flues, H H. The whole of this upper part is cast in two pieces only, so that there is but one joint. The cast-iron shell of the fire-place is first heated, as in every chimney, then the smoke and gases proceeding from combustion circulate between the two ovals, to which they impart an elevated temperature, and, after becoming cooled in part, escape through the chimney, F. The surfaces of the fire-place thus utilize 60 to 70 per cent. of the heat. The external air, which is introduced through the opening, R, is first heated by contact with the casting of the fire-place, A, then with the external surface of the oval, and a part enters the hot-air box, M, through the passages, H, and from thence escapes into the apartment through the flues, G. Fig. 3 represents the arrangement adopted for burning coal and coke. The back part of the chimney is lined with a refractory clay to protect the casting.

Heating by Hot Water.—The hot-air box, which in ordinary chimneys serves to heat the air coming from out-of-doors, may be converted into a reservoir of water provided with inlet and outlet pipes for the circulation of hot water. Fig. 4 shows how such an application may be made, without the necessity of describing it. The ingress of air and the egress

FIG. 7.

FRENCH HEATERS AND STOVES FOR AIR AND WATER.

of smoke are regulated by registers, which may be closed entirely in case of fire, or to stop the passage of the air into the chimney during the night and to keep the heat in the room.

Hot-Air Stove.—Figs. 5, 6, 7, and 8 show the details of a hot-air stove constructed on the Bolo de Sevray system. On the foundation of masonry, X, rests the well, A, containing water, and into which the ashes fall. D is the grate, and above it is the body of the fire-place, E, lined with fire-brick, and surmounted by the dome, G. The platforms, H (Fig. 7), support cylinders, I, through which alternately circulate the smoke and the air to be heated. The smoke passes first into the flues, J, and from thence into the flues, K, then traverses the compartments which are provided with smoke-boxes, M, and reaches (as indicated by the arrows in Fig. 5) the chimney, R, thus coming in contact with a large amount of heated surface. A reservoir, T¹, contains water to prevent the air from becoming too dry. The air to be heated is drawn in from the outside at V, and, coming in contact with the dome, a portion of it ascends around the apparatus, while another enters through the opening, L, of

case, there is inserted in the extreme upper compartment of the stove a copper boiler, F¹, the water in which, being heated by the products of combustion, rises through the pipe, G¹, and after circulating through the rooms to be warmed, returns to the boiler through the pipe, H. The apparatus just described are not only applicable to the economical heating of apartments, but may also be used to advantage in heating public establishments, offices, workshops, factories, churches, etc. The judicious arrangements adopted for the utilization of the heat allow of most excellent results being obtained, even when it becomes a question of establishing and maintaining a uniform temperature in such large volumes of air as are found in churches or extensive manufacturing establishments.

STEAM BOILER FURNACES FOR SMOKE PREVENTION.

By JOHN W. HILL, M.E.

THE Board of Commissioners of the Cincinnati Industrial Exposition (1879) offered a cash premium of five hundred dollars for the best furnace system for steam boiler use, designed to burn bituminous coal without smoke.

All competing devices to be submitted to expert trials, and to be durable, practical, and capable of ready application to the prevailing types of steam boilers.

Five entries were made for the trials, as follows: The Walker Twin Furnace, by R. L. Walker & Co., of Boston, Mass; this furnace formed part of the setting of an ordinary return tubular boiler at the dry goods house of John Shillito & Co. The Fisher furnaces, by Lawrence Foulds & Fisher, of Cincinnati; this furnace formed part of the setting of a return tubular boiler at the printing establishment of Strobridge & Co.

The Eureka furnace attachment, by Douglass, Ludlow & Hart, of Cincinnati; this device was connected with the setting of a battery of two return tubular boilers at the Lane & Bodley Co. machine shops.

The Price furnace, by Wm. Price, of Cincinnati; this furnace formed part of the setting of a return tubular boiler at the Price hill inclined plane.

The Murphy furnace, by Thomas Murphy, of Detroit, Mich.; this furnace was built specially for the trials, and was set with an independent boiler on the direct and drop flue plan.

The connected boilers of all the furnaces, excepting the Murphy, furnished steam for the daily requirements of the several establishments where they were located. The steam from the Murphy boiler was blown into the atmosphere, and wasted.

THE WALKER TWIN FURNACE.

This furnace consists essentially of two independent grates, located in separate fire chambers, at opposite ends of the boiler. A pair of dampers—one at each end of the setting, so arranged that when one is closed the other is opened, and vice versa—control the direction given the gases of combustion in transit to the chimney.

The grates are alternately charged with coal, the gases of quick evolution from the freshly charged coal passing through two perforated bridge walls, and over the bed of glowing coal on the opposite grate.

The fire chamber containing the green coal, acts as a retort for the distillation of the volatile matter, which matter, as it passes through the air chamber and over the incandescent fire, is oxidized and reduced to carbonic acid, or oxide, vapor of water and sulphurous acid.

The Walker furnace at the Shillito buildings was set with

FIG. 8.

FRENCH HEATERS AND STOVES FOR AIR AND WATER.

the lower platform, diffuses itself through the compartments not occupied by the smoke, traverses the parts, L, enters the air chamber, A¹, and makes its exit through the outlet flue. The direction taken by the hot air is indicated by the arrows. The fire-brick lining of the fire-place is designed, in the first place, to prevent any wear on the casting; secondly, to prevent the latter from becoming red-hot, and thus to guard against the production of carbonic oxide. The apparatus is very durable; the only portions which are liable to wear out are the grate and fire-place, and these may be easily replaced without taking the stove apart. Any kind of fuel can be used in it—wood, coal, coke, etc. Fig. 8 represents a hot-air stove specially designed for cases where the furnace-room has a low ceiling, and which often happens where it is situated in the cellar or basement. The hot-air furnace described above may be converted into a thermostat or into a thermosiphon. In the first case, when the desired temperature has been obtained and the fire is well under way, both the door of the furnace and a register at L¹ above the furnace are closed. The whole body of the fire-place is then filled with coke, through J, and the register, M, is opened. A draught is then set up through the flue, R, and the combustion will last from six to eight hours, according to the charge of coke employed. In the second

a horizontal tubular boiler, furnishing steam for working the elevators, and for warming the building.

The following are the principal dimensions of furnace and boiler:

DIMENSIONS.		
Boiler.		Tubular.
Length of shell.....	16 ft.	
Diam. ".....	60 ins.	
Number of tubes.....	48	
Diam. " (outside).....	4 ins.	
Heating surface shell.....	142-992	
" " tubes.....	804-249	
" " heads.....	16-396	
" " total.....	963-637	
Cross section of tubes.....	344 sup. ft.	
Furnace.		
Length of fire chamber.....	34 ins.	
Width ".....	60 ins.	
Grate surface, ".....	14-165	
" both.....	28-33 sup. ft.	
Heating to grate surface.....	34-015	
Grate surface to cross-section of tubes.....	8-235	
Grate surface to cross-section of chimney.....	2-555	
Distance from grate to boiler.....	20 ins.	

Bridge Walls.	Perforated.
Chimney from surface of grate.....	148-33 ft.
Cross section of chimney.....	11-09 sup. ft.

THE FISHER FURNACE.

In this furnace the ash pit is divided transversely by a brick wall built close up under the grate; two-thirds of the ash pit being forward of the division wall. The grate is supposed to be divided into surfaces: a forward surface and a rear surface. The bars and air spaces of the forward surface are parallel to the axis of boiler, and inclined downward seven inches in thirty-two. The rear grate is horizontal, with bars and air spaces transversely of axis of boiler. The bridge is vertical, and is built up to within seven and one-half inches of the bottom of boiler.

An air duct passes from front to rear through the bridge wall; the opening in front, being directly under the rear grate, and the opening in the rear within two or three courses of the crest of the wall.

The opening in the rear of the bridge wall is covered with a perforated iron plate, through which the air is distributed in fine jets. Similarly perforated openings are provided in the side wall opposite the fire chamber, and aft of the bridge wall. The perforated plates in the side walls are fitted with slides to regulate the amount of opening, or close the perforations entirely.

The furnace was set with a well proportioned return flue boiler, furnishing steam to work the elevator and machinery in the printing establishment.

The following are the principal dimensions of furnace and boiler:

Boiler.	Flue.
Length of shell.....	24 ft.
Diam. ".....	48 ins.
Number of flues.....	6
Diam. " (outside).....	2-10 in.
Diam. ".....	4-8 "
Heating surface shell.....	180-95
Heating surface flues.....	326-72
" " heads.....	11-78
" " total.....	519-45 sup. ft.
Cross-section of flues.....	2-212 "

Furnace.	Single.
Length of fire chamber.....	50 ins.
Width ".....	48 "
Grate surface.....	16-640 sup. ft.
Heating to grate surface.....	31-970
Grate surface to cross-section of flues.....	7-523
Grate surface to cross-section of chimney.....	4-160
Distance from grate to boiler.....	17-24 ins.
Space over bridge wall.....	75 "
Chimney from surface of grate.....	58-33 ft.
Cross-section of chimney.....	4-00 sup. ft.

THE EUREKA FURNACE ATTACHMENT.

This device consists of a series of steam jets, surrounded by circular bell-shaped muzzles, set in the furnace front, through which air is drawn into the fire chamber by induction.

The device, as tried under a battery of two boilers, embraced eight steam nozzles, having a free orifice, 0-0425" diameter and eight air nozzles, having a free orifice, 1-25" diameter.

The steam nozzles are all connected to a horizontal pipe passing across the furnace front over the fire doors. This pipe receives steam from the boilers, the flue being regulated by an ordinary stop valve.

The furnace is unchanged in applying this attachment, except the drilling of a horizontal series of holes in the fire front for the reception of the air nozzles.

The boilers' return tubular furnished steam for the foundry and machine shop of the Lane & Bodley Co., and were set in the manner common to their class.

The following are the principal dimensions of furnace and boilers:

Boilers.	Tubular.
Length of shell.....	16 ft.
Diameter of shell.....	38 ins.
Number of tubes (each boiler).....	21
Diameter of tubes (outside).....	4
Heating surface shells.....	160-000
" " tubes.....	703-718
" " heads.....	16-446
" " total.....	880-158 supft
Cross section of tubes.....	3-010 "

Furnace.	Single.
Length of fire chamber.....	48 ins.
Width ".....	72 "
Grate surface.....	24 sup. ft.
Heating to great surface.....	36-673
Grate surface to cross section of tubes.....	7-973
Grate surface to cross section of chimney.....	2-396
Distance from grate to boiler.....	17 ins.
Space over bridge wall.....	7 "
Chimney from surface of grate.....	57-34 ft.
Cross section of chimney.....	10-017 sup. ft.

THE PRICE FURNACE.

This furnace consists of two parallel fire chambers and grate surfaces, made by dividing the usual fire chamber with a longitudinal wall, built from the floor of the ash-pit, close up to the boiler. Near the forward end the wall is perforated with a throat, to form a connection between the two fire chambers. The gases of quick evolution from the green coal of one grate passes through the throat and over the incandescent coke on the opposite grate in transit through the furnace.

The division wall extends back to the bridge wall, which, in this furnace, is built close up to, and with an inverted arch embraces the bottom of the boiler.

Through the lower portion of the bridge wall are cut two flues or openings, capable of being alternately closed and opened by a sliding damper. By a proper working of the damper and charging of the coal, the two fire chambers are alternately made to act as retorts. The volatile matter from the freshly charged coal passes forward in the fire chamber, where it is distilled through the throat and back over the coke on the opposite grate.

The gases of combustion from both fire chambers pass back through the open flue in the bridge wall, thence through the furnace and tubes of the boiler in the usual manner.

The following are the principal dimensions of furnace and boiler:

Boiler.	Tubular.
Length of shell.....	16 ft.
Diameter of shell.....	54.5 ins.
Number of tubes.....	40
Diameter of tubes, outside.....	4 ins.
Heating surface: shell.....	136.976
" " tubes.....	670.208
" " heads.....	15.866
" " total.....	823.050 sup. ft.
Cross-section of tubes.....	2.867 "
Furnace.	Double.
Length of fire chambers (each).....	60 ins.
Width " " ".....	27 "
Grate surface, each.....	11.25
" both.....	22.50 sup. ft.
Heating to grate surface.....	36.58
Grate surface to cross-section of tubes.....	7.848 "
Grate surface to cross-section of chimney.....	4.2.2 "
Distance from grate to boiler.....	23.27 ins.
Bridge wall.....	Perforated.
Chimney from surface of grate.....	88 ft.
Cross-section of chimney.....	5.245 sup. ft.

THE MURPHY FURNACE.

This furnace consists principally of an independent oven, set forward of the boiler (after the manner of furnaces for burning spent tan from the leach), in which combustion is completed before the gases are permitted to impinge upon the heating surfaces of the boiler.

In the other furnaces the bottom of the boiler forms the roof of the fire chamber. In this furnace the roof of the fire chamber is a fire brick arch of large radius.

The grate bars are single and set to form a V-shaped fire bed, similar to the well known Waddington grate. The grate is divided into two distinct surfaces on the axial line of fire chamber, each section of bars being mounted at the inner end on a revolving shaker shaft, operated from the front, for the removal of clinkers and ash.

The two sections of the grate are separated at the inner ends, about six inches, for the reception of a toothed clinker bar, the squared end of which is projected through the furnace front, and worked with a socket wrench.

Upon each side of the oven a hopper or magazine is placed for the reception of finely broken coal, which is fed on the grate by a reciprocating plunger sliding under the mouth of the hopper, and worked by a rock shaft from the front of the furnace.

All coal charged to the grate is first passed through the two hoppers, from which it is delivered in a partially coked state, and in small charges.

The sharp inclination of the grate bars precipitates nearly if not quite all the fusible and vitrifying matter in the coal upon the clinker bar, from which it is readily removed as desired by a partial rotation of the bar.

No hand stroking of the fire is necessary with this furnace; the entire manipulation of the coal, after it is charged into the magazines, being accomplished from the front, by the devices already mentioned.

The rear end of the oven terminates in a throat, through which the gases of combustion pass into the tubes of the boiler. The boiler, direct tubular, was set on the drop flue plan, the whole tendency of the hot gas being from above downward.

A system of water heating tubes was connected to the under side of the boiler, into which the feed water was introduced direct from the pump, and around which the hot gas circulated just before passing into the chimney.

The following are the principal dimensions of furnace and boiler:

Boiler.	Tubular.
Length of shell.....	8 ft.
Diameter of shell.....	36 in.
Number of fire tubes.....	30
Diameter " " (outside).....	3 in.
Number of water tubes.....	49
Length of water tubes.....	8 ft.
Diameter " " (inside).....	1 in.
Heating surface shell.....	32.987
" " fire tubes.....	188.496
" " heads.....	3.686
" " water tubes.....	102.626
" " total.....	327.795 sup. ft.
Cross-section of fire tubes.....	1.127 "
Furnace.	Single.
Length of furnace.....	36 in.
Width " " ".....	43 "
Grate surface.....	10.50 sup. ft.
Heating to grate surface.....	31.22 "
Grate surface to cross-section of fire tubes.....	9.313 "
Grate surface to cross-section of chimney.....	9.822 "
Chimney from surface of grate.....	40 ft.
Cross-section of chimney.....	1.069 sup. ft.

Pittsburg coal was chosen for the trials for several reasons: First, the high percentage of volatile matter and facility with which it is distilled from the fuel renders it a difficult coal to work in furnaces designed for smoke prevention, and a furnace capable of working this coal successfully (in the matter of smoke prevention) can be relied upon to furnish equivalent, if not better, results with any other coal. Second, Pittsburg coal contains a higher percentage of combustible and a higher thermal value per unit of combustion than any other known coal; and economic results obtained from this coal exhibit the maximum efficiency of furnace under the conditions of trial. Third, Pittsburg coal is well known wherever bituminous coal is used in the United States, and the results of trials with this coal can be easily compared with the results of many former trials reduced to a Pittsburg coal basis.

The coal used for the trials was obtained from the yards of Marmet & Co (Cincinnati), and was of excellent quality. From the analysis for the purpose of the trials by Prof. Bruno Kniffer, and the known distribution of heat in the trial of the Murphy furnace, the thermal value of the combustible has been taken at 15,500 units.

The coal was weighed to all the furnaces excepting the Murphy in uniform charges of 200 pounds.

The comparatively small dimensions of the Murphy furnace and boiler and low actual rate of coal consumption suggested the propriety of uniform charges of 100 pounds in this instance.

The charges (time and weight) of coal were noted and checked independently by two observers, and no charge was permitted to be removed from the scale until both observers were satisfied as to the weight and had entered the charge in their note books.

At the end of trial, after the fire was restored to its original condition under the direction of the writer, the unburnt coal was weighed back and deducted from the total quantity charged.

The fire and ash pit having been carefully cleaned at commencement of trial, all ash and clinker on the grate and in the ash pit at end of trial was weighed back dry, and the difference between this weight and the net weight of coal charged, is held to represent the weight of combustible fired.

Of the weight of ash and clinker returned was a small percentage of combustible, which worked through the grate, the value of which is obtained by deducting from the observed weight of non-combustible, the weight of non-combustible as determined by analysis.

Each competitor had complete control of his coal and furnace during the trial.

The water delivered to the boilers was measured in a tight tank, divided into two compartments, one compartment containing 1,728.5 pounds, and the other 1,727.0 pounds, with water at 70° Fahr. In the upper edge of the partition dividing the tank a notch was cut with beveled edges. The compartments of the tank were alternately filled to the crest of the dividing partition, from the city mains, and drawn down to the lower edge of the outlet pipe in the side of the tank. Uniform volumes of water were delivered by the measuring tank for all the trials.

From either compartment of the measuring tank the water was drawn into a supplemental tank connected with the feed pump. The level of water in the supplemental tank being carefully noted at commencement of trial, the same level obtained at end of trial, and the number of full tanks charged together with the final partial tank, held to represent the total delivery of water to the boilers during the trial.

To determine the thermal value of steam furnished by the boiler, a small quantity was drawn through a calorimeter and condensed. The condensation was collected in a tight tin can and periodically weighed. The water expended in condensing the steam was measured into a tight barrel through a Worthington meter.

From the barrel the water entered the condenser at the bottom at a normal temperature and passed out at the top at an elevated temperature; the elevation of temperature being due the heat transferred from the steam to water, which was all it contained, except the small quantity resident in the condensation as it flowed from the end of the worm. The temperatures of the condensing water as it entered and left the condenser, and the temperature of the condensation as it left the worm, were read to quarter degree regularly every fifteen minutes.

The observations of smoke issuing from the chimney were taken regularly every seven and one-half minutes during the trial, except in cases when the darkness near the end of trial prevented an accurate reading of the chimney.

In reading the chimney, the following arbitrary code governed the observers.

The entire absence of smoke was taken at 100, indicating the best possible smoke-prevention. Faint traces of smoke in the waste gases was taken at 90, indicating a result sometimes obtained with an excellent construction of furnace and a skillful manipulation of the fire. Discoloration of the waste gases, readily perceptible, was taken at 75, indicating a state of smoke-prevention above the average of furnace performance. Ordinary smoke issuing from the chimney was taken at 50. Fairly black smoke was taken at 30, and thick, dense, black smoke was taken at 10.

The trials were made upon the following dates:

Walker furnace.....	Oct. 1.
Fisher ".....	" 4.
Eureka " attachment.....	" 7.
Price ".....	" 10.
Murphy ".....	" 14.

The trials were limited to ten hours each, by reason of all the furnaces, excepting the Murphy, being in manufacturing establishments, where night runs would have been objected to.

The duration of trials was as follows:

Walker.....	8:30 A.M. to 6:30 P.M.
Fisher.....	8:00 " 6:00 "
Eureka.....	8:15 " 6:15 "
Price.....	8:45 " 6:45 "
Murphy.....	8:30 " 6:30 "

The steam pressures were read from a Bourdon gauge which had been carefully prepared for the trials, and the following are means of forty-one readings:

STEAM PRESSURES.	
Walker.....	38.755 pds.
Fisher.....	80.287 "
Eureka.....	76.181 "
Price.....	82.100 "
Murphy.....	81.575 "

The temperature of air, water from city mains, and feed to the boiler were taken with Green and Tagliabue thermometers; and the temperature of feed, when water was heated by exhaust steam from the connected engine, was taken in the feed pipe close to the check valve. The Walker and Murphy boilers were unprovided with feed heating apparatus, and took water direct from the supplemental tank. The following are means of forty-one observations:

TEMPERATURE OF AIR.	
Walker.....	100.07° Fahr.
Fisher.....	83.27 "
Eureka.....	82.21 "
Price.....	83.46 "
Murphy.....	80.28 "

TEMPERATURE OF WATER FROM CITY MAINS.	
Walker.....	70.025° Fahr.
Fisher.....	71.069 "
Eureka.....	72.640 "
Price.....	73.569 "
Murphy.....	74.550 "

TEMPERATURE OF FEED.	
Walker.....	70.025° Fahr.
Fisher.....	166.012 "
Eureka.....	169.112 "
Price.....	176.360 "
Murphy.....	74.550 "

The pressure of atmosphere was read from a compensated aneroid barometer, and the following are means of forty-one observations:

Walker.....	29.760 ins.
Fisher.....	29.693 "
Eureka.....	29.630 "
Price.....	29.334 "
Murphy.....	29.156 "

The temperature of waste gases was taken with a high range centigrade thermometer. In the front connection, near the chimney, a hole was cut for the reception of an iron tube, closed at the lower end, in which the thermometer was suspended with a bath of linseed oil. With the exception of the Fisher trial, where the oil boiled over several times, the following are the means of forty-one observations:

TEMPERATURE OF WASTE GASES.	
Walker.....	541.29° Fahr.
Fisher.....	542.28 "
Eureka.....	468.30 "
Price.....	423.05 "
Murphy.....	279.67 "

The temperatures of hot gas in the fire chamber and in the back connection were taken by calorimeter process; pieces of one inch bar iron, six inches long, were drilled axially for the introduction of a steel rod, upon which the wrought iron bar was mounted and thrust into the center of the fire chamber and back connection through apertures cut in the brick work. The iron rods were made to weigh precisely one pound and to fit the steel rod loosely. Into a pail ten pounds of water was carefully weighed; the iron rods being allowed to remain in the furnace a sufficient length of time to acquire the temperature of the enveloping hot gas, they were carefully withdrawn and dropped into the pail. The known weights of iron and water and elevation of temperature of water, together with the specific heat of wrought iron, constitute the elements of the calculations. The temperatures of water were taken with a Green thermometer, and the specific heat of the iron rods was taken at 0.1139. The actual specific heat of water at observed temperatures was neglected, and the specific heat uniformly taken as 1.0000. The following are means of ten set of observations during each trial:

TEMPERATURE OF FIRE.	
Walker.....	chamber with incandescent fire. 1931.24° Fahr.
Fisher.....	chamber with green fire. 1486.68 "
Eureka.....	1902.94 "
Price.....	2369.30 "
Murphy.....	chamber with incandescent fire. 3053.00 "
	chamber with green fire. 2491.07 "
	3056.75 "

TEMPERATURE BACK END.	
Walker.....	See green fire.
Fisher.....	665.12° Fahr.
Eureka.....	1043.15 "
Price.....	1587.92 "
Murphy.....	812.35 "

To determine the amount of heat expended in elevating the temperature of the vapor of water in the air hygrometer, readings were made half hourly during each trial, with the following results, as means of twenty-one observations:

HYGROMETER.	Air.	Dew Point.	Dryness.
Walker.....	97.65	84.83	12.82
Fisher.....	83.82	71.54	12.28
Eureka.....	81.52	69.85	11.68
Price.....	83.34	75.15	8.19
Murphy.....	80.70	72.18	8.52

The calorimeter data, from which the quality of steam furnished is calculated, have been averaged for each trial, and are given in the following table:

INITIAL TEMPERATURE, CONDENSING WATER.	
Walker.....	74.09° Fahr.
Fisher.....	73.94 "
Eureka.....	73.43 "
Price.....	76.40 "
Murphy.....	74.37 "

FINAL TEMPERATURE, CONDENSING WATER.	
Walker.....	87.66° Fahr.
Fisher.....	86.14 "
Eureka.....	81.42 "
Price.....	97.22 "
Murphy.....	114.96 "

THERMAL UNITS PER POUND OF CONDENSING WATER.	
Walker.....	13.57° Fahr.
Fisher.....	12.20 "
Eureka.....	7.99 "
Price.....	20.82 "
Murphy.....	40.59 "

TEMPERATURE OF CONDENSATION.	
Walker.....	85.43° Fahr.
Fisher.....	83.40 "
Eureka.....	79.00 "
Price.....	85.71 "
Murphy.....	77.08 "

CONDENSING WATER, PER POUND OF STEAM.	
Walker.....	3288.75 water 64.483 pounds.
Fisher.....	51 steam 72.240 "
Eureka.....	10041.53 water 116.012 "
Price.....	139 steam 68.233 "
Murphy.....	6633.61 water 33.611 "
	57.18 steam 165.56 steam

The utter unreliability of boiler efficiency, based upon the water pumped into the boiler, and the coal fed on the grate, was never better shown than by these trials. None of the boilers were hard worked, and without data to the contrary, it would naturally be supposed that the low rate of evaporation per unit of heating surface and low rate of coal consumption per unit of grate surface would guarantee saturated steam.

In the following table the heat per pound of steam is based upon the total water fed to boiler, or rather upon the proportion of that water as evaporation diverted to the condenser. In the Walker, Fisher, and Eureka boilers, a material portion of the water pumped in was entrained in the steam, producing a mean thermal value per pound of steam

considerably less than that of saturated steam at observed pressures. Upon the other hand the Price and Murphy steam exhibits a very high superheat.

TOTAL HEAT PER POUND OF STEAM CONDENSED.

Walker.....	960.46 units.
Fisher.....	964.73 "
Eureka.....	1005.93 "
Price.....	1566.32 "
Murphy.....	1441.35 "

The air entering the furnace per pound of combustible has been calculated from the known temperature of fire, thermal value of the combustible, and mean specific heat of the gases of combustion.

The mean observed temperature of fire in the Walker furnace was 1931.24, and taking the mean specific heat of the gases of combustion at 0.238; then the weight of hot gas per pound of combustible becomes

15,500

—=35.565 pounds.

(1931.24—100.07) 0.238

Of this quantity one pound was combustible from the coal. The mean observed temperature of fire in the Fisher furnace was 1902.94; and the weight of hot gas per pound of combustible

15,500

—=35.789 pounds. Of this

(1902.94—83.27) 0.238

quantity one pound was combustible from the coal.

The mean observed temperature of fire in the Eureka furnace was 2369.30; and weight of hot gas per pound of combustible

15,500

—=28.475 pounds. Of this quan-

(2369.30—82.21) 0.238

tity one pound was combustible from the coal.

The mean observed temperature of fire in the Price furnace was 3053.00; and weight of hot gas per pound of combustible

15,500

—=21.931 pounds. Of this quantity

(3053—83.46) 0.238

one pound was combustible from the coal.

The mean observed temperature of fire in the Murphy furnace was 3056.75; and weight of hot gas per pound of combustible

15,500

—=21.880 pounds. Of this quan-

(3056.75—80.28) 0.238

tity one pound was combustible from the coal.

AIR PER POUND OF COMBUSTIBLE.

Walker.....	34.565 pounds.
Fisher.....	34.789 "
Eureka.....	27.475 "
Price.....	20.931 "
Murphy.....	20.880 "

The weight of vapor of water in the air supporting combustion is stated in decimal of a pound per pound of air supplied.

VAPOR OF WATER IN THE AIR.

Walker.....	0.02314
Fisher.....	0.01556
Eureka.....	0.01485
Price.....	0.01787
Murphy.....	0.01612

In the following table are given the total quantities of coal charged, ash and clinker returned, water pumped into boilers, percentage of net coal charged, utilized as combustible, and combustible in ash in percentage of net coal charged.

COAL CHARGED.

Walker.....	3,800 pounds.
Fisher.....	1,866 "
Eureka.....	3,420 "
Price.....	2,694 "
Murphy.....	779 "

ASH, CLINKER, AND COMBUSTIBLE RETURNED.

Walker.....	202.00 pounds.
Fisher.....	87.50 "
Eureka.....	113.00 "
Price.....	119.00 "
Murphy.....	28.75 "

PERCENTAGE OF COMBUSTIBLE.

Walker.....	94.685
Fisher.....	95.365
Eureka.....	96.692
Price.....	95.682
Murphy.....	96.306

COMBUSTIBLE IN ASH.

Walker.....	2.273
Fisher.....	1.593
Eureka.....	0.262
Price.....	1.376
Murphy.....	0.652

WATER TO BOILERS.

Walker.....	28,859.00 pounds.
Fisher.....	10,896.00 "
Eureka.....	33,133.77 "
Price.....	23,282.92 "
Murphy.....	6,854.50 "

EVAPORATION.

The apparent evaporation per pound of coal with the

28859

Walker furnace and boiler was —=7.5946 pounds; but

3800

the mean heat per pound of steam condensed in the calorimeter was 960.46 units, and total heat per pound of coal in the steam was 7.5945×960.46=7294.21 units. Of this quantity 70.025×7.5945=513.8 units were in the feed water, and the evaporation per pound of coal from and at a tempera-

7294.21—513.8

ture of 212° Fahr. becomes —=7.019 pounds.

966

The combustible was 0.94685 of net coal charged and evaporation per pound of combustible, from and at 212° Fahr.

7.019

was —=7.413 pounds.

0.94685

The apparent evaporation per pound of coal with the

10896

Fisher furnace and boiler was —=5.839 pounds; but the

1866

mean heat per pound of steam condensed in the calorimeter was 964.73 units, and total heat per pound of coal in the steam was 5.839×964.73=5633.058 units. Of this quantity 166.012×5.839=969.34 units were in the feed water, and the evaporation per pound of coal from and at a temperature

5633.058—969.34

of 212° Fahr. was —=4.828 pounds.

966

The combustible was 0.95365 of net coal charged and evaporation per pound of combustible from and at 212° Fahr.

4.828

was —=5.062 pounds.

The apparent evaporation per pound of coal with the Eu-

reka furnace and boiler was —=9.688 pounds; but the

3420

mean heat per pound of steam condensed in the calorimeter was 1005.93 units, and total heat per pound of coal in the steam was 1005.93×9.688=9,745.45 units. Of this quantity, 169.112×9.688=1638.357 units were in the feed water, and evaporation per pound of coal from and at 212° Fahr.

9745.45—1638.357

was —=8.392 pounds.

966

The evaporation by the Eureka boiler should be reduced by the amount of steam expended in maintaining the jets. The orifices in the nozzles were 0.0625 in. diameter, and area

8×0.0625²×0.7854

of eight nozzles —=0.00017 sup. ft.

144

Considering the form of the nozzle and approach thereto, it is probable that the velocity of flow referred to full area of orifice was about 1,000 feet per second, from which is obtained the weight of steam expended per hour in the jets, as 3,600×0.00017×1000×0.2139=131.33 pounds, and percentage of steam absorbed by the device,

131.33

—=0.0516.*

2545

From which is deduced the net evaporation per pound of coal from and at 212° Fahr. as 0.9484×8.392=7.957 pounds.

The combustible was 0.96692 of net coal charged, and evaporation per pound of combustible from and at 212° Fahr.

7.959

was —=8.231 pounds.

The apparent evaporation per pound of coal with the

23282.92

Price furnace and boiler was —=8.6425 pounds; but

2694

the mean heat per pound of steam condensed in the calorimeter was 1506.32 units, and total heat per pound of coal in the steam was 1506.32×8.6425=13018.37 units. Of this quantity 176.36×8.6425=1524.17 units were in the feed water, and the evaporation per pound of coal from and at

13018.37—1524.17

212° Fahr. was —=11.8988 pounds.

966

The combustible was 0.95582 of net coal charged, and evaporation per pound of combustible from and at 212° Fahr.

11.8988

was —=12.449 pounds.

0.95582

The apparent evaporation per pound of coal with the

6854.5

Murphy furnace and boiler was —=8.7991 pounds; but

779

the mean heat per pound of steam condensed in the calorimeter was 1441.35 units, and total heat per pound of coal was 1441.35×8.7991=12682.58 units. Of this quantity, 74.55×8.7991=655.973 units were in the feed water, and the evaporation per pound of coal from and at 212° Fahr.

12682.58—655.973

was —=12.4499 pounds.

966

The combustible was 0.96306 of net coal charged, and evaporation per pound of combustible from and at 212° Fahr.

12.4499

was —=12.9274 pounds.

0.96306

CAPACITY OF BOILER.

The rate of evaporation per superficial foot of heating surface per hour from and at 212° Fahr. was for the Walker

7.019×380

boiler, —=2.7679 pounds.

963.637

For the Fisher boiler, —=1.7343 pounds.

519.45

For the Eureka boiler, —=3.2062 pounds.

7.959×342

For the Price boiler, —=3.8947 pounds.

880.158

For the Murphy boiler, —=2.9587 pounds.

11.8988×269.4

823.05

12.4499×77.9

327.795

RATE OF COMBUSTION.

The coal charged per superficial foot of grate per hour,

380

was for the Walker furnace, —=13.413 pounds.

28.33

For the Fisher furnace, —=11.214 pounds.

186.6

For the Eureka furnace, —=14.25 pounds.

16.64

For the Price furnace, —=11.973 pounds.

342

For the Murphy furnace, —=7.419 pounds.

24

269.4

22.50

77.9

10.5

* In the report of this trial to the Commissioners of the Exposition, an error occurs in stating the fraction of total steam expended in maintaining the jets. The calculation resulting in 131.33 pounds supposes steam only to pass the orifices. The error lay in overlooking the fact that the percentage of water entrained in the steam passed through the calorimeter would also apply to the steam passed by the jets. In other words, the denominator of the fraction representing the steam expended in maintaining the jets should have been the net evaporation per hour instead of the water per hour pumped into the boilers. The water entrained

0.7681

(23.19 per cent.) had a relative volume of 291.66 —=965 or 1 per cent. of the volume of steam discharged.

0.2319

RESUME OF RESULTS.

Steam per pound of coal from and at 212° Fahr.

Walker.....	7.019 pounds.
Fisher.....	4.828 "
Eureka.....	7.959 "
Price.....	11.898 "
Murphy.....	12.450 "

Steam per pound of combustible from and at 212° Fahr.

Walker.....	7.413 pounds.
Fisher.....	5.062 "
Eureka.....	8.231 "
Price.....	12.449 "
Murphy.....	12.927 "

Steam per sup. foot of heating surface per hour.

Walker.....	2.7679 pounds.
Fisher.....	1.7343 "
Eureka.....	3.2062 "
Price.....	3.8947 "
Murphy.....	2.9587 "

Coal per sup. foot of grate surface per hour.

Walker.....	13.413 pounds.
Fisher.....	11.214 "
Eureka.....	14.250 "
Price.....	11.973 "
Murphy.....	7.419 "

SMOKE PREVENTION.

In comparing results in the following table it should be observed, that absolutely no smoke was rated 100, and the ordinary condition of chimney gases was taken at 50:

Walker.....	86.923
Fisher.....	80.125
Eureka.....	86.140
Price.....	81.203
Murphy.....	98.467

THE DISTRIBUTION OF HEAT.

Specimen lumps of coal were taken from the several lots furnished the competitors in the trials, and submitted to analysis by Prof. Bruno Kniffler, with the following result:

Fixed carbon.....	61.038
Volatile matter.....	32.750
Sulphur.....	0.863
Moisture.....	2.307
Ash.....	3.042
	100.000

As already stated, the thermal value of the combustible has been taken at 15,500 units; equivalent to an evaporation from and at 212° Fahr. of 16.045 pounds.

WALKER FURNACE.

	Thermal units.	Steam.	Percentage.
Steam.....	7161.155	7.413	46.201
Chimney gas.....	3734.725	3.866	24.095
Vapor of water.....	169.415	0.175	1.093
Moisture in coal.....	30.070	0.031	0.194
Combustible gas.....	775.000	0.802	5.000
Radiation.....	3629.635	3.758	23.417
	15500.000	16.045	100.000

FISHER FURNACE.

	Thermal units.	Steam.	Percentage.
Steam.....	489.940	5.062	31.548
Chimney gas.....	7710.320	7.982	49.744
Vapor of water.....	238.700	0.247	1.540
Moisture in coal.....	30.225	0.031	0.195
Combustible gas.....	1085.000	1.123	7.000
Radiation.....	1545.815	1.600	9.973
	15500.000	16.045	100.000

EUREKA FURNACE.

	Thermal units.	Steam.	Percentage.
Steam.....	8384.570	8.679	54.094
Chimney gas.....	2616.555	2.709	16.881
Vapor of water.....	75.640	0.078	0.488
Moisture in coal.....	28.985	0.030	0.187
Combustible gas.....	620.000	0.642	4.000
Radiation.....	3774.250	3.907	24.350
	15500.000	16.045	100.000

PRICE FURNACE.

	Thermal units.	Steam.	Percentage.
Steam.....	12026.140	12.449	77.588
Chimney gas.....	1772.890	1.835	11.438
Vapor of water.....	60.295	0.063	0.389
Moisture in coal.....	28.830	0.030	0.186
Combustible gas.....	387.500	0.401	2.500
Radiation.....	1224.345	1.267	7.899
	15500.000	16.045	100.000