action: (1) The outside surface of the tube is attacked and eaten away by the steam and free oxygen in the gases of combustion; the result is a "burn" or "scab". (2) The metal becomes more ductile and is stretched by the internal pressure; the result is a "bag" or "blister". When either kind of action is allowed to go far enough, the weakened metal will burst open, often with very serious results.

This action usually takes place in portions of the two bottom rows of tubes nearest the fire, and nearly always in spots on account of the uneven distribution of the scale or oil. It is therefore of prime importance not to allow more than a very little scale to accumulate in the tubes in these rows, and every effort should be made to keep oil and grease out of a boiler, because a very little is apt to cause serious trouble. If it is known or suspected that the tubes are heavily coated with scale, or that oil has entered the boiler, the fire should be kept as low as possible until the boiler can be taken out of service.

Treatment of Feed Water.—The various methods of treating feed water are classified as follows: (1) Filtration with or without the aid of some coagulant like alum for removing visible impurities. (2) Chemical

treatment within or without the boiler which precipitates or neutralizes the harmful impurities in solution. (3) Heating of water, as in exhaust or live-steam heaters, which makes use of the precipitating effects of higher temperatures on the carbonate and sulphate of calcium. (4) The use of substances like petroleum or graphite which form a thin coating on the metallic surface and prevent scale from adhering to it. (5) Combinations of two or more of the above, as in water-softening plants.

There is no single remedy or "compound" that is effective for all boiler waters. In every case the remedy must be chosen with especial regard to the impurities in the particular water to be treated. Where the water is bad and the method of treatment is not satisfactory, the problem should be submitted to a competent chemist or engineer who has had experience in this field.

Use of Caustic Lime and Soda Ash—The substances most commonly used for treating feed water are caustic lime (CaO) and sodium carbonate (Na_2CO_3). Crude caustic lime is the same as "builders' lime". Impure carbonate of soda is known as "soda ash" or "crude soda". Caustic lime is much used for the precipitation of the bicarbonates before the water is pumped to the boiler. A typical reaction is as follows:

Calcium bicarbonate + Caustic lime = Calcium carbonate + Water

$$CaH_2(CO_3)_2 + CaO = 2CaCO_3 + H_2O$$

The soluble bicarbonate is reduced to the insoluble carbonate which is precipitated and can be removed by filtration.

Sodium carbonate (soda ash) is used to precipitate certain sulphates, thus:

Calcium sulphate + Sodium carbonate = Sodium sulphate + Calcium carbonate

$$CaSO_4 + Na_2CO_3 = Na_2SO_4 + CaCO_3$$

The calcium sulphate, which will bake into a very hard scale if precipitated within the boiler, is chemically replaced by sodium sulphate which is very soluble and does not form scale. The calcium carbonate formed is precipitated and may be removed by filtration if the treatment is external, or if the treatment is internal, as when soda ash is fed to the boiler direct, the calcium carbonate may be removed in part by blowing off. The residue will form a soft scale which is much less objectionable than that from calcium sulphate.

Both caustic lime and soda ash are much used to neutralize acids;

also, soda ash is very effective for removing oil from within a boiler. There is a limit to the amount of soda ash that can be injected into a boiler without causing priming.

Testing for Sea Water.—The objectionable effects of sea water are well known. In plants equipped with surface condensers and using sea water for condensing, it is common practice to check the tightness of the condensers once every hour or oftener by treating a sample of the condensate with a test solution of nitrate of silver, which can be bought at a drug store. Plants situated near the sea coast, and using river water for the boilers, sometimes get salty water during the dry season. When this occurs precautions should be taken to guard against priming and foaming especially. To keep down the concentration of salt, the blow-off should be used frequently, once every four hours or oftener, when the amount of salt in the water has reached about 600 grains per gallon. The blow-off should be opened quickly when piping conditions permit and should be left open only a few seconds at a time. The most practical way to determine the concentration is with the instrument used to determine the specific gravity of liquids—the hydrometer. 600 grains per gallon corresponds to a specific gravity of about 1.01, or to about 1.5 degrees Baumè. Boilers using salty water should not be forced, as objectionable results are increased thereby.

Where to Sample Water.—It is obvious that the quality of water within a boiler may be very different from the water delivered to it by the feed pump on account of continuous concentration and the chemical effects which take place at the higher temperatures. Hence, to determine the cause of troublesome results from feed water, the sample must be representative of the water in circulation within the boiler. It is recommended that samples of water from Edge Moor boilers be drawn through the lower water-column pipe, the mouth of which is in the active part of the drum, either by means of a special connection, or through the water-column drain. The water column should be blown out thoroughly immediately before taking a sample. The sample should be taken while the boiler is in active service, when the impurities will be distributed throughout the water.

Steam Calorimeters.—The percentage of moisture in steam, if any, is determined by means of a steam calorimeter. The throttling type is used when the percentage of moisture will not exceed about 4 per cent. by weight for pressures of 100 pounds and over. For moisture in excess of this the separating calorimeter must be used. Since steam

containing more than 4 per cent. of moisture would hardly be tolerated in a modern plant the throttling calorimeter alone is ordinarily sufficient for testing purposes.

Both construction and theory of the throttling calorimeter are very simple. It is merely an orifice with provision for determining temperature or pressure of the steam, or both, before and after passage through the orifice, and it is constructed mechanically to minimize the loss of heat by radiation and conduction. By the law of conservation of energy, the heat on both sides of the orifice must be the same (assuming no loss); hence the formula

$$x = 100\frac{H - U - k\,(t - t_o)}{H - h}$$

where x is the percentage of moisture in the steam by weight, H the total heat above 32° F. of one pound of saturated steam at the initial pressure, U the total heat above 32° F. of one pound of saturated steam at the final pressure, k the specific heat of superheated steam at the final pressure, t the observed temperature of the steam discharged from the calorimeter in degrees F., t_o the temperature in degrees F. corresponding to saturated steam at the final pressure, and h the heat of the water above 32° F. at the initial pressure.

If the discharge is into the atmosphere at a pressure of 14.7 lbs. per sq. in., $U = 1150.4$, $k = 0.47$ appr., and $t_o = 212$. The formula is then

$$x = 100\frac{H - 1150.4 - 0.47\,(t - 212)}{H - h}$$

H and h may be taken directly from Marks and Davis steam tables.

Determining the Source of Priming.—Because wet steam is received at an engine, it does not necessarily follow that the moisture originates at the boiler. In several investigations made by our engineering department where there was unmistakable evidence of very wet steam, the cause was traced to defective drainage of the steam piping and the "priming" stopped as soon as the drainage was corrected.

The proper instrument for determining moisture is, of course, the throttling calorimeter but such an instrument, or several of them, is not always available. In lieu of this an ordinary ¼ in. air cock can be used. To illustrate, suppose very wet steam is received at the throttle of an engine and it is desired to find where the moisture originates. The first suspicion would probably be directed to the boiler. Therefore tap a horizontal section of the steam pipe near the boiler nozzle at the sides or top, but not at the bottom, and install a ¼ in. air cock. With the boiler in service open the cock until a jet of steam flows freely and observe the character of the discharge.

If the steam within a pipe does not contain more than a few per cent. of moisture, the discharge into the atmosphere will become superheated on account of the reduced pressure. Now superheated steam is almost colorless and feels cool and dry when the hand is passed through it, but wet steam will burn the hand and, of course, looks wet. To observe this, install the cock where steam is known to be practically dry or superheated but interpose a piece of ¼ in. pipe about 18 inches long between the steam pipe and cock. Wrap some lagging around the ¼ in. pipe, open the pet cock and let the steam flow until the pipe is thoroughly heated. The discharge should be as described above for superheated steam. Then remove the lagging and pour cold water on the ¼ in. pipe to chill the steam inside. The change in the nature of the discharge will be unmistakable.

Returning to the assumed case, if the steam at the boiler is found to be dry then install one or more cocks along the steam line, and try each until the source of the trouble is found. A "dip" in the piping is a frequent cause of wet steam.

Properties of Saturated and Superheated Steam[1]

Marks and Davis

Temperature in degrees Fahrenheit.................. T
Temperature Fahrenheit absolute .... T +459.6°
Specific volume in cubic feet per pound............. V
Total heat per pound above 32° in B. T. U.......... H

Press. Lbs. Gauge	Press. Lbs. Abs.		Water	Sat. Steam	Superheated Steam—Degrees of Superheat 50°	60°	70°	80°	90°	100°	110°	120°	130°
85.3	100	T	327.8	327.8	377.8	387.8	397.8	407.8	417.8	427.8	437.8	447.8	457.8
		V	0.02	4.43	4.79	4.86	4.93	5.00	5.07	5.14	5.21	5.27	5.34
		H	298.3	1186.3	1213.8	1219.1	1224.3	1229.5	1234.6	1239.7	1244.7	1249.7	1254.7
90.3	105	T	331.4	331.4	381.4	391.4	401.4	411.4	421.4	431.4	441.4	451.4	461.4
		V	0.02	4.23	4.58	4.65	4.71	4.78	4.84	4.91	4.97	5.04	5.10
		H	302.0	1187.2	1214.9	1220.2	1225.4	1230.6	1235.7	1240.8	1245.9	1250.9	1255.9
95.3	110	T	334.8	334.8	384.8	394.8	404.8	414.8	424.8	434.8	444.8	454.8	464.8
		V	0.02	4.05	4.38	4.45	4.51	4.57	4.64	4.70	4.76	4.83	4.89
		H	305.5	1188.0	1215.9	1221.2	1226.5	1231.7	1236.9	1242.0	1247.1	1252.1	1257.1
100.3	115	T	338.1	338.1	388.1	398.1	408.1	418.1	428.1	438.1	448.1	458.1	468.1
		V	0.02	3.88	4.20	4.27	4.33	4.39	4.45	4.51	4.57	4.63	4.69
		H	309.0	1188.8	1216.9	1222.3	1227.6	1232.8	1237.9	1243.1	1248.2	1253.2	1258.2
105.3	120	T	341.3	341.3	391.3	401.3	411.3	421.3	431.3	441.3	451.3	461.3	471.3
		V	0.02	3.73	4.04	4.10	4.16	4.22	4.28	4.33	4.39	4.45	4.50
		H	312.3	1189.6	1217.9	1223.3	1228.6	1233.8	1238.9	1244.1	1249.2	1254.2	1259.3
110.3	125	T	344.4	344.4	394.4	404.4	414.4	424.4	434.4	444.4	454.4	464.4	474.4
		V	0.02	3.58	3.88	3.94	4.00	4.06	4.11	4.17	4.22	4.28	4.33
		H	315.5	1190.3	1218.8	1224.2	1229.5	1234.8	1240.0	1245.1	1250.2	1255.3	1260.4
115.3	130	T	347.4	347.4	397.4	407.4	417.4	427.4	437.4	447.4	457.4	467.4	477.4
		V	0.02	3.45	3.74	3.80	3.85	3.91	3.96	4.02	4.07	4.13	4.18
		H	318.6	1191.0	1219.7	1225.1	1230.4	1235.7	1240.9	1246.1	1251.2	1256.3	1261.4
120.3	135	T	350.3	350.3	400.3	410.3	420.3	430.3	440.3	450.3	460.3	470.3	480.3
		V	0.02	3.33	3.61	3.67	3.72	3.77	3.83	3.88	3.93	3.98	4.03
		H	321.7	1191.6	1220.6	1226.1	1231.4	1236.6	1241.8	1247.0	1252.1	1257.2	1262.3
125.3	140	T	353.1	353.1	403.1	413.1	423.1	433.1	443.1	453.1	463.1	473.1	483.1
		V	0.02	3.22	3.49	3.54	3.60	3.65	3.70	3.75	3.80	3.85	3.90
		H	324.6	1192.2	1221.4	1226.8	1232.2	1237.5	1242.8	1248.0	1253.1	1258.2	1263.3
130.3	145	T	355.8	355.8	405.8	415.8	425.8	435.8	445.8	455.8	465.8	475.8	485.8
		V	0.02	3.12	3.38	3.43	3.48	3.53	3.58	3.63	3.68	3.72	3.77
		H	327.4	1192.8	1222.2	1227.7	1233.1	1238.4	1243.6	1248.8	1254.0	1259.1	1264.2
135.3	150	T	358.5	358.5	408.5	418.5	428.5	438.5	448.5	458.5	468.5	478.5	488.5
		V	0.02	3.01	3.27	3.32	3.37	3.42	3.46	3.51	3.56	3.61	3.66
		H	330.2	1193.4	1223.0	1228.5	1233.9	1239.2	1244.4	1249.6	1254.8	1259.9	1265.0

[1] Abstracted by permission from "Steam Tables and Diagrams" (copyright) by Marks and Davis. Published by Longmans, Green & Co.

Press. Lbs.			Water	Sat. Steam	Superheated Steam—Degrees of Superheat								
Gauge	Abs.				50°	60°	70°	80°	90°	100°	110°	120°	130°
140.3	155	T	361.0	361.0	411.0	421.0	431.0	441.0	451.0	461.0	471.0	481.0	491.0
		V	0.02	2.92	3.17	3.22	3.27	3.31	3.36	3.41	3.46	3.50	3.55
		H	332.9	1194.0	1223.6	1229.2	1234.7	1240.0	1245.2	1250.5	1255.7	1260.8	1265.9
145.3	160	T	363.6	363.6	413.6	423.6	433.6	443.6	453.6	463.6	473.6	483.6	493.6
		V	0.02	2.83	3.07	3.12	3.17	3.21	3.26	3.30	3.35	3.40	3.44
		H	335.6	1194.5	1224.5	1230.0	1235.5	1240.8	1246.1	1251.3	1256.5	1261.6	1266.7
150.3	165	T	366.0	366.0	416.0	426.0	436.0	446.0	456.0	466.0	476.0	486.0	496.0
		V	0.02	2.75	2.99	3.04	3.08	3.12	3.17	3.21	3.26	3.30	3.35
		H	338.2	1195.0	1225.2	1230.7	1236.1	1241.5	1246.8	1252.0	1257.2	1262.3	1267.4
155.3	170	T	368.5	368.5	418.5	428.5	438.5	448.5	458.5	468.5	478.5	488.5	498.5
		V	0.02	2.68	2.91	2.95	3.00	3.04	3.08	3.12	3.17	3.21	3.25
		H	340.7	1195.4	1225.9	1231.5	1237.0	1242.3	1247.6	1252.8	1258.0	1263.1	1268.2
160.3	175	T	370.8	370.8	420.8	430.8	440.8	450.8	460.8	470.8	480.8	490.8	500.8
		V	0.02	2.60	2.83	2.87	2.91	2.96	3.00	3.04	3.08	3.12	3.16
		H	343.2	1195.9	1226.6	1232.2	1237.7	1243.0	1248.3	1253.6	1258.8	1263.9	1269.0
165.3	180	T	373.1	373.1	423.1	433.1	443.1	453.1	463.1	473.1	483.1	493.1	503.1
		V	0.02	2.53	2.75	2.80	2.84	2.88	2.92	2.96	3.00	3.04	3.08
		H	345.6	1196.4	1227.2	1232.8	1238.4	1243.8	1249.1	1254.3	1259.5	1264.6	1269.7
170.3	185	T	375.4	375.4	425.4	435.4	445.4	455.4	465.4	475.4	485.4	495.4	505.4
		V	0.02	2.47	2.68	2.72	2.76	2.81	2.85	2.89	2.93	2.97	3.01
		H	348.0	1196.8	1227.9	1233.5	1239.0	1244.4	1249.7	1255.0	1260.2	1265.3	1270.5
175.3	190	T	377.6	377.6	427.6	437.6	447.6	457.6	467.6	477.6	487.6	497.6	507.6
		V	0.02	2.41	2.62	2.66	2.70	2.74	2.78	2.81	2.85	2.89	2.93
		H	350.4	1197.3	1228.6	1234.3	1239.8	1245.1	1250.4	1255.7	1260.9	1266.1	1271.2
180.3	195	T	379.8	379.8	429.8	439.8	449.8	459.8	469.8	479.8	489.8	499.8	509.8
		V	0.02	2.35	2.55	2.59	2.63	2.67	2.71	2.75	2.78	2.82	2.86
		H	352.7	1197.7	1229.2	1234.9	1240.4	1245.8	1251.1	1256.4	1261.6	1266.7	1271.9
185.3	200	T	381.9	381.9	431.9	441.9	451.9	461.9	471.9	481.9	491.9	501.9	511.9
		V	0.02	2.29	2.49	2.53	2.57	2.61	2.64	2.68	2.72	2.76	2.79
		H	354.9	1198.1	1229.8	1235.5	1241.1	1246.5	1251.8	1257.1	1262.3	1267.4	1272.5
190.3	205	T	384.0	384.0	434.0	444.0	454.0	464.0	474.0	484.0	494.0	504.0	514.0
		V	0.02	2.24	2.44	2.47	2.51	2.55	2.58	2.62	2.66	2.69	2.73
		H	357.1	1198.5	1230.4	1236.1	1241.7	1247.1	1252.4	1257.7	1262.9	1268.0	1273.2
195.3	210	T	386.0	386.0	436.0	446.0	456.0	466.0	476.0	486.0	496.0	506.0	516.0
		V	0.02	2.19	2.38	2.42	2.45	2.49	2.53	2.56	2.60	2.63	2.67
		H	359.2	1198.8	1231.0	1236.7	1242.3	1247.7	1253.1	1258.4	1263.6	1268.7	1273.8
200.3	215	T	388.0	388.0	438.0	448.0	458.0	468.0	478.0	488.0	498.0	508.0	518.0
		V	0.02	2.14	2.33	2.36	2.40	2.43	2.47	2.51	2.54	2.57	2.61
		H	361.4	1199.2	1231.6	1237.3	1242.9	1248.3	1253.7	1259.0	1264.2	1269.3	1274.5
205.3	220	T	389.9	389.9	439.9	449.9	459.9	469.9	479.9	489.9	499.9	509.9	519.9
		V	0.02	2.09	2.28	2.31	2.35	2.38	2.42	2.45	2.49	2.52	2.55
		H	363.4	1199.6	1232.2	1237.9	1243.5	1248.9	1254.3	1259.6	1264.8	1269.9	1275.1

Press. Lbs.			Water	Sat. Steam	Superheated Steam—Degrees of Superheat								
Gauge	Abs.				50°	60°	70°	80°	90°	100°	110°	120°	130°
210.3	225	T	391.9	391.9	441.9	451.9	461.9	471.9	481.9	491.9	501.9	511.9	521.9
		V	0.02	2.05	2.23	2.26	2.30	2.33	2.37	2.40	2.43	2.47	2.50
		H	365.5	1199.9	1232.7	1238.5	1244.1	1249.5	1254.9	1260.2	1265.4	1270.5	1275.7
215.3	230	T	393.8	393.8	443.8	453.8	463.8	473.8	483.8	493.8	503.8	513.8	523.8
		V	0.02	2.00	2.18	2.22	2.25	2.28	2.32	2.35	2.38	2.42	2.45
		H	367.5	1200.2	1233.2	1239.0	1244.7	1250.1	1255.4	1260.7	1266.0	1271.1	1276.3
220.3	235	T	395.6	395.6	445.6	455.6	465.6	475.6	485.6	495.6	505.6	515.6	525.6
		V	0.02	1.96	2.14	2.17	2.21	2.24	2.27	2.30	2.34	2.37	2.40
		H	369.4	1200.6	1233.8	1239.6	1245.2	1250.7	1256.1	1261.4	1266.6	1271.7	1276.9
225.3	240	T	397.4	397.4	447.4	457.4	467.4	477.4	487.4	497.4	507.4	517.4	527.4
		V	0.02	1.92	2.09	2.13	2.16	2.20	2.23	2.26	2.29	2.32	2.35
		H	371.4	1200.9	1234.3	1240.1	1245.8	1251.3	1256.6	1261.9	1267.1	1272.3	1277.5
230.3	245	T	399.3	399.3	449.3	459.3	469.3	479.3	489.3	499.3	509.3	519.3	529.3
		V	0.02	1.89	2.05	2.09	2.12	2.15	2.18	2.22	2.25	2.28	2.31
		H	373.3	1201.2	1234.8	1240.7	1246.3	1251.8	1257.2	1262.5	1267.7	1272.8	1278.0
235.3	250	T	401.0	401.0	451.0	461.0	471.0	481.0	491.0	501.0	511.0	521.0	531.0
		V	0.02	1.85	2.02	2.05	2.08	2.11	2.14	2.17	2.21	2.24	2.27
		H	375.2	1201.5	1235.4	1241.3	1246.9	1252.3	1257.7	1263.0	1268.2	1273.4	1278.6
240.3	255	T	402.8	402.8	452.8	462.8	472.8	482.8	492.8	502.8	512.8	522.8	532.8
		V	0.02	1.81	1.98	2.01	2.04	2.07	2.11	2.14	2.17	2.20	2.23
		H	377.1	1201.8	1235.9	1241.8	1247.4	1252.9	1258.3	1263.6	1268.8	1273.9	1279.1
245.3	260	T	404.5	404.5	454.5	464.5	474.5	484.5	494.5	504.5	514.5	524.5	534.5
		V	0.02	1.78	1.94	1.97	2.00	2.04	2.07	2.10	2.13	2.16	2.19
		H	378.9	1202.1	1236.4	1242.3	1247.9	1253.4	1258.8	1264.1	1269.3	1274.5	1279.6
250.3	265	T	406.2	406.2	456.2	466.2	476.2	486.2	496.2	506.2	516.2	526.2	536.2
		V	0.02	1.75	1.91	1.94	1.97	2.00	2.03	2.06	2.09	2.12	2.15
		H	380.7	1202.3	1236.9	1242.8	1248.4	1253.9	1259.3	1264.6	1269.8	1275.0	1280.2

$$\text{Factor of evaporation} = \frac{H - h}{970.4}$$

where H is the total heat as given in the tables and h is the heat in the feed-water entering the boiler. h is almost equal to the temperature of the water, in degrees Fah.. minus 32.

Proportioning Flues and Chimneys

IN 1884 William Kent published a simple formula for proportioning chimneys for coal burning plants, together with a table of chimney capacities calculated therefrom (Trans. A. S. M. E., vol. vi, p. 81). When this table was published, and for many years afterward, coal was almost universally hand fired with natural draft and boilers were not operated

Chimney Sizes by Kent's Formula

Inside diam., inches	Area, square feet	Height in feet.									
		90	100	110	125	150	175	200	225	250	300
		* Commercial boiler horsepower									
30	4.91	113	119	..	..	..	..	..	..	..	..
33	5.94	141	149	156	..	..	..	..	..	..	..
36	7.07	173	182	191	204	..	..	..	..	..	..
39	8.30	208	219	229	245	268	..	..	..	..	..
42	9.62	245	258	271	289	316	342	..	..	..	..
48	12.57	330	348	365	389	426	460	492	..	..	..
54	15.90	427	449	472	503	551	595	636	675	..	..
60	19.64	536	565	593	632	692	748	800	848	894	..
66	23.76	..	694	728	776	849	918	981	1040	1097	1201
72	28.27	..	835	876	934	1023	1105	1181	1253	1320	1447
78	33.18	..	..	1038	1107	1212	1310	1400	1485	1565	1715
84	38.48	..	..	1214	1294	1418	1531	1637	1736	1830	2005
90	44.18	..	..	..	1496	1639	1770	1893	2008	2116	2318
96	50.27	..	..	..	1712	1876	2027	2167	2298	2423	2654
102	56.75	..	..	..	1944	2130	2300	2459	2609	2750	3012
108	63.62	..	..	..	2090	2399	2592	2771	2939	3098	3393
114	70.88	..	..	..	..	2685	2900	3100	3288	3466	3797
120	78.54	..	..	..	..	2986	3226	3448	3657	3855	4223
132	95.03	..	..	..	..	3637	3929	4200	4455	4696	5144
144	113.10	..	..	..	..	4352	4701	5026	5331	5618	6155

*Based on five pounds of coal burned per hour per Bl. H.P. For limitations see Kent's Handbook.

at much above rated capacity. For this practice, with medium grade bituminous coal and short direct flues, chimneys according to Kent's table have generally given satisfactory results.

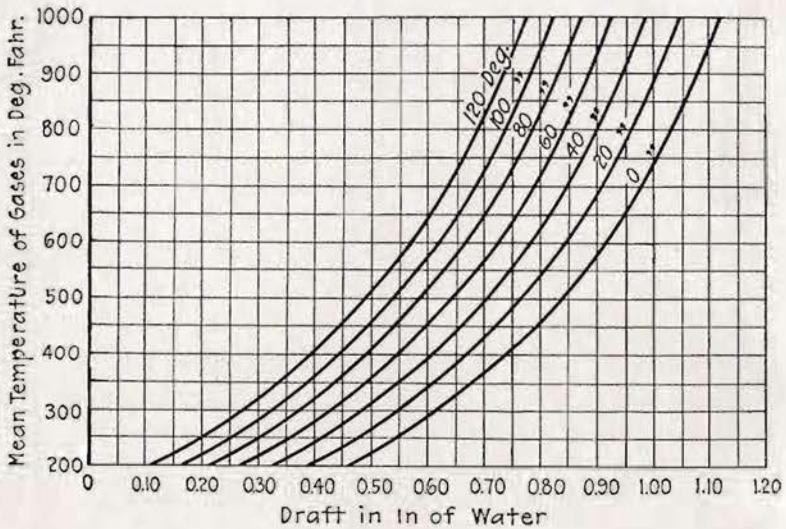
Later developments in boiler plant practice have introduced complex factors which vary greatly for the same boiler horsepower developed. Fuels other than coal have come into extensive use; the hand firing of coal has been largely superseded by mechanical stokers with both natural and forced draft; boilers of different types, and the same boiler differently baffled, have friction losses which are far from uniform for the same volume of gases passing through the setting; and maximum rates of steam generation per square foot of heating surface have increased from two to three times the customary rate when Kent's formula was deduced. As a consequence other methods have been suggested for determining the size of a chimney.

For the general case, because of the great variation in the factors involved, there can be no simple relation between the size of a chimney and either the maximum amount of fuel which can be burned through its draft producing power or the maximum amount of steam which the boilers connected to it can generate. Since a chimney is analogous to an induced draft fan, which sucks gas through a series of complex conduits and discharges it into the atmosphere, methods have been suggested for proportioning a chimney based on the laws commonly used for the transmission of fluids.

Because the density of the hot gases within a chimney is less than the density of the surrounding air a chimney produces a suction, or draft, which induces gas to flow into it. Draft is the same as pressure difference and may be expressed in any unit of pressure. The common unit is the inch of water column and the common instrument for measuring it is the draft gauge, which is made in various forms.

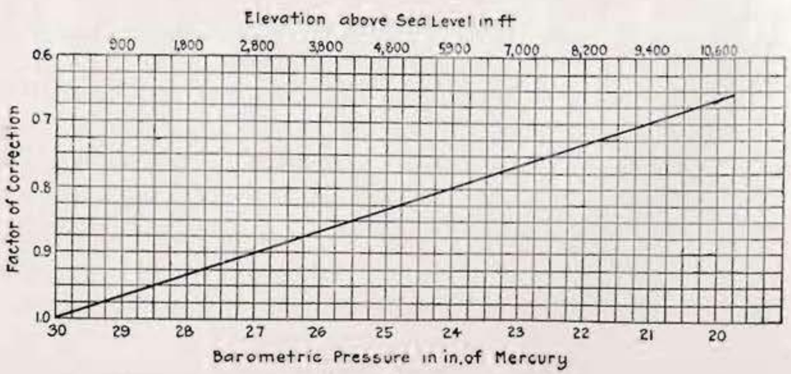
Maximum Draft of a Chimney.—If a draft gauge is connected to a chimney just above the point where the gases enter, the draft indicated is the effective draft of the chimney. If the flow of gases could be gradually reduced without altering the temperature of the gases, so as to diminish the loss by friction in the chimney, the draft indicated would increase and become a maximum when the flow is zero.

This maximum draft of the chimney depends primarily on the temperature of the external air, the temperature of the gases entering the chimney, the height of the chimney and the altitude of location. Wind, humidity, variation of the barometric pressure from the normal, variation in the composition of gases and cooling of gases in the chimney also affect the maximum draft, but generally to a minor extent. In practice it is customary to determine the maximum draft from temperature of air, temperature of chimney gases, altitude and height. This may be obtained from the accompanying curves (taken from Trans. A. S. M. E., vol. 37, pp. 1075, 1076).



MAXIMUM DRAFT AT SEA LEVEL PER 100 FT. OF CHIMNEY HEIGHT CORRESPONDING TO THE AIR TEMPERATURES NOTED ON THE CURVES

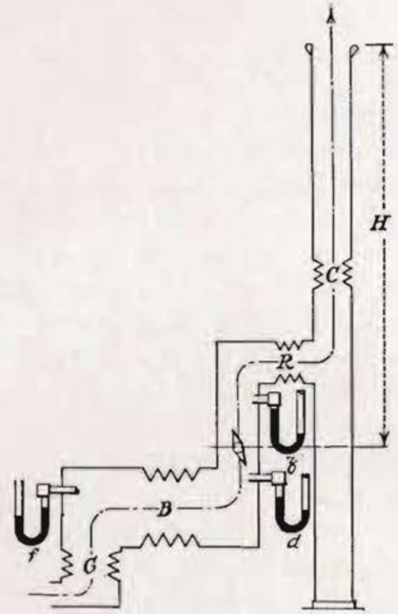
For any other height H in ft. multiply by 0.01 H
For any other altitude, multiply by the corresponding factor of correction from the curve below.



FACTORS OF CORRECTION FOR MAXIMUM DRAFT ABOVE SEA LEVEL

For example, the maximum draft per 100 ft. of height at sea level for an air temperature of 80° F. and gases at 550° F. is 0.63 in. from the draft curves. A chimney 200 ft. high would therefore produce a maximum draft of 2 × 0.63 or 1.26 in. For an elevation of 5900 ft. above sea level the factor of correction is 0.8 and the chimney would therefore produce a maximum draft of 1.26 × 0.8 or 1.01 in.

The consumption of the maximum draft produced by a chimney is illustrated in the drawing which follows.



TYPICAL ARRANGEMENT OF A BOILER PLANT SHOWING DRAFT LOSSES

The gauge f indicates the draft in the furnace, which is equal to the draft loss from the boiler room to the furnace irrespective of whether air for combustion is supplied by natural or forced draft. The difference between the readings of gauges d and f indicates the draft loss through the boiler, the difference between gauges z and d indicates the draft loss through the boiler damper frame, R represents the draft loss in the flues and C the draft loss in the chimney. The effective height of the chimney, H, is shown as the height above the boiler damper since vertical components of the flue may be considered a part of the chimney on account of their draft producing power. The structural height of the chimney may be higher by twenty feet or more but this extension has no draft producing power.

Effective Draft and its Utilization.—The effective draft of a chimney is its maximum draft less the draft loss in the chimney. This effective draft is consumed in furnaces, boilers and flues, to accelerate the gases to the ultimate velocity of discharge, to overcome all friction between gases and contact surfaces and to overcome the loss of pressure from eddies in the gas stream. In practice, the effective draft of a chimney must equal the sum of the following:

(*a*) The draft in the furnace.

(*b*) The draft loss from furnace to boiler damper ("draft loss through the boiler").

(*c*) The draft loss through the boiler damper frame.

(*d*) The draft loss through the economizer, if any.

(*e*) The draft loss in the flues between boiler damper and chimney.

The sum of these is the draft required at the entrance to the chimney. Where more than one boiler is served by a single chimney only one pathway from a boiler to the chimney need be considered but the boiler selected should be the one which requires the highest draft at its outlet or is situated furthest from the chimney. The other boilers may have too much draft but this can be overcome by partly closing the dampers.

Allowances for Operating Conditions.—The data for proportioning a chimney should be based on the least favorable conditions for generating the required amount of steam continuously with reasonable upkeep of equipment. The average drafts and draft losses observed in boiler tests should be increased by an amount sufficient to allow for poorer fuel and less efficient firing, which may be expected at times. But if the allowances are too liberal the corresponding size of chimney not only involves a waste of investment but may also cause a waste of fuel as a consequence of excessive draft. This is especially true when the fuel is oil.

Draft Required in the Furnace.—This is the draft required to produce or to assist in producing the desired combustion. For boilers fired with steam atomizing oil burners furnace drafts for 150, 200 and 250 per cent. of rating may be assumed at .10 in., .15 in. and .25 in., respectively. For most of the forced draft underfeed stokers a furnace draft of .10 in. is ample for all rates. For natural draft stokers and hand fired grates there is a wide variation for different ratios of heating surface to grate surface, for different sizes of openings in the grates and for different grades of

coal; hence the furnace draft to be allowed should be obtained from the builder of the firing equipment.

Draft Loss through the Boiler.—For the same volume of gases from the furnace the draft loss through a boiler varies principally with the size and arrangement of tubes and the number of passes. The allowances in the following tables will ordinarily be ample for Edge Moor boilers with a superheater above the first and second passes. The actual losses observed during efficient operation will be less than the tabulated allowances, since the latter are for abnormal percentages of excess air. With oil, the air entering the furnace is easily controlled, and hence the allowances may be less than for coal.

Draft Loss Allowances for Three-pass Edge Moor Boilers with 18 Ft. Tubes and Superheater

Maximum percentage of rating to be developed.	125	150	200	250
Draft loss allowance for coal, in. of water column	.35	.45	.65	.80
Draft loss allowance for oil, in. of water column	.20	.25	.45	.65

Draft Loss Allowances for Four-pass Edge Moor Boilers with 20 Ft. Tubes and Superheater

Maximum percentage of rating to be developed.	125	150	200	250
Draft loss allowance for coal, in. of water column	.50	.65	.85	1.00
Draft loss allowance for oil, in. of water column	.25	.40	.65	.85

Draft Loss through the Boiler Damper Frame.—For maximum evaporation the damper is, of course, assumed to be wide open. As a rule, the damper frame is of such liberal proportions that the draft loss through it is negligible, but this may not always be the case.

Draft Loss through the Economizer.—In general, when economizers are installed an induced draft fan must be included, because the total draft required cannot be produced by a chimney of desirable height on account of the low temperature of the escaping gases. But for moderate overloads and firing equipment which requires a low furnace draft a chimney may be used. For such cases the draft loss through the economizer should be obtained from the builder.

Draft Loss in Flues and Area of Cross Section.—The total draft loss should include the loss from friction in the straight parts and the loss from turns, including the turn into the chimney. When the gases are discharged from a flue into a chimney of much smaller cross section a considerable loss of draft will result from accelerating the gases into the latter. When the cross section of the flue is 20 per cent. greater than the cross section of the chimney this loss theoretically amounts to about .05 in. of water column. Flues are generally proportioned so that the loss in the straight parts will be about .10 in. per 100 ft. of length.

Other conditions remaining the same the draft loss varies with the weight of gases transmitted. For coal burning plants an allowance of 80 lb. of gas per horsepower developed should ordinarily be ample for 150 per cent. of rating and 60 lb. of gas per horsepower developed for 200 per cent. of rating. Both assumptions reduce to 120 lb. of gas per rated horsepower. From the published formulæ for draft losses in flues and from these gas weights the cross-sectional areas of unlined steel flues can be determined. These areas, allowing a draft loss of .10 in. per 100 ft. of length, are given in the following table, together with the losses from turns.

SIZE OF FLUES AND DRAFT LOSSES FOR RATINGS UP TO 200 PER CENT. FOR COAL

Rated H. P. of boilers.	250	500	750	1000	1500	2000	3000	4000
Area of unlined steel flue in sq. ft.	10.6	18.5	25.6	32.2	44.6	56.1	77.6	97.7
Draft loss per 90° turn, in. of water column	.05	.06	.07	.08	.10	.11	.13	.15
Draft loss per 45° turn, in. of water column	.01	.02	.02	.02	.03	.03	.04	.04

For 250 per cent. of rating the tabulated areas should be multiplied by 1.12. When the fuel is to be oil the tabulated areas may be multiplied by .8 for 150 per cent. of rating, by .9 for 200 per cent. of rating and taken the same as the tabulated areas for 250 per cent. of rating. If a flue is to be of brick or concrete the area for an unlined steel flue should be multiplied by 1.13. For these larger areas the draft loss from turns will be approximately eight-tenths of the tabulated losses.

The draft loss in a rectangular flue with sides in the ratio of $1\frac{1}{2}$ to 1 will be only 2 per cent. greater than in a square flue of the same area. For sides in the ratio of 1 to 2 the loss will be 6 per cent. greater and for sides as 1 to 3 the loss will be 16 per cent. greater. This refers only to the draft loss in the straight parts—the draft losses from turns are theoretically the same. Hence areas as above may be of such shape as to best meet local requirements, but for a given area a square flue will be cheaper than a rectangular flue with unequal sides.

Example: An installation is to consist of four 500 H.P. boilers, set side by side, to operate at a maximum of 200 per cent. of rating with coal. An unlined steel flue is to run directly above the boiler uptakes and discharge into the chimney at an angle of 45°. The length of flue, from the center line of the end boiler to the chimney, is to be 70 ft.

Starting with the end boiler, the cross section of the flue just beyond the first uptake should have an area of 18.5 sq. ft. The area should increase gradually to just beyond the last uptake where it should be 56.1 sq. ft. From here to the chimney the area should remain the same. The draft losses to be allowed will be as follows:

Loss due to length of flue = .7 × .10 in. or	.07 in.
Loss from 90° turn, uptake to flue	.06 in.
Loss from two 45° turns into chimney	.06 in.
Acceleration loss if cross sectional areas of flue and chimney are to be about equal	.00 in.
Total draft loss due to flue	.19 in.

General Formulæ for Diameter and Height of Chimney.—The general formula for the diameter of an unlined circular steel chimney at sea level is

$$d = \sqrt[5]{\frac{.0000172\ T\ (H.P.)^2\ W^2}{p}}$$

where d is the inside diameter of the chimney in in., T is the absolute temperature of the chimney gases (equals temperature in deg. F. + 460), $H.P.$ is the *maximum* boiler horsepower to be developed, W is the weight of gases passing through the chimney in lbs. per hr. per H.P. developed, and p is the draft loss per 100 ft. of height in in. of water column. To obtain the diameter of a circular brick or brick-lined chimney, d should be multiplied by 1.06. Calculations by this formula are easily made by means of logarithms.

The formula for height is

$$H = \frac{100\ R}{P - p}$$

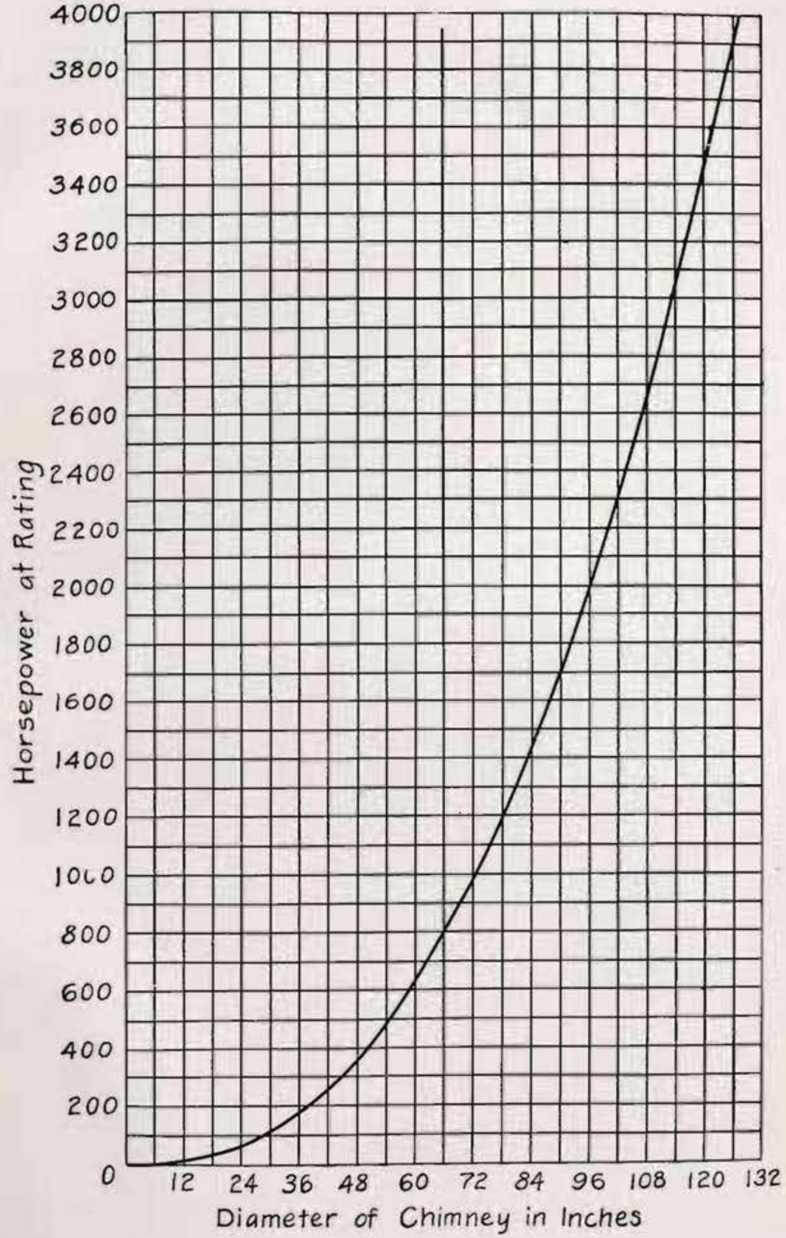
where H is the effective height of the chimney in ft., R is the draft required just above the entrance to the chimney, P is the maximum draft of the chimney per 100 ft. of height and p, as before, is the draft loss in the chimney per 100 ft. of height. By assuming different values of p for a fixed set of conditions these two formulæ will give different sizes of chimneys having the same capacity.

Simplified Formulæ for Ordinary Installations.—It is customary to assume that a chimney will be well proportioned when the draft loss in the chimney is two-tenths of its maximum draft. With this assumption, allowing for coal 80 lb. of gas per hr. per H.P. developed for 150 per cent. of rating, 60 lb. of gas per hr. per H.P. for 200 per cent. of rating, 55 lb. of gas per hr. per H.P. for 250 per cent. of rating, and assuming the same air and gas temperatures as for the subsequent formulæ for height, the formula for diameter of an unlined steel chimney becomes—

$$d = \sqrt[5]{910\ (H.P.)^2} \text{ for 150 per cent. of rating.}$$
$$d = \sqrt[5]{490\ (H.P.)^2} \text{ for 200 per cent. of rating.}$$
$$d = \sqrt[5]{410\ (H.P.)^2} \text{ for 250 per cent. of rating.}$$

where d, as before, is the inside diameter of the chimney in in. and $H.P.$ is the *maximum* horsepower to be developed.

Diameters for 150 and 200 per cent. of rating by the above formulæ but expressed in terms of rated horsepower are practically the same, hence a single curve answers for both rates. This curve is given on the opposite page and may be used instead of the formulæ. Diameters for 250 per cent. of rating should be 5 per cent. larger. When the fuel is to



Diameters of Unlined Steel Chimneys for Ratings up to 200 Per Cent. For Coal.

be oil the allowance of gas per horsepower may be reduced. For 150 per cent. of rating the diameter may be 90 per cent. of the diameter according to the curve, for 200 per cent. of rating it may be 95 per cent. of this diameter and for 250 per cent. of rating it may be the same as this diameter. For a brick or a brick-lined chimney multiply the diameter obtained as above by 1.06.

The height at sea level may be calculated by the formulæ

H = 216 R for 150 per cent. of rating.
H = 198 R for 200 per cent. of rating.
H = 187 R for 250 per cent. of rating.

where, as before, H is the effective height of the chimney in ft. and R is the draft required just above the entrance to the chimney in in. of water column. These formulæ are obtained from the general formula by allowing two-tenths of the maximum draft of the chimney for friction loss in the chimney and assuming maximum drafts as follows: For 150 per cent. of rating $P = 0.58$ in. (external air at 80° F. and chimney gases at 500° F.); for 200 per cent. of rating $P = 0.63$ in. (air at 80° and gases at 550°); for 250 per cent. of rating $P = 0.67$ in. (air at 80° and gases at 600°).

Using the curve and corrective factors for diameter and the proper formula for height, the size of chimney for an ordinary installation is easily obtained. For example, an installation at about sea level is to consist of stoker-fired boilers aggregating 2000 rated H.P. to be operated up to 200 per cent. of rating. From the curve on page 141 the diameter of an unlined steel chimney should be approximately 96 in. A brick chimney should have an inside diameter of 96 × 1.06, or 102 in.

To determine the height it is necessary to calculate the draft required just above the entrance to the chimney. For the specific problem this is assumed as follows:

Draft in the furnace	.10 in.
Draft loss in boiler	.65 in.
Draft loss in flue (see page 139)	.19 in.
Total draft required at entrance to chimney	94 in.

The effective height according to the second formula above should be 198 × .94, or 186 ft. If the boiler dampers are to be 14 ft. above the ground level the structural height of the chimney should be 186 + 14, or 200 ft.

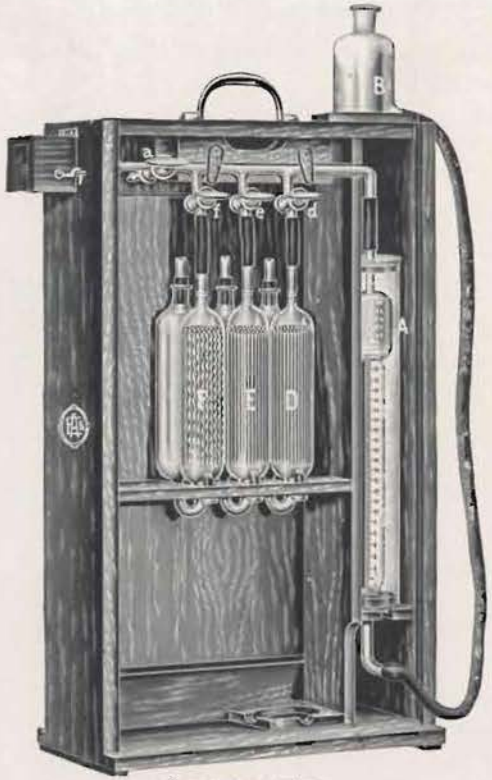
In certain cases the size of the chimney by the above method may not be the cheapest to build or it may not be suitable on account of local conditions. For such cases other sizes may be obtained by means of the general formulæ on pages 139 and 140 by assuming values of p less than .12 in. for larger diameters, and greater than .12 in. for smaller diameters, using the same values of T, W, P and corrective factors as above, unless conditions warrant different assumptions.

Chimneys at High Altitude.—From comparative tests at high altitudes and at sea level it seems that the draft required at the boiler outlet with similar equipment and fuel may be the same at all altitudes for the same rate of evaporation. For a given weight of gases passing through the boiler the draft loss should increase theoretically because the volume of gases increases with the altitude. But as it does not, it is likely that with air of lower density less excess air by weight is required and such compensations result that allowances for draft losses may be taken the same as at sea level. Thus, if the assumed installation considered above is to be at an elevation of 5900 ft. the draft required at the entrance to the chimney may also be taken at .94 in.

However, the size of chimney must be increased and, generally, the flue as well on account of the lower maximum draft of the chimney. See page 134. For calculating the size of the chimney the general formulæ on pages 139 and 140 may be used, allowing values of p less than .10 in. and assuming T and W the same as at sea level.

Testing Instruments

IF the performance of a steam generator is good, certain conditions must exist. There must not be too much excess air in the gases, which is indicated by the amount of oxygen present, the draft loss through the boiler must be normal and the temperature of escaping gases must not be high. It is therefore possible to find out a great deal about boiler performance by means of certain instruments without weighing any water or fuel.



Orsat apparatus

Three classes of instruments are commonly used: gas analyzers, draft gauges, and thermometers and pyrometers.

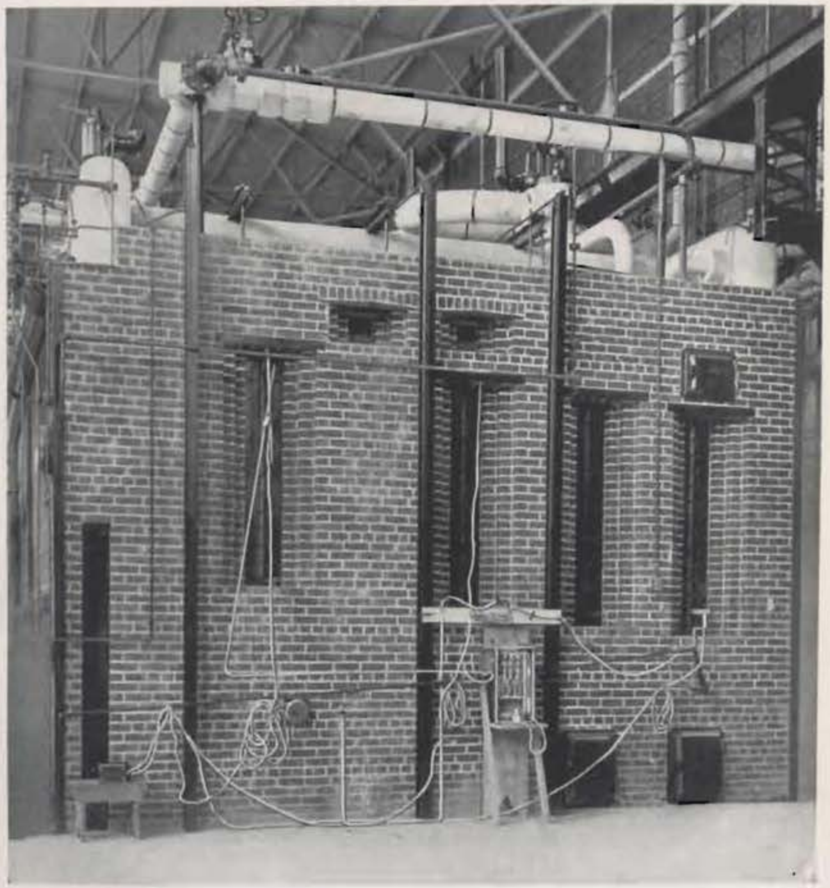
Orsat Apparatus.—The best known and the most commonly used of the gas analyzers is the "Orsat" of which the accompanying illustration is typical. Gas is drawn into the graduated "burette" *A*, measured, and then passed successively into "pipettes" *D*, *E*, and *F*. The absorption in each pipette is determined by returning the gas to the burette and noting the shrinkage in volume. The residue of gas is usually taken to be nitrogen, but there may be small quantities of other gases present.

The pipette *D* is filled with caustic potash for absorbing the carbon dioxide (CO_2); the pipette *E* usually with a solution of pyrogallic acid in caustic potash for absorbing the oxygen; and the pipette *F* with an acid solution of cuprous chloride for absorbing the carbon monoxide (CO).

Preparing the Solutions.—The solutions for absorbing the carbon dioxide and excess oxygen are easily prepared by anyone, but it is ordi-

narily preferable to have the solution for the carbon monoxide furnished by a chemist ready for use.

For Carbon Dioxide.—Dissolve the best quality of caustic potash in water in the proportion of 5.5 ounces caustic potash to one pint of water. Let the solid particles settle and use only the clear solution.



Edge Moor boiler equipped with pyrometer, draft gauge, and Orsat for the study of boiler performance

For Oxygen.—Dissolve white resublimed pyrogallic acid in caustic solution as above in the proportion of 0.8 ounce acid to one-half pint caustic solution. Prepare shortly before filling the Orsat apparatus and protect from the air

Absorbing Power of Solutions.—One pipette (about 125 c.c.) of the fresh caustic potash solution will quickly absorb the CO_2 in about fifty samples of flue gas; one pipette of fresh pyrogallic acid solution protected from the air can be used for 30 to 40 determinations of oxygen; and one pipette of the cuprous chloride solution for the absorption of about 50 c.c. of CO. Of course, the solutions will not be saturated when these limits have been reached but the rate of absorption will usually begin to be slow enough to warrant changing the solutions.

Ellison Differential Draft Gauges.

Draft Gauges.—The most satisfactory draft gauges for taking drafts within a boiler setting are of the direct reading (differential) type with graduations to .01 in. of water. The liquid used in these is commonly a colored oil approximating kerosene in specific gravity. This is much superior to water because the capillary attraction is less, the liquid is more easily seen, and the glass will not become coated with a deposit as the liquid evaporates. The graduations are made so that the readings will be equivalent to those on a water gauge. The draft pipe should be inserted so that the mouth points at right angles to the path of the gas and not in a direction parallel with it: in the latter case a false draft may be indicated on account of the pressure or suction produced by velocity.

Thermometers and Pyrometers.—With mercury instruments errors are apt to result because of incomplete exposure of the stem. Mercury pyrometers for taking gas temperatures should not be inserted through brick walls because a considerable part of the stem will be exposed to a

colder temperature, resulting in low readings. For boiler testing, electric pyrometers are much more convenient and usually more accurate than mercury instruments.

It is important that the thermocouple, or bulb and stem, be placed in the active path of the gas passage and not in a "dead" space as behind a partially opened damper. Also, care should be taken to keep the exposed part of the instrument as far as possible from the relatively cold heating surface of the boiler on account of the chilling effect due to radiation. When taking temperatures within a bank of tubes with an electric pyrometer the actual temperature of the gases in contact with the tubes is somewhat higher than indicated even when care is taken to adjust the couple for minimum radiation effect, which should always be done by moving the couple in and out, about a half-inch at a time, until the highest temperature is indicated for a steady rate of firing.

Miscellaneous Information

THE closing pages have been devoted to information suggested by experience as useful in the management and design of steam-boiler installations.

Calculating Horsepower from Fuel Consumption.—It is sometimes desirable to determine, approximately, the horsepower developed by a boiler without going to the expense of making a regular test. In such a case the method outlined below has been found useful.

Weigh the fuel fired during several hours, the longer the better, and calculate the fuel burned per hour. If the fuel is coal, it should be fired so there will be about as much on the grate at the end as at the beginning of the run. From a knowledge of the fuel, boiler, stoker and firing conditions assume a calorific value for the fuel as fired and a reasonable combined efficiency, and calculate the horsepower by the formula

$$H.P. = \frac{W \times H \times E}{33480}$$

Where W is the weight of fuel burned per hour in pounds, H is the assumed calorific value of the fuel in B. T. U. per pound, E is the combined efficiency of the steam generator and 33480 is the heat equivalent of one boiler horsepower.

Example: An average of 500 pounds of coal was burned per hour, the estimated B. T. U. in the coal was 14,000 and the estimated efficiency was 70 per cent. What is the horsepower developed?

Ans.:

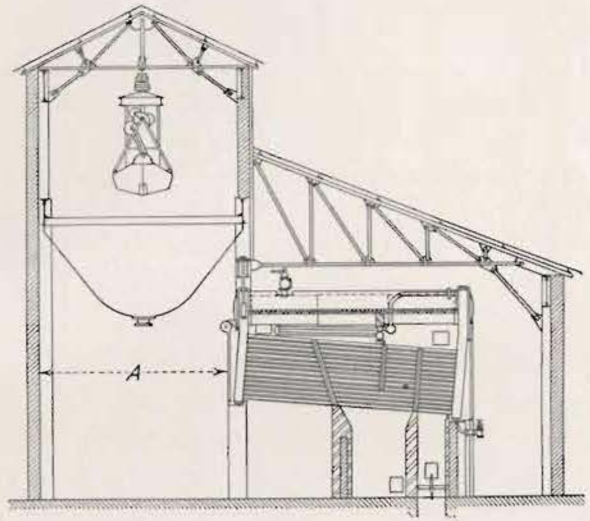
$$\frac{500 \times 14{,}000 \times 0.70}{33480} = 146 \text{ H.P.}$$

The horsepower calculated in this way will represent, of course, only the average developed and may be considerably less than the maximum. If a damper regulator is used there may be wide variations in the horsepower developed by the boiler even though the demand for steam is fairly constant. Hence hand regulation of the damper should be employed and adjustments made slowly when making a run as indicated above.

Provision for Replacing Tubes.—We give below the minimum linear distances which should be allowed, either at the front or rear of boilers, for replacing tubes. While in some plants it has not been

necessary to replace a single tube in many years of service, yet there is always a possibility that a tube will give way due to scale, corrosion, or other causes; and it is therefore wise to provide for this.

In general, it is better not to install any coal-handling apparatus in such location that it will have to be taken down to replace a tube, not only because of the extra labor required but also because of the extra time required, as the failure of a tube may occur just when a shut-down can be least afforded.



For 16 ft. tubes, A should not be less than 15 ft. 0 in.
" 18 " " " " 17 ft. 0 in.
" 20 " " " " 19 ft. 0 in.

Of course, it is not necessary to have the clear space for replacing tubes entirely in the boiler room. Windows or doors of the proper size may be placed opposite the tube sheets of either header, through which the tubes can be passed, provided pilasters and columns are set so they will not interfere.

Flow of Steam through Open Pipes.—For the flow of steam into the atmosphere Napier's formula has been found to give results which agree closely with those obtained experimentally. If w is the weight of steam discharged into the air through an orifice in pounds per second, p the initial absolute pressure in pounds per sq. in., and a the area of the orifice in sq. in., then, according to Napier,

$$u = \frac{p\,a}{70}$$

Modified by the introduction of a coefficient (0.96 and 0.925 are two values given), this formula is used to calculate the discharge capacities of the safety valves used in boiler practice. The very great amount of steam that is discharged through drains and open pipes for heating is indicated in the table below. The outflow was calculated by Napier's formula, uncorrected, and reduced to boiler horsepower by dividing by 30.

BOILER HORSEPOWER DISCHARGED INTO THE AIR THROUGH OPEN PIPES

Initial pressure Lbs. gauge	Nominal size of extra heavy pipe. Inches						
	1/4	1/2	3/4	1	1 1/4	1 1/2	2
100	13	45	84	140	250	345	577
150	19	65	120	200	359	495	828
200	25	85	156	261	468	645	1080
250	31	105	193	322	577	795	1330

Leakage of Air.—The tabular values below are for the ideal case of zero friction and contraction and must be multiplied by a coefficient C to obtain the actual leakage. For the equivalent of an orifice in a thin plate, $C = 0.6$ appr. For a short cylindrical pipe with inner corners not rounded, $C = 0.75$ appr.

THEORETICAL LEAKAGE OF AIR AT 70 DEGREES FAHRENHEIT

Effective draft in inches of water	Leakage in pounds per hr. per sq. in. of opening	Effective draft in inches of water	Leakage in pounds per hr. per sq. in. of opening
0.2	56	1.5	153
0.4	79	2.0	177
0.6	97	2.5	197
0.8	112	3.0	216
1.0	125	3.5	234

Four-inch Boiler Tubes.—The external surface per foot of length is 1.047 sq. ft.

No. 10 B. W. G.: Thickness = 0.134 in. Nominal weight per ft. = 5.62 lb
No. 9 B. W. G.: " = 0.148 in. " " " = 6.09 lb.
No. 8 B. W. G.: " = 0.165 in. " " " = 6.78 lb.

Brickwork and Foundations.—The sizes of red and fire brick and the quality of the materials used in brickwork and foundations vary considerably; hence the following information is approximate and intended for preliminary estimates only.

Size of standard firebrick is 9 in. x 4½ in. x 2½ in. Weight about 7 pounds.
Size of standard red-brick is 8¼ in. x 4 in. x 2 in. Weight about 4½ pounds.
One barrel of Portland cement equals 3.8 cu. ft. and weighs about 380 pounds.
Quick lime weighs from 50 to 75 pounds per cu. ft.
Dry sand weighs from 90 to 110 pounds per cu. ft.

Weight of brickwork, red or firebrick, is about 120 pounds per cu. ft.
Weight of cinder concrete is about 112 pounds per cu. ft.
Weight of concrete made with gravel, limestone, sandstone, etc., is about 150 lbs. per cu. ft.

Number of red brick usually allowed per sq. ft. of 4½-inch wall . . . 7.0
Number of firebrick per sq. ft. of 4½-inch wall, no bonding 6.0
Number of firebrick per sq. ft. of 4½-inch wall, bonding every sixth course 7.0
Number of firebrick per sq. ft. of 4½-inch wall, bonding every fifth course 7.2

It is important that sub-foundations for boilers shall be built with due regard to the character of the soil beneath, as settling will cause bad cracks in the brickwork.

ALLOWABLE BEARING CAPACITIES OF VARIOUS KINDS OF SOILS

Kind of material	Bearing power Tons per sq. ft.	
	Minimum	Maximum
Rock (the hardest) in thick layers, in native bed	200	..
Rock equal to best ashlar masonry	25	30
Rock equal to best brick masonry	15	20
Rock equal to poor brick masonry	5	10
Clay on thick beds, always dry	4	6
Clay on thick beds, moderately dry	2	4
Clay, soft	1	2
Gravel and coarse sand, well cemented	8	10
Sand, compact, and well cemented	4	6
Sand, clean dry	2	4
Quicksand, alluvial soils, etc.	0.5	1

[1] From Ira O. Baker's Treatise on Masonry Construction.

Equivalents and Constants:—

1 inch of water at 62° F. = 0.03609 lb. per sq. in = 0.5774 oz. per sq. in. = 5.196 lbs. per sq. ft. = 0.0736 in. of mercury at 62° F.
1 U. S. gallon = 231 cu. in. = 0.1337 cu. ft. = 8.33 lb. of water at 70° F.

1 B. T. U. is the heat required to raise one pound of pure water 1° F. at or near the temperature of maximum density (39.1° F.).
1 kilogramme-calorie is the heat required to raise one kilogramme of pure water 1° C. at or near the temperature of maximum density.
1 pound-calorie is the heat required to raise one pound of pure water 1° C. at or near the temperature of maximum density.

1 B. T. U. = 778.1 ft.-lb. = 0.252 kg.-cal. = 0.000393 hp.-hr.
1 kilogramme-calorie = 3.968 B. T. U. 1 pound-calorie = 1.8 B. T. U.

1 boiler horsepower = 34.5 lb. × 970.4 B. T. U. or . 33,478.8 B. T. U. per hr.
1 engine or motor horsepower equals . . . . . . 2,544.7 " "
1 kilowatt equals . . . . 3,412.4 " "
1 kilowatt = 1.341 engine horsepower. 1 horsepower = 0.746 kilowatt.

Volume of one pound of air at 62° F. . . . . 13.1 cu. ft.
Volume of one pound of flue gases at 500° F. . . . . . . 23.2 "
Volume of one pound of flue gases at any temperature is

$$V = 0.0242\ (t + 459.6)$$

where V is volume in cu. ft. per pound, and t is the temperature of the gas in degrees F.

Specific heat of flue gases, approximately 0.237
Degrees Fahrenheit = 1.8 × degrees Centigrade + 32.
Degrees Fahrenheit absolute = degrees Fahrenheit + 459.6.

Coefficient of linear expansion of brass per 100 deg. F., appr. . . . 0.001
Coefficient of linear expansion of steel per 100 deg. F., appr. . . . 0.00065
Coefficient of linear expansion of brick per 100 deg. F., appr. . . . 0.000306

$g = 32.2$ ft. per sec. per sec. = 981 cm. per sec. per sec.
$\pi = 3.1416.$ $\pi \div 4 = 0.7854.$ $\sqrt{\pi} = 1.7724.$ $\pi^2 = 9.8696.$

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