Combustion of Coal

AND THE

Prevention of Smoke

BARR

Combustion of Coal
and the Prevention of Smoke

A Practical Treatise for
Engineers, Firemen and All Others Interested
in Fuel Economy and the Suppression of
Smoke from Stationary Steam-Boiler
Furnaces, and from Locomotives

Contains nearly 500 questions, with their answers,
covering everything relating to combustion,
heat, and steam generation

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PREFACE.

THIS edition of combustion of coal is so entirely different from my former treatise that it is to all intents a new book. Much of the original material has been retained, but worked over and presented in new form. The aim of the writer is sufficiently indicated by the title page, in which it will be seen that the subject has special reference to the economical and smokeless combustion of ordinary fuels in the generation of steam.

The best book for practical and busy men is the one which is nearest complete in itself. In view of this fact, the writer has included in these pages much collateral information and useful data, not always bearing directly upon furnace combustion, in the belief that such information would be helpful and gladly received by those wishing to acquire a broader knowledge, including all the facts relating to the subject of combustion in general.

Unavoidable repetitions occur in this book, as it was thought improbable that it would in all cases be studied systematically from end to end, in which case the subject-matter might have been shortened by means of cross references. In view of the probability that this book will be commonly used as its contained information is required, which will then be sought out by means of the index, it was thought best to make each answer as complete as possible, and without reference to the fact that the same data occurred elsewhere in this volume.

There has been a somewhat unlooked-for demand for such a book as this, mainly from locomotive engineers and firemen, by reason of the insistance on the part of the management of the more important railway lines that their locomotive engineers and firemen shall, among other requirements, undergo a satisfactory examination in the principles of the combustion of coal and of the laws governing the prevention of smoke; this, with a view to securing a better or more rational method of firing, as well as leading up to the abatement of the smoke nuisance, which in many localities has become almost unbearable. For this purpose my former treatise was wanting in practical detail, and is a reason for a new presentation and restatement of this important subject.

The publishers have had marked success in the several catechisms issued from their press, and it was their desire that this book should conform in size and method of presentation with their other publications. But aside from this, no apology is needed, for no form of presentation is so popular with practical and busy men as the simple one of question and answer.

The questions are intended to cover every detail relating to the economic combustion of such fuels as are employed in steam engineering. The answers are, so far as the writer is able to prepare them, scientifically accurate. The authorities quoted in my former treatise have been used in this, and in addition thereto free use has been made of the several excellent papers by Professor Thorpe, on fuels, heat, combustion, etc. Acknowledgment is also made of materials selected from the writings of such authorities as Hoadley, Snow, Kent, Bell, Thurston, Sinclair, Barrus, Carpenter, and others.

WILLIAM M. BARR.

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COMBUSTION OF COAL.

CHAPTER I.

FUEL.

Q. What is meant by term fuel?

Fuel expresses in a word and in general terms any substance which may be burned by means of atmospheric air, with sufficient rapidity to evolve heat capable of being applied to economic purposes. The economic value of any fuel will depend upon its heating power. The two elements contributing this property to fuel are carbon and hydrogen. The more important varieties of fuel include wood, peat, lignite, coal, natural and producer gas, and petroleum.

Q. Of what does fuel consist?

All fuel consists of vegetable matter or the products of its alteration. The elementary constitution of fuel is consequently much the same, carbon, hydrogen, oxygen, nitrogen, and inorganic matter that constitutes the ash. The gradual process of woody tissue into anthracite is shown in the following analytical results in which the hydrogen and oxygen percentages are based on that of carbon:

TABLE 1.—COMPOSITION OF FUEL.

Fuels.	Carbon.	Hydrogen.	Oxygen.
Wood	100	12.18	83.07
Peat	100	9.85	55.67
Lignite	100	8.37	42.42
Bituminous coal	100	6.12	21.23
Anthracite	100	2.84	1.74

The following table shows the chemical alterations in approximate percentages of carbon, hydrogen, and oxygen as occurring in the different fuels:

TABLE 2.—COMPOSITION OF FUEL.

Fuels.	Carbon.	Hydrogen.	Oxygen.
Wood	52.65	5.25	42.10
Peat	60.44	5.96	33.60
Lignite	66.96	5.27	27.76
Bituminous	76.18	5.64	18.07
Semi-anthracite	90.50	5.05	4.40
Anthracite	92.85	3.96	3.19

Q. What is coal?

Coal, as defined by Dr. Percy, is a solid stratified mineral substance, black or brown in color, and of such a nature that it can be economically burnt in furnaces or grates.

Our acquaintance with the chemistry of coal is almost entirely confined to a knowledge of its ultimate composition. We know it to be made up of variable proportions of carbon, hydrogen, oxygen, and nitrogen; but there are reasons for believing that in bituminous coals there exist ready formed definite compounds, at all events, of hydrogen and carbon.

Besides these strictly organic ingredients coals contain varying amounts of what must be regarded as impurities in the shape of mineral matters, which constitute the ash, and pyrites or bisulphide of iron. Sulphur in the free state is sometimes present in coal.

Q. What is the commercial classification of coals ?

The coals of the United States range in hardness from the dense anthracite through all gradations to the soft, easily crumbled lignite. The commercial classification separates them broadly into hard and soft coals, or into anthracite and bituminous coals. This classification includes among the anthracite coals the semi or gaseous anthracites. The bituminous coals include semi-bituminous, caking, non-caking, cannel, block, and other varieties, as well as all the gradations of lignite, a faulty classification, but one which works little or no inconvenience, because orders for bituminous coals are usually placed in open market designating whether intended for coke-making, gas-making, blacksmith and forge work, boiler furnaces, or other need of the customer; large orders not infrequently specifying the locality if not the particular mines from which the coals are to be shipped.

Q. What are the physical properties of the coals in Gruner's classification ?

In Gruner's classification of coals the following physical properties predominate:

1. Anthracite, or lean coals; burning with a short flame; having a black color, and a specific gravity of 1.33 to 1.4. These coals form the transition to true anthracite. On coking they yield 82 to 90 per cent fritted or pulverulent coke, and 12 to 18 per cent of gas. Evaporative factor, 9 to 9.5.

This coal adapted for domestic use.

2. Caking coals (fat coals) burning with a short flame;

color, black, shining, often with lamellar structure. Specific gravity, 1.30 to 1.35. Yields 74 to 82 per cent fairly hard coke, caked together very densely, and 12 to 15 per cent gases. Evaporative factor, 9.2 to 10.

Adapted for coking and for heating steam boilers.

3. Caking coals proper, or furnace coals. Burning with longer flame; color, black, shining, lustre more marked; these coals swell under the action of heat more than those of classes 1 and 2. Specific gravity, 1.30. Yields 68 to 74 per cent caked fairly dense coke, and 13 to 16 per cent gases. Evaporative power, 8.4 to 9.2.

Adapted for coking and smithy use.

4. Caking coals, long flaming (gas coal). These coals burn with a long flame. Color, dark, high lustre. Coals hard and tough. Specific gravity, 1.28 to 1.30. Yields 60 to 68 per cent caked but very friable coke and 17 to 20 per cent gases. Evaporative factor, 7.6 to 8.3.

Adapted for gas manufacture and for reverbatory furnaces.

5. Dry coals, burning with a long flame. Color, intense black. Coals hard, break with conchoidal fracture (splint coal). Specific gravity, 1.25. Yields 50 to 60 per cent pulverulent coke and 20 per cent gas. Evaporative factor, 6.7 to 7.5.

Adapted for reverbatory furnaces.

The ash-forming constituents of coal vary from 0.5 to 30 per cent, averaging from 4 to 7 per cent in the best coals; 8 to 14 in medium; and upward of 14, with 0.5 to 2 per cent of sulphur in the worst.

Q. What is meant by evaporative factor as employed by Gruner in his classification of coals?

The evaporative factor, as employed by Gruner, means the number of times its weight of water is evaporated by a unit weight of coal starting at 100° C., or 212° F.

Q. What is anthracite coal?

Anthracite is the most rich in carbon, greatest in density, and hardest of all varieties of coal. Typical anthracite coals contain:

Carbon	90 to 95 per cent.
Hydrogen	1 to 3 "
Oxygen and nitrogen	1 to 3 "
Moisture	1 to 2 "
Ashes	3 to 5 "

The best varieties of anthracite coal are slow to ignite, conduct heat badly, burn at a high temperature, radiate an intense warmth, and once ignited are difficult to quench. Generating almost no water during its combustion, anthracite coal powerfully desiccates the atmosphere of an apartment in which it is burning. Anthracite coals occur principally in Pennsylvania.

J. P. Lesley states that anthracite is not an original variety of coal, but a modification of the same beds which remain bituminous in other parts of the region. Anthracite beds, therefore, are not separate deposits in another sea, nor coal measures in another area, nor interpolations among bituminous coal, but the bituminous beds themselves altered into a natural coke, from which the volatile bituminous oils and gases have been driven off.

Q. What is the commercial classification of anthracite coal?

The larger sizes are known as lump, steamboat, egg, and stove coals, the latter in two or three sizes. For steam-making, the commerce is confined almost exclusively to pea and smaller sizes.

TABLE 3.—COXE BROS. & CO.'S STANDARDS FOR SMALL ANTHRACITE COALS.

Size.	Made through.	Made over.	Approximate price at mines.
Chestnut	$1\frac{1}{2}$ inches.	$\frac{7}{8}$ inch.	$2.75
Pea	$\frac{7}{8}$ inch	$\frac{9}{16}$ "	1.25
Buckwheat	$\frac{9}{16}$ "	$\frac{3}{8}$ "	.75
Rice	$\frac{3}{8}$ "	$\frac{3}{16}$ "	.25
Barley	$\frac{3}{16}$ "	$\frac{3}{32}$ "	.10

The above meshes are all round-punched.

Q. What is the composition of Pennsylvania anthracite coal?

In physical appearance anthracite coal differs sufficiently from other coals that once known it may be ever after distinguished at sight. The fracture presents a conchoidal appearance and is quite homogeneous in structure.

Anthracite coal from Tamaqua, Pa., is compact, slaty, conchoidal, grayish black, splendant (Geol. Sur. Pa.). Specific gravity, 1.57 = 98.13 pounds per cubic foot.

Fixed carbon	92.07	per cent.
Volatile matter	5.03	"
Ash, white	2.90	"
	100.00	"

Heat units in one pound of coal = 14,221, equal to an equivalent evaporation of 14.72 pounds of water from and at 212° F. per pound of coal.

LEHIGH COUNTY, PA., ANTHRACITE COAL—PROXIMATE ANALYSIS.

Fixed carbon	88.15	per cent.
Volatile combustible	5.28	"
Moisture	1.01	"
Ash	5.56	"
	100.00	"

Heat units in one pound of coal = 13,648, equal to an equivalent evaporation of 14.13 pounds of water from and at 212° F. per pound of coal.

The Buck Mountain, Carbon County, Pa., anthracite coal, in the smaller sizes, such as pea or buckwheat, is largely employed as a steam coal. Such coals, by reason of the small sizes, contain an excess of slaty matter, which remains on the grate as ash. In average composition they run about as follows:

Carbon	82.66	per cent.
Volatile combustible	3.95	"
Moisture	3.04	"
Ash	10.35	"
	100.00	"

Heat units in one pound of coal = 12,634, equal to an equivalent evaporation of 13.08 pounds of water from and at 212° F. per pound of coal.

Semi-anthracite coal from Wilkesbarre, Pa., in the smaller sizes, such as buckwheat, shows an excess of ash due to the impracticability of picking the slate out of the coal, as is done in stove and larger sizes. The average composition of fine coals from this locality is as follows:

Carbon	76.94	per cent.
Volatile combustible	6.42	"
Moisture	1.34	"
Ash	15.30	"
	100.00	"

Heat units in one pound of coal = 12,209, equal to an equivalent evaporation of 12.64 pounds of water from and at 212° F. per pound of coal.

Q. What is culm?

Culm is fine anthracite coal. Formerly this was waste product and had no commercial value. Culm heaps abound in the anthracite regions of Pennsylvania, and much attention has been given to various processes for its employment as fuel. The late Eckley B. Coxe, an expert in all matters relating to the subject of coal, devoted much time to the utilization of culm in steam-making, but without satisfactory commercial results; that is, no demand for culm has been created outside the mining regions. Anthracite differs from bituminous or coking coals in that it burns only at the surface. Hence it is absolutely essential to provide for the necessary air spaces around the pieces on the grate. This can be accomplished only by careful sizing. With coal not carefully sized the interstices between the larger particles are filled by the smaller; and, the air being unable to find a free enough passage, combustion is imperfect. Culm banks are mixed fine coal, of many sizes, with a considerable proportion of slate and pyrites; requiring careful attention as to draft, firing, and details of grate, upon which it is to be burned.

Q. What is semi-anthracite coal?

The semi-anthracite coals are restricted, with few exceptions, to those coals which possess on an average from seven to eight per cent of volatile combustible matter. In consequence of this combustible matter, part of which at least resides probably in a free or gaseous state in the cells of the coal, this variety kindles more promptly; and when sufficiently supplied with air, burns more rapidly than the hard anthracites.

This coal occurs principally in Pennsylvania. Samples from Wilkesbarre average as below: The semi-anthracites of this locality are compact, conchoidal, iron-black, splendant. Specific gravity, 1.40 = 87.5 pounds per cubic foot.

Fixed carbon	88.86	per cent.
Volatile matter	7.66	"
Earthy matter	3.46	"
	100.00	"

The calorific power of this coal is 14,199 heat units per pound; this is equal to an equivalent evaporation of 14.59 pounds of water from and at 212° F. per pound of coal.

This coal is held in high estimation for domestic use, and for the generation of steam.

Q. What is semi-bituminous coal?

Semi-bituminous coal is not so hard, and contains more volatile matter than the anthracite coals proper. In this as in all other classifications of coals its limits must be fixed somewhat arbitrarily. In appearance it more closely resembles the anthracite than the bituminous coals, differing from anthracite in fracture, as being less conchoidal; it is not so hard; it is of less specific gravity; and when thrown upon the fire it kindles much more readily and burns faster than anthracite.

Cumberland, Md., semi-bituminous coal. Specific gravity, 1.41 = 88.13 pounds per cubic foot.

Fixed carbon	68.19	per cent.
Volatile matter	17.12	"
Sulphur	.71	"
Ash	13.98	"
	100.00	"

This coal takes high rank as a fuel. Although containing less carbon than anthracite, it is quite as desirable on account of the readiness with which it kindles and the quantity of heat it is capable of giving off when burned in steam-boiler furnaces.

Blossburg, Pa., semi-bituminous coal. Specific gravity, 1.32 = 82.50 pounds per cubic foot.

Fixed carbon	73.11	per cent.
Volatile matter	15.27	"
Sulphur	.85	"
Ash	10.77	"
	100.00	"

Semi-bituminous coals are much more easily regulated in the furnace when burning than in the case of anthracites. It is characteristic of these coals that they burn almost entirely smokeless.

Q. What are the properties of bituminous coal?

Bituminous coal is the product of the decomposition of vegetable matter, and was formed previously to or in the Cretaceous period. Chemically it occupies a place between lignite and anthracite coal, but the transition of lignite into bituminous coal is as gradual as the latter is into anthracite, so there is no precise line of demarcation between these classes of coal. The use of the term bituminous is a misleading one, because none of the so-called bituminous coals in this country contain any bitumen in their composition. The true bitumens are destitute of organic structure; they appear to have arisen from coal or lignite by the action of subterranean heat, and very closely resemble some of the products yielded by the destructive distillation of those bodies. It is possible that its name has been applied to certain varieties of coal on account of a similarity between the burning of a coal rich in hydrocarbon and bitumen.

The latter is very inflammable, and burns with a red smoky flame.

All coals which contain as much or more than 18 or 20 per cent of volatile combustible matter are quite indiscriminately classed among bituminous coals. Some coals contain as much as 50 per cent of volatile combustible.

In external properties the common bituminous coals range in color from a pitch black to a dark brown. Their lustre is vitreous, resinous, or in the more fibrous varieties silky; their structure is compact and cuboidal, slaty, columnar, and even fibrous; their fracture, irrespective of structural joints and cleavage, is conchoidal, and often flat and rectangular, and sometimes fibrous.

It is distinctive of these coals to burn with a more or less smoky yellow flame, and to emit when burning a bituminous odor.

Q. What is the composition of bituminous coal?

In proximate composition—namely, in fixed carbon or coke, volatile matter or combustible gases, and earthy sedimentary residue or ashes—they may be regarded as ranging between the following general limits:

PROXIMATE COMPOSITION.

Fixed carbon	52 to 84	per cent.
Volatile matter	12 to 48	"
Earthy matter	2 to 10	"
Sulphur	1 to 3	"

Dried at a temperature of 212° F., from 1 to 5 per cent of moisture may be driven off, with occasionally higher percentages.

The proportion of earthy matter, or ash, is too variable to fix a maximum limit, as all bituminous coals may, by impurities, graduate into carbonaceous shales.

Bituminous coals may be regarded as ranging:

ULTIMATE COMPOSITION.

Carbon	60 to 80 per cent.
Hydrogen	5 to 6 "
Nitrogen	1 to 2 "
Oxygen	4 to 10 "
Sulphur	0.5 to 4 "
Ash	3 to 12 "

The proximate composition of coals as given in Table 4 is intended to give a general survey of the principal bituminous coal fields of the United States, and is not at all complete as to localities.

TABLE 4.—SELECTED AMERICAN BITUMINOUS COALS.

W = Water. G = Gas. C = Carbon. A = Ash.

Locality.	Volatile matter.	Coke.	Heat units per pound.	Evaporation from and at 212°.
Alabama	W. 3.01	C. 48.30		
Jefferson Co	G. 42.76	A. 5.93	14,017	14.51
Arkansas	W. 1.52	C. 74.49		
Johnson Co	G. 14.73	A. 9.26	13,217	13.68
California	W. 18.08	C. 35.61		
Alameda Co	G. 39.30	A. 7.01	11,608	12.01
Colorado	W. 3.93	C. 47.16		
Tremont Co	G. 42.43	A. 6.48	13,797	14.28
Georgia	W. 1.20	C. 60.50		
Dade Co	G. 23.05	A. 15.25	12,553	12.99
Illinois	W. 8.40	C. 54.80		
Mercer Co	G. 31.20	A. 5.60	13,063	13.52
	W. 5.78	C. 45.37		
Vermilion Co	G. 43.70	A. 5.15	13,746	14.23
Indiana	W. 13.05	C. 48.78		
Block Coal	G. 32.34	A. 5.83	12,377	12.81
	W. 3.50	C. 42.00		
Cannel Coal	G. 48.00	A. 6.50	13,962	14.45
	W. 5.50	C. 46.00		
Vermilion Co	G. 44.00	A. 4.50	13,886	14.37
Indian Territory	W. 6.66	C. 51.32		
Choctaw Nation	G. 35.42	A. 6.60	13,248	13.71
Iowa	W. 5.16	C. 45.88		
Monroe Co	G. 40.21	A. 8.75	13,247	13.71

Locality.	Volatile matter.	Coke.	Heat units per pound.	Evaporation from and at 212°.
Kansas	W. 1.94	C. 52.45		
Cherokee Co.	G. 36.77	A. 8.84	13,585	14.06
Kentucky	W. 3.60	C. 58.80		
Muhlenberg Co	G. 30.60	A. 7.00	13,544	14.02
Maryland	W. 1.23	C. 73.57		
Cumberland	G. 15.47	A. 9.79	13,205	13.67
	W. .59	C. 74.31		
George's Creek	G. 18.52	A. 6.58	13,812	14.30
Missouri	W. 9.03	C. 46.24		
Putnam Co.	G. 37.48	A. 7.25	12,852	13.30
Montana	W. 3.01	C. 59.71		
Cascade Co.	G 30.23	A. 7.05	13,616	14.10
Nebraska	W. 0.21	C. 60.88		
Adams Co	G. 27.82	A. 11.09	13,390	13.86
New Mexico	W. 3.10	C. 51.50		
Colfax Co	G. 35.00	A. 10.40	13,208	13.67
North Carolina	W. 1.79	C. 58.30		
Guilford Co.	G. 29.56	A. 10.35	13,302	13.77
Ohio	W. 8.25	C. 53.15		
Hocking Valley	G. 35.88	A. 2.72	13,591	14.07
	W. 2.47	C. 64.25		
Mahoning Co.	G. 31.83	A. 1.45	14,537	15.05
Oregon	W. 8.00	C. 45.17		
Tillamook Co.	G. 37.83	A. 9 00	12,754	13.20
Pennsylvania	W. 1.80	C. 54.94		
Pittsburg	G. 35.34	A. 7.92	13,762	14.25
	W. 1.93	C. 63.26		
Connellsville	G. 28.71	A. 6.10	13,881	14.37
	W. 1.00	C. 58.40		
Youghiogheny	G. 35.00	A. 5.60	14,208	14.71
Tennessee	W. 3.16	C. 54.81		
Marion Co	G. 31.94	A. 10.09	13,185	13.65
Texas	W. 6.67	C. 43.54		
Palo Pinto	G. 40.20	A. 9.59	12,906	13.36
Utah	W. 3.50	C. 43.11		
Iron Co	G. 43.66	A. 9.73	13,411	13.88
Virginia	W. 1.34	C. 56.83		
Rockingham Co.	G. 30.98	A. 10.85	13,321	13.79
West Virginia	W. .76	C. 72.99		
Mineral Co.	G. 19.39	A. 6.86	13,764	14.25
	W. .50	C. 75.63		
Pocahontas (semi-bit.)	G. 19.83	A. 4.04	14,218	14.72
Washington	W. 1.10	C. 54.50		
Pierce Co.	G. 35.10	A. 9.30	13,659	14.14
Wyoming	W. 4.20	C. 41.50		
Weston Co	G. 40.60	A. 13.70	12,676	13.12

Q. How are bituminous coals classified?

Gruner's classification is given on page 11, and in addition thereto the classification for economic purposes, by Percy, is also given:

1. Non-caking or free-burning coals rich in oxygen.
2. Caking coals.
3. Non-caking coals rich in carbon.

This classification of coals is based on their chemical composition, and therefore on their calorific powers.

Q. What are the distinguishing properties of a caking coal?

Caking coal is the name given to any coal which, when heated, the lumps seem to fuse together and swell in size, having a pasty appearance and emitting a gummy or sticky substance over the surface, liberating meanwhile small streams of gas, which appear to escape as from a considerable pressure from within the coal; this escaping gas burning with a yellow and sometimes a reddish flame terminating in smoke. A characteristic of caking coal is that lumps, either large or small, being rendered pasty by the action of the heat, will cohere in the fire and form a spongy looking mass, which not unfrequently covers almost the whole surface of the grate; this is the property called caking.

Q. For what purposes are caking coals especially desirable?

Caking coals are employed in forges where a hollow fire is wanted for heating iron or steel. Caking coals rich in hydrocarbons are highly esteemed by gas manufacturers, because after driving off the gas the remaining coke is a valuable by-product which commands a ready sale. Caking coals which will yield a hard strong coke are valuable, inasmuch as coke having these properties is greatly in demand in the manufacture of iron and steel.

Q. What is coke?

Coke is the solid product left after the expulsion of the volatile matter from coal by the action of heat. The only coke of any commercial value is that made from caking coals. The fine coal, screenings, or small lumps of caking coals, when heated sufficiently high and protected from the atmospheric air, as in a coke oven, gas retort, or in a closed furnace, will have the volatile portions of the coal driven off, and a coherent mass of fixed carbon, containing usually 5 to 10 per cent of earthy matter, alone remains; this final product is called coke.

A very excellent quality of coke is made in the Connellsville region, Pennsylvania. It is there produced in enormous quantities for the manufacture of iron and steel in and near Pittsburg, and for the remelting of pig iron in cupola furnaces in other localities. The coal from which this coke is made is mined in Fayette County, Pa.; it is of columnar structure, inclined to be granular, and easily broken into small fragments. In appearance this coal displays prismatic colors on every side; its specific gravity is 1.28 = 80 pounds per cubic foot. By proximate analysis it contains:

Fixed carbon	65.00	per cent.
Volatile combustible	24.00	"
Moisture	4.50	"
Ash, white	6.50	"
	100.00	"

Coke 71.50 per cent, of steel-gray color, having a metallic lustre, columnar, very strong, dense, slightly puffed

on the surface—this coke occurs in long pieces, not unlike ordinary cord wood sawed in half. It is an excellent fuel for melting iron. It requires a strong draft, about the same as hard anthracite coal. It yields an intense heat, burns free under a strong blast, and will support a considerable weight of iron above it in the cupola without crushing.

Q. What is the object in coking coals?

1. The coking of bituminous coal is intended to drive off the volatile combustible gases and thereby to concentrate the carbon which the coal contains, so that the coke may be capable of producing a higher temperature.

2. To remove the volatile substances which on burning, chiefly for domestic purposes, have an unpleasant smell.

3. To deprive the coal of the property of becoming pasty at a high temperature, in iron blast furnaces for instance, in consequence of which the blast cannot penetrate sufficiently, and the process of the furnace becomes disordered.

4. To remove part of the sulphur, which coal frequently contains in the form of sulphide of iron.

The production of good coke requires a combination of qualities not very frequently met with in coal, and hence first-rate coking coals can be procured only from certain districts.

Q. What are the general properties of coke?

The properties of coke must in some degree be influenced by the properties of the coal from which it is made. In external features it will depend whether the coke is the product of a gas retort or that of an oven, the general appearance being wholly unlike. As an article of commerce cokes contain: Carbon, 80 to 96 per cent; ash, 2 to 15;

hygroscopic moisture, 1 to 5; and is capable of absorbing from 5 to 10 per cent additional water if exposed to the weather.

Coke weighs 40 to 60 pounds per cubic foot and the denser varieties more. About 60 cubic feet of space are required for storage per ton.

Q. What properties in the coal are required for making the best coke?

To make a homogeneous good coke the fixed carbon of the coal must be of a kind that will melt at the lowest possible temperature; for if the process of coking produces the least pressure on the volatile hydrocarbons whereby there is an increase of heat, such pressure causes so complete a liquefaction and expansion of the fixed carbon that the coke is left cellular instead of being compact.

Q. For what purposes is coke chiefly employed?

Coke may be employed in all kinds of firing which do not require a large flame, but it is most effective in those instances in which great heat is required in a small space, as, for instance, in crucible meltings, in smelting of iron ores in blast furnaces, in remelting of pig iron in cupola furnaces, etc. When a sufficient quantity of air is admitted, coke produces a far greater heat than charcoal. As it remains longer in the furnace than charcoal before being ignited, it undergoes a better preparatory heating before ignition, and by this means its effect is increased.

Q. What is cannel coal?

Cannel coal is a variety of bituminous coal very rich in hydrogen. In appearance this coal differs from all other bituminous coals. Its structure is more nearly homogeneous than others, being a compact mass, varying from brown to black in color, and having usually a dull resinous lustre. When broken it does not usually preserve any distinct order of fracture, and is liable to split in any direction. On account of its being excessively rich in hydrocarbons it is highly esteemed as a gas coal, preference being given to those coals in which hydrogen bears the greatest proportion to the contained oxygen.

The amount of combustible matter which it contains, and the readiness with which this is given off in combustion, account for the name given it by the miners as "cannel," a corruption of candle coal. This coal kindles readily and burns without melting, emitting a bright flame like that of a candle. When thrown in the fire the piece splits up into fragments, producing a crackling noise, which, from a fancied resemblance, has also received the name of "parrot" coal. It is highly esteemed for domestic use, being especially bright and cheerful when burned in an open grate. Cannel coals are used for enriching gas made from coals containing a large amount of volatile combustible, but somewhat deficient in illuminating power.

Q. What is the composition of cannel coal?

Cannel coal occurs in so few localities that the variations in composition are less noticeable than is the case with other varieties of bituminous coal. Cannel coal from Breckenridge, Ky., analyzed by Dr. Peters, resulted in:

PROXIMATE ANALYSIS.

Carbon	32.00	per cent.
Volatile combustible	54.40	"
Moisture	1.30	"
Ash	12.30	"
	100.00	"

ELEMENTARY ANALYSIS.

Carbon	68.128	per cent.
Hydrogen	6.489	"
Nitrogen	2.274	"
Oxygen and loss	5.833	"
Sulphur	2.476	"
Ash	14.800	"
	100.000	"

Cannel coal from Davis County, Ind. Analysis by E. T. Cox. Specific gravity, 1.229 = 76.81 pounds per cubic foot.

PROXIMATE ANALYSIS.

Carbon	42.00	per cent.
Volatile combustible	48.50	"
Moisture	3.50	"
Ash, white	6.00	"
	100.00	"

Coke, 48 per cent, laminated, not swollen, lustreless.

ELEMENTARY ANALYSIS.

Carbon	71.10	per cent.
Hydrogen	6.06	"
Oxygen	12.74	"
Nitrogen	1.45	"
Sulphur	1.00	"
Ash	7.65	"
	100.00	"

Q. What is the calorific value of cannel coal?

The calorific power of cannel coal from Davis County, Ind., analysis of which is given on this page, is 13,131 heat units per pound of coal. This is equal to an equivalent evaporation of 13.58 pounds of water from and at 212° F. per pound of coal.

Q. What properties do non-caking coals exhibit in the fire?

Non-caking coals have the property of burning free in the fire much the same as wood charcoal burns; that is, heat does not cause them to fuse or run together in the fire. Perhaps the representative non-caking bituminous coal is the block coal of the Western States, and noticeably that of Indiana.

Q. What is block coal?

Block coal is a non-caking bituminous coal occurring in large quantities in Indiana. It may be described as laminated in structure, consisting of successive layers of coal, easily separated into thin horizontal slices, not unlike slate. Between these slices of coal is a layer of fibrous carbon resembling charcoal. In appearance it has a dull, lustreless face on the line of separation, and glistening or resinous black when broken at right angles to its horizontal face. A peculiarity of this formation, and that which gives it its name, is the presence of fractures occurring in the coal bed at right angles, or nearly so, and extending from top to bottom of the seam, enabling the miner to get it out in rectangular blocks, as these lines of fracture indicate or permit. It is a very strong coal, and will burn well under a heavy load without crushing. The blocks are very compact, and will endure rough handling and stocking without suffering material loss from abrasion.

A sample of typical block coal from near Brazil, Clay County, Ind., has the following characteristics: The coal of a dull lustreless black, in thin laminæ, separated by fibrous charcoal partings, very strong across the bedding lines, free from pyrites and calcite. A sample fresh from the mine, and holding an excess of moisture, analysis by E. T. Cox. Specific gravity, 1.285=80.31 pounds per cubic foot.

Fixed carbon	56.50 per cent.
Volatile combustible	32.50 "
Moisture	8.50 "
Ash, white	2.50 "
	100.00 "

Coke = 59 per cent, laminated, not swollen, lustreless.

The 8.50 per cent of moisture was reduced by exposure to the air to about 3.50 per cent. The heat units in the wet coal=13,588, and that of the dry coal = 14,400.

This coal is used as fuel in blast furnaces for smelting iron, and in puddling furnaces. It is largely used for steam-making and for domestic stoves, grates, etc.

A test of Indiana block coal by A. F. Nagle in steam-making yielded as follows:

Ratio of heating to grate surface	= 50 to 1
Ash, per cent	= 7.25
Rate of combustion, pounds per square foot of grate	= 15
Temperature of escaping gases	= 557° F.
Evaporation per pound of combustible from and at 212°	= 10.05 pounds.

Q. What is brown coal?

Brown coal is an imperfect coal. The term is often used interchangeably with lignite. The brown coal of the Germans is distinguished from true coals by the large proportion of oxygen in its composition. The chemical difference between brown coal and lignite may be determined by dry distillation, in which the lignite yields acetic acid and acetate of ammonia, whereas the brown coal produces only ammoniacal liquor. Woody fibre gives rise to acetic acid. Lignite must therefore still contain undecomposed woody fibre. It, together with brown coal, belongs chiefly to the Cretaceous and Tertiary periods (Cox). According to their geological age brown coals have either a distinct texture (true lignite, fibrous brown coal), or are without organic structure and earthy in fracture (earthy brown coal), or black, shining, with conchoidal fracture.

Thorpe's analysis of organic substance consists of: Carbon, 60; hydrogen, 5; oxygen, 35 = 100 in fibrous brown coal; and carbon, 75; hydrogen, 5; oxygen, 20 = 100 in conchoidal brown coal.

The analysis of brown coal from Ballard County, Ky., shows it to contain 20 to 30 per cent less fixed carbon than coals of the Carboniferous epoch, and a larger quantity of hygrometric moisture. The specific gravity of this coal is 1.173.

Fixed carbon	31.0	per cent.
Volatile combustible	48.0	"
Moisture	11.5	"
Ash, white	9.5	"
	100.0	"

The large quantity of hygrometric moisture in this coal lessens its evaporative power as compared with any average bituminous coal for steam-making. It is quite improbable that any considerable quantity of available heat is given off by the volatile combustible in this coal; and that its heating power is limited, almost if not entirely, to the fixed carbon, yielding 4,495 heat units, or an equivalent evaporation of 4.66 pounds of water from and at 212° F. per pound of coal.

Q. What is lignite?

Lignite is classed among mineral coals, and includes those varieties which form the intermediate stage between peat and true coals of the Carboniferous age. It is believed to be of later origin than bituminous coal, and is in a less advanced stage of decomposition. The woody fibre and vegetable texture of lignite are almost entirely wanting in coal, though there is little doubt that they are of one common origin.

Lignite varies considerably in appearance and structure, usually, however, preserving a wood-like appearance when broken. The fracture is uneven, presenting a brown to a very dark brown-black color, with a dull and frequently a fatty lustre. Lignites break easily and crumble in handling; they will not bear rough transportation to great distance; neither will they bear long-continued exposure to weather, crumbling rapidly. As a fuel lignite must be used in its natural state, and near where it is mined, to get the best results. It is non-coking in the fire, and yields but moderate heat as compared with the best bituminous coals.

In specific gravity lignites vary from 1.10 to 1.35, corresponding to 68.75 to 84.38 pounds per cubic foot.

Q. Where are lignites principally found?

Lignites and "brown coal" occur plentifully on the continent of Europe. In the United States very extensive deposits occur in Colorado, Nevada, Utah, Wyoming, New Mexico, California, Oregon, and Alaska, and in lesser quantity in some other States. As the States and Territories west of the Mississippi are developed, lignite will become a matter of growing importance, as it must become their chief fuel after the disappearance of the forests.

Q. What is the composition of lignite?

The lignites of the United States vary greatly in their chemical composition, consisting of:

Fixed carbon	40 to 70 per cent.
Volatile combustible	23 to 48 "
Moisture	4 to 40 "
Ash	3 to 20 "

Colorado lignite, Cañon City: Color, jet black; specific gravity, 1.279.

Fixed carbon	56.80	per cent.
Volatile combustible	34.20	"
Moisture	4.50	"
Ash, ochre yellow	4.50	"
	100.00	"

Coke = 61.30 per cent, slightly swollen, unchanged, semi-lustrous (Cox).

Washington lignite, Billingham Bay: Color, glossy black; fracture slaty and parallel to stratification. In the opposite direction the fracture is irregular and brittle.

PROXIMATE ANALYSIS.

Fixed carbon	58.25	per cent.
Volatile combustible	31.75	"
Moisture	7.00	"
Ash, reddish brown	3.00	"
	100.00	"

Coke = 61.25 per cent, slightly shrunken, dull black.

ULTIMATE ANALYSIS.

		First sample.	Second sample.
Carbon	Per cent	68.454	67.090
Hydrogen	"	6.666	4.555
Sulphur	"	1.000	1.000
Water at 212° F.	"	7.000	7.000
Ashes	"	3.400	3.100
Oxygen, nitrogen and loss	"	13.480	17.255
		100.000	100.000

Samples contained a large amount of oxygen and were deficient in the amount of hydrocarbons, and therefore more difficult of ignition than most of the Western varieties of bituminous coals; but it is rich in fixed carbon in the coke and will therefore be durable. It is intermediate in composition of its ultimate elements to cannel coal and lignites (Cox).

Kentucky lignite, Ballard County: Sample had much the appearance of coal, hence apt to be mistaken for it; but it is of much more recent origin. Specific gravity, 1.201.

Fixed carbon	40	per cent.
Volatile combustible	23	"
Moisture	30	"
Ash, reddish yellow	7	"
	100	"

Coke = 47 per cent. Reduced in bulk and nearly the same shape as original specimen (Cox).

Arkansas lignite, Ouachita County: This lignite has a rhomboidal cleavage. Can be cut with a knife, and receives a good polish, which gives it a much blacker appearance. It is solid, heavy, compact, of a bluish-brown color, disintegrating, however, by exposure to the atmosphere.

Fixed carbon	34.50	per cent.
Volatile combustible	28.50	"
Moisture at 260° F.	32.00	"
Ash	5.00	"
	100.00	"

Coke = 39.5 per cent.

Vancouver's Island lignite: Color, dull black, submetallic. Fracture, foliated and slaty, numerous partings filled with scales of carbonate of lime.

Fixed carbon	62	per cent.
Volatile combustible	31	"
Moisture	4	"
Ash, reddish brown	3	"
	100	"

Coke = 65 per cent. This lignite shrinks slightly in coking, and is dull black in color (Cox).

Texas lignite, Robertson County: Sample taken from seam ten feet thick. Color, lustreless, dull brown, with irregular fracture and much inclined to shrink, crack, and fall to pieces on exposure to air. Specific gravity, 1.232.

Fixed carbon	45.00	per cent.
Volatile combustible	39.50	"
Moisture	11.00	"
Ash, white	4.50	"
	100.00	"

Coke, slightly shrunken, lustreless, and bears a close resemblance to wood charcoal. Heat units, 13,068.

The ash of lignites is extremely variable as to quality as well as to quantity. In composition it is similar to that of bituminous coal. It differs from the ash of peat in the low percentage of phosphoric acid. Usually it is rich in sulphur, as gypsum, iron pyrites, and sometimes as free sulphur.

Q. What is the quality of coke obtained from lignite?

Lignites are in general non-caking in an open fire. The coke obtained by distillation from the best lignites is not of good quality and takes rank much below the inferior grades of coke made from gas coals.

Q. How are woods classified?

Wood as a fuel is commonly divided into two classes—hard and soft. Hard woods include the heavy compact varieties, such as oak, hickory, beech, elm, ash, walnut, etc. The soft woods include pine, birch, poplar, willow, etc.

The specific gravity of wood varies considerably. Air-dried woods, with 20 per cent hygroscopic moisture, having a specific gravity of more than 0.55 are classed as hard woods; with a lower specific gravity they are classed as soft woods. After complete expulsion of air from the pores the specific gravity is the same in all woods, viz., 1.5.

Q. What is the composition of wood?

Wood consists of about 96 per cent of organic tissue and 4 per cent of sap, containing a small proportion of inorganic matter. Freshly cut green wood contains on an average about 45 per cent of moisture; and after long exposure to the atmosphere under favorable conditions it still retains from 18 to 20 per cent of moisture, a matter of practical importance in the direct application of wood as fuel. The accompanying table, by M. Eugene Chevandier, shows the composition of several well-known varieties of wood:

TABLE 5.—COMPOSITION OF WOOD (Chevandier).

Woods.	Composition in Per Cent.				
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
Beech	49.36	6.01	42.69	0.91	1.00
Oak	49.64	5.92	41.16	1.29	1.97
Birch	50.20	6.20	41.62	1.15	.81
Poplar	49.37	6.21	41.60	.96	1.86
Willow	49.96	5.96	39.56	.96	3.37
Average	49.70	6.06	41.30	1.05	1.80

Q. What quantity of moisture is contained in wood?

Wood contains about 45 per cent of moisture when freshly cut. Some of this is lost by subsequent evaporation in the atmosphere, but there still remains about 20 per cent of moisture which cannot be expelled except by means of artificial heat. The following table, prepared by M. Violette, shows the proportion of water expelled from wood at gradually increasing temperatures. The samples of wood operated upon had been kept in store during two years. In each experiment the specimens were exposed during two hours to desiccation in a current of superheated steam, of which the temperature was gradually raised from 257° to 437° F. When wood, which has been strongly dried by means of artificial heat, is left exposed to the atmosphere, it reabsorbs about as much water as it contains in its air-dried state.

TABLE 6.—WATER EXPELLED FROM 100 PARTS OF WOOD (Violette).

Temperatures.	Oak.	Ash.	Elm.	Walnut.
257° F	15.26	14.78	15.32	15.55
302° F	17.93	16.19	17.02	17.43
347° F	32.13	21.22	36.94 ?	21.00
392° F	35.80	27.51	33.38	41.77 ?
437° F	44.31	33.38	40.56	36.56

Q. What is a distinguishing property of wood as a fuel?

Though the calorific intensity of wood is small as compared with coal, its combustibility is greater than that of any other solid fuel, and it gives more flame.

Q. What is bagasse?

Bagasse is the woody fibre of sugar-cane after the saccharine juices have been expelled for sugar-making. Special furnaces have been contrived for burning it, and with fair results. The contained water is about 50 per cent of the gross weight. The remaining fibre is not unlike wood in its heat-giving power. On an average six pounds of bagasse are equivalent to one pound good bituminous coal.

Q. What is tan?

Tan is the spent bark from which the tannic acid has been extracted in the process of tanning leather. The barks commonly used are oak and hemlock. The principal drawback to tan as a fuel is its contained moisture, and for this reason special furnaces are made for burning it. Tan bark, as commonly used for fuel, will yield about 3,600 heat units per pound, which is one-half the value of ordinary dry wood, and about one-fourth the value of good bituminous coal.

If it were not for the contained moisture in tan very much higher calorific results could be obtained. According to M. Peclet 5 parts of oak bark produce 4 parts of dry tan, and the heating power of perfectly dry tan, containing 15 per cent of ash, is 6,100 heat units, while that of tan in an ordinary state of dryness, containing 30 per cent of water, is only 4,284 heat units. The equivalent evaporation from and at 212° F. would be:

Perfectly dry tan, $\frac{6,100}{966} = 6.31$ pounds of water.

Wet tan, 30 per cent water, $\frac{4,284}{966} = 4.44$ pounds of water.

Results which are much higher than obtain in average practice.

Q. What is peat?

Peat is the product of the decay of plants which are undergoing a gradual transformation by a process of slow burning or carbonization, in which the oxygen of the plants is being liberated under special conditions of air and moisture, leaving a spongy, carbonaceous mass, in which the remains of the plants are often so well preserved that species may easily be distinguished.

In color peat varies from a yellowish brown through all gradations to a very dark brown, almost black. The structure of the former is light, spongy, and fibrous; the latter is more compact and pitchy in appearance, the fibrous texture being almost entirely obliterated. In advanced stages of decomposition it is compact and dense, presenting an earthy fracture when broken; in general the darker the peat the richer it is in carbon.

Q. What is the composition of peat?

In its natural and more advanced state peat contains about 75 per cent of its entire weight of water. In the earlier stages of decomposition the quantity of water more nearly approaches 90 per cent, the peat being of the consistency of mire, and is of course totally unfit for any of the purposes for which fuel is employed.

Peat shrinks very much in drying, yet 20 to 30 per cent of moisture still remain in ordinary air-dried samples. The remaining product is decomposed vegetable matter and contains the elements common to plants. The chemical composition of peat varies according to its stage of decomposition. The following analysis of Irish peat is upon the authority of Sir Robert Kane:

	Light fibrous.	Compact and dense.
Carbon	58.53	56.34
Hydrogen	5.73	4.81
Oxygen	32.32	30.20
Nitrogen	.93	.74
Ash	2.47	7.90

These samples yielded by distillation:

	Light fibrous.	Compact and dense.
Water	38.1	38.1
Crude tar	4.4	2.8
Charcoal	21.8	32.6
Gas	35.7	26.5

The tar when redistilled yielded water, paraffine oils, charcoal, and gas. The water yielded chloride of ammonium, acetic acid, and wood spirit.

The inorganic constituents of peat vary from 0.5 to 20, or even 50 per cent, according to the elevation at which the peat was formed. The average ash-giving constituent is from 6 to 12 per cent, and, unlike that of wood, the ash is poor in alkalies, and consists chiefly of a mixture of:

Argillaceous sand	up to	35	per cent.
Magnesia-bearing gypsum	"	40	"
Ferric oxide	"	30	"
Alkalies	"	3	"

With traces of phosphoric acid and chlorine.

Q. What is the density of peat?

The density of peat varies according to its occurrence with reference to the surface of the ground, that belonging to the upper stratum being lightest. The specific gravity of the light fibrous peat in the preceding question is but 0.280, while the compact and dense peat in the same paragraph is 0.655. Thus the light fibrous peat = 17.5 pounds per cubic foot, or 114 cubic feet per ton of 2,000 pounds. The compact and dense peat = 40.94 pounds per cubic foot, or 48.85 cubic feet per ton of 2,000 pounds. Compressed peat will weigh from 70 to 85 pounds per cubic foot, or from 24 to 30 cubic feet per ton of 2,000 pounds. The dense peat found in the lower strata of peat beds, and which is in a more advanced state of decomposition, is not easily compressible. Its specific gravity is seldom greater than that of water or unity; therefore the densest varieties will seldom weigh more than 62.5 pounds per cubic foot, or 32 cubic feet per ton.

Q. How is peat prepared for use as fuel?

The machinery used for making peat fuel is not expensive, and requires but little attention when in operation. If the fibre of the upper formation of peat is crushed or milled while it is still wet, the contraction in drying is much increased; and as surface peat is always fibrous and spongy, it is the lightest. This breaking up of its fibres facilitates its subsequent compression for use as fuel, the degree of compression varying with the density of the peat, which grows more dense in the lower strata, where the fibrous texture is nearly or wholly obliterated.

In Canada the peat is cut and air-dried, after which it is pulverized by being passed through a picker and automatically deposited in a hopper, which feeds a steel tube about two inches in diameter and fifteen inches long.

The pulverized peat is forced through this tube by pressure, and formed into cylindrical blocks three inches in length and almost equal in density to anthracite coal. The fuel is non-friable and weather-proof by reason of its solidity and the glaze imparted to it by frictional contact with forming dies. The inherent moisture of the peat is reduced to 12 per cent of the mass. It is claimed that peat can be thus prepared at a cost of 60 cents per ton.

Q. What are the properties of peat charcoal?

The charcoal produced by the carbonization of ordinary air-dried peat is very friable and porous; it takes fire readily, and when ignited continues to burn until its carbonaceous matter is wholly consumed; it scintillates in a remarkable degree when burnt in a smith's fire; its extinction when in mass is difficult, and hence this is the troublesome part of its manufacture by the usual method of carbonization in piles; and it is so little coherent that it cannot be conveyed without much of it being crushed to dust.

When sufficiently coherent, and when the percentage of phosphoric acid is low, it may be used in low, small furnaces. Peat charcoal is easily kindled, and has a calorific power of 11,700 to 12,600 heat units. It is not adapted for iron-making, but may advantageously be used for gas furnaces on account of the large size of the lumps, absence of clinkers, and the fact that the ash readily falls through the bars.

Q. Where is peat principally found?

Peat formations are confined to cold and temperate countries and swampy ground. It occurs in the United States, Canada, Ireland, Sweden, Germany, France, and other countries. In Europe peat is used not only for domestic purposes, but for metallurgical purposes as well. One of the most extensive peat beds known is in the Kankakee valley, Indiana, the bed being some three miles wide and sixty miles long, varying from five to fifty feet in thickness.

Q. How may peat be classified?

Peat may be classified: (1) according to the localities where it has been formed, as lowland and mountain peat; (2) according to its age, as recent peat with distinct vegetable structure, and old peat of a dark brown or black color, with more traces of organic texture; (3) according to the mode in which it has been extracted, as cut peat or dredge peat (Thorpe).

Q. What are fuel briquettes?

Briquette is a name given to a small body of prepared fuel, made up chiefly of the culm of bituminous coal held together by a bonding material, also combustible, the mixture being then compressed into a compact mass, of a size and shape suitable for use as fuel.

Briquette-making has become quite an industry in Germany, Austria, and France, where the fuel question is much more important than it is with us. The culm piles are being utilized in those countries and made a profitable source of income.

Brown coal has so far been the chief material for briquettes. Some recent experiments with briquettes made of solidified petroleum or residuum have been made, which, however, did not result satisfactorily, for the reason that the boilers were unable to withstand the intense heat developed by this kind of fuel.

L'Industrie describes a process devised by the chemist Velna, who uses petroleum or mineral tar only for enriching culm and other inferior, formerly worthless combustibles, and produces briquettes from this material the heating power of which is 30 per cent higher than that of good coal. He first prepares a mixture consisting of petroleum or bituminous shale tar, oleine and soda in suitable proportion, and by this means the culm, slack, or coal dust is cemented together. Three kinds of briquettes are produced in this way, namely, industrial briquettes for general firing purposes, gas briquettes for the manufacture of illuminating gas, and metallurgical coke.

The cost of briquettes by this method is said to be as follows: If culm or dust from a good coal, valued at $1.20 per ton (France = 2, 205 pounds), be taken for their manufacture, six per cent of the mixture would be sufficient. The price of a ton of briquettes would be:

94 per cent coal	2,073 pounds	@ 6 cents =	$1.24
6 " mixture	132 "	@ 60 " =	79
Labor			40
		Total cost per ton =	$2.43

It is claimed that the heating power of these briquettes exceeds that of average coal by at least 25 per cent.

Q. What is patent fuel?

Patent fuel is a term much used in Europe to designate compressed fuels as a class. Numerous patents have been taken out for producing a good fuel by mixing various substances with small coal, in proportions sufficient to enable the mixture to be pressed into a coherent block. Various binding materials have been tried, such as soluble glass, asphalt, turpentine. Meal from potatoes was abandoned because the blocks were not water-tight. Coal tar (Warlick's process) was tried at Swansea, England, the blocks being baked after compression, whereby a quantity of tar was recovered. On the Continent cellulose (German patent) and treacle (crude molasses) have been tried. Pitch made from coal tar has been used for many years with great success.

In the dry process small coal is carried by an elevator into a large bunker, whence it is lifted by another elevator to a chute, into which it is tipped with the contents of a small elevator containing pitch. The mixture then passes into a disintegrator, and the resulting product, containing 8 to 12 per cent of pitch, passes to heaters, and finally to the presses, which turn out 100 to 200 blocks, weighing 10 to 30 pounds, per day of twelve hours.

In the steam process there is used a large vertical iron cylinder with arms revolving inside, constantly kept full of a mixture of pitch and coal. High-pressure steam is injected near the bottom and allowed to percolate up through the mass, while the arms expose every portion to its action.

Attempts have been made to utilize peat by mixing it in a state of powder with small coal and sawdust, and pressing the mixture into blocks (Thorpe).

Q. What advantages are claimed for artificial fuels?

The advantages claimed for patent fuels over ordinary coal are stated to consist—

1. In their efficacy in generating steam.
2. In occupying less space; that is to say, 500 tons of patent fuel may be stowed in an area which will contain only 400 tons of coal.
3. They are used with much greater ease by the firemen than coal, and they create little or no dust or dirt, considerations of some importance where no bulkhead separates the fire-room from the engine-room.
4. They produce a very small proportion of clinkers, and are far less liable to choke and destroy the furnace grates than coal.
5. The combustion is so complete that comparatively little smoke and only a small quantity of ashes are produced by them.
6. From the mixture of the patent fuel and the manner of its manufacture it is not liable to enter into spontaneous ignition.

Q. What is the composition of Grant's patent fuel?

This fuel is composed of coal dust and coal-tar pitch. These materials are mixed together, under the influence of heat, in the following proportions: Twenty pounds of pitch to 112 pounds of coal dust, by appropriate machinery, consisting of crushing rollers for breaking the coal in the first instance, to pass through a one-fourth inch screen; secondly, of mixing pans or cylinders heated to a temperature of 220° F., either by steam or by heated air; and thirdly, of moulding machines by which the fuel is compressed, under a pressure, equal to five tons, into the size of a common brick. The fuel bricks are then whitewashed, which prevents their sticking together, either in the coal bunkers or in hot climates.

Q. What is the Strong method of making artificial fuel?

The combination of materials and processes of manufacturing artificial fuel or coal briquette by R. S. Strong's method is to wash the small coal in order to free the same from shale and dirt, and convey it from the drainers to a disintegrator by which it is ground, adding about 2 per cent of fresh calcined powdered alkaline earth, preferably lime, in order to absorb the moisture in the coal. To this is added 4 to 10 per cent (according to the nature of the coal or the purpose for which the fuel is intended) of pyroligneous acid, preferably from a steam-jacketed tank. This acid is the whole of the distillate from destructive distillation of wood or other ligneous substances and immediately absorbs the lime and solidifies the mixture, which is at once pressed in briquette form in the usual way, and on leaving the press may be cooled by a fan or blower and shipped or used at once.

In carrying out the process with unwashed coal only one per cent or less of the caustic alkaline earth is used to give a hook to the pyroligneous acid to act on, all other treatment being as before described.

Fuel manufactured as described is suitable for household, steam, or metallurgical purposes, and burns with a clear bright flame, and is produced at a reasonable cost.

Q. What is the Corning method of making artificial fuel?

In the working of the Gardner Corning process the binding ingredients employed for uniting the coal dust into briquettes are suitable bitumens and quick or fresh-burned lime. Of the bitumens natural asphaltum is preferred, although the artificial bitumens, such as the by or residual products of petroleum, are suitable. The crude natural asphaltum, however, is too brittle for the purpose and requires tempering by the admixture of some artificial bitumen, especially a residuum oil of petroleum, to impart elasticity and tenacity. To properly combine the coal dust and bitumen, both are heated to as high temperature as practicable without injury by burning or cooking. By thorough intermixture while thus heated the thinnest possible film or coating of bitumen is given to the dust particles to secure their firm adhesion when cooled. The preferable temperatures employed with natural asphaltum have been found to be about 300° F. for the dust and 320° to 340° for the asphaltum. If other bitumens are used, the temperatures may be varied to adapt them to the different melting points of the bitumens. To secure the most efficient binding action of the lime, it is slaked with sufficient water to make a liquid mass of about the consistency of cream, and which is therefore known as "cream of lime." This is intermixed with the combined dust and bitumen while their mass is still hot, and this step of the process is the most essential part of the method.

The proportions of the ingredients are: Coal-dust, about 1,870 pounds; bitumen, about 80 pounds; and lime, about 50 pounds.

Where natural asphaltum is employed, about 5 pounds of the artificial or tempering agent is mixed with about 75 pounds of the asphaltum.

Either anthracite, bituminous, or lignite coal dust may be worked by this process; but the best results have been secured by combining bituminous dust with the other.

The process in detail is as follows: The coal dust is heated to the requisite temperature, the asphaltum melted and the tempering oil mixed with it, and the mixture heated to the requisite degree. These are then thoroughly combined in a mixer, which requires usually about three minutes. The cream of lime is then added to the hot mass, the mixing operation being continued until the water begins to vaporize. The mass is then delivered to a press while still hot and moist, and formed as quickly as possible into briquettes under heavy pressure.

CHAPTER II.

SOME ELEMENTARY DATA.

PHYSICS.

Q. What is meant by the term work?

Work is done when resistance is overcome. If a force acts upon a body and produces motion in that body, the force is said to have done work; but if the force applied fails to produce motion in the body thus acted upon, no work has been done by that force. The work done by a force is measured by the product of the force into the distance through which that force moves in its own direction, or work = force × distance.

Q. What is unit of work?

The unit of work adopted in this country is the foot-pound, or that quantity of work done if a body weighing one pound be lifted one foot high against the action of gravity. The foot-pound is a gravitation unit, and is wholly independent of time.

Q. What is meant by lost work?

Of the work put into a machine a certain portion of it must be expended in merely keeping the different parts in motion, and the work thus absorbed is lost work. The friction diagram of a steam-engine, for example, represents so much lost work, inasmuch as it is necessary to overcome all the resistances represented by the diagram before any useful effect can be obtained. Lost work = force absorbed in overcoming internal resistances × the distance it acts.

Q. What is meant by useful work?

Useful work is the work given out by a machine after deducting the frictional and other resistances incident to running the machine empty at its normal speed. Suppose a steam-engine should indicate 220 H. P. and the friction diagram of the engine at the same speed indicated 25 H. P., the useful work of the engine would be: $220 - 25 = 195$ H. P., or, as it is sometimes expressed, the net horse power. Useful work = force given out × the distance it acts.

Q. What is meant by the term power?

Power is the rate of doing work. It is not the same as force; it is not the same as pressure, because force and pressure act independently of time; but time is an essential element when estimating the quantity of work done by a man or by a machine.

Q. What is the unit of power?

The unit of power in mechanical engineering is called the horse power. It is the rate of doing work at 33,000 foot-pounds per minute.

Q. How did the horse-power unit originate?

James Watt ascertained by experiment that an average cart horse could develop 22,000 foot-pounds of work per minute; and being anxious to give good value to the purchasers of his engines, he added 50 per cent to this amount, thus obtaining (22,000 + 11,000) the 33,000 foot-pounds per minute unit, by which the power of steam and other engines has ever since been estimated (Jamison).

Q. What is meant by the term energy?

Energy is commonly explained as the capability of doing work, and by doing work is meant overcoming resistance. Energy is of two types, known as kinetic and potential; but more specifically we have:

1. Kinetic energy.
2. Gravitation energy.
3. Heat.
4. Energy of elasticity.
5. Cohesion energy.
6. Chemical energy.
7. Electrical energy.
8. Magnetic energy.
9. Radiant energy.

This list includes all known separate forms.

Q. What is potential energy?

Potential energy is the energy due to position, or that form of energy which a body possesses in virtue of its condition. Energy due to position may be illustrated in the case of a weight, say 50 pounds raised 10 feet high. This would represent a potential energy of $50 \times 10 = 500$ foot-pounds, because if liberated it would through proper means accomplish that quantity of work. This can be considered, in the case of falling bodies, as gravitation energy. Energy due to condition may be illustrated in the case of the coiled spring of a clock, which when wound up can do work in driving the train of mechanism, an example of energy due to the elasticity of the steel spring. Coal when burned under proper conditions gives out heat which may be utilized for generating steam and doing work through the medium of a steam-engine.

Q. What is kinetic energy?

Kinetic energy is the energy due to motion. It is not easy to conceive of energy apart from motion, and this has led some physicists to the conclusion that all energy is probably kinetic.

Q. Are the two types of energy, kinetic and potential, mutually independent?

The energy of motion and the energy of position or condition are being continually changed one into the other. The conversion of one form of energy to another is seen in a head of water employed to turn a water wheel. The water possesses energy due to its height above the wheel. The weight of the water impinging against the buckets of the wheel gives it motion and is thus capable of doing work.

Q. What is the great characteristic of enegy?

That it may be transformed or transmuted from one kind of energy into another kind of energy; but through all its transformations the quantity present always remains the same, though known by different names, which after all are but those of convenience in classification. It has been suggested that each form of energy arises from a mode of motion of some portion or portions of substances or of matter, and that therefore all energy is kinetic.

Q. What is meant by transmutation of energy?

By transmutation of energy is meant the changing of one kind of energy into another. There are many varieties of visible energy, but there is energy which is invisible; and the one may be converted into the other. The most common illustration of this is the conversion of work into heat. This occurs when motion is arrested, whether by percussion or by friction. It is the conversion of visible or actual energy into heat; that is, into molecular or invisible energy.

Q. What is meant by energy of fuel?

Its capacity to do work. Taken altogether the heating power of coals will range ordinarily from 13,000 to 14,300 heat units per pound. The energy of fuel or its power to do work may be easily computed thus:

Suppose a sample of coal to equal 14,000 heat units per pound; this multiplied by 772, the thermal unit known as Joule's equivalent, we have: $14{,}000 \times 772 = 10{,}808{,}000$ pounds raised one foot high in one minute, this representing the potential energy of one pound of coal. It will be understood that the above represents the maximum limit of work done by the complete combustion of one pound of coal, an amount of energy expressed in foot-pounds of work, far beyond any means at our command for its complete utilization.

Q. Can energy be transferred from one form into another without loss?

This is quite impossible; and it must not be supposed that the various forms of energy may be transformed into mechanical energy or made to do work without loss incident to the absorption by the various other forms of energy which are contiguous, and which are constantly seeking fresh supplies of energy from a higher source than their own. If these processes were not only transformable but reversible, then perpetual motion would be a fact. We know that heat, as a form of visible mechanical energy, is available only as we use it from a higher to a lower temperature; and we know further that once the heat has spent its energy or capacity for doing work, there is no way by which it can be restored. Heat may be made to do work, and work may be transferred into heat, but the processes are not reversible.

Q. What is meant by dissipation of energy?

The principle of dissipation of energy is that as any operation going on in nature involves a transformation of energy, and transformation involves a certain amount of degradation (degraded energy meaning energy less capable of being transformed than before), energy is therefore continually becoming less and less transformable. As these changes are constantly going on in nature, the energy must of necessity be getting lower and lower in the scale, so that its ultimate form must be that of heat so diffused as to give all bodies the same temperature. In order to get any work out of heat, it is absolutely necessary to have a hotter body and a colder one; but if all the energy be transformed into heat, and if it be in all bodies at the same temperature, then it is impossible to raise the smallest part of that energy into a more available form.

Q. What is a thermometer?

A thermometer is an instrument for measuring temperatures constructed upon the principle of the expansion of bodies by heat.

It consists in its common form of a glass tube terminating in a bulb containing mercury, which fills the bulb and part of the tube; and the rise or fall of the mercury in the tube, according as the mass of it in the bulb expands or contracts, indicates any change of temperature in the surrounding medium.

Q. Why is mercury commonly used for indicating temperatures in a thermometer?

For general purposes mercury is the most suitable substance for use in thermometers because the range between its points of solidification and ebullition is greater than that of any known fluid. It is also a good conductor of heat, and is consequently rapid in its indications and sensitive to sudden changes of temperature. Liquids are progressively more expansive at higher than at lower temperatures; but in the case of mercury the higher expansion at higher temperatures is less than in any other fluid body. Hence it is better adapted than any of them for the construction of thermometers.

Q. What are the limiting temperatures of a mercury thermometer?

Mercury freezes at −40° F. and boils at 600° F. Reliable readings of temperature of a mercury thermometer are therefore limited between −30° to 550° F.

Q. What constants are employed when fixing standards of temperature?

In order to measure temperature, certain fixed temperatures must be determined upon. The constants generally employed are the melting point of ice and the boiling point of water at the average atmospheric pressure.

Q. What is absolute zero?

The absolute zero of temperature may be defined as the temperature corresponding to the disappearance of gaseous elasticity. It has been fixed by reasoning, and has never been measured. The law of expansion of a perfect gas is that, the temperature remaining the same, its volume is inversely proportional to the pressure of the gas; so also, the pressure remaining the same, the volume of the gas will be proportional to the temperature.

The rate of expansion of a perfect gas per degree is 0.00203 at 32° F., so that for each degree in rise of temperature the gas increases $\frac{1}{493}$ in volume, therefore the volume of the gas would be doubled if its temperature be raised 493° F. This law holds good above the freezing point, there is no reason for doubting that it holds equally good for temperatures below freezing; we have then -493 less $32 = -461°$ F. as the absolute zero of temperature.

Q. What are the two thermometric scales in common use?

The two thermometric scales in common use are the Fahrenheit and the Centigrade. The zero point in the Fahrenheit scale corresponds to that temperature obtained by a mixture of snow and salt, which is marked 32° below the freezing point of water. The height of the mercury at the boiling point of water at atmospheric pressure having been marked on the scale, the whole distance between the freezing and the boiling point of water is divided into 180 equal parts, called degrees, and this graduation is continued to the zero point, the whole number of degrees $= 180 + 32 = 212$.

The Centigrade scale has its zero at the freezing point of water, and the interval between the freezing and the boiling points of water at atmospheric pressure is divided into 100 equal parts called degrees.

The freezing point of water is 32° on the Fahrenheit scale, and 0° on the Centigrade. The boiling point of water at atmospheric pressure is 212° on the Fahrenheit scale and 100° on the Centigrade.

TABLE 7.—CENTIGRADE TEMPERATURES WITH CORRESPONDING TEMPERATURES ON THE FAHRENHEIT SCALE.

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
— 40	— 40	6	42.8	52	125.6	98	208.4
— 39	— 38.2	7	44.6	53	127.4	99	210.2
— 38	— 36.4	8	46.4	54	129.2	100	212.0
— 37	— 34.6	9	48.2	55	131.0	101	213.8
— 36	— 32.8	10	50.0	56	132.8	102	215.6
— 35	— 31	11	51.8	57	134.6	103	217.4
— 34	— 29.2	12	53.6	58	136.4	104	219.2
— 33	— 27.4	13	55.4	59	138.2	105	221.0
— 32	— 25.6	14	57.2	60	140.0	106	222.8
— 31	— 23.8	15	59.0	61	141.8	107	224.6
— 30	— 22	16	60.8	62	143.6	108	226.4
— 29	— 20.2	17	62.6	63	145.4	109	228.2
— 28	— 18.4	18	64.4	64	147.2	110	230.0
— 27	— 16.6	19	66.2	65	149.0	111	231.8
— 26	— 14.8	20	68.0	66	150.8	112	233.6
— 25	— 13	21	69.8	67	152.6	113	235.4
— 24	— 11.2	22	71.6	68	154.4	114	237.2
— 23	— 9.4	23	73.4	69	156.2	115	239.0
— 22	— 7.6	24	75.2	70	158.0	116	240.8
— 21	— 5.8	25	77.0	71	159.8	117	242.6
— 20	— 4	26	78.8	72	161.6	118	244.4
— 19	— 2.2	27	80.6	73	163.4	119	246.2
— 18	— 0.4	28	82.4	74	165.2	120	248.0
— 17	1.4	29	84.2	75	167.0	121	249.8
— 16	3.2	30	86.0	76	168.8	122	251.6
— 15	5.0	31	87.8	77	170.6	123	253.4
— 14	6.8	32	89.6	78	172.4	124	255.2
— 13	8.6	33	91.4	79	174.2	125	257.0
— 12	10.4	34	93.2	80	176.0	126	258.8
— 11	12.2	35	95.0	81	177.8	127	260.6
— 10	14.0	36	96.8	82	179.6	128	262.4
— 9	15.8	37	98.6	83	181.4	129	264.2
— 8	17.6	38	100.4	84	183.2	130	266.0
— 7	19.4	39	102.2	85	185.0	131	267.8
— 6	21.2	40	104.0	86	186.8	132	269.6
— 5	23.0	41	105.8	87	188.6	133	271.4
— 4	24.8	42	107.6	88	190.4	134	273.2
— 3	26.6	43	109.4	89	192.2	135	275.0
— 2	28.4	44	111.2	90	194.0	136	276.8
— 1	30.2	45	113.0	91	195.8	137	278.6
0	32.0	46	114.8	92	197.6	138	280.4
1	33.8	47	116.6	93	199.4	139	282.2
2	35.6	48	118.4	94	201.2	140	284.0
3	37.4	49	120.2	95	203.0	141	285.8
4	39.2	50	122.0	96	204.8	142	287.6
5	41.0	51	123.8	97	206.6	143	289.4

For other temperatures: (Deg. Fahr. — 32) $\times \frac{5}{9}$ = deg. Cent.; $\frac{9}{5}$ deg. Cent. + 32 = deg. Fahr.

Q. How may the temperature readings on the Fahrenheit and Centigrade scales be interconverted?

The distance between the freezing and the boiling point of water is, of course, the same for both thermometers, but the Fahrenheit scale contains 180 divisions while the Centigrade scale contains only 100 divisions between these two points. If these numbers are divided by 20, we have 9 and 5 respectively; smaller, therefore more convenient numbers to be used in the conversion of one scale into the other. The zero point of the Fahrenheit scale is 32° below the freezing point of water.

To convert one scale into the other is quite simple, thus:

$$\text{Fahr.} = 32 + \tfrac{9}{5}\ \text{Cent. degrees, or}$$
$$\text{Cent.} = \tfrac{5}{9}\ (\text{Fahr. degrees} - 32).$$

that is, add 32° to $\frac{9}{5}$ of the number indicated on the Centigrade scale and the result is the number which would be indicated by the Fahrenheit scale. Subtract 32° from the number indicated on the Fahrenheit scale, and $\frac{5}{9}$ of the remainder is the number which would be indicated by the Centigrade scale.

Example 1. What would be the Fahrenheit temperature corresponding to 130° C.?

$$32 + \tfrac{9}{5}\ \text{of}\ 130 = 266°\ \text{F.}$$

Example 2. What would be the Centigrade temperature corresponding to 266° F.?

$$\tfrac{5}{9}\ \text{of}\ (266-32) = 130°\ \text{C.}$$

Q. Does a thermometer indicate the quantity of heat in a substance?

It does not. The use of a thermometer is merely to indicate the sensible heat, or that which is capable of being radiated or communicated from one material to another. Its indications are merely relative and do not express the actual amount of heat which a substance contains.

CHEMISTRY.

Q. What is an atom?

The atomic theory affirms that every portion of matter of sensible size is built up of a vast number of small particles which are not themselves capable of further subdivision. Each particle corresponding to this definition would be called an atom (a term borrowed from the Greek), and means indivisible. In chemistry it means the smallest quantity by weight of an element which is capable of existing in a chemical compound.

Q. What is meant by atomic weight?

One of the properties of matter is that it has weight; atoms, therefore, have weight because an atom is a definite and fixed quantity of matter. Hydrogen, being the lightest known substance, has by general consent been made the unit of comparison; the atomic weight of hydrogen is always represented by 1.

TABLE 8.—ATOMIC AND COMBINING WEIGHTS OF GASES.

Element.	Atomic weight.	Combining weight.
Hydrogen	1	
Nitrogen	14	$4\frac{2}{3}$
Oxygen	16	8
Carbon (diamond burnt to CO_2)	12	3

By combining weight is here meant the smallest mass of the element which combines with eight parts by weight of oxygen, or one part of hydrogen.

TABLE 9.—ATOMIC WEIGHTS.

Name.	Symbol.	Atomic weights.
Calcium	Ca	40
Carbon	C	12
Hydrogen	H	1
Nitrogen	N	14
Oxygen	O	16
Phosphorus	P	31
Potassium	K	39
Silicon	Si	28.5
Sodium	Na	23
Sulphur	S	32

The above list of elements are those commonly found in coal by elementary analysis. Aluminum and iron are also found in the analysis of coal ashes.

Q. What is a molecule?

A molecule is the smallest possible portion of a particular substance, whether elementary or compound, which exhibits the characteristic properties of that substance. Every substance, therefore, whether simple or compound, has its own molecule; and if this molecule be divided, its parts are molecules of a different substance or substances from that of which the whole is a molecule. An atom is the smallest particle of an element which enters into the composition of molecules. In the case of the molecule of an element the atoms are all of one kind; in the case of the molecule of a compound the atoms are of two or more than two different kinds. As the properties of the molecule of a compound are very different from the properties of the atoms which compose it, so it is probable that the properties of the molecule of an element are different from the properties of the atoms by the union of which the molecule is produced.

Q. What is one of the characteristics of molecules?

That they are always in motion. These motions of molecules are, in the case of solid bodies, confined within so narrow a range that even with our best microscopes we cannot detect that they alter their places at all; but in the case of liquids and of gases the molecules are not confined within any definite limits, but work their way through the whole mass, even when that mass is not disturbed by any visible motion. This process of diffusion, as it is called, which goes on in gases and liquids and even in some solids, can be subjected to experiment, and forms one of the most convincing proofs of the motion of molecules.

Q. What is meant by symbolic notation?

Symbolic notation belongs to an agreed employment, as far as practicable, of the first letter of the Latin name of an element, by which it may be recognized at sight, thus facilitating the representation of chemical changes, by which reactions of a complicated character may be understood at a glance. Thus carbon is represented by the letter C, oxygen by O, hydrogen by H, etc. Carbonic oxide by the letters CO; carbonic acid gas by the formula CO_2, etc.

Q. Give some examples of the symbolic notation of compounds occurring in the process of combustion?

A combination of elements is represented by a combination of symbols placed side by side. If one atom of carbon and one atom of oxygen be united we have the symbol CO, carbonic oxide. It will be understood that one atom each of carbon and oxygen unite and form, not one atom, but one molecule of carbonic oxide. So also in the previous question the combination of one atom of carbon with two atoms of oxygen, written CO_2, is the symbolic expression of one molecule of carbonic-acid gas. Hydrogen is represented by H; its atomic weight is 1. The formula H_2O means that two atoms of hydrogen have united with one atom of oxygen to form two molecules of water.

Q. Does this method of symbolic notation express other than an abbreviation of the name of an element?

Yes, the symbols employed are not only abbreviations of the Latin names of the elements, but they represent the atomic weights of the several elements for which they stand. Thus carbon, represented by C, has an atomic weight of 12; and as there is no other element having an atomic weight of 12, the letter C and figure 12 may always be thus associated. It will be understood that C always stands for one atom of carbon, the atomic weight of which is 12; and if more than one atom of an element appears in a formula, the number of such atoms are expressed by numerals, thus: CO_2 for carbonic acid gas, meaning thereby that one atom of carbon and two atoms of oxygen have entered into chemical union.

When two or more atoms of an element unite in the formation of a molecule of a compound substance the written formula is simplified by writing a small figure to the right of the symbolic letter and below the line. Thus C_3 indicates three atoms of carbon, H_8 indicates eight atoms of hydrogen.. The formula C_3H_8 indicates one of the products of coal occurring in the marsh gas series, and known as propyl hydride; and this formula is the symbolic expression of one molecule.

Secondary compounds, such as salts, are expressed in an analogous way, the metal being usually placed first,

$CaCO_3$ representing one molecule of carbonate of calcium, calcium being the metallic base.

Q. What is meant by the chemical properties of a body?

Those which relate to its action upon other bodies, and to the permanent changes which it experiences in itself, or which it effects upon them. When a body undergoes chemical change it almost invariably destroys the physical properties held by it previous to this change; but experiment has fully demonstrated that matter is indestructible, so that whatever changes are made in the physical appearance or form of matter by any chemical process, none of it is destroyed.

Q. What is meant by affinity?

By affinity is commonly meant the unknown cause of the combination of atoms. Hydrogen and chlorine combine very readily. They have, as we say, a strong affinity for each other; yet they are monovalent with reference to each other. Carbon and chlorine do not combine readily. They do not have a strong affinity for each other, yet an atom of chlorine is capable of holding four atoms of carbon in combination. The two properties, valency and affinity, are possessed by every atom, and exhibit themselves whenever atoms act upon one another, the latter determining the intensity of the reaction, the former the complexity of the resulting molecule.

Q. What is meant by chemical affinity?

Chemical affinity is that property of bodies in virtue of which, when brought in contact, they react on each other, forming new bodies. It can be called a force, in so far as by its action energy is produced—namely, heat, light, electrical or mechanical energy; and *vice versa,* energy must be employed to reverse the action of chemical affinity and to decompose the combined substances. Nothing is known as yet about the nature of chemical affinity, nor has a satisfactory hypothesis been suggested concerning it.

Q. What is meant by chemical attraction?

Chemical attraction is distinguished from other chemical forces which act within minute distances by the complete change of characters which follows its exertion, and must from its very nature be exerted between dissimilar substances. Hydrogen and oxygen are both gaseous and are wholly dissimilar in their chemical properties; yet under proper conditions they will unite with great avidity, the combination forming gaseous steam, which upon cooling yields only pure water.

The physical and other changes brought about as a result of chemical attraction do not destroy the combining elements, but simply rearrange them in another form, and give to the new compound properties not held by any element singly.

Q. What is meant by the term equivalent?

The equivalent of an element is that mass of an element which combines with one atom of hydrogen. In the case of oxygen it corresponds to half an atom, in that of nitrogen to one-third the atom, and in that of carbon to one-fourth the atom. With those elements which do not combine with hydrogen some other element like hydrogen in respect to the ratio between the equivalent and atomic weight is taken as the measure of the equivalent.

Q. What law governs the combining weights of the elements?

The laws of chemical combination are all included in the two statements: 1. The elements combine in the ratios of their combining weights, or in ratios which bear a simple relation to these. 2. The gaseous elements combine in the ratios of their combining volumes, or in ratios which bear a simple relation to these.

By combining weight is here meant the smallest mass of an element which combines with unit mass of some specified element taken as a standard; and by combining volume is meant the smallest volume of a gaseous element which combines with unit volume of some specified gaseous element taken as a standard. The first statement has been amply verified by accurate experiment; the second does not yet stand on so firm an experimental basis.

Q. What is the law of definite proportions?

The law of definite proportions may be stated thus: In any chemical compound the nature and the proportions of its constituent elements are fixed, definite, and invariable. For example: One hundred parts of water by weight contain 88.9 of oxygen and 11.1 of hydrogen. These gases will combine in no other proportions to form water, and any excess of either gas will remain unchanged.

The law of definite proportion assumes that atoms have definite weight; that an atom is a fixed and definite quantity; that atoms of the same substance are of the same size and weight. When the elements unite chemically, they invariably do so in the proportions by weight represented by the numbers attached to them, as in Table 9, or in multiples of these numbers. Dalton accounted for this law by supposing that the constituent particles of matter are indivisible, and believed that if it were possible to place such particles in the balance, their relative weights would be found to correspond with the numbers given in the table.

Q. What is the law of multiple proportions?

When two or more compounds are formed of the same elements, there is no gradual blending of one into the other, as in the case of mixtures, but each compound is sharply defined and exhibits properties distinct from those of the others, and of the elements of which the compounds are composed. For example:

There are two compounds of carbon and oxygen—

	Carbon by weight.	Oxygen by weight.	Atomic weight.
Carbonic oxide CO	12	16	28
Carbonic acid gas CO_2..................	12	32	44

It will be observed that, the quantity of carbon remaining the same, the quantity of oxygen must be doubled in order to form the other compound. These proportions constitute the only two direct inorganic compounds of carbon and oxygen.

Q. Is the atomic value of an element changed by entering into chemical combination with another element?

No, the atomic value of each element in a compound remains unchanged, and the aggregate weight of the atoms forms the molecular weight of the compound thus:

One molecule of carbonic oxide equals:
1 atom of carbon, C, at wt. 12 = 12
1 atom of oxygen, O, at wt. 16 = 16
Weight of one molecule CO = 28

One molecule of carbonic-acid gas equals:
1 atom of carbon, C, at wt. 12 = 12
2 atoms of oxygen, O, at wt. 16 = 32
Weight of one molecule CO_2 = 44

Q. Is chemical attraction influenced by temperature?

In all cases of ordinary combustion it is essential that the temperature of the uniting substances be raised to the point of ignition. A mixture of oxygen and hydrogen may be preserved unchanged at ordinary temperatures any length of time, but a mere spark, or the introduction of a body heated to redness, so completely alters their mutual attraction that sudden combination attended with explosion is the result. This is as pure a case of augmentation of chemical attraction as can be met with, since both the components are thoroughly mixed; and as both are perfect gases, heat cannot in this case act by diminished cohesion, and so bring their particles into more intimate contact.

Q. What is meant by energy of chemical separation?

A combustible body like coal may be taken as a fair representative of potential energy because it occupies a position of advantage over a non-combustible body in this, that it will unite with another body for which it has chemical affinity like oxygen, and this energy of position leading, as it can in this case, to a process of chemical separation during the act of burning, in which we have potential energy or the energy possessed by the coal before ignition, and the energy due to molecular activity by reason of the act of combustion, or the energy of motion changed into another form of energy represented by heat.

The energy of chemical separation when produced by the combustion of coal is always intense, and as the observed effects are so much below the theoretical value ascribed to the fuel, it would seem as if for once the law of conservation of energy was at fault; but this is not the case. Our methods of manipulation are wasteful and the ordinary construction of furnaces so faulty that a very large proportion of the waste can be directly accounted for. One thing with reference to the energy of chemical separation is certain, and that is, that any given quantity of carbon or other combustible under given conditions will always produce the same quantity of heat.

CHAPTER III.

THE ATMOSPHERE.

Q. What is the composition of air?

The composition of air free from water and carbonic acid is found to be, by weight: 77 per cent of nitrogen and 23 per cent of oxygen; or by volume: 79 volumes of nitrogen and 21 volumes of oxygen. In addition to these two gases atmospheric air contains aqueous vapor, carbonic acid, ozone, ammonia, with traces of nitrous and nitric acids, etc.

Air, owing to the oxygen it contains, is a magnetic substance.

Q. Is air a chemical compound?

It is not. The union of these two gases in the proportions of 79 volumes of nitrogen to 21 of oxygen gives common air; and this union is distinguished by no properties which may not be attributed individually to these gases. All experiments made thus far have shown no indication that the union is other than mechanical.

Q. What proofs sustain the statement that air is not a chemical compound?

That air is not a chemical compound of its component gases is proven by the facts:

1. That the gases nitrogen and oxygen are not present in any constant ratio.

2. That air can be made by simply mixing its constituents in the proportion indicated by the analysis of air, without contraction or any thermal disturbance resulting.

3. That on treating air with water and expelling the dissolved air by boiling, the proportion of the oxygen to the nitrogen is found to be increased, and in amount corresponding with the law of partial pressures.

4. That the constituents of the air can be mechanically separated by processes of diffusion.

5. That the refractive power of the air is equal to the mean of the refractive powers of its constituents, whereas in compound gases the refractive power is either greater or less than the refractive power of the elements in a state of mixture (Thorpe).

Q. What is oxygen?

Oxygen is present in the atmosphere in a free and uncombined state, forming 21 per cent of its total volume. Priestly first obtained the gas in 1774, and gave it the name *dephlogisticated air*. It was isolated independently and almost simultaneously by Scheele, who termed it *empyreal*, or fire air. Lavoisier regarded it as an essential constituent of all acids, and hence gave it its present name oxygen. The discovery of oxygen was the means of leading Lavoisier to the true theory of combustion.

Oxygen is somewhat heavier than the air, it having a specific gravity of 1.1056, air = 1.0000. One hundred cubic inches of oxygen weigh 34.206 grains. The specific heat of oxygen for equal weights at constant pressure = 0.2182; for constant volume = 0.1559. When pure, oxygen is colorless, tasteless, and inodorous. It is sparingly soluble in water. As with all gases the quantity dissolved depends on the tension of the oxygen in the atmosphere in contact with the water. Thus pure water shaken up in contact with pure oxygen will absorb nearly five times as much oxygen as it would when shaken up, at the same temperature and under the same pressure, with air, which only contains 21 per cent by volume of oxygen.

Oxygen is the least refractive of all the gases. It is slightly magnetic, but its susceptibility in this respect is diminished or temporarily suspended by elevation of temperature.

Though long regarded as a permanent gas, oxygen was liquefied in 1877 by Pictet, who attributed to liquid oxygen a density near that of water, about 0.9787. The critical temperature of oxygen is −113° C., the pressure needed to liquefy it at that temperature being about 50 atmospheres. Liquid oxygen is a pale, steel-blue, transparent, and very mobile liquid, boiling at −181° C. at ordinary pressures. When the pressure is reduced or removed, evaporation takes place so rapidly that a part of the oxygen is often frozen to a white solid. Liquid oxygen is a very perfect insulator, and is also comparatively inert in its chemical properties.

There are only seven elements which do not unite directly with oxygen, viz., fluorine, chlorine, bromine, iodine, silver, gold, and platinum. All the non-metallic elements with two exceptions unite with oxygen to form anhydrous acids. Of the exceptions hydrogen forms a neutral oxide (water), while no oxide of fluorine has yet been obtained.

The product of the union of oxygen with another element is called an oxide. Thus when lead is heated in contact with air it combines with oxygen, forming lead oxide, PbO. Carbon burns in oxygen, forming carbon dioxide, CO_2.

The chemical activity of air depends upon the oxygen it contains, air being simply in its chemical relations oxygen diluted with nitrogen. Free oxygen, whether diluted with nitrogen or not, manifests considerable chemical activity, even at ordinary temperatures, this activity increasing with rise of temperature. With most substances an initial heating is necessary to start free oxidation, the heat evolved being then sufficient to maintain it. Various substances which expose large surfaces to air (or oxygen) become gradually heated through slow oxidation or combustion; and if the heat cannot get away, ignition eventually occurs. Thus oily or greasy woollen and cotton waste or rags and refuse are capable of absorbing oxygen very rapidly, and if present in any considerable quantity the heat produced may accumulate and cause spontaneous combustion; and this action is a not infrequent cause of fires in factories.

Q. What is nitrogen?

Nitrogen, one of the most widely diffused of the elements, occurs free in the air, of which it constitutes about 79 per cent by volume. It is a colorless, inodorous, tasteless, neutral gas, of 0.972 specific gravity (air = 1); 100 cubic inches at 60° F. and 30 inches barometer pressure, weigh 30.052 grains. It is slightly soluble in water; 100 volumes of water dissolve 1.5 volumes of nitrogen at 15° C. The specific heat of nitrogen = 0.244, at constant pressure. Nitrogen has been liquefied by the cold produced by its expansion from a compression of 300 atmospheres at +13° C. Liquid nitrogen boils at −193° C. under atmospheric pressure.

Q. Is nitrogen a supporter of combustion?

Nitrogen is incombustible, and does not support combustion. Its negative qualities are very pronounced; it will not take fire; it puts out the combustion of everything, and there is nothing that will burn in it in ordinary circumstances. It is not a poisonous gas, but animal life cannot be sustained in it for want of oxygen.

Q. Are the negative qualities of nitrogen a hindrance in furnace combustion?

The useful effect of nitrogen in combustion is that it lowers the intensity of the fire and makes it moderate, useful, and easily controlled. An atmosphere of oxygen without nitrogen would be wholly uncontrollable. The iron grate and furnace front would burn even more powerfully than coal, because iron is more combustible in oxygen than is carbon. The neutral qualities of nitrogen then become of the greatest importance in combustion.

Q. Is nitrogen then so inert that it will not combine with other substances?

While it is true that nitrogen in its free state is remarkable for its inactivity in furnace combustion, it may be made to unite directly under certain conditions with hydrogen, oxygen and carbon—as, for example, when a series of electric sparks is passed through oxygen and nitrogen gases, standing over a solution of caustic alkali, when a nitrate of the metal is produced. Traces of nitric acid and ammonium nitrate are produced by burning hydrogen gas mixed with nitrogen in an atmosphere of air and oxygen. Nitrogen can unite with hydrogen when one or both of the gases are in the nascent state, to form ammonia. Carbon and nitrogen unite directly when nitrogen gas or atmospheric air is passed over an ignited mixture of charcoal and potash.

Q. What economic quality does nitrogen display in furnace combustion?

Nitrogen in its ordinary state is an active element, notwithstanding its negative qualities in the furnace. No action short of the most intense electric force, and then in small degree, can cause the nitrogen to combine directly with the other element of the atmosphere, or with things round about it. It is perfectly indifferent, and therefore to say a safe substance. The part which nitrogen plays in furnace combustion is analogous to that of a vessel in which the oxygen is delivered into the body of incandescent fuel. The oxygen then separates from the nitrogen to combine with the carbon of the fuel. This delivery having been made, the vessel is no longer of any value in that connection and passes on through the fire. By reason of its lighter gravity it assists in maintaining a good draught, a matter of prime importance in furnace combustion.

Q. What quantity of carbonic acid is present in the air?

There is in the air, besides the aqueous vapor, 3.36 parts in every 10,000 of carbonic-acid gas. Any circumstance which interferes with ready diffusion of the products of respiration and the combustion of fuel will of course tend to increase the relative amount of carbonic acid of a town; hence during fogs the amount may be as great as 0.1 per cent. The pressure exerted by the carbonic acid in the air is so small that its amount is not perceptibly diminished by rain. The amount is also not sensibly altered in the higher regions of the atmosphere.

Q. What quantity of ammonia is present in the air?

Ammonia is present in the air in minute quantities only; it exists mainly as carbonate and is subject to very great variations as to quantity. Rain water collected in towns always contains large quantities of ammonia, probably due to the influence of animal life and to the constant presence in greater proportion than in the country of readily decomposable nitrogenous organic matter in the air.

Q. What quantity of aqueous vapor is present in the air?

Aqueous vapor in the air varies in quantity with the temperature; but more of it can be sustained in warm air than in cold. Air at a temperature of 32° F. can sustain the $\frac{1}{160}$ part of its own weight of aqueous vapor, but at 86° F. it can sustain $\frac{1}{140}$ part of its own weight. The humidity of the air is usually estimated by means of hygrometers. The barometer gives the combined weight of the oxygen, nitrogen, and gaseous vapor of the air, and the portion of this weight which is due to aqueous vapor is called the elastic force of vapor. With a barometer standing at 30 inches, and with a hygrometer indicating an elastic force of vapor of .45, very nearly one-fourth pound of the entire pressure of fifteen pounds is due to the vapor. When more vapor is generated than can be at once carried away, the barometer necessarily rises; when vapor is condensed in the atmosphere the barometer falls; when the temperature of saturated air is reduced from 80° to 60°, five grains of aqueous vapor are deposited from each cubic foot. This is the effective cause of rain.

Q. Is ozone always present in the air?

Ozone is always present in minute quantities in normal air. Atmospheric ozone is probably formed by the action of electricity on air and on the water contained in it, and by the evaporation of water. It appears that the amount of ozone varies with the seasons; it is greatest in spring, becomes gradually less during summer and autumn, and is least in winter. Ozone is more frequently observed on rainy days than in fine weather. Thunder storms, gales, and hurricanes are frequently accompanied by relatively strong manifestations of it.

Q. What is the weight of air?

The weight of one cubic foot of air at 32° F. is .080728 pound, or 565.1 grains; at 62° F. it is .076097 pound, or 532.7 grains. The volume of one pound of air at 32° F. at ordinary atmospheric pressure (14.7 pounds) is 12.4 cubic feet.

Q. What is atmospheric pressure?

Air in common with other bodies possesses the property of weight; and as the pressure of water at the bottom of a tank is greater than near its upper surface, so the pressure of the atmosphere is greater at the level of the sea than at the top of a high mountain. We are not certain as to the height of the atmosphere, but it is commonly supposed to be not less than forty-five miles, measured from the sea level. Whatever its height, we know that a vertical column of this air produces an average pressure on the earth's surface of about 14.73 pounds per square inch; but the pressure even at the same place is continually varying from a variety of causes. In steam engineering the pressure of the atmosphere is commonly assumed to be fifteen pounds per square inch.

Q. What is the unit of pressure?

The unit of pressure adopted by European engineers and others, and styled an *atmosphere*, is an amount equal to the average pressure at the level of the sea. In British measures an "atmosphere" is the pressure equivalent to 29.905 inches of mercury at 32° F. at London, and is about 14.73 pounds to the square inch. Steam engineers in this country make their calculations for pressures in terms of pounds per square inch, it being a more convenient unit than an "atmosphere."

Q. How is the pressure of the atmosphere measured?

By means of an instrument called a barometer; one variety of which consists of a vertical glass tube of uniform diameter, hermetically sealed at the top end, and of about 33 inches in length, into which mercury has been poured until it has been completely filled and then inverted, its lower and open end being placed in a vessel also containing mercury. A graduated scale reading to inches, and by means of a vernier to hundredths of an inch is located near the top of the glass tube for reading the level of the mercury. The pressure of the atmosphere acting on the surface of the mercury in the open vessel causes a rise or fall of the mercury directly proportional to the pressure of the atmosphere.

Q. Is the atmosphere of the same density throughout its height?

The density of the air rapidly diminishes with the height. For air of constant temperature its density, or what comes to the same thing, the height of the barometric mercury column, should diminish in geometric progression, while the distance from the earth increases in arithmetic progression.

Q. How does the law of Mariotte and Boyle apply in determining the density of the air?

Mariotte and Boyle have established the law that every time the pressure upon air is doubled its volume is halved. This is the obvious reason why air is more rare and light, bulk for bulk, at the higher regions of the atmosphere than it is near the surface of the earth. At a height of three miles the air has a doubled volume and half its original density. It is again doubled in volume at about six miles high; and it is probable that no animal could continue to live and breathe at a height of eight miles.

Q. How may pounds of air be converted into an equivalent volume in cubic feet?

As we have no convenient means for weighing air in bulk, and as air is known to weigh 532.7 grains per cubic foot at 62° F., it will be a near enough approximation as between summer and winter temperatures to assume that one pound of air = 12.5 cubic feet.

Q. May air be readily heated and cooled?

The difficulty in either heating or cooling air is its non-conducting capacity; or, more strictly speaking, the difficulty in obtaining a sufficiently rapid convection of heat to and from the mass of air employed. To heat or cool air, very extensive surfaces, together with very great differences of temperature, are necessary. Siemen's regenerators have about 17 pounds of fire brick for each increment of gaseous fuels that can be developed from one pound of coal. As, however, only about one-fourth of the total regenerative capacity is being heated to the full temperature of the gases passing down through the ports, this amount has to be increased fourfold, so that nearly 70 pounds of fire brick are probably used per pound of product of combustion.

Q. Does the density of the air affect the passage of heat through it?

An interesting phenomenon relating to the weight or density of the air is the variation in what is known as its diathermancy, or heat passing through it without being apparently absorbed. The greater the tenuity of the air, the more nearly diathermanous is it. Pure air is virtually quite pervious to heat; none stops in the air, but all passes through. The absolute diathermacy of dry air accounts for the scorching heat of mountain tops as the retentive power of aqueous vapor does for the soft heat of low-lying regions in the tropics.

Q. How is atmospheric air affected by heat?

Air is expanded by increase of temperature, the increase in volume being $\frac{1}{489}$ part for each degree Fahrenheit. For example, 1,000 cubic inches at 32° F. would be increased at 212° to 1,336 cubic inches.

Q. Why is it necessary to provide for a supply of air through the fuel in furnace combustion?

Atmospheric air is the only available source of oxygen for supporting the combustion of fuels.

Q. What is the physical effect of heat upon the air entering the fire?

The first physical effect of heat upon air is its expansion, and this of necessity takes place in the most confined space, namely, in the interstices of the fuel, and acts equally in all directions. Although all in motion upward through the fire, its upward portion, being most greatly expanded, is moving more rapidly than its less expanded lower portion; and its expansive force, acting downward, simply retards the upward flow of entering air. Lateral expansion aids in bringing fresh oxygen into contact with unconsumed carbon. Upward expansion aids, and downward expansion retards the draught. Now it is plain that this effect must be the greater the greater the degree of expansion which takes place within the interstices of the fuel. With air supply at 60° F. it is 5.7-fold; with equal air supply, by weight, at 385 F. it is 3.5-fold, as shown on page 80.

Q. What would be the physical effects if air at 60° F. be heated to 385° F. and supplied a furnace at the latter temperature?

If to the sensible temperatures 60° and 385° we add 461°, we shall have the corresponding absolute temperatures of 521° and 846° respectively; and the volume of the heated air will be increased in the ratio of these two numbers, or $\frac{846}{521} = 1.624$. Therefore 8 cubic feet of air at 60° would occupy $8 \times 1.624 = 12.992$, say 13 cubic feet at the higher temperature, at which we will suppose it to be conveyed to the fire. The density of the air will be in the same inverse ratio; that is, 13 cubic feet of air at 385° must be admitted to the fire and to contact with glowing fuel in order to introduce as much oxygen as would be contained in 8 cubic feet of the air at 60° F. Equally, of course, the entering velocity must be greater in the same proportion, since the aggregate area of all the orifices through the grates and fuel may be regarded as constant. This has been urged as an objection to heating air before its introduction to the fire.

Q. Is the increase in volume due to preheating air, as suggested above, a valid objection to its use?

Cold air in necessary quantity will enter the ash pit and will pass through the openings in the grates with less velocity than will the same quantity of heated air. But in these passages the area is amply large and the velocity moderate. It is also true that on entering the lower stratum of fuel the velocity of the heated air will be the greater. The very first effect of the chemical union of any part of the oxygen with any part of the carbon is to heat the gases associated with such oxygen—that is, its associated nitrogen and the atmospheric air yet containing its oxygen, together with the carbonic-acid gas resulting from such union or combustion, to the full extent to which the entire heat of combustion can raise the given mass of gases. This will approximate the temperature of the furnace, modified by the subsequent union of further portions of oxygen with new portions of carbon encountered during the farther progress of the mixed gases through the fuel, until they emerge at the surface of the fire.

If their temperature be now 2500° F. or 2961° absolute, their volume will be $\frac{2961}{521} = 5.7$ times that of the air temperature, 60° F., and $\frac{2961}{846} = 3.5$ times that of air of temperature 385° F. Now it is this volume of the gases at their final emergence from the interstices of the fuel that determines their flow; determines the force of draft or blower required to produce that flow. The difference between 3.5 times, as against 5.7 times, is favorable and compensates, as far as it goes, for the greater force required to introduce the heated air with its greater volume and higher velocity.

Q. What are the combined physical and chemical effects of heated air for furnace combustion?

Carbon and oxygen will unite at all temperatures usually met. Coals waste in the open air by slow combustion, the resulting heat being dissipated by radiation and the convection of the air. The rapidity of combustion is augmented with the rise of temperature, and is very great at high incandescence. The temperature of the oxygen is no less important than that of the carbon; the higher the sum of their temperatures, the more rapid is their union. So far as the associated gases are concerned, their higher temperature only serves to communicate more heat to the mass, or, which amounts to the same thing, to abstract less heat from it. With heated air the resulting temperature is higher and the combustion will be more rapid.

Q. How may the quantity of air required for the combustion of any fuel be determined?

The quantity of oxygen required for the complete combustion of any given quantity of carbon or hydrogen has been experimentally determined and is well known; the quantity of oxygen in the atmosphere being practically constant, the process of determining the amount of air required for these two elements is quite simple, thus:

One pound of hydrogen requires 8 pounds of oxygen for its complete combustion; this requires about 36 pounds of air.

One pound of carbon requires 2⅔ pounds of oxygen for its complete combustion (to CO_2), or about 12 pounds of air.

One pound of carbon incompletely burnt, or to carbonic oxide (CO), requires 1⅓ pounds of oxygen, or about 6 pounds of air.

All the above are based on the assumption that 4.5 pounds of air are required to supply 1 pound of oxygen.

The above applies only to such fuels as have undergone analysis, the elemental constituents being known.

A table giving the theoretical quantity of air required for a variety of fuels was prepared by Rankine, and has very general acceptance. This table is here reproduced.

Table 10.—Air Required for Perfect Combustion.

Fuel.	Carbon.	Hydrogen.	Oxygen.	Air Required.
I. Charcoal, from wood	0.93			11.16
from peat	0.80			9.6
II. Coke, good	0.94			11.28
III. Coal, anthracite	0.915	0.035	0.026	12.13
dry bituminous	0.87	0.05	0.04	12.06
caking	0.85	0.05	0.06	11.73
caking	0.75	0.05	0.05	10.58
cannel	0.84	0.06	0.08	11.88
dry long flaming	0.77	0.05	0.15	10.32
lignite	0.70	0.05	0.20	9.30
IV. Peat, dry	0.58	0.06	0.31	7.68
V. Wood, dry	0.50			6.00
VI. Mineral oil	0.85			15.65

Q. What quantity of air is usually estimated per pound of coal?

The theoretical quantity of air required for boiler furnaces is assumed to be 12 pounds of air for each pound of coal, regardless of its composition. From 18 to 24 pounds of air per pound of coal burnt is a common allowance when making up estimates; 24 pounds of air is a near approximation to the average quantity supplied the burning fuel per pound of coal.

Q. What is the specific heat of air?

The specific heat of air at constant pressure is 0.2374 (Regnault).

Q. Under what conditions may air be liquified?

Under the critical pressure of 39 atmospheres, and at the low temperature of 312° below the Fahrenheit zero (− 191° C.), air may be liquefied.

CHAPTER IV.

COMBUSTION.

Q. What is combustion?

Any manifestation of chemical energy attended by combination and accompanied by production of much heat is, strictly speaking, an instance of combustion. In steam engineering it means the controlled chemical combination of the elements carbon and hydrogen in the fuel with the oxygen of the atmosphere, by which an evolution of heat is secured and maintained in a suitably constructed furnace for the purpose of generating steam.

The term combustion, as commonly used, carries with it the idea of incandescence, or the glowing whiteness of a body caused by intense heat, which is quite characteristic of burning carbon; the term also includes that of inflammation, which is, however, best restricted to instances of combustion in which the incandescent substances are gaseous. All phenomena of burning are instances of combustion, and in the great majority of cases they consist in the union of the oxygen of the atmosphere with the substance which is being burnt, the visible signs of combustion, *i.e.*, the heat and light, being the result immediate or proximate of the chemical energy so expended.

Q. What is the nature of combustion as applied particularly to coal?

Coal is mainly composed of the two elements, carbon and hydrogen, both of which have an affinity for oxygen;

but before they unite chemically to produce heat it is necessary that certain conditions be fulfilled, the first of which is that a considerable mass of the coal must be heated to the point of ignition before the oxygen in the air will unite with it.

The oxygen having a choice of two partners, as Professor Tyndall happily puts it, closes with that for which it has the strongest attraction. It first unites with the hydrogen and sets the carbon free. Innumerable solid particles of carbon thus scattered in the midst of burning hydrogen are raised to a state of incandescence. The carbon, however, in due time, closes with the oxygen, and becomes, or ought to become, carbonic acid. The light and heat produced by the burning of coal are due to the collision of atoms which have been urged together by their mutual attractions.

An isolated piece of coal will not burn in the open air, because the temperature will soon fall below the point of ignition, consequently chemical action will cease; but an ignited mass of coal, as in a furnace or a stove, will give off great heat, depending upon the quality and quantity of coal burned; but once the hydrogen having united with the oxygen to form water, and the carbon with the oxygen to form carbonic-acid gas, their mutual attractions are satisfied, and all the heat has been given off that is possible under any conditions.

Q. In what proportion does oxygen unite with hydrogen and with carbon?

Oxygen and hydrogen unite in the ordinary processes of combustion in one proportion only, viz., two atoms of hydrogen unite with one atom of oxygen, the product of the combustion being aqueous vapor, or water, H_2O.

Oxygen and carbon unite in the ordinary process of combustion in two proportions, viz., one atom of carbon and two atoms of oxygen, the product being carbonic-acid gas, CO_2; and one atom each of carbon and of oxygen, the product being carbonic-oxide gas, CO.

Q. What are the ordinary combinations of hydrogen with carbon fuel?

Hydrogen is rarely found in a free state, though it is an essential element in all organic substances, from which it may be separated by a process of destructive distillation. It occurs in nature in combination with carbon. The compound which contains it in greatest abundance is marsh gas, of which hydrogen forms one-fourth, CH_4. Olefiant gas consists of 2 atoms of carbon and 4 atoms of hydrogen, C_2H_4. These are the commonest proportions in which the two elements, hydrogen and carbon, are found in coal. The complete series, however, of hydrocarbons is so extended that it cannot be reproduced here. Reference can only be made to the Marsh gas and Olefiant gas series, which are given elsewhere in this volume.

Q. Is oxygen a supporter of combustion?

Oxygen is an active supporter of combustion. It will unite chemically with the hydrogen and the carbon in the fuel, the burning of the latter accompanied by characteristic flames followed by a body of incandescent carbon on the grate, which will continue to burn at high temperature and with great brilliancy, until entirely consumed, if a proper supply of atmospheric oxygen is furnished.

Oxygen will not unite with hydrogen and carbon at ordinary temperatures. A mixture of oxygen and hydrogen may be thus kept for any length of time, but if the temperature of any part of the mixture be raised to bright redness—either by an electric spark, by the presentation of a flame, or by other means—ignition at once takes place with explosive force throughout the whole mass.

Q. How may the volume of oxygen required for combustion be estimated?

By weight, air consists of 23 per cent of oxygen and 77 per cent of nitrogen; therefore, $77 \div 23 = 3.391$ pounds of nitrogen accompanies each pound of oxygen.

By volume, one pound of air averages 12.5 cubic feet, of which 21 per cent, or 2.625 cubic feet, is oxygen, and 79 per cent, or 9.875 cubic feet, is nitrogen.

One pound of carbon requires for its complete combustion to CO_2 about 12 pounds of air, or 150 cubic feet, of which 21 per cent, or 31.5 cubic feet, is oxygen, and 79 per cent, or 118.5 cubic feet, is nitrogen.

One pound of hydrogen requires for its complete combustion to H_2O 8 pounds of oxygen supplied by 31 pounds of air, or 387.5 cubic feet, of which 21 per cent, or 81.375 cubic feet, is oxygen, and 79 per cent, or 306.125 cubic feet, is nitrogen.

Q. What is meant by the term ignition?

Ignition is simply the incandescence of a body unattended by chemical change, and must not be confused with combustion. The ignition of solids is a source of light, the combustion of solids is a source of heat. Every combustible must be heated to a certain definite temperature before it will combine with oxygen. This temperature is usually called the point of ignition, or its kindling temperature. In furnace combustion the temperature of ignition cannot be much less than dull red heat, say 800°

to 900° F., and maintain an active fire. For steam-boiler furnaces the combustion is quite active, even for moderate fires, and the temperature of the incandescent bed of fuel seldom if ever below 1100° to 1200° F. and usually much higher than that, while the full furnace temperature may range from 2000° to 3000° F.

Q. What are the ignition temperatures of gases?

We have as yet no very exact information concerning the ignition temperatures of gases. The experimental difficulties in the way of carrying out such determinations are very considerable. It is, however, certain that the ignition temperatures of gaseous mixtures are as a rule by no means so high as is commonly supposed, and they lie within extremes of temperature admitting of comparatively easy determination. When once initiated, the continuance of the combination of unlimited amounts of the constituents of a combustible mixture, or, in other words, the continued existence of a flame, depends primarily upon the condition that the combining gases are maintained at the temperature required to bring about their union. Any agency or condition which lowers the temperature below this point will extinguish the flame.

Q. What is the effect upon combustion if too little air is supplied the fire?

So far as the carbon of the fuel is concerned the effect is a serious one. One pound of carbon combining with two pounds of oxygen results in perfect combustion, the product being carbonic-acid gas, CO_2, developing 14,500 heat units; but if too little air, which means too little oxygen, is present at the instant and focus of combustion, the carbonic-acid gas already formed will take up additional carbon, thus changing the product to carbonic oxide, or from CO_2 to CO, the latter developing only 4,450 heat units, or 10,050 less than the first union. This represents a loss approximating 69 per cent of the fuel, merely as a result of too little air in the fire at the right time and place.

Q. What is the effect upon combustion if too much air is supplied the fire?

The effect of too much air in the fire is the mechanical one of cooling the furnace. The carbon having united with its full combining weight of oxygen to form CO_2 can take up no more oxygen, and any surplus air in the furnace is merely a dilutant of the gases. Inasmuch as the free air abstracts heat from the furnace and does no useful work, its presence acts against the economy of the furnace.

Q. Does so large an excess of air as 150 per cent over that necessary for complete combustion commonly occur in steam boiler furnaces?

An excess of air as large as 150 per cent in steam-boiler furnaces is by no means uncommon. There is a general tendency to use a stronger draught than is necessary for the combustion of fuel. It so happens that 100 per cent excess of air in steam-boiler furnaces is an ordinary condition, and 150 per cent excess is much more common than is generally supposed.

Q. What advantages accompany the heating of air required for furnace combustion?

A direct economical effect of heating the air is that of raising the intensity of furnace combustion, and this may be explained on the probable hypothesis that the chemical affinity of heated air for carbon is much greater than that of cold air; one consequence of which is that, when heated air is employed, it is deprived of its oxygen within a very short travel, the combustion is thereby more concentrated and localized at the focus where the heat has to be applied and to do its work. This is favorable to the economy of fuel, for combustion and high temperature beyond the point where heat has to be applied are useless.

Q. How may the effect of heated air and chemical action be estimated?

It is known that one pound of carbon combined with $2\frac{2}{3}$ pounds of oxygen will develop 14,500 heat units. This will require under theoretical conditions 12 pounds of air; but to place it under ordinary conditions, say 24 pounds of air. We have then 25 pounds of gaseous product, of which $3\frac{2}{3}$ pounds will be carbonic-acid gas, and $21\frac{1}{3}$ pounds of inert waste gas. The more nitrogen there happens to be mingled with the oxygen, the greater the weight of matter that will have to be uselessly heated; and the greater its capacity for absorbing heat—the greater its specific heat—the greater the amount of heat that would be taken up.

The specific heat of carbonic acid gas $= 0.217$, of nitrogen $= 0.245$. The mean of $3\frac{2}{3}$ pounds of the first and $21\frac{1}{3}$ pounds of the latter $= 0.237$. Then: $\frac{14{,}500}{0.237 \times 25} = 2{,}447°$ F. as the temperature of the products of combustion, in the form of about 1,800 cubic feet of fire gases.

Preheating the air facilitates the union of oxygen with the carbon, and the fourfold useless volume of nitrogen should not rob the furnace of heat at the very moment and focus of its combustion. A gain would also be effected the more nearly the temperature of the nitrogen is raised to that of the fire; and whatever can be done by means of the escaping gases is pure saving.

Q. Is there an economical limit to the heating of air for combustion?

It has been found in practice that the greater the affinity of any fuel for oxygen, the lower need be the temperature of the air. It is hence used at a lower heat in charcoal furnaces than in coke furnaces, and less in the latter than in anthracite blast furnaces. This explains the fact, which has been found on trial, that a reverbatory furnace, supplied with hot air at the grate only, has actually been found to have its efficiency diminished and not increased. The gaseous combination or chemical union being thereby accelerated, the combustion takes place more on the grate and less in the body of the furnace, where the actual work has to be done.

Q. What is flame?

Flame is the surface burning of an inflammable gas or vapor, the surface of which is in contact with or receives constant supplies of atmospheric air. As all flames depending upon oxygen for their support are specifically lighter than air, they naturally ascend in a stream from burning bodies. Flames are usually, though not necessarily, accompanied by luminosity at ordinary atmospheric pressure.

Q. What is known regarding the nature of the chemical processes in flames?

Attempts have been made to study the nature of the chemical processes in flames of candles and of coal gas by aspirating the gases from different parts of the flame and analyzing them. Such investigations can only give a very partial conception of the changes which occur, or have occurred, in the different areas of the flame, owing to the intense molecular movements, due to the high temperature and specific differences of diffusive power of the gaseous constituents. Nevertheless it is possible to obtain some idea of the manner in which the several combustible gases in such a complex mixture as that of coal gas, or of the gas obtained by the distillation of wax or tallow, behave toward oxygen, and to trace the rates at which they are severally burnt. Thus, broadly speaking, it is found that of these gases, the hydrogen up to a certain point is most rapidly consumed, then the carbonic oxide, next the marsh gas, while the heavy hydrocarbons burn comparatively slowly. The amounts of these gases burnt, and especially of the hydrogen and carbonic oxide, are, however, modified by processes of dissociation and by the mutual action of the products of combustion at high temperatures. At the very high temperatures water vapor and carbonic-acid gas are dissociated, while carbonic oxide is formed by the action of separated carbon upon carbonic-acid gas.

Q. How is an isolated flame such as a candle built up?

It is usual to describe the structure of a flame as built up of four zones, as sketched in Fig. 1, intended to illustrate the main reaction taking place in the flame of a burning candle, in which:

A = the inner zone of heavy vapor.
B = the inner zone of lighter gas.
C = the luminous zone.
D = the outer or cooling zone.

The inner zone A, nearest to and surrounding the wick, is a vapor of the material of which the candle is composed.

The zone B is an envelope of highly rarified vapor of A heated to the point of ignition. The zone C is luminous, and is that portion of the flame where the chemical reactions occur, beginning along the surface of the zone B and extending into the zone D. The outer zone D is that in which the cooling and diluting influence of the entering air renders a thin layer non-luminous, and finally extinguishes it.

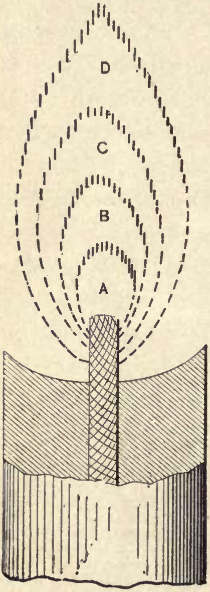


FIG. 1.

It will be understood that flame does not consist of envelopes in such contrast as the engraving would seem to indicate. This is for the purpose of illustration only.

Q. What are the successive developments of a luminous hydrocarbon flame?

The hydrocarbon issues from the wick of the candle, Fig. 1, let us suppose as a cylindrical column. This column is not sharply marked off from the air, but is so penetrated by the latter that we must suppose a gradual transition from the pure hydrocarbon in the centre of the column to the pure air outside. Take a thin, transverse slice of the flame, near the lower part of the wick. At what lateral distance from the centre will combustion begin? Clearly where enough oxygen has penetrated the column to give such partial combustion as takes place in the inner cone of a Bunsen burner. This, then, defines *the blue region.*

Outside this, the combustion of the carbonic oxide, hydrogen, and any hydrocarbons which pass from the blue region takes place, and constitutes the *faintly luminous region.*

These two layers form a sheath of active combustion, surrounding and intensely heating the hydrocarbons in the central parts of the column. These heated hydrocarbons rise, and are heated to a higher temperature as they ascend. They are accordingly decomposed with the separation of carbon in the higher parts of the flame, giving us the *yellow region;* but there remains a central cone in which neither is there any oxygen for combustion nor a sufficiently high temperature for decomposition. This constitutes the *dark region of unburned gases.*

A flame is, however, not cylindrical, but has in the case of a candle an inverted peg-top shape. Again, the blue region only surrounds the lower part of the flame, while the faintly luminous part surrounds the whole.

Q. How will the processes outlined in the above question differ in parts above the small section of the flame?

Let us suppose that the changes have gone on in the small section of the flame exactly as described above. The central cone of unburned gases will pass upward, and may be treated as a new cylindrical column, which will undergo changes just as the original one, leaving, however, a smaller cone of unburned gases; or, in other words, each succeeding section of the flame will be of smaller diameter. This is what gives the conical structure to the flame. Again, the higher we go in the flame, the greater proportionally is the amount of separated carbon, for we have not only the heat of laterally outlying combustion to affect decomposition, but also that of the *lower* parts of the flame. The lower part of a luminous flame is accordingly cooler, and contains less separated carbon than the upper.

Q. What chemical changes produce the blue region in a flame?

When the hydrocarbons are cool until admixed with sufficient air for combustion, in the lower part of the flame, there is every facility for the occurrence of the chemical changes to which the existence of the blue region has been ascribed, and the blue region here is most evident; whereas in the upper parts of the flame, where the quantity of hydrocarbon decomposed (with separation of carbon) by heat is relatively much greater, there is not enough left to form outside the yellow part the mixture to which the blue region of flame is due. The blue region, therefore, rapidly thins off as we ascend the flame.

Q. Are the several processes of flame development supported by complete combustion?

Whether the first combustion taking place within the flame is that of undecomposed hydrocarbon with limited oxygen, or of the decomposed hydrocarbon with limited oxygen, we may be sure that the products will contain carbonic oxide, and perhaps hydrogen; and we shall therefore have *all round the flame* a faintly luminous region of completed combustion.

Q. Is the flame of a candle characteristic of other steady or continuous flames?

In other steady, continuous flames these areas or zones, as shown in the candle, are very different in character and in number. In some the luminous cone is absent, and others have no mantle. All have, of course, the dark internal cone, and the majority have an area corresponding to the blue zone in the candle flame. The flame of carbonic oxide consists of a dark internal cone of unburnt gas surrounded by a yellowish-red mantle, somewhat ill-defined at its external edge, and at the base is a comparatively large blue zone.

Q. How can it be shown that the flame of a candle is hollow?

The fact that the candle flame is hollow, and that the internal cone immediately surrounding the wick consists of comparatively cold, unignited gas free from oxygen, may be demonstrated by thrusting a fragment of burning phosphorus into the cone when its combustion ceases.

A piece of stiff thick paper thrust down on the flame to the level of the dark internal area is seen to be charred on the upper surface in the form of a ring. If the paper be placed simply across the luminous area and above the dark cone, the charring is simply a circular patch.

Q. What is the rate of propagation of combustion in flames of hydrogen and carbonic oxide?

Bunsen's investigations show that the rate of propagation of the combustion of a mixture of oxygen and hydrogen, and of carbonic oxide and oxygen, mixed in the exact quantities for complete combustion to be:

In the oxyhydrogen mixture the velocity of the inflammation was 111.5 feet per second; in that of carbonic oxide and oxygen it was less than 40 inches per second. By adding to the mixture increasing amounts of an indifferent gas the rate is rapidly diminished until the progress of the flame throughout the mass may be followed with the eye.

Q. Is combustion complete and the consequent high flame temperature maintained in cases where the combustible gases are mixed in their exact combining proportions?

According to Bunsen, in a mixture of carbonic oxide, CO, or hydrogen, with oxygen in the exact quantity needed for complete combination, only one-third of the carbonic oxide, CO, or hydrogen, is burnt at the maximum temperature, the remaining two-thirds at the high temperature (2558°–3033°) having lost the power of combination. If an indifferent gas is present the temperature of the flame is reduced, and larger quantities of the gases combine together, as much as half the amount of carbonic oxide, CO, or hydrogen combining within a range of temperature between 2471° and 1146°.

It would appear therefore that gases in combining together with the production of such an amount of heat as to produce flame unite, as it were, at a single leap, and that the combustion is not a continuous uninterrupted process.

Q. What variations of temperature occur in flames incident to the combustion of carbonic oxide, CO?

When two volumes of carbonic oxide, CO, are mixed with one volume of oxygen, both gases at 0°, and the mixture is ignited, the temperature is raised to 3033°, and two-thirds of the CO is left unburnt. By radiation and conduction the temperature is lowered to 2558° without any combustion of the CO. At a little below this point combustion recommences, and the temperature is again raised to 2558°, but not above this point. This temperature continues until half the CO is burnt, when combustion ceases, until by cooling and radiation the gaseous mixture has cooled to 1146°; and these alternate phases of constant temperature and of decreasing temperature are repeated until the whole of the combustible gas is burnt.

Q. What is the cause of the luminosity of flame?

The main cause of the luminosity of flame was first traced by Davy as the outcome of experiments which led him to the invention of the safety lamp. It is, to use his own words, "owing to the *decomposition* of a part of a gas toward the interior of the flame, where the air was in smallest quantity, and the decomposition of solid charcoal, which first by its ignition and afterward by its combustion increases in a high degree the intensity of the light."

The proofs that solid carbon is present in luminous hydrocarbon flames are the following:

1. Chlorine causes an increase in the luminosity of feebly luminous or non-luminous hydrocarbon flames. Since chlorine decomposes hydrocarbons at a red heat with separation of carbon, it follows that the increase in luminosity is due to the production of solid carbon particles.

2. A rod held in the luminous flame soon becomes covered on its lower surface, *i.e.*, the surface opposed to the issuing gas, with a deposit of soot. The solid soot is driven against the rod. If the soot existed as vapor within the luminous flame, its deposition would be due to a diminution of the temperature of the flame, and would therefore occur on all sides of the rod.

3. A strongly heated surface also becomes covered with a deposit of soot. This result could not occur if the deposit were due to the cooling action of the surface.

4. The carbon particles in the luminous flame are rendered visible when the flame comes in contact with another flame, or with a heated surface. The separated par-

ticles are agglomerated into large masses, and the luminous mantle becomes filled with a number of glowing points, giving a very coarse grained soot.

5. The transparency of a luminous flame is no greater than that of the approximately equally thick stratum of soot which rises from the flame of burning turpentine, and which is generally allowed to contain solid particles. A flame of hydrogen made luminous with solid chromic oxide, which is non-volatile, is as transparent as the hydrocarbon flame.

6. Flames which undoubtedly owe their luminosity to finely divided solid matter produce shadows in sunlight. The only luminous flames incapable of producing shadows are those consisting of glowing gases and vapors.

7. Luminous hydrocarbon flames produce strongly marked shadows in sunlight. These flames, therefore, contain finely divided solid matter. This solid matter must be carbon, since no other substance capable of remaining solid at the temperature of these flames is present. Moreover, if the soot in luminous flames is present as vapor, a high temperature after condensation should again cause it to assume the gaseous condition; but soot is absolutely non-volatile, even at the highest temperatures.

Q. What conditions affect the color of flame?

The conditions under which a flame is produced not only modify its temperature, but also, as an effect of temperature, its color. Thus the prevailing tint of sulphur burning in air is blue, and the mantle is correspondingly small and of a violet color. In oxygen the flame becomes hotter and the violet color is more pronounced. Precisely the same change is produced by heating the air or by burning a jet of heated sulphur vapor. Cold carbonic oxide gives a blue flame in air, but it becomes yellowish-red if the gas be previously heated.

The flame of a candle, whether of wax, tallow, or parafin, is seen to consist of four distinct cones, which are comparatively sharply defined, and which are rendered evident by their different appearance. Immediately surrounding the wick is a dark inner cone of unburnt gases or vapors. Adjoining the inner cone is a light blue zone of small area consisting of combustible matter from the wick. Surrounding the inner cone is a bright luminous area, from which the greater part of the light emitted by the flame is derived. Surrounding the luminous area, which seems to constitute the greater portion of the visible flame, is an envelope or mantle of a faint yellowish color and of feeble luminosity. This consists of the final products of combustion of the constituents of the luminous cone mixed with atmospheric air heated to incandescence.

Owing to the intense glare of the luminous cone the feebly luminous mantle is not readily perceived, but it may be rendered evident by holding a piece of card, of the shape of the flame, in such a manner as to hide the luminous cone, when the mantle is seen lining the outer edge of the cone.

Q. Upon what does the temperature of flame depend?

The temperature of a flame depends mainly upon the heats of combination of the constituents and the specific heats of the products of combustion. Flames which depend upon the presence of oxygen are much hotter when the combustion takes place in an atmosphere of pure gas than in air. In the latter case the oxygen is mixed with four times its volume of nitrogen, which plays no part in the chemical reaction, and therefore contributes nothing to the heating effect; but, on the contrary, abstracts a considerable amount of heat from the products of combustion, and thereby lowers the temperature of the glowing mass of gas. Hence sulphur burning in oxygen gives a much hotter flame than when burning in air, and the oxyhydrogen flame is much hotter than that of hydrogen in air. The effect of the indifferent gas in lowering the temperature is well illustrated by the following numbers given by Bunsen:

	Cent.	Fahr.
Flame of hydrogen burning in air	2,024°	3,675°
" " " " " oxygen	2,844	5,151
" " carbonic oxide burning in air	1,997	3,626
" " " " " " oxygen	3,003	5,437

Q. Is flame in immediate contact with the orifice from which the gas issues?

If the flame of a candle or of coal gas be closely examined it will be seen that the one does not touch the rim of the burner nor the other the wick. The intermediate space in the case of the coal gas may be increased by mixing it with an indifferent gas, as nitrogen or carbonic-acid gas, CO_2. These phenomena are due to the cooling effect of the wick or the burner.

Q. May flame be extinguished by a rapid absorption of its heat?

A coal gas flame may be extinguished by a cold mass of copper, and a candle flame by a helix of cold copper wire. The metal abstracts sufficient heat from the gases to lower their temperature below the point of combination. If the metal is heated prior to its introduction into the flames, they are not extinguished.

Q. May not a flame be extinguished in other ways than by the cooling action of metals?

A flame may be extinguished by mixing the combustible gases with a sufficiently large quantity of an indifferent gas, which will act by absorption of heat in the same way as metal. The effect even of small quantities of indifferent or chemically inactive gases in lowering the temperature of a flame is very marked, and is well illustrated in the different characters of the flame of hydrogen burning in air and oxygen. In extinguishing a flame, say of a candle or coal gas, by blowing it out, the puff of air acts partly by suddenly scattering the glowing gases from the area of supply and partly by its cooling action.

Q. What are the flame characteristics in the burning of anthracite coal?

In burning, anthracite coal neither softens nor swells, and does not give off smoke. The flame is quite short and has a yellowish tinge when first thrown upon the fire, which soon changes to a faint blue, with occasionally a red tinge. The flame, being quite short and free from particles of solid carbon, has the appearance of being transparent.

Q. How is the rapidity of flow, or the volume of air supplied a furnace-fire, estimated, when employing natural draft?

By means of an instrument contrived for measuring the force and velocity of currents of air, called an anemometer. Those composed of a small light fan wheel, whose motion is transmitted to a counter which registers the number of turns, are most certain and convenient for use, though they must previously be tested, or the relation existing between the velocity of the wind and the number of turns of the wings must be accurately determined.

The anemometer shown in Fig. 2 is by Keuffel & Esser Company, New York. Each instrument is tested and a chart of corrections furnished with it, so that no calculations are necessary for obtaining the velocity of the current in which it is placed.

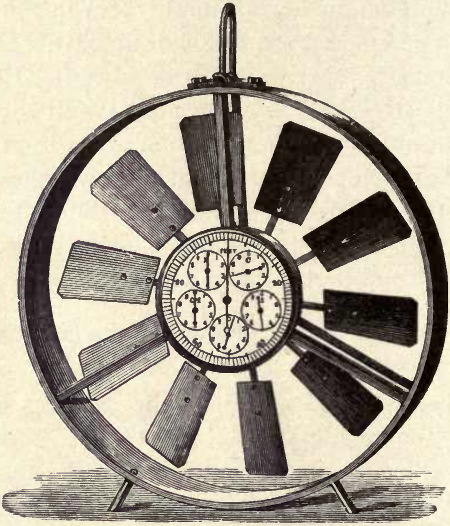


FIG. 2.

CHAPTER V.

PRODUCTS OF COMBUSTION.

Q. What are the principal products in the furnace after the combustion of coal?

The principal products in the furnace after the combustion of coal are: carbonic-acid gas, carbonic oxide, nitrogen, air furnished in excess, and unconsumed, gaseous steam.

Q. What is the product of the combustion of hydrogen?

Hydrogen unites with oxygen, forming gaseous steam, which, upon cooling, is condensed into water, H_2O. This chemical combination is complete, and the product incombustible.

Q. What are the products of the combustion of carbon?

The products of the combustion of carbon in oxygen are two in number, carbonic oxide, CO, and carbonic-acid gas, CO_2, in which each compound is sharply defined and exhibits properties distinct from each other, and of the elements of which they are composed. The quantity of carbon remaining the same, the quantity of oxygen must be doubled in order to form the other compound. These proportions constitute the only two direct inorganic compounds of carbon and oxygen.

Q. What are the properties of carbonic-acid gas?

Carbonic-acid gas, CO_2, is composed of one part or atom of carbon and two parts of oxygen, its atomic weight being $12 + (16 \times 2) = 44$. By percentage of volume: carbon = 27.27, oxygen = 72.73 = 100.00. Its specific gravity is 1.53, air = 1.00. It is a colorless, inodorous, heavy gas, neither combustible nor a supporter of combustion.

It liquefies under a pressure of 36 atmospheres at 0° C. The specific gravity of the liquid carbonic acid is 1.057 at – 34° C. Liquid carbonic acid is colorless, very soluble in alcohol, ether, and volatile oils, but does not mix with water. When the pressure is suddenly relieved, part of the carbonic acid immediately vaporizes, producing sufficient cold to solidify the remainder. Solid carbonic acid is a white flocculent, snowlike mass, and may be left exposed to the air for some time without sensible evaporation. An air or spirit thermometer immersed in it sinks to – 78° C. It can, however, be placed on the hand without any acute sensation of cold. By mixing with ether its refrigerating power is greatly increased. The cold produced in this manner is sufficient to solidify mercury and to liquefy several gases.

Carbonic-acid gas is a constant constituent of the atmosphere, which contains on an average about 0.034 per cent.

In the combustion of coal, carbonic-acid gas is formed by the combination of the carbon in the coal by the oxygen of the air, and is thus a constant product of the ordinary processes of combustion. The presence of moisture is necessary for the burning of carbon in an atmosphere of pure oxygen. In furnace combustion the coal itself furnishes all the moisture needed for intense combustion.

Q. What are the properties of carbonic oxide?

Carbonic oxide, CO, is composed of one part or atom each of carbon and oxygen, its atomic weight being $12 + 16 = 28$. By percentages of volume: carbon $= 42.86$, oxygen $= 57.14 = 100.00$. Its specific gravity is 0.9678, air $= 1.0000$. It is a colorless, tasteless, combustible gas. Pure carbonic oxide forms a colorless, transparent liquid under 200 to 300 atmospheres pressure at $-139°$ C., and solidifies to a snowy mass in vacuo at $-211°$ C.

Carbonic oxide burns with a blue flame, which by previous heating becomes red, generating carbonic-acid gas, CO_2. The temperature of its flame in air is about 1400° C. When dry it is not changed by the electric current nor by ignited platinum wire, but when standing over water it is decomposed by a glowing platinum spiral; when not absolutely dry it may be exploded with oxygen by the electric spark or by platinum wire heated to 300° C., or by spongy platinum at ordinary temperatures. Two molecules of carbonic oxide, CO, unite with 1 atom of oxygen, O, to form 2 molecules of carbonic-acid gas, CO_2. The combination takes place very slowly in the presence of small quantities of steam, and increases in rapidity with the quantity of steam present. Hence the steam acts as the carrier of oxygen to the carbonic oxide. Small quantities of other gases than steam have been tried. If the gas contained no hydrogen, no explosion occurred. When a mixture of carbonic oxide and steam is heated to about 600° C. a portion of carbonic oxide is oxidized. If the carbonic-acid gas is removed as it is formed, the whole may be oxidized.

Carbonic oxide is a highly poisonous gas, producing giddiness and ultimate asphyxia when inhaled.

Q. What is the product of the combustion of sulphur?

Sulphur combines with oxygen to form sulphurous oxide, SO_2, a colorless gas, with a suffocating odor. It is a non-supporter of combustion, instantly extinguishing flame when brought within its influence. Sulphurous oxide, in absorbing vapor of water, changes from sulphurous oxide, SO_2, to sulphurous acid, SO_2, H_2O.

Q. What is the effect of sulphur in coal upon the surfaces of steam boilers?

If the sulphurous oxide generated by the combustion of sulphur in the furnace simply passed off with the other products of combustion, without lodging against the surfaces of the boiler, no bad effects would follow; but numerous instances are on record where sulphurous oxide was included in the deposits of soot in contact with portions of a steam boiler, which oxide had been converted into acid by the subsequent absorption of moisture. The transformation of sulphurous into sulphuric acid, under the action of water, or steam and air, in presence of a metal, is well known, and exterior corrosion of boilers attributed to the action of smoke is wholly confined to those parts of the iron which were wetted by infiltration or by accident.

Q. What quantity of nitrogen is present in the products of combustion?

Whatever the quantity of air required for the perfect combustion of carbon or hydrogen there will remain in the furnace 3.35 pounds of nitrogen for every pound of oxygen combined with the fuel; or by volume 3.76 volumes remain in the furnace for each volume of oxygen uniting with the fuel.

Nitrogen is non-combustible, and so far as the other products of combustion in the furnace are concerned it is wholly inert.

Q. What is the effect of surplus air in the furnace in combination with the products of combustion?

Surplus air, or air in excess of that necessary to supply oxygen to the burning fuel, acts as a dilutant of the furnace gases. Inasmuch as this surplus air has to be heated by the furnace to the temperature of the escaping gases, it occasions loss by abstracting heat from the furnace gases, which might otherwise be employed in doing useful work.

Q. What weight of gases commonly emerges from a steam-boiler furnace for the combustion of each pound of carbon?

It is not easy to carry on complete combustion by means of natural draft with less than 100 per cent excess air; and some experiments, made by Hoadley, to ascertain the composition, volume, and temperature of the gases from seventeen boilers, burning good anthracite coal at known rate, with great care, and under most favorable conditions of draft, grate area, rate of combustion, area of heating surface, and general management, gave by analysis carbonic-acid gas, CO_2 (no carbonic oxide, CO), nitrogen, and free atmospheric air, the latter being one-half the whole.

A check upon the accuracy of these results was found in the temperature of the furnace. This should be, with double supply of air, about 2600° F. It was found to be a little over 2400° F. It appears therefore that it is understating rather than overstating the matter to say that the average good practice would show a double supply of air.

Q. What weight of gases emerges from the furnace for perfect combustion of one pound of carbon; also the additional weight occasioned by air in excess of that needed for combustion?

In anthracite coal we may neglect all the constituents except carbon, which, when perfectly burned, with just sufficient air to supply the oxygen, will produce 12.6 pounds of mixed gases for each pound of carbon. Thus:

Carbon	1.0	Carbon	1.00
Air	11.6	Oxygen	2.66
	12.6	Product CO_2	3.60
		Nitrogen	8.94
			12.60

1 lb. carbon burnt with 0% excess of air = 12.6 lbs. gases.
1 " " " 50 " " = 18.4 " "
1 " " " 100 " " = 24.2 " "
1 " " " 125 " " = 27.1 " "
1 " " " 150 " " = 30.0 " "

Q. What is included in the term ashes?

The term ashes includes all the mineral matter left on the grates after the complete combustion of fuel. Every variety of mineral fuel contains more or less incombustible matter called ashes. The presence of this incombustible substance in coal is due in part to the inorganic matter contained in the plants of which the coal is formed, and partly by the earthy matter in the drift of the coal period. The inorganic matter thus obtained frequently differs both in amount and in proximate composition from that originally present in the unburnt substance. At the high temperature of burning some of the mineral constituents may be volatilized, or be mechanically carried away by the gases which may be evolved, and changes in the proximate nature may be induced either by the heat itself or by the action of the heated carbonaceous substances.

Q. What is the specific heat of ashes?

The specific heat of ashes may be assumed to be 0.215 without sensible error in engineering calculations.

Q. Of what do ashes principally consist?

Coal ashes are found to consist mainly of silica, alumina, lime, and oxide and bisulphide of iron. As wood contains from 1 to 3.5 per cent of ash, it is probable that much of the inorganic matter required to make up the five to ten per cent in coal is principally earthy substances drifting into and incorporated in the coal during its formation. The nature and color of coal ashes are greatly modified by the proportions in which the above substances are united in the composition. In all analyses of coal ashes, silica and alumina predominate.

Q. What substances are found in analysis of ashes of anthracite coal?

The analysis of ashes of Pennsylvania anthracite coal, by Professor Johnson, yielded:

Silica	53.60
Alumina	36.69
Sesquioxide of iron	5.59
Lime	2.86
Magnesia	1.08
Oxide of magnesia	.19
	100.01

Q. What substances are found in the analysis of ashes from bituminous coal?

Ohio bituminous coal, containing 5.15 per cent of ash, yielded upon analysis:

Silica	58.75
Alumina	35.30
Sesquioxide of iron	2.09
Lime	1.20
Magnesia	0.68
Potash and soda	1.08
Phosphoric acid	0.13
Sulphuric acid	0.24
Sulphur combined	0.41
	99.88

Block coal is a non-caking, bituminous coal found in Indiana. It occurs in thin laminæ, separated by fibrous charcoal partings, with fractures occurring in the coal at right angles to the bed. A sample of this coal yielded 2.5 per cent of white ash, of which the composition was:

Alumina	48.00
Sesquioxide of iron	32.80
Silica, lime, magnesia, etc	19.20
	100.00

Of the sulphur present in this coal,

.947	per cent.	was in combination with iron.
.483	"	with other constituents.
1.430	"	of sulphur in the sample.

Q. What does the color of coal ashes indicate?

Coal ashes are usually either white, brown, or variously tinged with red. It is a common designation to say of coals that they are white-ash or red-ash. When the amount of iron is very small, or not sufficient to tinge the ashes, they are then usually white. A larger quantity of iron produces a red-ash. Thus the color enables one to judge of the probable nature of the ashes, whether they will clinker in the fire or not. The intensity of the red color, taken in connection with the amount of ashes in coal, may also serve as an indication of the proportion of sulphur existing in the state of pyrites.

Q. Judging from the color of the ash alone, which coals will clinker least under high temperatures?

Those coals are best, the ashes of which are of nearly pure white, and which with large amounts of silica and alumina in their composition, contain little or no alkali, nor any lime, nor oxide of iron. Of this character are the earthy residue of the best white-ash anthracites of Pennsylvania, and in an eminent degree the ashes of some of the semi-anthracites. In general, it requires a high temperature to fuse these ingredients when taken by themselves, but the presence of the oxide of iron tends to lower the point of fusion.

Q. Will not all coal ashes fuse, or clinker, under intense heat?

There are, perhaps, no coals whose ashes, when exposed to the extremest heats procurable by artificial blasts, will not soften to a cohering cinder, or even melt in part into a stony clinker; but as the tendencies to these several degrees of fusion are very various, it proves to be a distinction affecting the practical value of coals, which is of the utmost importance. In domestic consumption, where the heat of combustion is comparatively moderate, the quantity rather than the quality or fusibility of the ashes is the point of greatest consideration; but where an excessive and melting heat is required, as in many modes of generating steam, the practicability of employing a coal at all will oftentimes be determined by this one quality of clinkering of the ashes.

Q. What is the effect of the presence of oxide of iron in coal ashes?

The amount of the oxide of iron present in coal ashes is one of great importance, especially as it unites with potash, soda, lime, and silica, also present, to form clinker. The presence of oxide of iron in ashes, when in any considerable quantity, may be detected without analysis by the red color imparted to them. The particular objection to the combination and fusing of the silica, lime, potash, etc., in the ashes of the coal into a vitreous mass is that, unless the greatest care is exercised, it will accumulate upon the grate bars in sufficient quantity to exclude the passage of the air needed for combustion, and thus lower the temperature of the furnace.

Q. How is the presence of the oxide of iron accounted for in coal ashes?

Nearly every variety of coal contains more or less iron pyrites. This is the probable source of the oxide of iron in ashes. The greater part of the sulphur being expelled by heat, its equivalent of oxygen unites with the iron, with which hydrogen also combines, forming the sesquioxide of iron occurring in the analysis of coal ashes.

Q. What is the effect of iron pyrites included in the ashes of coal?

Coal always contains more or less of sulphur in its composition, and this sulphur occurs mainly as a native bisulphide of iron, or iron pyrites, a mineral of bright yellow color often mistaken for gold. Pyrites approximate equal parts of iron and sulphur with a ten-per-cent variation on either side. About one-half the sulphur may be driven off by heat; and if the fire is intense, the remaining portion of the pyrite is present in the ashes as a black sulphuret of iron, which, in combination with other substances, may form a hard clinker, difficult to remove from the grates if once allowed to cool.

Unless the conditions are favorable a less percentage of sulphur is distilled from the pyrites than that noted in the preceding paragraph, as indicated in tests made in Germany, on coals of the carboniferous period:

TABLE 11.—SULPHUR EVOLVED IN THE BURNING OF COAL AND RETAINED IN THE ASHES.

Ash in 100 pounds of coal.	Sulphur in 100 pounds of coal.	Sulphur in 100 pounds of ash.	Sulphur in the ash from 100 pounds of coal.	Sulphur evolved in burning 100 pounds of coal.
Pounds.	Pounds.	Pounds.	Pounds.	Pounds.
7.360	0.789	9.464	0.696	0.093
5.760	0.973	14.663	0.844	0.129
16.530	3.264	18.174	2.424	0.840

Q. Is sulphur always present in coal as iron pyrites?

There is no doubt that sulphur is present in coal in combination with the organic elements of which it is composed; but what the definite compound may be which contains it is unknown. For example, a coal from New Zealand containing 2.50 per cent of sulphur yielded an ash remarkably white; the coke contained 2.35 per cent of sulphur. No sulphuric acid was detected in the hydrochloric acid in which the powder of the coal had been boiled. It would appear that the sulphur was present in the same state of combination in the coal as that in which it exists in albumin, fibrine, etc.; for it could not have been combined with iron, as in this case the ash would have had a decided red color.

Q. What is clinker?

Clinker is a product formed in the furnace by fusing together the impurities in the coal, such as oxide of iron, silica, lime, etc. There are few colored ashes, and especially red ashes, that will not soften under the action of intense heat and form clinker; white-ash coals produce the least clinker.

Q. How is alumina present in ashes?

Alumina is the oxide of the metal aluminum; it is the pure earth of clay. It is infusible in any temperature yet obtained in furnaces. The alumina present in ashes is in the form of a clay or a mixture of the two simple earths, alumina and silica, generally tinged with iron. The floor, or pavement, immediately under the coal beds is, almost without exception, a grayish slate-clay, which strongly resists the fire. This clay varies in thickness from a fraction of an inch to many feet, and is often disseminated through the shale found in coal.

The presence of alumina in analyses of wood ashes from trees, such as beech, pine, fir, etc., is not easily accounted for inasmuch as no inorganic substance can find its way into a plant except in a state of solution in water, when it is absorbed by the roots; and, certainly, neither rain water nor ordinary mineral water contains any salt of alumina, nor does water impregnated with carbonic acid, which dissolves phosphate of lime or magnesia, dissolve even a trace of phosphate of alumina.

Ashes of *lycopodium* contain from 52 to 57 per cent of alumina, 13 per cent of silica, and 12 per cent of potash. This species of plants has contributed largely to the production of coal. It appears, therefore, that the inorganic matter in coal, of which alumina is a notable constituent, may have been in great measure derived from that originally existing in the coal-forming plants, and the alumina originally present in these plants would be uniformly diffused through the mass of coal.

Q. How is silica present in ashes?

The only known oxide of silicon [symbol, Si.; atomic weight = 28.33] occurs abundantly in nature, pure, or nearly so, in quartz, flint, etc. It enters largely into the constitution of sandstones, felspar, and many other rocks. Silica, known also as silicic acid, silex (formula, SiO_2), is infusible except at very high temperatures; it is non-volatile; it decomposes fused sodium carbonate and melts to a transparent glass. It is insoluble in water and all acids except hydrofluoric acid, which decomposes it into water and silicon fluoride. Silica dissolves readily, as a rule, in caustic alkalies, forming solutions of alkaline silicate (water-glass). Silica is decomposed at a red heat by carbon in presence of iron and at white heat by carbon monoxide, CO, a metallic silicide being formed.

Silica plays a very important part in the formation of slags, and fusion is not necessarily required to produce combination. Thus, when certain mixtures of silica and lime are strongly heated, there is not the slightest indication of fusion, yet it is certain that the silica has entered into combination. The bases which most frequently occur in slags are lime, magnesia, protoxide of iron, potash in small quantity, and alumina.

Silica is an abundant element in the ashes of straw, as shown in the following:

	Per Cent.
Potassa	10.51
Soda	1.03
Lime	5.91
Magnesia	1.25
Sesquioxide of iron	0.07
Sulphuric acid	2.14
Silica	73.57
Phosphoric acid	5.51
Total	99.99

Q. How is potash present in ashes?

Potash occurring in ashes is in various states of combination, as carbonate, sulphate, and as chloride of potash. The percentage of potash is much greater in wood than in coal ashes. The following table (12) shows, according to Höss, the proportions of ash and potash in some of the leading woods:

TABLE 12.—POTASH CONTAINED IN ASHES OF SEVERAL WOODS.

Wood.	Ash Per Cent.	Potash Per Cent.
Pine	.34	.045
Beech	.58	.127
Ash	1.22	.074
Oak	1.35	.150
Elm	2.55	.390
Willow	2.80	.285

Pure, dry carbonate of potash is a hard, white solid, specific gravity of 2.207, having a strong alkaline reaction and taste. It melts at a full red heat, and at a higher temperature slowly volatilizes.

The following, from Berthier's original analysis, shows the composition of pine-tree ash:

	Per Cent.
Solution in water:	
Carbonate of potash	1.86
Sulphate of potash	3.63
Chloride of potash	1.88
Carbonate of soda	6.03
Silica	.18
Insoluble in water:	
Lime	38.51
Magnesia	9.56
Oxide of iron	.09
Oxide of manganese	.36
Carbonic acid	32.77
Phosphoric acid	.91
Silicic acid	4.19
	99.97

Q. How is lime present in ashes?

Lime occurring in ashes is a product of one of the carbonates present in the coal, in which its contained carbonic acid is driven off by heat, leaving a white or pale gray substance, acrid and caustic to the taste, and exhibits a powerful alkaline reaction. Lime heated by itself is one of the most refractory substances known, and no temperature has as yet been attained which has caused it to exhibit the slightest indication of fusion; but lime promotes the fusion of some other oxides in a remarkable manner, and hence it is used as a flux. Carbonate of lime is an essential ingredient in all fertile soils, and occurs in every kind of rock.

Q. How do the substances which form clinker affect the efficiencies of coals?

The several substances, silica, lime, potash, etc., occurring in coal ashes are variable in their nature; and thus by the forms they take under different intensities of combustion much affect the efficiencies of the coals to which they belong. Being differently fusible themselves, and affecting differently the fusion of each other, no two of the earths, alkalies, or metallic oxides of the ashes but differ in their agency when subjected to an elevated heat; and their mutual reactions are moreover changed, as the temperatures are changed to which they are exposed. It hence arises that the residue from many coals melts to a large extent, under no very intense combustion, into various descriptions of hard, semi-vitreous slags; others yield a less stony clinker; and some again at a far more elevated heat result only in a partially agglutinated, spongy, open cinder, or even in a pulverulent or flaky ash.

Q. What quantity of ash is present after the complete combustion of coal?

The percentage of ash varies considerably for different coals, but it is generally less in anthracite than in the bituminous varieties. Taking hard and soft coals as a whole, the average quantity of ash will lie between five and ten per cent, with occasional variations on either side.

Q. What is smoke?

Smoke is a general term often applied to all the products of combustion escaping from the furnace, whether visible or invisible. In a more restricted application it denotes the sooty products of the furnace escaping with the waste gases. These sooty particles are solid carbon, and usually very light and small. So far as mere weight is concerned, the blackest smoke is not perceptibly heavier than if the products of combustion were transparent. The objection to black smoke, as such, is not the actual loss in weight of carbon. It is rather that in cities and towns these sooty particles find their way through the ordinary currents of air into business places, dwellings, etc., the sooty deposit being practically constant in the neighborhood of such a chimney, causing much annoyance to housekeepers, merchants, and others. Colored smoke is a product of incomplete combustion.

Q. Is colored smoke then no indication of waste in furnace combustion?

Colored smoke is sure evidence of wasteful combustion, because it indicates a low temperature of furnace. Anthracite coal and coke give off no sooty particles when burning. In the case of bituminous coal the first effect of the heat is to detach small particles of carbon from the surfaces next the incandescent fuel on the grate. These particles are so light that they are easily carried out of the furnace and up the chimney by the mechanical agency of the draft. If the furnace temperature was sufficiently high, and there was enough free oxygen over the bed of fuel to burn these soot particles, they would be converted into carbonic-acid gas and become wholly invisible. Black smoke is not a product of a high, but always that of a low furnace temperature.

Q. How may smoke prevention be accomplished?

Bituminous coals, rich in hydrocarbons, require a furnace of much greater cubic content to render their combustion complete and wholly smokeless, than is required for anthracite coal or coke. The combustion chamber for bituminous coal ought always to be large and roomy. The temperature must always be high. Provision must be made for a controlled air admission above the fuel to supply the additional oxygen required for the conversion of the carbonic oxide into carbonic-acid gas. The fuel should be free from large lumps, and either frequently or continuously fed to the furnace.

In admitting air above the fuel, unless it can be supplied at the right place and time, and in the right quantity, it may prove a worse evil than the smoke itself, by lowering the temperature of the gases in the furnace to a point below which ignition is insured.

In an ordinary boiler furnace, with flat grates, a nearly smokeless fire can be maintained by breaking up the coal and banking it immediately inside the fire door, that the gases may distill from the coal slowly. These gases passing over the bed of incandescent coke, through which an excess of air is passing, will burn the volatile combustible of the coal smokelessly. When the fuel is well coked, it can be broken up, distributed over the grates, and a fresh supply of raw coal banked up as before.

Q. What rule is there for measuring the shades of intensity of smoke?

In any thorough study of smoke a scale of intensity is very important. As to the number of shades of intensity it has been proposed variously from three to ten. The latter was adopted by the South Kensington and Manchester Smoke Abatement Commissions (1881), and upon trial was found to be quite undesirable, as it was difficult to discriminate between so many slightly differing shades. The second English Smoke Commission, in 1895, adopted a scale of only three shades—faint, medium, and black; but three shades were found to be too few, as ten were found to be too many.

The best scale to adopt, according to the view now held by most of the authorities, seems to be one having five shades, viz.:

1. White transparent vapor.
2. Light brown smoke.
3. Brownish-gray smoke.
4. Dense smoke.
5. Thick black smoke.

The determining of the different shades is largely empirical, the shade varying with each observer according to his sight and sense of color.

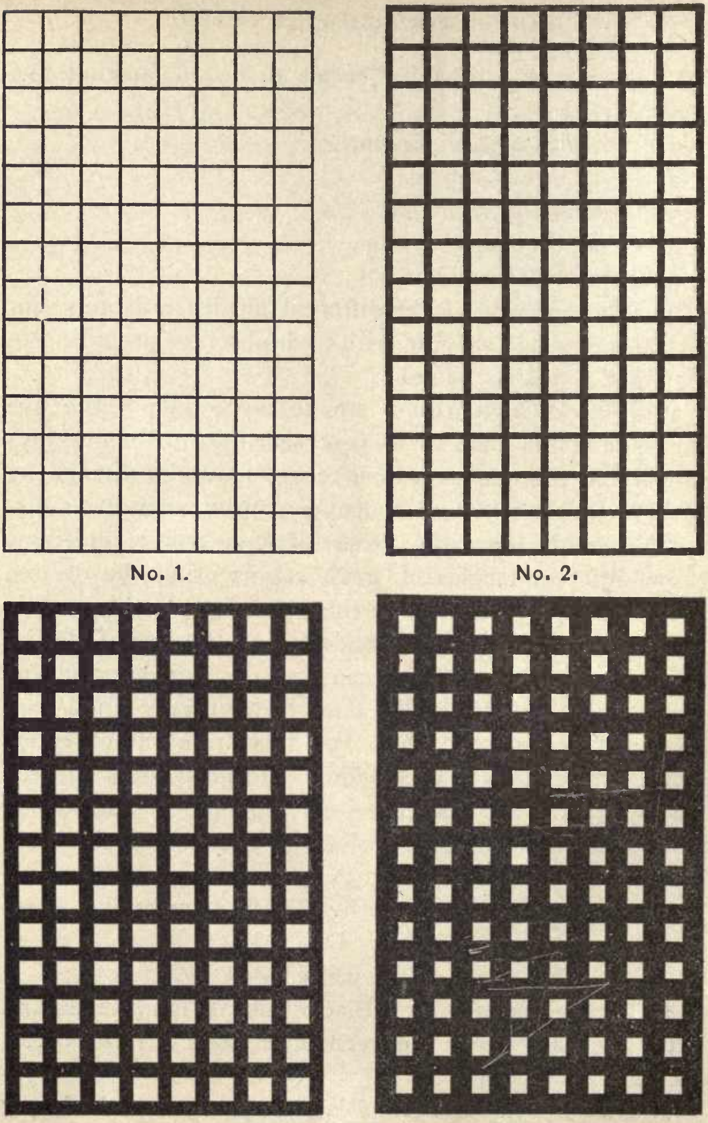
Professor Ringlemann's smoke scale adopts the five shades, and his plan is to represent the different grays into which the shades of smoke are naturally divided by black cross lines on white paper. Seen at a given distance from the observer, these black and white diagrams show different shades of gray, representing the desired smoke tints. Variations in the shade can be obtained by varying the thickness of black lines or the size of the interstices of white left between them. A given cross line arrangement will represent one shade of gray when seen at a distance, say, of 80 to 100 feet from the observer, while if the black lines be doubled in thickness and the white intervals between them correspondingly diminished by half, another and darker shade of gray will at the same distance be shown (see Fig. 3).

The principles on which the Ringlemann smoke scales are designed are as follows:

No. 0. No smoke. All white.

1. Light gray smoke. Black lines 1 mm. thick, and white spaces of 9 mm. between, all crossed at right angles like a chess board.

2. Darker gray smoke. Black lines 2.3 mm. thick, 7.7 mm. apart.



No. 1. No. 2.

No. 3. No. 4.

FIG. 3.—Professor Ringlemann's Smoke Chart.

3. Very dark gray smoke. Black lines 3.7 mm. thick, 6.3 mm. apart.

4. Black smoke. Black lines 5.5 mm. thick, 4.5 mm. apart.

5. Very black smoke. All black.

This is probably the best smoke scale yet produced. It is in use in portions of England, France, and in the United States.

Q. Can soft coal be burned without smoke in ordinary locomotive fire boxes?

That railway smoke nuisance can be almost, if not wholly, abated, by simply exercising proper care and judgment in firing, is the expressed opinion of Mr. Angus Sinclair, an engineer of wide experience and excellent judgment. His recommendations, based upon actual practice, consist merely in reducing the coal to small sizes, no large lumps, and firing in what is known as the single-shovelful method.

The practical working of this method of firing has shown, according to the records of the Burlington, Cedar Rapids & Northern Railway, that bituminous coal burning locomotives, without any specially contrived fire box or fixtures (except the ordinary brick arch), can be operated in any service from yard switching to heavy freight trains, quite as smokeless as if anthracite coal were used. This method of firing now permits passenger trains to be run comfortably over that road with the windows open. Further, an economy of about one-sixth of the money formerly paid for coal is now saved to the company; the engines steam much more freely than under the old method of heavy intermittent firing; the annoyance of leaky tubes has almost ceased; there is no filling up of smoke boxes with cinders; and there has been a decided reduction in the work of the boiler-maker; and last, but not least, the fireman has less work of coal-throwing to do, and he and the engineer are acting together to produce satisfactory results.

Q. What results have been accomplished on the Cincinnati, New Orleans & Texas Pacific Railway in smokeless firing with bituminous coal?

Mr. J. W. Murphy, superintendent of the above road, says there is no detail in connection with the operation of the road to which the management gives so much special and continued attention as in the efforts to prevent the emission of black smoke by locomotives on passenger trains.

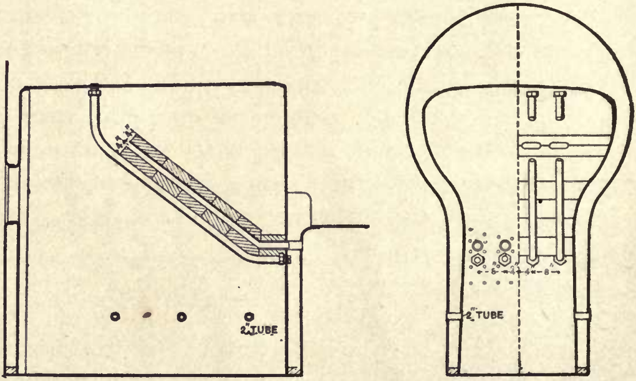


FIG. 4.

To secure these results, it was necessary, first, to equip the engines with brick arches, as indicated in Fig. 4. Four holes are shown on each side of the fire box for the purpose of admitting air. Four tubes run through the arch, and the outside air, passing through these tubes, is heated to a high temperature. This heated air supplies oxygen to the unconsumed gases and produces complete combustion. The four holes in each side of the fire box are located twelve inches above the grates, and into these openings are inserted the Sharp patent deflecting air tubes, deflecting the air to the fire.

Q. What instructions were issued to engineers for firing passenger locomotives on the "Queen and Crescent Limited," Cin., N. O. & T. P. Ry.?

After firing each shovelful of coal, the door must be left open one or two inches for a few seconds, admitting enough air to produce complete combustion of the gases driven off from the coal. Care must be taken not to leave the door open longer than necessary to consume the gases.

Firemen must learn to work with as light a fire as possible. Great care must be taken that steam is not wasted at the safety valve, either when the train is in motion or when standing still.

Before starting, the blower must be put on and a sufficient supply of coal put into the fire box to insure a good solid fire. After the coal has been put in, the door must be left partly open by placing the latch on the first notch of the catch, so to remain until the smoke entirely disappears, when the door must be closed.

After starting the door must be left partly open after each shovelful of coal is put into the fire box, by placing the latch on the first notch of the catch until such time as the smoke disappears, when the door must be closed.

On approaching tunnels the fire must be replenished in ample time, obtaining sufficient fire to carry the train through the tunnel without smoke, the door to be kept closed while passing through tunnels.

The engineman should so arrange the water supply that the fireman may be able to fire the engine regularly and economically, and this can be done best when the water is supplied to the boiler continuously.

Firemen must pay particular attention to the manner in which the engineman works the injector and handles the engine, in order to regulate the fire accordingly.

Care must be taken to have the blower applied and the door partly open when approaching a station where a stop is to be made, and no smoke must be allowed to show from the stack at such times or when descending grades.

While the blower is being used, except when approaching a station where a stop is to be made, care should be taken to keep the door closed as much as possible, more especially when cleaning the fire, as the blower causes the cold air to be drawn into the flues.

While lying on side tracks, both dampers should be closed to save the fire.

Grates should be shaken only when absolutely necessary, as too frequent shaking causes a loss of fuel by allowing the unconsumed coal to fall into the ashpan, where it ignites and causes the pan to heat and warp. Ashpans should be examined as frequently as stops will permit, and under no circumstances must they be allowed to become filled.

When possible to avoid it, the fire box must not be left wide open. To leave the fire door wide open is especially bad when using steam or blower.

It is beneficial to wet the coal before firing, and firemen should, as far as possible, use wet coal.

Intelligent firing and economical results in the use of fuel will be considered in the selection of firemen for passenger engines or for promotion to freight enginemen.

These rules must be strictly observed on night as well as on day passenger trains.

Q. How may smokeless combustion be best secured in locomotive practice?

The best examples of smokeless firing occur in locomotives using no device but the brick arch in connection with careful firing. A general sentiment, based upon experience on Western railroads, where soft coal only is used for fuel, is that a good fireman without a special device is productive of better results than any of the mechanical devices if poorly managed. The conclusion reached in Chicago, St. Louis, and other Western cities where efforts have been made to reduce the amount of smoke made by locomotives, is that steam jets and other similar devices are not to be seriously considered as successful smoke preventives; and, second, the most effectual method of preventing smoke is by the use of the brick arch and skilful firing.

Q. What is the device for smoke prevention by the Locomotive Smoke Preventer Company?

This device as applied to a locomotive is shown in Fig. 5, and further illustrated in detail in Fig. 6, which shows the heating coil in the smoke-box extension; Fig. 6a, which is another view of the heating coil; Fig. 7, which shows plan arrangement of the manifold, a group of three jets passing through the front end of the fire box; Fig. 8, an enlarged section of the combined steam and air jet, and the seamless water jacket. The elevation of a locomotive (Fig. 5) shows the entire device when applied; it consists of a funnel-shaped pipe A, which is attached to the smoke box at B; this pipe continues to one end of a

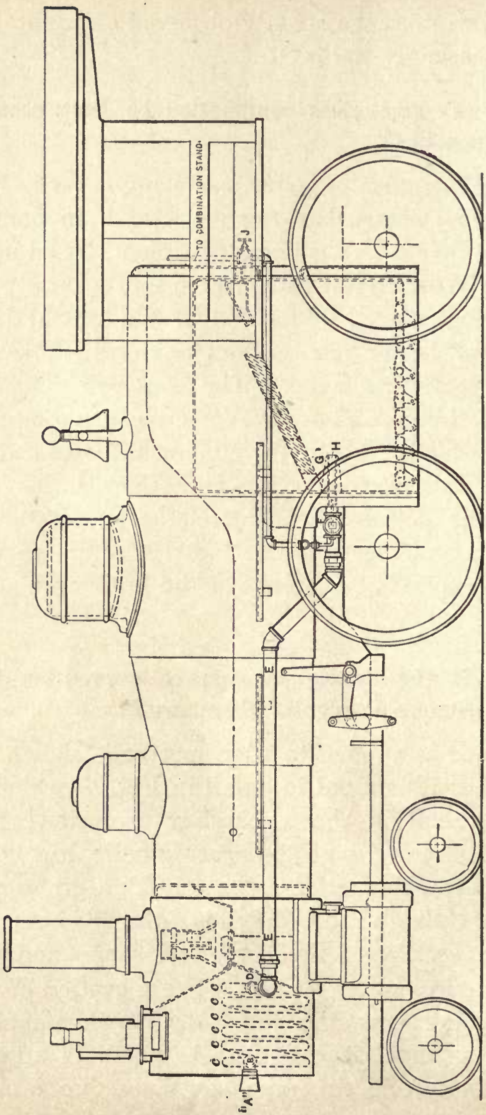


FIG. 5.

series of bends or coils of pipe called the heater C, whose axis is parallel with the axis of the boiler shell—

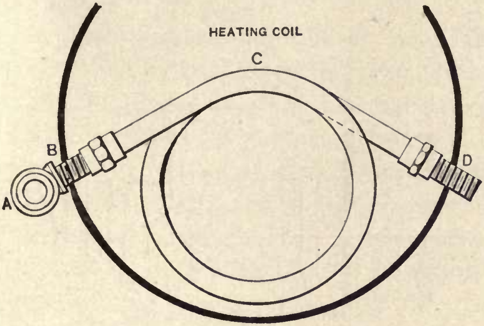


FIG. 6.

FIG. 6a.

the other end being attached to a pipe which leaves the smoke box at D on the opposite side from A. By means of an elbow it connects to the pipe E extending along the side of the boiler close under the running boards back to a

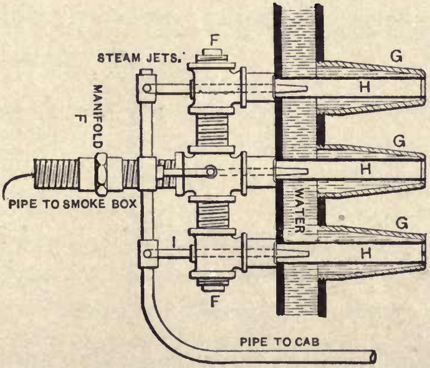


FIG. 7.

point in front of the throat sheet—where by 45° elbows it passes under the barrel and enters at the centre of the manifold F placed in front and close to the throat sheet. The three or more openings in the manifold exactly tally with the air ducts leading into the fire box. In the inside of the fire box at the tube sheet and close to the under side of the fire-brick arch are three or more cylindrical tapered water-jackets, G, G, which screw into the tube sheet and extend into the fire box a distance of about twelve or fourteen inches, their interior being open direct to the water leg of the boiler; concentric with the jacket and extending from the throat sheet through the water leg and jacket is the air tube H referred to above, its ends being expanded and beaded into the sheet and jacket respectively. It will thus be seen that we have a contin-

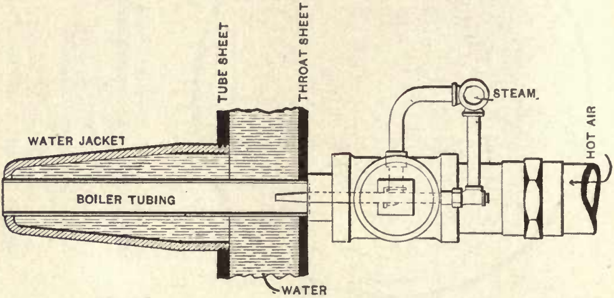


FIG. 8.

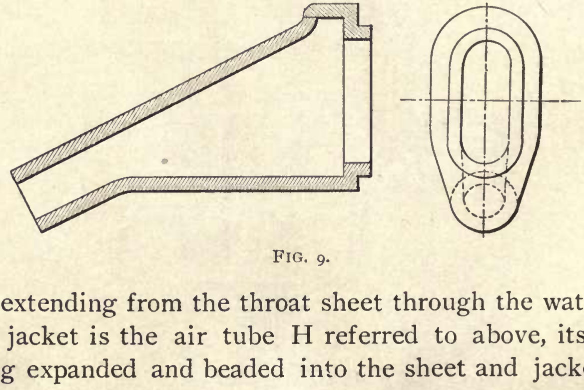


FIG. 9.

uous air passage from the air funnel at the front of the engine through the hot smoke box to the fire zone in the fire box.

A side elevation and plan of manifold F, together with the method of attaching the steam jets, is shown in Figs. 7 and 8. The manifold is tapped for a one-fourth inch pipe terminating in an one-eighth inch opening in the air tube H. The flow of steam through it is controlled by a valve J in the cab. The special function of this jet is to force hot air into the fire box when the engine is at rest, or when running with the throttle shut. When an application of coal is made, it is met by a large volume of air heated to the point of ignition by previous contact with the incandescent fire-brick arch, thus furnishing oxygen where it is most needed to produce smokeless combustion.

The door sheet nozzles shown in Fig. 9 are used on engines having long fire boxes and a comparatively short fire-brick arch.

Q. What is the objection to a combined steam and air jet in a locomotive furnace?

Steam jets which introduce both steam and air above the fire have a temporary dampening effect when the engine is standing, as they produce a pressure on the fire box equal to the draft, and the current of gas and smoke through the stack is stopped. In other words, smoke is prevented because combustion has almost ceased. When the engine is working, the effect of the steam jets is very slight. The steam is condensed by contact with cold air, and it enters the fire box as moisture, and its effect must be to lower the temperature of the gases, and it does not support combustion. The air which is drawn in is also cool, and there is no real combination with the gases until it is heated up to their temperature. From any point of view, according to the committee of the Western Railway Club on smoke prevention, the steam and air jet cannot be considered as a promising device from which any successful smoke preventer may be evolved, and the committee believe it to be important that this fact be emphasized for two reasons: first, because valuable time has been wasted already in continued and unsuccessful experiments with steam jets; and second, because their presence on the engine and occasional use have the effect of relieving both master mechanic and engineman of responsibility to a certain extent. If the steam jet is given up as hopeless, then more attention and effort will be directed toward better proportions of fire box and other features in the original construction of the locomotive.

Q. What is an econometer?

The econometer, designed by Max Arndt, and shown in Fig. 10, is a gas-weighing machine on an entirely new principle, fixed in an air-tight case 7 with a plate of glass in front. In the case 7 there are two connecting joints, 39 and 40, 40 is connected by a 3/8″ pipe to the flue of the boiler about two feet from the damper, and 39 is connected by a $\frac{3}{8}$″ pipe to an aspirator in the main flue between the damper and the chimney, or the chimney itself, and which constantly draws a sample of the gases from the boiler flue through filters, gas pipes, and balance, discharging it into the chimney. In the interior of the econometer case 7, the joint 40 is connected with the ascending pipe 23, and the joint 39 with the descending pipe 22 by means of India rubber tubes 34 and 35.

The gas-weighing machine itself consists of a very finely adjusted, highly sensitive balance, to which is fixed the pointer or index 17. On one end of the balance is suspended an open glass globe 18, with a capacity of about a pint, and on the opposite end a compensating rod 32, to which is affixed a scale pan with a number of glass beads and filings by which the gas holder can be balanced. The

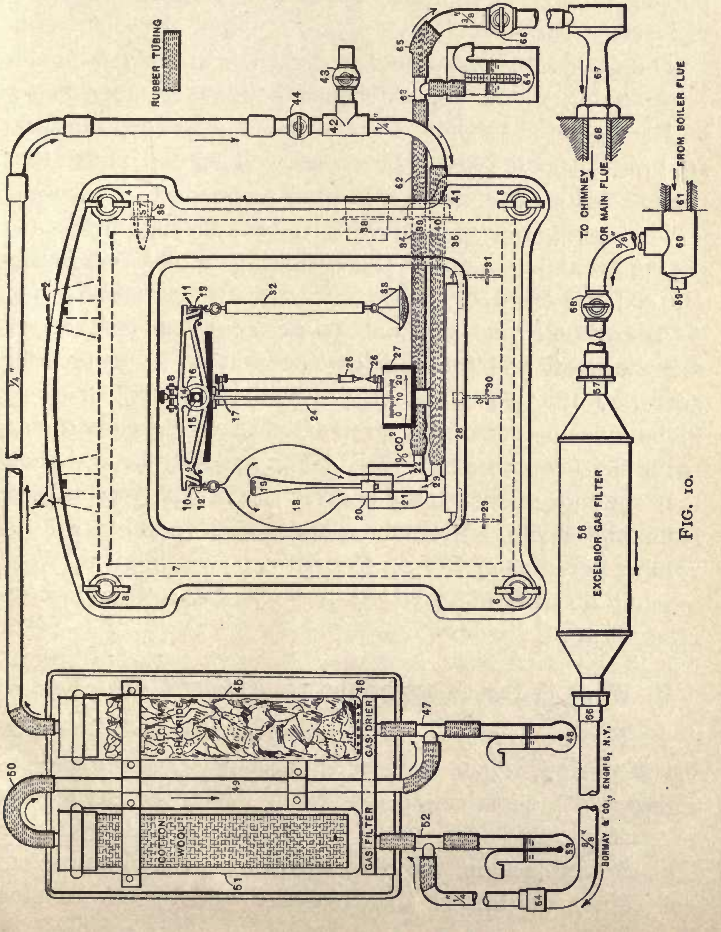


FIG. 10.

knife-edges of the balance are steel gilded, and the caps are agate. The whole balance works on a pillar screwed on a cast plate 28. The latter has adjusting screws by which the balance is set, both horizontally and vertically. For this purpose a small pendulum is attached to the supporting pillar. A frame 27 is fixed on the pillar in which is inserted the scale.

The gas-ascending pipe 23 reaches into the gas holder or weighing globe 18, which has a neck 20 open below and surrounded by cup 21 open above. The neck 20 has free play around glass tube 19, as well as cup 21, so that the gas holder can swing free from resistance.

The combustion gases, having to pass through filters and drying chambers, enter the weighing globe thoroughly cleaned and dried.

As carbonic acid is about 50 per cent heavier than atmospheric air and the other gases contained in combustion gases, so the gases which continually fill the weighing globe must be heavier in proportion to the amount of carbonic acid contained therein. The scale 27 is so divided that the movement of the pointer 17 of the gas balance from one dividing line to another corresponds with the volume per cent of CO_2 in the gases to be weighed. The amount of carbonic acid in the gases can therefore be read off at all times.

Q. What is the object of the econometer?

In Europe, where coal economy has received the greatest attention, it has long been the custom to provide engineers with chemical apparatus, by which the percentage of carbonic-acid gas could be determined at intervals. This determination, though irregular, proved of the greatest value, and led to the invention of the econometer, which indicates continuously the exact percentage of carbonic acid contained in the escaping products of combustion. The value of having a continuous indication, rather than one obtained at infrequent intervals, can hardly be overestimated, for a constant guide to firing is thus obtained.

In order to produce combustion, carbon, the vital element in the coal, must unite with oxygen, which it does in certain unvarying proportions. In the first stage of combustion, one part of carbon unites with one part of oxygen, forming a combustible gas, known as carbon monoxide, and in this process about one-fourth of the heat is liberated. In the second stage, the carbon monoxide absorbs another part of oxygen, forming a gas known as carbon dioxide or carbonic acid, and in this process the balance of the heat is liberated.* As there is twenty-one per cent of oxygen in the air that is conveyed to the carbon, it is easily seen that perfect combustion would produce twenty-one per cent of carbonic acid, since all of the oxygen would unite with all of the carbon and every heat unit contained in the coal would be liberated.

It is next to impossible to obtain perfect combustion in any steam-boiler furnace for many reasons, but it is possible to obtain and maintain good combustion, with proper firing and correct manipulation of the draughts and dampers. It is easy to see that the only test to be applied is that of determining the percentage of carbonic acid present in the escaping gases, and that the value received from the burning of all coal is in exact proportion to this percentage of gas. Chemistry has determined these

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* This is from Arndt's point of view. The generally accepted theory is that CO_2 is first formed, which passing up through the bed of incandescent fuel takes up another equivalent of carbon, resulting in CO.—ED.

values, so that when the per cent of carbonic acid is known, the value received from the burning of any coal can be ascertained. Table 13 shows the relative values, from which the difference between burning coal properly and improperly can be ascertained at a glance.

Q. How are the econometer percentages of carbonic-acid gas affected by excessive air supply?

Carbonic acid is fifty per cent heavier than air, and thus the greater the percentage contained in any given volume of flue gases the greater the weight of that volume. In the econometer, a sample of the escaping gas from the boiler is drawn continuously through a balance scale, suspended in air, and the variations in weight that are produced by the different states of combustion are made to record the percentage of carbonic acid. The weight of this gas varies with the temperature, but in the econometer, the sample to be weighed, and the air in which the weighing is done, assume the temperature of the room, so that the proportion remains exact.

It is plainly evident that for each pound of coal a fixed amount of air is necessary for combustion, varying as the percentage of carbon varies in the different coals. For a pound of average quality, about one hundred and twenty-five cubic feet of air is necessary, and it is the inability to convey this precise amount to the furnace that prevents our obtaining and maintaining perfect combustion.

If too little air is admitted, combustion becomes imperfect because the carbon monoxide cannot find the necessary oxygen to complete its transformation into carbon dioxide, and this is the most wasteful condition of firing, for the largest part of the heat is given off in the second

TABLE 13.—SHOWING LOSS OF FUEL WITH FROM 2 TO 15 PER CENT. CARBONIC ACID IN THE COMBUSTION GASES.

The proportion of air actually used to the amount required is, in the case of coal combustion (according to Bunte), $\frac{18.9}{K}$, *K being the amount per cent of carbonic acid in the gases.*

For coal of average quality.	If the Econometer shows..........	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Per cent carbonic acid.
	Then the quantity of air passing through the flues is..	9.5	6.3	4.7	3.8	3.2	2.7	2.4	2.1	1.9	1.7	1.6	1.5	1.4	1.3	Times the theoretical requirements.
	With a surplus supply of air of 30 per cent or about 166 cubic feet of necessary air per pound of fuel, there will still be a further excess of about........	1977.6	1212.5	960.5	606.3	536.8	395.5	310.8	197.8	169.5	113	84.8	56.5	28.3	0.0	Cubic feet of superflous air heatedto a temperature of usually 518° Fahr.
	And the loss of fuel at 518° Fahr. amounts to......	90	60	45	36	30	26	23	20	18	16	15	14	13	12	Per cent.

stage of combustion.* This case is seldom met with in practice, for most boiler furnaces are supplied with too much air. Then the combustion is poor because there is a large amount of air passing through the fire, the oxygen of which cannot be consumed. This surplus air must be heated to the same temperature as the escaping gases, thereby absorbing the heat already generated, which should pass instead into the water contained in the boiler.

Q. In what manner may loss of fuel through imperfect furnace detail or management be detected by the econometer?

Loss of fuel calculated and shown in Table 13 can be caused in a variety of ways, and is to be sought for in all of the accessories of the furnace. It may result from an excessive or defective draft, from faulty grates or wrong proportion of grate surface, there may be defects in the boiler setting or in the fire and ash-pit doors, that should be remedied. The proper thickness of fire is something that must be determined, varying as it does with the many different conditions surrounding all steam plants.

By first obtaining the percentage of carbonic acid in the gases produced with ordinary firing and then experimenting with the boiler in connection with the econometer, any fireman can soon ascertain the proper thickness of fire and draft necessary to insure good combustion. If with a high percentage of carbonic acid the gauges should show too much steam, a case often experienced in practice, it is evident that the grate surface should be reduced, which can be done by bricking up at the back end of the ashpit, or at the back end or sides of grates over the bars.

A very common source of waste is the formation of

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* See foot note on page 135.

holes in the fire, and of the presence of these, the econometer is a never-failing indicator. By drawing samples of gas from the entrance and exit of the flues, and comparing the percentage of carbonic acid, any existing defects in the setting and brickwork will be discovered.

CHAPTER VI.

HEAT DEVELOPED BY COMBUSTION.

Q. What is heat?

In steam engineering heat is regarded from the dynamical or mechanical theory only, on the supposition that heat and mechanical force are convertible one into the other. From the great number of experiments in the generation of heat by mechanical processes, by friction, by the arrest of motion, either gradually or by percussion, by the change in the quantity of heat observed in the case of expansion, etc., has led investigators to the conclusion that heat is simply a motion of ultimate particles, and that the molecular structure of bodies has much to do with their capacities for heat; and an increase or decrease of temperature is simply an increase or decrease of molecular motion.

Q. What numerical value, in heat units, should be used in estimating the calorific power of carbon in connection with coal analysis?

Carefully conducted experiments by the earlier as well as the more recent investigators have yielded practically the same results. Three numerical values for carbon are in common use, viz., 14,544, 14,540, 14,500 heat units. These are so nearly alike as to cause no confusion, and practically no error in any calculations relating to the calorific value of fuel. The latter is the one in very general use.

In the examples given in this book the writer has followed as nearly as possible the numerical values given by investigators, those used in geological reports, and in any correspondence relating to the coal then under consideration.

Q. What quantity of heat is generated by the conversion of carbonic oxide, CO, into carbonic-acid gas, CO_2?

Calorimeter tests show that one pound of carbonic oxide burnt to carbonic-acid gas develops 4,325 heat units.

It will be seen that a loss of heat occurs even though all the carbonic oxide in the furnace be converted into carbonic-acid gas, because the chemical union which produces the latter gas yields 14,500 heat units, whereas burning carbon to carbonic oxide yields only 4,450 heat units, and the burning of CO into CO_2 yields 4,325 heat units, or a total of 8,775 heat units. This is 5,725 heat units per pound less than the direct conversion of carbon into carbonic-acid gas, a loss of 39 per cent.

Q. Can the loss of heat occasioned by burning carbon to carbonic oxide, CO, be recovered by its subsequent conversion into carbonic-acid gas, CO_2, before it leaves the furnace?

The burning of carbonic oxide, CO, in the combustion chamber above the fire is a wholly distinct operation from the combustion of the coal on the grates, one result of which is the formation of the CO.

There are two methods by which this conversion from CO to CO_2 may be accomplished: first, by the admission of surplus air through the bed of incandescent fuel; second, by the admission of air through perforations in the lining of the fire door, through the side walls of the furnace, through a perforated pipe in the furnace, through perforations in or adjoining the bridge wall. All of the above connect in some manner with the atmosphere. Shortening the grates so as to leave a space at the end to allow passage of air between the grates and the bridge wall. All of these methods have been tried with more or less success depending upon local conditions.

Q. Upon what is the temperature of fire conditioned?

The temperature of combustion is conditioned upon the nature of the fuel burned; the nature of the products of combustion; the quantity of the products of combustion; the specific heat of the gases present in the furnace resulting from combustion, including the quantity of air present at the moment of combustion in order to render it complete.

Q. How may the temperature of the combustion of carbon be estimated?

In the complete combustion of one pound of carbon we have:

Carbon	1
Oxygen	2.67
	3.67

pounds of carbonic-acid gas.

In addition thereto we have 8.94 pounds of nitrogen left after the separation of the oxygen from the atmospheric air.

The specific heat of carbonic-acid gas is 0.216, and that of nitrogen 0.244. We have then:

Products.	Pounds.	Specific heat.	Heat units.
Carbonic-acid gas	3.67 ×	.216 =	.794
Nitrogen	8.94 ×	.244 =	2.181
Total			2.975

heat units absorbed in raising the temperature of the products of combustion of one pound of carbon, 1° F.

The combined weight of the two products are 3.67 + 8.94 = 12.61 pounds. Then: $\frac{\text{Heat units } 2.975}{\text{Pounds } \quad 12.61} = 0.236$, their mean specific heat.

The total heat of the combustion of one pound of carbon in oxygen gas is 14,544 heat units; divide this by the 2.975 heat units absorbed, we have: $\frac{14,544}{2.975} = 4889°$ F. as the highest theoretical temperature attainable by the complete combustion of one pound of carbon, using 11.61 pounds of air per pound of carbon, the minimum theoretical limit.

Example 2. Suppose that eighteen pounds of air are used instead of the theoretical quantity given above, and that the combustion is complete, we then have

Carbon	1
Oxygen	2.67
Nitrogen	8.94
Surplus air	6.39
	19.00

pounds of furnace products.

The specific heat of air is 0.237, proceeding as before:

Products.	Pounds.	Specific heat.	Heat units.
Carbonic-acid gas	3.67 ×	.216 =	.794
Nitrogen	8.94 ×	.244 =	2.181
Air, uncombined	6.39 ×	.237 =	1.519
Totals	19.00		4.494

Then: $\frac{4.494}{19} = 0.237$, the mean specific heat. $\frac{14,544}{4.494} =$ 3236° F., the temperature of the fire under the above conditions. It will be noted that a reduction of 1653° F.

occurs through the admission of 50 per cent more air than was needed for combustion. Had double the quantity of air passed through the fire, the temperature would be about 2450° F.

TABLE 14.—WEIGHT AND SPECIFIC HEAT OF THE PRODUCTS OF COMBUSTION, AND THE TEMPERATURE OF COMBUSTION.

(From D. K. Clark's Rules, Tables, and Data.)

One pound of combustible.	GASEOUS PRODUCTS FOR ONE POUND OF COMBUSTIBLE.				
	Weight.	Mean specific heat.	Heat to raise temperature 1° F.	Temperature of combustion.	
	Pounds.	Water = 1.	Units.	Deg. F.	Ratio.
Hydrogen	35.8	.302	10.814	5744	100
Olefiant gas	15.9	.257	4.089	5219	91
Coal (average)	11.94	.246	2.935	4879	85
Carbon, or pure coke	12.6	.236	2.973	4877	85
Alcohol	10.09	.270	2.680	4825	84
Light carburetted hydrogen	18.4	.268	4.933	4766	83
Sulphur	5.35	.211	1.128	3575	62
Coal, with double supply of air.	22.64	.242	5.478	2614	45

Q. How may the quantity of heat developed by combustion be determined?

The heat developed by chemical action or combustion is best determined by the use of an apparatus known as a calorimeter, by means of which a combustible is burnt in oxygen gas, the heat liberated by combustion being absorbed by the water which surrounds the combustion chamber. The weight of combustible, the oxygen, and the water being known, the quantity of heat evolved by the combustion of each substance can easily be calculated by the rise in temperature of the water.

The apparatus used by Favre and Silberman for measuring the heat evolved by the combustion of various substances in oxygen gas is represented, with the omission of minor details, in Fig. 11, in which C is a vessel of gilt brass plate, immersed in a water calorimeter, A A, of silvered copper plate, and the latter is enclosed in an outer vessel, B B, the space between A and B being filled with swandown to prevent the escape of heat from the water A. The vessels A and B are closed with lids having apertures for the insertion of tubes and thermometers. The combustions are performed in the vessel C, into which oxygen is introduced through the tube *c d*, and the gaseous products of the combustion escape by the tube, *e f g h*, the lower part of which is bent in numerous coils, to facilitate as much as possible the transmission of the heat of these gases to the water in the calorimeter. The extremity, *h*, of this tube is connected with a gasometer or with an absorbing apparatus. To insure uniformity of temperature in the water, a flat ring of metal, *i i*, is moved up and down by means of the rod *Ki*. Combustible gases were introduced into the vessel *C*, by means of fine tubes, the gas being previously set on fire at the aperture. Solid bodies were attached to fine platinum wires suspended from the lid of the calorimeter. The liquids were burned in small capsules or in lamps with asbestos wicks. Charcoal was disposed in a layer on a sieve-formed bottom, through the openings of which the

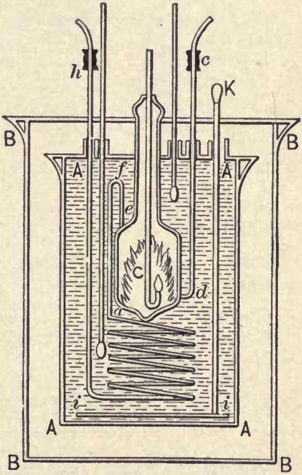


FIG. 11.

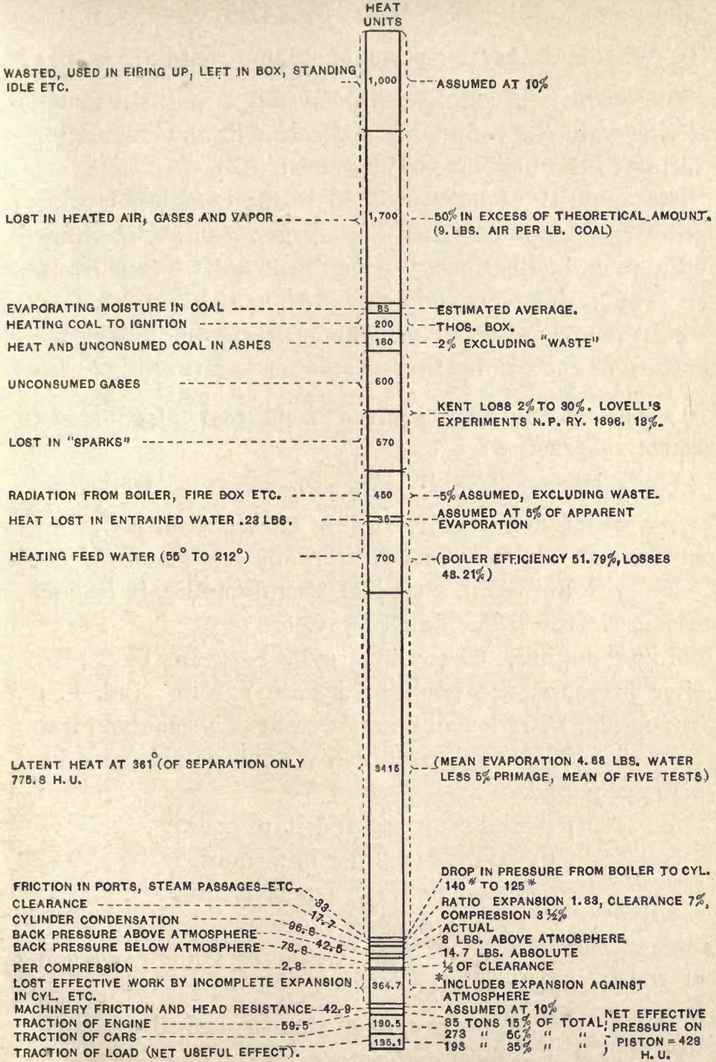
oxygen had access to it. The heat evolved was measured by the rise of temperature of the known quantity of water in the calorimeter.

TABLE 15.—QUANTITIES OF HEAT EVOLVED BY THE COMBUSTION OF ONE POUND OF COMBUSTIBLE WITH OXYGEN. (Favre and Silberman).

Substances.	Formula.	Product.	British thermal units.
Gases:			
Hydrogen	H	H_2O	62,032
Carbonic oxide	CO	CO_2	4,325
Marsh gas	CH_4	CO_2 and H_2O	23,513
Olefiant gas	C_2H_4	CO_2 and H_2O	21,343
Liquids:			
Oil of turpentine,	$C_{10}H_{16}$	CO_2 and H_2O	19,533
Alcohol	C_2H_6O	CO_2 and H_2O	12,931
Spermaceti (solid)	$C_{32}H_{64}O_2$	CO_2 and H_2O	18,616
Sulphate of carbon	CS_2	CO_2 and SO_2	6,122
Solids:			
Carbon (wood charcoal)	C	CO	4,451
		CO_2	14,544
Gas coke			14,485
Graphite from blast furnaces			13,972
Native graphite			14,035
Sulphur (native)	S	SO_2	4,048
Phosphorus (by Andrews)	P	P_2O_5	10,715

Q. What are the relations between quantity of heat and temperature developed in combustion?

The actual amount of heat given out during the complete oxidation of any substance is the same whether the combination is slow or rapid, and is carried on in air or in oxygen. But it is quite different in regard to the temperature developed, this depending on the concentration of the heat; and so being higher, the more rapid the combustion and the less extraneous matter is present to absorb the heat. The temperature of a hydrogen or a coal-gas flame burning in oxygen is very much higher than that of a similar flame burning in air.



* This item includes errors of assumption as follows: That expansion is hyperbolic, that latent heat of separation is a constant at all temperatures, and that no latent heat (of separation) is transformed into work. The net error probably does not exceed 25 h. u.

Where the Coal Goes When Burned in a Locomotive Firebox.

FIG. 12.

Q. What is the heating power of sulphur contained in coal?

The quantity of sulphur in good coal is so small that its calorific value is commonly neglected in any calculations relating to the heating power of coal.

The quantity of heat evolved in the complete combustion of one pound of sulphur in oxygen gas, as determined by Favre and Silberman, is 4,048 heat units. The equivalent evaporation from and at 212° F. would be $4048 \div 966 = 4.19$ pounds of water per pound of sulphur. The temperature of the combustion of sulphur is about 3575° F.

Q. How is the heat evolved from coal distributed in locomotive practice?

The accompanying diagram (Fig. 12), by E. H. McHenry, chief engineer Northern Pacific Railway, shows heat losses and net effective work of one pound of Red Lodge coal burned in a typical Mogul engine, in ordinary service, Northern Pacific Railway.

Mogul engine; Class D2; cyl., $18\frac{1}{8}$ in. by 24 in.; boiler pressure, 140 pounds; cut off, $12\frac{3}{8}$ in.; ind. h. p., 381; speed, 16 miles an hour; weight of engine and train, 550 tons. Red Lodge coal (by analysis), 10,000 heat units per pound.

1 pound coal = 0.168 h. p. hour.
5.95 pounds coal per h. p. hour.
27.73 pounds water per h. p. hour.

The motion of the train represents the conversion into work of but

51 per cent of the theoretically available heat in the steam by a non-condensing engine.
36.2 per cent of the theoretically available heat in the steam by a condensing engine.
7.4 per cent of the total heat in the steam.
3.8 per cent of the total heat in the coal.

The chart was compiled from actual tests of a Mogul engine on the Yellowstone Division of the Northern Pacific Railway, in which the coal was weighed and the water measured, frequent indicator cards taken, and the final net effective traction at the periphery of the drivers determined by a dynamometer, thus affording an opportunity of checking the calculations at several points in the length of the column, with the effect of localizing minor errors. The efficiency of some modern engines is considerably higher than that shown, but the chart will closely apply to the great majority of the engines in present service all over the United States.

Q. Is heat generated by chemical action convertible into mechanical energy?

Chemical changes are either atomic or molecular, and all differences in the temperature of bodies are due to the changes in their molecular condition; therefore, chemical action, heat, and mechanical energy should be mutually convertible. Chemical changes are always attended by a change in the thermal conditions of the bodies acted upon, in which combinations as a rule produce heat, while decompositions produce cold or a disappearance of heat. The amount of heat any particular body is capable of giving off must be determined as yet experimentally. The researches of Favre and Silberman, Andrews, Thompson, Joule, and others, have given us a very close approximation to the dynamic value of heat and the heating power of different fuels.

Q. What is the effect of heat upon water?

Water within the range of its solidifying point and that at which it becomes an elastic vapor is subject to very great irregularities. If water be taken in a solid state, or at a temperature of 32° F. before it has solidified, and heat be communicated to it, instead of expanding, it actually contracts until it marks about 39.4° F., at which it has attained its greatest density. Above this it expands in the same ratio that the contraction took place for an equal number of degrees, but beyond that point it obeys the general law.

Q. What is the effect of heat upon gases?

All gases at ordinary temperatures are in a state in which the atomical aggregation manifests a highly repulsive tendency. It is evident, therefore, that gases will be influenced to a greater extent by heat than either solids or liquids.

A remarkable coincidence or uniformity exists among the different gases; and knowing the rate of expansion of one, the same may be taken as the expansive power of the other permanent gases when subjected to an equal increase of temperature. It was found, however, by Magnus and Regnault, that the operation of this law is not perfectly uniform, especially with reference to the easily liquefied gases, which are more expansible than air when exposed to equal increments of heat, as the following table will show:

TABLE 16.—EXPANSION OF GASES BETWEEN 32° AND 212° FAHR.

Gases.	Constant volume.	Constant pressure.
Air	0.3665	0.3670
Nitrogen	0.3668	
Hydrogen	0.3667	0.3661
Carbonic oxide	0.3667	0.3669
Carbonic acid	0.3688	0.3710
Nitrous oxide	0.3676	0.3720
Cyanogen	0.3829	0.3877
Sulphurous acid	0.3845	0.3903

A sensible increase in the rate of expansion is also found when the gas is submitted to pressure, compared with that which takes place when it is in a rarefied state. The expansion of perfect gases has been employed in the enunciation and perfecting of a new scale of temperature, known as the absolute scale of temperature.

Q. What is the rate of expansion of air by the application of heat?

By former investigations this was found to amount to about 375 parts in 1,000 of air when heated from the freezing to the boiling point of water. Later researches, however, have shown that the true expansion of air within these limits is 365 parts, or $\frac{1}{493.2}$ of the whole for each degree of the Fahrenheit scale. Below the freezing and above the boiling point of water the expansion is in the same ratio.

Q. What is the British thermal unit?

A British thermal unit is that quantity of heat necessary to raise the temperature of one pound of water from 39° to 40° F., the former being the temperature of its greatest density. This is equivalent to 772 foot-pounds.

Q. What is a calorie?

A calorie is the metric unit of heat. It is that quantity of heat required to raise one gram of water from 4° to 5° C. Some writers give the range of temperature from 0° to 1° C., which is in error, as the greatest density of water occurs at 3.94° C., or 39.4° F.

1 calorie = 3.968 British thermal units.
1 British thermal unit = .252 calorie.

Q. What is the relation of atomic weights to specific heat?

In regard to the atomic weights and their relation to specific heat, it is a noteworthy fact that as the specific heat increases the atomic weight diminishes, and *vice versa;* so that the product of the atomic weight and specific heat is, in almost all cases, a sensible constant quantity. For equal weights the specific heat of the several gases entering into the problem of coal combustion ought to bear a direct relation to each other, for example:

The specific heat, for equal weights, of the following gases, were found by Regnault to be:

Air,	specific heat for equal weight	0.237
Oxygen	" " " "	0.218
Nitrogen	" " " "	0.244
Hydrogen	" " " "	3.409

On the supposition that, for equal volumes, gases contain the same number of atoms, we should expect the gases oxygen and nitrogen, as well as the mixture of the two latter to form air, to have the specific heat of each practically equal, according to their atomic weights. The atomic weight of hydrogen is 1, and its specific heat is 3.409. We should then expect:

$3.409 \div 14 = 0.243$, specific heat nitrogen, N 14.
$3.409 \div 16 = 0.213$, " " oxygen, O 16.
0.237, " " 23% O 16, 77% N 16 = air.

A result which experimentally verifies the above conclusion so far as these two gases are concerned.

The temperatures at which determinations were made were: Carbon, 980° C.; sodium, −34° to + 7° C.; silicon, 232° C.; phosphorus, −78° to + 10° C.; potassium, −78° to + 10° C.; mercury, −78° to −40° C. For all the other elements the determinations were made somewhere between 0° and 100° C. The numbers in these cases may be regarded as approximately representing the mean specific heats for the temperature interval, 40° to 60° C.

TABLE 17.—SPECIFIC HEATS OF THE SOLID ELEMENTS.

Element.	Specific heat.	Atomic weight.	Specific heat × atomic weight.	Observer.
Carbon	.463	11.97	5.5	Weber.
Sodium	.293	23	6.7	Regnault.
Magnesium	.25	24	6	"
Aluminum	.214	27.02	5.8	"
Silicon	.203	28	5.7	Weber.
Phosphorus	.174	30.96	5.4	Regnault.
Sulphur	.178	31.98	5.7	"
Potassium	.166	39.04	6.5	"
Calcium	.170	39.9	6.8	Bunsen.
Manganese	.122	55	6.7	Regnault.
Iron	.114	55.9	6.4	"
Nickel	.108	58.6	6.3	"
Copper	.095	63.4	6.1	"
Zinc	.095	64.9	6.2	"
Silver	.057	107.66	6.1	"
Tin	.0562	117.8	6.6	"
Antimony	.0508	120	6.0	"
Platinum	.0324	195	6.3	"
Gold	.0324	197	6.4	"
Mercury (solid)	.0319	199.8	6.4	"
Lead	.0307	206.4	6.3	"
Bismuth	.0308	208	6.3	"

Q. What is the specific heat of water?

Water exists in three states—solid, liquid, gaseous or steam. The specific heats of each are as follows: Ice, 0.504; water, 1.000; gaseous steam, 0.622.

Q. What is meant by conduction of heat?

This property of heat, although by many supposed to be due to radiation, owing to the particles of matter not being in absolute contact, is, however, generally acknowledged to be due to a distinct action, that of conduction. Dense and heavy substances are generally good conductors; light and porous bodies have this property only imperfectly.

TABLE 18.—THERMAL CONDUCTIVITY OF METALS.

Silver	100.0
Copper	73.6
Gold	53.2
Brass	23.6
Tin	14.5
Iron	11.9
Lead	8.5
Platinum	6.4
German Silver	6.3
Bismuth	1.8

Liquids in general are bad conductors of heat; but liquids do conduct heat in some measure, subject to the same laws as solids, although as regards water and other such mobile liquids, very feebly.

Q. Do all bodies conduct heat alike?

They do not. Good conductors are those bodies in which any inequality of temperature is quickly equalized, the excess of heat being transmitted with great promptitude and facility from particle to particle. The metals in general are good conductors, but different metals have different degrees of conductivity.

Imperfect conductors are those bodies in which the heat passes more slowly and imperfectly through the dimensions of a body, and in which, therefore, the equilibrium of temperature is more slowly established.

Non-conductors are bodies in which the excess of heat fails to be transmitted from particle to particle before it has been dissipated in other ways. Earths and woods are bad conductors, and soft or spongy substances still worse.

Q. What is meant by convection of heat?

Convection means to carry or to convey. As applied to the transfer of heat to liquids and gases it means the carrying or conveying of heat from one particle to another by an actual movement of each heated particle among those of lower temperature, and as each colder particle with which the heated particle comes in contact takes up a portion of the heat, the movement of all the particles will continue until all are of equal temperature.

Q. What is the practical or useful effect of the convection of heat in furnace gases?

The application of currents of heated air is of great practical importance; for example, the heat derived from the combustion of coal on the grate expands the air and gases in the furnace and causes their ascent up the chimney, while an influx of air to the fire, through the ash pit, takes its place. The force of the current or draft thus formed will be in proportion to the greater expansion of a column of air of the height of the chimney than that of an equal column externally. Common air like other gases increases nearly $\frac{1}{500}$ of its bulk for each degree Fahrenheit. Hence by ascertaining the internal temperature and height of the chimney the force of the draft may be calculated.

Q. How do gases conduct heat?

Gases resemble liquids in their mode of conducting heat —that is to say, their power of actual conduction is inappreciable; but by their property of convection currents are instituted by which the heat is disseminated throughout the mass. To observe this, hold the hand by the side of a lighted candle and then at the same distance above it. Little heat is received by the hand in its first position, while in the second the increase of temperature is immediately obvious, the greater portion of the heat being carried off by the ascending current, which in gases is more active than in liquids, owing to their power of expansion being so much greater.

Q. What is radiation of heat?

When heat emanates, or is thrown off by a body, as from a bar of hot iron, heat is said to be radiated from it, and is denominated radiant heat. The rate of cooling expresses the radiating power; and the radiating power of bodies is more influenced by the state of their surface than by the nature of the material. Bright or polished surfaces radiate heat much more slowly than rough or black ones.

Q. What is meant by the term latent heat?

Latent heat is the quantity of heat which must be communicated to a body in a given state in order to convert it into another state without changing its temperature; or, to put it in another form, it is that quantity of heat which disappears, or becomes concealed in a body, while producing some change in it other than a rise in temperature. By exactly reversing the change, the quantity of heat which had disappeared is reproduced. Latent heat is commonly divided into latent heat of fusion and latent heat of evaporation.

Q. What is latent heat of fusion?

The act of liquefaction, such as the melting of ice, consists of interior work—that is, of work expended in moving the atoms into new positions. If a piece of ice, reduced in temperature to, say, 0° F., is subjected to the influence of heat, its temperature will rise progressively for each increment of heat received, until the temperature of the ice reaches 32° F., when the melting of the ice will begin. It will also be observed that, continuing the application of the heat to the ice, as before, there is no corresponding rise in temperature either in the ice or in the water in contact with the ice so long as any of the latter remains unmelted; and that during the process of melting the temperature of the water is constant, and at 32° F.

This change of state from solid to liquid, in the melting of one pound of ice, requires 143 units of heat, the temperature being constant at 32° F. The heat does not raise the temperature of the ice, but disappears in causing its condition to change from the solid to the liquid state. This is called the latent heat of fusion.

Q. What is Joule's equivalent?

The exact mechanical equivalent of heat was first demonstrated experimentally by Dr. Joule, of Manchester, England, the apparatus employed by him being represented in Fig. 13. A known weight was connected by means of

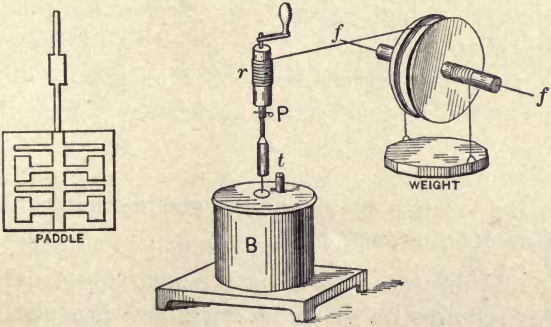


FIG. 13.

cords to a shaft *f*, mounted on friction wheels not shown in the illustration. On this shaft a pulley was secured, which through the medium of another cord imparted motion to the shaft *r*, and caused it to revolve. At the lower end of this shaft *r* were fitted eight sets of paddles, which, when connected by means of a pin P, revolved with it. To the interior of the copper vessel B were attached four stationary vanes, cut out in such manner as to permit the free revolution of the revolving paddles. Precautions were taken to prevent a transfer of heat from the vessel B, which need not be described here. This vessel was filled with a known weight of water, at the temperature of its greatest density, 39° F., and a thermometer *t* was inserted in the vessel B, to mark the rise in the temperature of the water. The experiment consisted in allowing the weight to descend by its own gravity, and, through the medium of the cords, to cause the paddles to revolve and agitate the water in the vessel B.

After many hundreds of experiments extending through several years, Dr. Joule finally fixed upon 772 pounds, raised one foot high against the action of gravity, as the mechanical equivalent of the quantity of heat necessary to raise the temperature of one pound of water through 1° F., at the maximum density of water, 39° to 40° F.

Q. Is the relation between heat and mechanical energy a fixed or definite one?

Heat and mechanical energy are mutually convertible; and heat requires for its production, and produces by its disappearance, mechanical energy in the proportion of 772 foot-pounds for each British unit of heat, the said unit being the amount of heat required to raise the temperature of one pound of water by 1° F., near the temperature of its greatest density, 39° to 40° F.

Q. What is specific heat?

The specific heat of a substance means the quantity of heat which must be transferred to a unit of weight (such as a pound) of a given substance, in order to raise its temperature, by one degree, as compared with that quantity of heat necessary to raise an equal weight of water through one degree at its greatest density, *i.e.*, from 39° to 40° F. The specific heat of water is greater than that of any other known substance; it thus becomes the standard for comparison.

For ordinary calculations we may assume: Woods average one-half the specific heat of water; coal and coke, two-tenths the specific heat of water; wood charcoal, one-fourth the specific heat of water.

The specific heat of gases varies as between specific heat under constant volume, and specific heat under constant pressure. Suppose one pound of gas to be heated—air, for example; a rise in temperature occurs, and if the air is free to expand additional heat will be required to perform the work thus done by expansion; but if the air is confined so that no expansion can occur, less heat will be required to raise its temperature through one degree. The specific heat of air for equal weights (water $= 1$) at constant pressure is 0.2377, at constant volume it is 0.1688, the difference in quantity of heat is $0.2377 \div 0.1688 = 1.4081$ times.

CHAPTER VII.

FUEL ANALYSIS.

Q. What is meant by the elementary analysis of coal?

The separation of coal into its constituent elements may be simply to know what elements compose it; such a process is called *qualitative* analysis. When the quantity of each element is to be determined, it is then known as *quantitative* analysis.

The elementary analysis of coal shows it to be principally composed of the following simple substances: carbon, hydrogen, nitrogen, oxygen, sulphur, ash. Ash is not a simple substance, but represents the incombustible matter of whatever composition remaining in the furnace after combustion.

The elementary analysis of coal is not now the general practice; for all ordinary purposes the shorter method of determining the moisture, volatile combustible matter, the fixed carbon and ash by proximate analysis is employed in furnace work.

Q. What is carbon?

Carbon is one of the most widely diffused and abundant of the elements. It occurs in nature in a free state and in combination with other elements, notably in the form of carbonates and as an essential constituent of organic bodies.

Carbon in its free state is a solid, infusible, non-volatile substance, without taste or smell, exhibiting great diversity in the physical characteristics of its three allotropic forms—diamond, graphite, and charcoal. It is the principal constituent of anthracite coal. It constitutes about one-half of bituminous coal. It may be separated from wood in the form of charcoal by distilling off the more volatile elements.

Carbon unites directly with oxygen, sulphur, nitrogen, and a few of the metals, the latter at high temperatures only. The two direct inorganic compounds of carbon and oxygen are known as carbonic oxide, CO, and carbonic acid, CO_2. The proportions are shown in the following table:

TABLE 19.—ELEMENTARY COMPOSITION OF CARBONIC OXIDE AND CARBONIC ACID GASES.

	COMPOSITION.					
	By weight.			Percentage.		
	Carbon.	Oxygen.	Total.	Carbon.	Oxygen.	Total.
Carbonic oxide CO.	12	16	28	42.86	57.14	100
Carbonic acid CO_2.	12	32	44	27.27	72.73	100

These are the two principal gases formed in the furnace by the combustion of the carbonaceous portions of the fuel.

Carbon and hydrogen unite in the production of an extended series of hydrocarbons, the simpler ones being the marsh gas series, the olefiant gas series, and the benzole series. When carbon and hydrogen are further combined with the addition of nitrogen the hydrocarbon series is greatly extended, including aniline, pyridine, etc., all of which may be obtained by the distillation of coal.

Almost all the elementary substances of which the specific heat and atomic weight are known, give, when these two properties are multiplied into each other, a product averaging not far from 6.34. Carbon is one of the exceptions, as shown in the accompanying table.

Weber, about 1872, made a careful series of determinations of the specific heat of carbon, the results of which are as follows:

TABLE 20.—SPECIFIC HEAT OF CARBON.

	Temperature.	Specific heat.	Specific heat × atomic weight.
Carbon (diamond)	− 50° C.	.0635	0.76
" "	+ 10	.1128	1.35
" "	85	.1765	2.12
" "	250	.3026	3.63
" "	606	.4408	5.29
" "	985	.4589	5.51
Carbon (graphite)	− 50	.1138	1.37
" "	+ 10	.1604	1.93
" "	61	.1990	2.39
" "	201	.2966	3.56
" "	250	.325	3.88
" "	641	.4554	5.35
" "	978	.457	5.50
Porous wood carbon	0°— 23° C.	.1653	1.95
" "	0°— 99	.1935	2.07
" "	0°—223	.2385	2.84

These numbers show that the specific heat of carbon increases as the temperature increases, and that the value of this increase for a given temperature is considerably less at high than at low temperatures.

Q. What is meant by the allotropic states of carbon?

The term allotropic merely expresses the several conditions in which carbon exists, each condition having widely different physical properties, while the chemical properties remain the same. Carbon occurs as diamond, graphite, and charcoal. These three solids are wholly unlike in physical properties, yet chemically they are the same—that is, they yield upon analysis nothing but pure carbon.

Investigations by Petersen, undertaken with a view to determine, if possible, the relation between changes of volume and of energy in passing from one allotropic modification of an element to another, led him to the conclusion that true allotropic varieties differ in the variety of energy they contain, in specific gravity, in specific heat, and in solubility. Color and crystalline form he considers of secondary importance. His results are:

Carbon.	Heat of oxidation (CO_2).	Atomic volume.
Amorphous....................	965.3 to 969.8	6.7 to 8.0
Graphite......................	933.6	5.3
Diamond......................	932.4 to 945.5	3.4

Q. What are the physical properties of the diamond?

The diamond is a natural form of carbon, crystallizing in the cubic system. It was shown to be combustible in 1694, and Lavoisier proved that the sole product of its combustion was carbonic-acid gas, CO_2. The diamond is noted for its great hardness. Its specific gravity ranges from 3.51 to 3.55, averaging about 3.51. The purest stones are practically colorless. The index of refraction is higher in the diamond than in any other known transparent substance.

On exposure to the heat of the electric arc the diamond swells up, cracks on the surface, and becomes coated with a substance resembling graphite. The study of the action of heat upon the diamond, with and without the presence of air, gave the earliest clew to its chemical composition. On the combustion of the diamond there remains a quantity of a colorless or reddish ash, varying from $\frac{1}{500}$ to $\frac{1}{2000}$ of the original weight of the mineral. Microscopic examination of this delicate spongy ash has led investigators to the belief that it shows traces of cellular tissue, suggestive of a vegetable origin. In its ordinary state the diamond does not conduct electricity, but the cokelike mass obtained by exposure to the arc is a good conductor.

Q. What are the physical properties of graphite?

Graphite is an impure variety of native carbon, known also as plumbago, and popularly known as black lead. It occurs usually in compact and crystalline masses, but occasionally in six-sided tabular crystals which cleave into flexible laminæ parallel to the basal plane. Its color is iron black or steel gray, with metallic lustre. Its specific gravity is 1.9 to 2.6.

Graphite is largely used in the manufacture of crucibles and other objects required to withstand high temperatures. It is also used in the manufacture of lead pencils, as a lubricating agent, as a stove polish, as a paint, etc.

Graphite is a good conductor of electricity, and is much used in electrotyping, the moulds upon which the metal is to be deposited receiving a conducting surface by being coated with finely divided graphite.

Q. What are the physical properties of charcoal?

Charcoal is the carbonaceous residue from wood or other vegetable matter, partially burnt under circumstances which exclude the air, and from which all watery and other volatile matter has been expelled by heat.

The composition of charcoal depends on the temperature at which it is produced. At high temperatures all the oxygen and hydrogen are expelled and the black charcoal consists of carbon and the mineral matter (ash) originally present. When produced at lower temperatures the charring is imperfect, and a reddish charcoal results, which contains both hydrogen and oxygen.

Good charcoal is black, gives a sonorous ring when struck, and breaks with more or less conchoidal fracture and a ligneous texture. It is easily pulverizable, but does not crumble under moderate pressure. It burns without smoke and in separate pieces without flame. The specific gravity of wood charcoal, exclusive of pores, is 1.5 to 2; inclusive of pores, from 0.20 to 0.35 in soft charcoal, and from 0.35 to 0.50 in hard charcoal.

Q. How is charcoal affected by the temperature at which it is made?

The composition of charcoal produced at various temperatures, as determined by Violette—the wood experimented on being that of black alder or alder buckthorn, which furnishes a charcoal suitable for gunpowder—is given in the annexed table:

TABLE 21.—COMPOSITION OF CHARCOAL. (Violette.)

Temperature of carbonization.	Composition of the Solid Product.				Carbon for a given weight of wood. Per cent.
	Carbon. Per cent.	Hydrogen. Per cent.	Oxygen, nitrogen and loss. Per cent.	Ash. Per cent.	
302° F	47.51	6.12	46.29	0.08	47.51
392	51.82	3.99	43.98	0.23	39.88
482	65.59	4.81	28.97	0.63	32.98
572	73.24	4.25	21.96	0.57	24.61
662	76.64	4.14	18.44	0.61	22.42
810	81.64	4.96	15.24	1.61	15.40
1873	81.97	2.30	14.15	1.60	15.30
2012	83.29	1.70	13.79	1.22	15.32
2282	88.14	1.42	9.26	1.20	15.80
2372	90.81	1.58	6.49	1.15	15.85
2732	94.57	0.74	3.84	0.66	16.36

The products obtained at the first two temperatures, viz., 302°, 392° F., cannot be properly termed charcoal.

Q. How is the combustibility of charcoal affected by the temperature at which it is made?

Regarding the combustibility of charcoal, that made at 500° F. burns most easily; and that made between 1832° and 2732° F. cannot be ignited like ordinary charcoal; that made at a constant temperature of 572° F. takes fire in the air when heated to between 680° and 715° F., according to the nature of the wood from which it has been derived. Charcoal from light woods, other things being equal, ignites most easily. Charcoal produces a greater heat than an equal weight of wood.

Charcoal, not being decomposable by water or air, will endure for any length of time without alteration.

Q. What elementary substances and compounds enter into the composition of charcoal?

The following analysis of charcoal shows the percentages of elements and compounds entering into its composition, instead of reducing to elements alone:

Carbon, C	85.10	per cent.
Carbonic acid gas, CO_2	3.26	"
Carbonic oxide, CO	1.36	"
Marsh gas, CH_4	0.70	"
Hydrogen, H	0.07	"
Nitrogen, N	0.51	"
Water, H_2O	7.00	"
Ash	2.00	"
	100.00	"

Q. What is the object of converting wood into charcoal?

The carbonization of wood is intended to remove those constituents which absorb heat, and to concentrate the carbon, which possesses great heating power. The substances absorbing heat are the hygroscopic water and oxygen contained in the wood, which, on combustion, cause the formation of so much water that the temperature is decreased to a considerable degree. Slow charring and low heat will produce the largest amount of charcoal, but it will be weak. A brisk heat, well conducted, will furnish less, but will make a strong coal. This determines which mode of charring is most profitable to maker and user. With a well-conducted operation in a pit containing at least 50 cords of wood the yield for air-dried wood ought to be in the proportion here shown:

Kind of wood.	Yield by weight.	Yield by measure.
Oak	23 per cent.	74 per cent.
Beech	22 "	73 "
Pine	25 "	63 "

A cord of 128 cubic feet of oak ought to furnish 64 bushels of 2,600 cubic inches each; pine wood must yield 54 bushels. This measure is actually reached by good burners, though not by the average workman.

Q. Is the heating power of carbon affected by its density?

Gruner has shown that the less the density of any form of carbon, the greater is its heating power. The tests he records also show that the coals containing hydrogen give a greater heating power than that calculated by theory from their elementary composition. It would naturally be inferred, therefore, that the coals which have the least density, and which contain the largest percentage of disposable hydrogen, would have the greatest heating power. Yet the reverse of this appears to be true, so that after the disposable hydrogen reaches four per cent its further increase seems to be actually accompanied by a decrease of heating power, as determined by a calorimeter, and by a still greater decrease, as shown in the diminution of efficiency, from 65 to 55 per cent in the industrial or steaming power. It is difficult to explain the anomaly, except upon the hypothesis that the calorimetric determinations of the more volatile coals were inaccurate (Kent).

Q. What is sulphur?

Sulphur is often found in coal in combination with iron, and is known as iron pyrites. Sulphur is highly inflammable, and when heated in the air to a temperature of about 482° F. it takes fire and burns with a clear blue, feebly luminous flame, being converted into sulphurous oxide, SO_2. In its chemical relations sulphur is the representative of oxygen, to which it is equivalent, atom to atom. Oxygen gas and sulphur vapor alike support the combustion of hydrogen, charcoal, phosphorus, and the metals to form precisely analogous compounds. The atomic weight of sulphur is 32; symbol S; specific heat, 0.1776; specific gravity, 2.00.

Q. What is hydrogen?

Hydrogen is found free in nature among the gases evolved from certain volcanoes; also in the gases given off from the oil wells of Pennsylvania. It is one of the many gases of which coal gas is a mixture. It exists in air in small quantities, in combination with nitrogen as ammonia.

Hydrogen when pure is a colorless, invisible gas, without smell or taste. It is the lightest body known, and has a specific gravity of 0.0693 (air = 1.0000). It is but slightly soluble in water. The specific heat of hydrogen for equal weights at constant pressure = 3.4046; for constant volume = 2.4096.

Hydrogen burns in the air with an almost colorless flame, but under certain conditions, even when pure, the centre of the flame is colored green while the external portions are of a violet blue color. On reducing the pressure the blue color is transferred to green, and from that successively to yellow, orange, and red. The refrangibility of the emitted light becomes less when the intensity of combustion is reduced by a diminution in the supply of oxygen or by a reduction of pressure. A lighted taper is extinguished on being placed in a jar of hydrogen, and the gas burns at the mouth of the jar, rapidly if the jar be mouth upward, slowly if mouth downward.

When mixed with air or oxygen, hydrogen burns with explosive rapidity. The loudest explosion is obtained by mixing two volumes of hydrogen and one volume of oxygen. The maximum explosive effect with air is obtained by mixing one volume of hydrogen with two and a half volumes of air, but the explosion in this case is not so powerful on account of the nitrogen present. In each of these cases the two gases are present in the proportion in which they unite to form water. This mixture of hydrogen and oxygen is not explosive at greatly reduced pressure. A rarefaction produced by diminution of pressure is more effective in weakening the force of an explosion than diluting the mixture with an indifferent gas.

Favre and Silbermann ascertained the heat of one pound of hydrogen burned in oxygen to be sufficient to raise the temperature of 62,032 pounds of water 1° F. This is not equalled by any other known substance.

The liquefaction and solidifying of hydrogen was accomplished by Pictet in 1878. The melting point of hydrogen ice as given by Dewar is 16° or 17° absolute (−257° or −256° C.). Solid hydrogen seems to possess the properties of the non-metallic elements rather than that of the metals, among which it has been usual to class hydrogen.

Q. What is carbureted hydrogen?

Carbureted hydrogen is obtained by the distillation of the volatile portions of bituminous coal. It has long been employed as an illuminating agent. Coal gas will vary according to the coal from which it is distilled, but the following fairly represents the average composition of carbureted hydrogen:

Hydrogen	41.85
Marsh gas	39.11
Carbonic oxide	5.86
Olefines	7.95
Nitrogen	5.01
Carbonic acid	.22
	100.00

Q. What is marsh gas?

Marsh gas is emitted from the surface of the ground in many parts of the world, notably in Italy, North America, and in the vicinity of the Caspian Sea. It is formed by the putrefaction of vegetable matter under water, and hence occurs in marshy places. It also occurs in the coal measures, where it is known as fire damp, being produced by the destructive distillation of carbonaceous matter, occurring to the extent of about forty per cent by volume in coal gas.

Marsh gas (methyl hydride) is colorless and odorless, and forms an explosive mixture with air. Its specific gravity is 0.5596 (air = 1.0000).

The marsh gas series consists of:

	Formula.	Specific gravity.
Methyl hydride	CH_4	0.5596
Ethyl "	C_2H_6	1.037
Propyl "	C_3H_8	1.522

	Formula.	Specific gravity.
Butyl hydride	C_4H_{10}	2.005
Amyl "	C_5H_{12}	2.489
Hexyl "	C_6H_{14}	0.669
Octyl "	C_8H_{18}	0.726
Decyl "	$C_{10}H_{22}$	

Q. What is olefiant gas?

This gas occurs through the dry distillation of many organic bodies; hence occurs to the extent of four to five per cent in coal gas.

It is a colorless gas, and liquefies at a pressure of 42½ atmospheres at −1.1° C. It forms an explosive mixture with oxygen.

The olefiant gas series consists of:

	Formula.	Specific gravity.
Methylene	CH_2	0.484
Ethylene (olefiant gas)	C_2H_4	0.978
Prophylene (tritylene)	C_3H_6	1.452
Butylene	C_4H_8	1.936
Amylene	C_5H_{10}	2.419
Caproylene (hexylene)	C_6H_{12}	2.970
Œnanthylene	C_7H_{14}	3.320

As a product of the dry distillation of coal it is largely used because it is an abundant illuminating constituent in coal gas, its technical name being ethylene, C_2H_4. Pure ethylene burnt at the rate of 5 cubic feet per hour emits a light equal to 68.5 standard candles. The illuminating power of a given quantity of ethylene is increased by moderate admixture with hydrogen, carbonic oxide, or marsh gas, although the actual amount of light given per cubic foot of the mixture is less than that given by pure ethylene. The intrinsic illuminating power is reduced by admixture with nitrogen, carbonic acid gas, water vapor, but increased by oxygen.

Q. What quantity of moisture or water is present in coal?

All coals contain a certain amount of water in their composition. This water can be evaporated by the application of heat, but coals thus deprived of moisture will regain by absorption from the atmosphere the precise quantity which had been previously expelled.

The quantity of moisture in coal varies with the density and structure, so that no averages can be given; for example:

Lignites vary from	5 to 30	per cent.
Bituminous coals from	1 to 12	"
Semi-bituminous coals from	1 to 5	"
Anthracite coals from	1 to 2	"

Q. What is meant by hygroscopic moisture?

The hygroscopic moisture in fuel is that quantity which is always held by the fuel when exposed to the atmosphere. All fuels contain a certain amount of moisture in their composition, which may be expressed as "water of condition." This moisture may be temporarily expelled by heat, only to be reabsorbed from the atmosphere in the exact amount thus driven off. The quantity of hygroscopic moisture thus held by any fuel is dependent upon its structure and density; the greater the density the less the contained moisture.

Q. What is the method employed for obtaining the proximate analysis of coal?

In order to estimate the value of a fuel, it is necessary to determine the moisture, volatile matter, fixed carbon, and sulphur. Professor Thorpe states that in the metallurgical laboratory of the Normal School of Science and

Royal School of Mines these assays are performed in the following manner:

1. *Hygroscopic moisture.* In a water bath heat for an hour 20 grains of powdered sample placed in a watch glass. Weigh repeatedly until the result is constant.

2. *Coke.* Heat 1,000 grains of finely powdered sample in large covered earthen crucible in furnace until no flame is evolved. Weigh when cold, or, better, heat 50 grains in platinum crucible with lid on, the loss of weight giving volatile matter.

3. *Ash.* Heat 20 grains of finely powdered sample in platinum capsule until no trace of carbon is left.

4. *Sulphur.* Deflagrate in platinum crucible 20 grains of powdered sample with 500 grains of a mixture of salt and nitre (2 : 1), dissolve in water, dilute to one-half pint, add HCl in slight excess, heat for twenty minutes, filter, and to filtrate add $BaCl_2$. Allow to stand for twelve hours, filter, weigh precipitate.

Q. Why does not the percentage of sulphur in coal appear in statements accompanying proximate analyses?

Because the proximate analysis determines, first, the volatile and non-volatile quantities; and, second, the combustible and non-combustible quantities of the coal.

No sulphur is driven off in the heating of the coal to expel its moisture.

When heating the coal to distil off its volatile combustible matter some of the sulphur passes off with the hydrocarbon gases. The sulphur is burnt to sulphurous acid, then a certain portion of this is oxidized to sulphuric acid. The amount so oxidized will depend upon circumstances. If the sulphurous acid is kept hot in the presence of moisture, then oxidation goes on more rapidly; but if it be cooled down almost immediately after it is formed, the action is very slow.

Whatever sulphur is not thus driven off remains in the fixed carbon and burns during the ordinary progress of the fire, a portion uniting with the earthy matters in the ash, becoming more or less inert.

Q. What is natural gas?

Natural gas is found locally in Western Pennsylvania, Northern Ohio, and Central Indiana in paying quantities; in lesser quantities it is found in many other localities. The composition of natural gas at Findlay, Ohio, is:

	By weight.	By volume.
Hydrogen	0.27	2.18
Marsh gas	90.38	92.60
Carbonic oxide	0.86	0.50
Olefiant gas	0.53	0.31
Carbonic acid	0.70	0.26
Nitrogen	6.18	3.61
Oxygen	0.66	0.34
Sulphydric acid	0.42	0.20
	100.00	100.00

The heat units in one pound of this gas = 21,520; the evaporative power of one pound of this gas from and at 212° F. = 22.27 pounds of water.

Tests of natural gas for steam-making conducted at Pittsburg, Pa., show that one pound of good bituminous coal equals from 7½ to 12¼ cubic feet of natural gas. Other experiments show that 1,000 cubic feet of natural gas equal from 80 to 133 pounds of bituminous coal, a variation of more than 60 per cent between the two extremes. Quality of coal and manipulation of furnace accounts for much of this difference.

The chemical composition of natural gas, as shown by an average of four samples from Indiana and three from

Ohio, by Prof. C. C. Howard, for the eleventh annual report of the U. S. Geological Survey, is as follows:

Marsh gas, CH_4	93.36
Nitrogen	3.28
Hydrogen	1.76
Carbon monoxide	.53
Oxygen	.29
Olefiant gas	.28
Carbon dioxide	.25
Hydrogen sulphide	.18
Total	99.93

The heat-producing value of natural gas, as compared with other fuel gases per 1,000 cubic feet at 40° F. and at atmospheric pressure, is given by Hosea Webster approximately as follows:

Natural gas	1,103,300	heat units.
Coal gas	735,000	"
Water gas	322,000	"
Producer gas (heated)	156,000	"

Assuming the generation of steam at 212° from water at 60°, the comparative value of natural gas per 1,000 cubic feet at atmospheric pressure is approximately as follows:

1,000	cubic feet	natural	gas	evaporate	900 pounds.
1,000	"	coal	"	"	600 "
1,000	"	water	"	"	250 "
1,000	"	producer	"	"	115 "

Natural gas is an ideal fuel if used near the source of supply, as no labor is required in its use except to regulate the supply in the furnace. It is not difficult to regulate the supply of air to insure perfect combustion. There is no soot, ashes, or other débris.

Q. What is producer gas?

Producer gas is a general name which covers any method of generating gas from a fuel by a process resembling distillation, the gases generated being conducted to the place where the heat of combustion is to be utilized, then mixed with air, ignited and consumed. This system offers a remedy for the imperfections of the ordinary fire and of various fuels. There is no cinder, no ashes, so that the surface of the bodies receiving the heat is not altered. The heating is effected by radiation as well as by conduction, and inferior classes of fuel may be used.

A higher calorific power may be obtained by producer gas or gaseous fuel, generally on account of the smaller quantity of air required for combustion and the consequently lessened dilution of heat by inert nitrogen and carbonic acid. The gas from producers worked by internal combustion contains 25 to 45 per cent of combustible ingredients, and has a calorific intensity of 2867° to 3992° F.

Water gas and ordinary illuminating gas contain 86 to 97 per cent combustible matter. The waste gases from furnaces may be used instead of producer gas when very high temperatures are not required, and where variations in temperatures are permissible, as steam boilers, hot blast, etc. Blast furnace gases rarely contain 30 per cent carbonic oxide, usually from 25 to 29 (Thorpe).

Q. What is the composition of water gas?

A sample of water gas from Lowe's gas producers, after passing through purifier at Novelties Exhibition, Philadelphia, 1885, analyzed as follows:

Carbonic oxide, CO		44.5	volume.
Hydrogen, H		50.9	"
Oxygen, O	air	.7	"
Nitrogen, N		2.8	"
Undetermined		1.1	"
		100.0	"

One cubic foot of water gas of the above composition will develop in burning 327 heat units, including the latent heat of evaporation of the superheated steam which escapes in the chimney.

Q. What is Siemen's gas?

Siemen's gas is a fuel gas generated in a furnace constructed upon principles developed by and named after its inventor.

The average composition of Siemen's gas, made at the Midvale Steel Works, Philadelphia, Pa., is:

Carbonic acid gas, CO_2	1.5	volume.
Carbonic oxide, CO	23.6	"
Hydrogen, H	6.0	"
Marsh gas, CH_4	3.0	"
Nitrogen, N	65.9	"
	100.0	"

Q. What are the calorific values of the ordinary gaseous fuels?

The comparative heating effects of the ordinary gaseous fuels are given below, together with hydrogen:

TABLE 22.—HEATING POWER OF GASEOUS FUELS.

	Heat units yielded by 1 cubic foot.	Cubic feet needed to evaporate 100 lbs. water at 212° Fahr.
Hydrogen, H	183.1	293
Water gas (from coke)	153.1	351
Blast furnace gas	51.8	1,038
Carbonic oxide, CO	178.3	313
Marsh gas, CH_4	571.0	93.8

CHAPTER VIII.

HEATING POWER OF FUEL.

Q. How may the calorific value of fuel be determined?

It may be closely estimated by calculation if the moisture, volatile matter, and fixed carbon have been previously obtained by proximate analysis, or it may be determined directly by means of a calorimeter. The total amount of heat obtainable on combustion of various fuels has been determined by Rumford, Lavoisier, Andrews, Favre and Silbermann, and others. The general principle of their methods consisted in the use of an apparatus (calorimeter) in which the entire heat of combustion was absorbed by a known weight of water, the increase in the temperature of the latter being ascertained by the indication of thermometers suspended in it.

Q. Knowing the calorific value of each of the constituents of any fuel, may not the total calorific power of fuel be determined by calculation?

The calorific power of a fuel may be calculated from the results of an organic analysis; but in any such calculation the oxygen must be considered to be in combination with sufficient hydrogen to form water, H_2O. It is thus only the excess of carbon and hydrogen (disposable hydrogen) after this deduction that is available for the generation of heat. Such calculations have been found only to approximate to the truth, coals, excluding lignite, giving a higher calorific power with the calorimeter than that obtained by calculation.

Q. What is the effect of moisture in coal?

Whatever moisture or water is contained in coal must of necessity be evaporated in the fire before any useful effect is obtained. Inasmuch as some of the poorer varieties of coal contain ten or even fifteen per cent of water, this evaporation is carried on at considerable loss in the furnace.

Q. How may the loss by evaporation of moisture in coal be estimated?

Suppose a furnace requires 10,000 pounds of coal per day, the coal containing 12 per cent moisture, we have:

10,000 × .12 = 1,200 pounds of water to be evaporated. If the coal is 60° F. it must be raised to 212°, and the contained water then converted into steam at 212°, after which it abstracts heat from the furnace until the steam and gases are of the same temperature, say 2,000° F.; we have then:

212° — 60° .... = 152° difference in temp.

Heat units per pound of water required to effect the conversion of water at 212° into steam at 212° .... = 966

Total .... 1,118 heat units per pound of water, or, for 1,200 pounds of water = 1,118 × 1,200..... = 1,341,600

Heat units to be supplied 1,200 pounds of steam at 212° to raise it to 2,000° = 2,000° — 212° × 1,200 .... = 2,145,600

Total .... 3,487,200 heat units, representing lost work in the furnace.

Q. How should the evaporation of the contained water in coal be credited with reference to the furnace?

Nothing should be credited the furnace but heat available for useful work. The evaporation of water from coal in the furnace is not, in steam-making, useful work. It counts, therefore, against the coal, but not against the possible efficiency of the boiler, for the reason that if a drier and better quality of coal were burnt, higher evaporative results would naturally follow. Coals heavily charged with moisture are used only because drier coals are not usually available at a price which would reduce the cost of steam-making.

Q. How is the calorific power of fuel expressed?

In expressing the calorific power of fuel, the amount of heat generated by the combustion of carbon to carbonic acid gas, CO_2, is taken as the standard of comparison. Experimental results vary only in slight degree, so that it is generally agreed that 14,500 heat units are evolved by the complete combustion of one pound of carbon in oxygen to CO_2. As the unit of heat varies with the thermometric scale and the unit of weight employed, it will be understood that the above refers to the British thermal unit, or that amount of heat required to raise one pound of water through 1° F. (39° to 40°).

Q. What is the unit of horse power for steam boilers?

The standard unit of horse power is the equivalent of 33,000 pounds raised one foot high in one minute. It is apparent that no such standard can be applied to steam boilers. The evaporation of 30 pounds of water from a temperature of 100° F. into steam of 70 pounds pressure above the atmosphere was the standard adopted for steam boilers by the Centennial Committee, on the belief that 30 pounds of water evaporated per hour represented the average requirement of steam engines per indicated horse power (1876). This is nearly equivalent to 34½ pounds of water evaporated from and at 212° F., this latter requiring 33,305 heat units.

Q. Is there any fixed relation between the quantity of fuel burnt in a boiler furnace and the unit of horse power ?

The quantity of fuel required to evaporate the water in a boiler into steam has nothing whatever to do with the horse-power unit. But if we may assume as fair average practice an evaporation of 8 pounds of water per pound of fuel, and a consumption of 3.75 pounds of fuel per horse power, we reach the figure of 30 pounds of steam per horse power per hour. For a horizontal tubular boiler set in brick work, 15 square feet of heating surface per horse power is a common allowance, and will develop a horse power of steam under all ordinary conditions, the ratio of grate surface to heating surface being commonly 30 to 1.

Q. What is meant by the evaporative power of coal ?

By evaporative power of coal is meant the number of pounds of water, which, under certain conditions, are capable of being evaporated per pound of coal. In making a complete evaporative test it is necessary to know the temperature of the feed water, the pressure and temperature of the steam, the number of pounds of coal burnt on the grate, and the number of pounds of water evaporated in a given time. The simple evaporation is determined by dividing the number of pounds of water evaporated in a given time, say ten hours, by the number of pounds of coal actually burnt during the same time; but when the temperatures of the feed water and of the steam are to be taken into account, it is then commonly referred to as evaporation from and at 212°.

Q. What quantity of heat is absorbed by the internal work done in liberating the volatile combustible from coal ?

The investigations of E. T. Cox, formerly State geologist, Indiana, upon the coals of that State, showed that the average thermal value of the volatile combustible matter liberated from bituminous coal by heat during its combustion was 20,115 heat units, and that to liberate one pound of these gases 3,600 heat units were expended in overcoming the internal resistances in the coal. This latter amount, 3,600 heat units, should therefore be deducted from the total heat evolved in any calculations based upon proximate analyses, to get accurate thermal values.

The calorific value of coal calculated in accordance with the above paragraph would be as follows :

A sample of Indiana bituminous coal yielded by proximate analysis—

Fixed carbon	49.51	per cent.
Volatile combustible	37.64	“
Moisture	4.30	“
Ash	8.55	“
	100.00	“

The theoretical calorific value with Professor Cox's deduction would be calculated thus—

		British thermal units.
Volatile combustible	.3764 × 20,115 =	7,571.29
Less	.3764 × 3,600 =	1,355.04
Net value of volatile combustible		6,216.25
Carbon	.4951 × 14,544 =	7,200.73
Total calorific value		13,416.98

Q. Knowing the quantity of fixed carbon in any coal, may the approximate heating value of such a coal be determined by calculation?

Having the ultimate analysis of a coal, Kent states that by the use of Dulong's law, it can be predicted what that coal will give in the calorimeter within three per cent. Having only the proximate analysis one can predict even from that very closely what the heating value of the coal is. Dulong's formula, as modified by Mahler, is—

$$Q = \frac{1}{100}\left[8,140 + 34,500\,H - \frac{(O + N - 1)}{8}\right]$$

in which Q is quantity of heat in Centigrade units, and H, O, and N the percentages of hydrogen, oxygen, and nitrogen.

Mahler's results indicate a law of relation between the composition of the coal as determined by proximate analysis and the heating value. The percentage of fixed carbon in the dry coal, free from ash, may, in the case of all coals containing over 58 per cent of fixed carbon, have the heating power predicted with a limit of error of 3 per cent.

TABLE 23.—APPROXIMATE HEATING VALUE OF COALS BASED UPON MAHLER'S TESTS.

Carbon, per cent, dry and free from ash.	Heating Value.		Carbon, per cent, dry and free from ash.	Heating Value.	
	Calories.	British thermal units.		Calories.	British thermal units.
97	8,200	14,760	63	8,400	15,120
94	8,400	15,120	60	8,100	14,580
90	8,600	15,480	57	7,800	14,040
87	8,700	15,660	54	7,400	13,320
80	8,800	15,840	51	7,000	12,600
72	8,700	15,660	50	6,800	12,240
68	8,600	15,840			

Q. What is Mahler's formula?

Mahler's formula for expressing the calorific power of coal and hydrocarbon fuels is a modification of Dulong's formula, and is thus given by William Kent:

Mahler's formula—

$$Q = \frac{8,140\,C + 34,500\,H - 3,000\,(O + N)}{100}$$

The maximum difference between Dulong's formula and the actual result in any single case is a little over three per cent; and between Mahler's formula and the actual, four per cent.

Dulong's formula, $Q = \frac{1}{100}\left[8,080 + 34,500\left(H - \frac{O}{8}\right)\right]$, has the advantage of being more strictly a theoretical formula, based merely upon the observed heating power of the two elements, carbon and hydrogen, and the assumption that the oxygen renders unavailable for heating power ⅛ of its weight of hydrogen, while Mahler's formula introduces a coefficient, 3,000, which is entirely empirical, and only on his own observations.

The figures given in the above formula are French and not British thermal units.

Q. What is Dulong's formula?

Dulong proposed the following formula as expressive of the calorific power of the elements carbon and hydrogen when burnt to carbonic acid gas, CO_2, and steam, H_2O:

Dulong's formula—$P = 8,080\ C + 34,462\ \left(H - \frac{O}{8}\right)$, when P = heating power; C = weight of carbon; O = weight of oxygen; H = free hydrogen, *i.e.*, total hydrogen less that already burnt to water by the oxygen which the based coal contains.

The figures in the above formula are French and not British thermal units.

It is now established by the labors of Favre, Silbermann, Regnault, Bertholet, and others, that the heat of combustion, like specific heat, varies with the density; for example:

	Calories.	British thermal units.
Carbon from charcoal develops	8,080	15,544
Carbon of gas retorts, more dense	8,047	14,484
Natural graphite	7,797	14,034
Diamond	7,770	13,986

Q. What are the details of construction of the Thompson calorimeter?

Referring to Fig. 14, the Thompson calorimeter consists of a glass cylinder A closed at the lower end only, to contain a given weight of water. B is a cylindrical copper vessel called the condenser, closed at one end with a copper cover, in which is fixed a metal tube C, communicating with the interior of the vessel B, and fitted at its upper extremity with a stopcock. The other end of B is open, and it is perforated near the open end by a series of holes, *b*, *b*. D is a metal base upon which B is fixed by means of three springs, which are attached to D, and press against the internal surface of B, but which are omitted from the engraving. A series of holes is arranged round the circumference of D to facilitate raising the apparatus through the water. E is a copper cylinder, called the furnace, closed at the lower end only, which fits into a metal ring or seat on the centre of D.

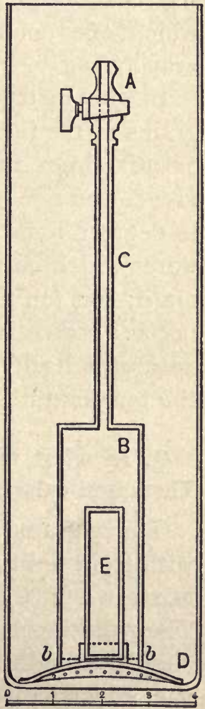


FIG. 14.

Q. In what manner are the results obtained in the Thompson calorimeter?

A known weight of fuel is burnt by means of chlorate of potash and nitre at the bottom of a vessel containing a known weight of water. The heat produced by the combustion of the fuel is communicated to the water, and from the rise in temperature of the latter is calculated the number of parts of water which the combustion of one part of the fuel will raise one degree in temperature. This number being divided by the latent heat of steam, 967 heat units, gives the evaporative power of the fuel, which one pound of the fuel is theoretically capable of evaporating.

In the instrument described, it is intended that 30 grains of the fuel should be burnt, and that 29,010 grains, or 967 times this weight, of water should be employed. Hence the rise in the temperature of the water expressed in degrees Fahrenheit is equal to the number of pounds of water which one pound of the fuel theoretically will evaporate; but ten per cent is directed to be added to this number as a correction for the quantity of heat absorbed by the apparatus itself, and consequently not expended in raising the temperature of the water.

Q. In what manner are experiments conducted with the Thompson calorimeter?

Thirty grains of finely powdered fuel is intimately mixed with from ten to twelve times its weight of a perfectly dry mixture of: Chlorate of potash, 3 parts; nitre, 1 part. The resulting mixture, which, for the sake of distinction, may be called the fuel mixture, is introduced into the furnace E, and carefully pressed or shaken down. The end of a slow fuse, about half an inch long, is next inserted in a small hole made in the top of the fuel mixture, and is fixed there by pressing the latter around it. The furnace is then placed in its seat on the metal base D, and the fuse lighted, and the condenser B with its stopcock shut fixed over the furnace.

The cylinder A is previously charged with 29,010 grains of water, the temperature of which must be recorded, and the apparatus is now quickly submerged in it. The fuse ignites the fuel mixture, and when the combustion is finished (indicated by the cessation of the bubbles of gas, produced by the combustion, which rise through the water), the stopcock is opened, and the water enters the condenser by the holes *b*, *b*. By moving the condenser up and down, the water is thoroughly mixed and acquires a uniform temperature, which is then recorded. By adding ten per cent to the number of degrees Fahrenheit which the water has risen in temperature, the theoretical evaporative power of the coal is at once approximately determined.

The furnace shown in Fig. 14 is intended to be used when bituminous coals are to be operated upon; but in experimenting on coke, anthracite, and other difficult combustible fuels, a wider and shorter furnace is preferred, and the fuel mixture should not be pressed down.

Q. What is the construction of the Barrus' coal calorimeter?

The Barrus' coal calorimeter, shown in Fig. 15, consists of a glass beaker, 5 inches in diameter and 10 inches high, which can be obtained of most dealers in chemical apparatus. The combustion chamber is of special form, and consists of a glass bell having a notched rib around the lower edge, and a bead just above the top, with a tube projecting a considerable distance above the upper end. The bell is 2½ inches inside diameter, 5½ inches high, and the tube above is ⅝ inch inside diameter, and extends beyond the bell a distance of 9 inches. The base consists of a circular plate of brass, 4 inches in diameter, with three clips fastened on the upper side for holding down the combustion chamber. The base is perforated, and the under side has three pieces of cork attached, which serve as feet. To the centre of the upper side of the plate is attached a cup for holding the platinum crucible, in which the coal is burned. To the upper end of the bell beneath the bead, a hood is attached, made of wire gauze, which serves to intercept the rising bubbles of gas and retard their escape from the water. The top of the tube is fitted with a cork, and through this is inserted a small glass tube which carries the oxygen to the lower part of the combustion chamber. The tube is movable up and down, and to some extent sideways, so as to direct the current of oxygen to any part of the crucible, and adjust it to a proper distance from the burning coal.

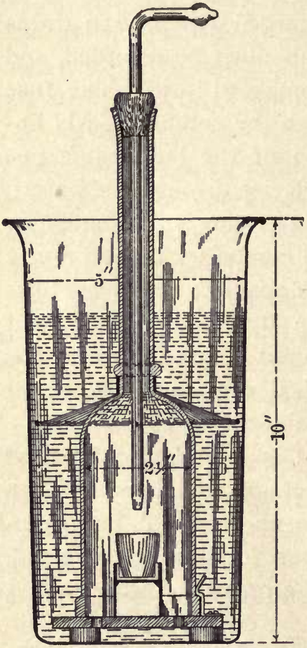


FIG. 15.

In addition to the apparatus here shown there is required a tank of oxygen, such as the calcium light companies furnish, scales for weighing water, and delicate balances for weighing coal, besides a delicate thermometer for taking the temperature of the water, and another for showing the temperature of the atmosphere. The former should be graduated to tenths of a degree Fahrenheit.

The quantity of coal used for a test is one gram, and of water 2,000 grams. The equivalent calorific value of the material of the instrument is 185 milligrams. One degree rise of temperature of the water corresponds to a total heat of combustion of 2,185 British thermal units. The number of degrees rise of temperature for ordinary coals varies from 5½ to 6½° F. Radiation is allowed for by commencing the test with a temperature as many degrees below the atmosphere as the temperature rises above the atmosphere at the end of the test. When very smoky coals are used, the sample is mixed with a small proportion of anthracite of known calorific value; and when anthracite coal is used, a small percentage of bituminous coal is likewise mixed with it.

Q. What is the process of making a test with the Barrus' calorimeter?

Having dried and pulverized the coal, and weighed out the desired quantities of coal and water, the combustion chamber is immersed in the water for a short time, so as to make the temperature of the whole instrument uniform with that of the water. On its removal, the initial temperature of the water is observed, the top of the chamber lifted, the gas turned on, and the coal quickly lighted, a small paper fuse having previously been inserted in the crucible for this purpose. The top of the combustion chamber is quickly replaced, and the whole returned to its submerged position in the water. The combustion is carefully watched as the process goes on, and the current of oxygen is directed in such a way as to secure the desired rate and conditions for satisfactory combustion. When the coal is entirely consumed, the interior chamber is moved up and down in the water until the temperature of the whole has become uniform, and finally it is withdrawn and the crucible removed. The final temperature of the water is then observed, and the weight of the resulting ash.

The initial temperature of the water is so fixed by suitably mixing warm and cold water that it stands at the same number of degrees below the temperature of the surrounding atmosphere (or approximately the same), as it is raised at the end of the process above the temperature of the air. In this way the effect of radiation from the apparatus is overcome, so that no provision in the matter of insulation is required, and no allowance needs to be made for its effect.

Q. What are some of the results obtained by the use of the Barrus' calorimeter?

A few results of tests with the Barrus' coal calorimeter are here given:

TABLE 24.

Kind of coal.	Per cent of ash.	TOTAL HEAT OF COMBUSTION PER POUND OF—	
		Coal.	Combustible.
Georges Creek, bituminous....	5.0	13,487	14,196
" "	6.5	12,921	13,819
" "	7.0	13,360	14,365
" "	8.6	12,874	14,085
Pocahontas, bituminous	3.2	14,603	15,085
" "	4.0	14,121	14,709
" "	5.0	14,114	14,856
" "	6.5	13,697	14,649
New River, bituminous	1.0	14,455	14,601
" "	3.5	13,922	14,426
" "	5.0	13,858	14,857
Youghiogheny, bituminous lump	5.9	12,941	13,752
slack..........	10.2	11,664	12,988
Frontenac, Kansas, bituminous.	17.7	10,506	12,765

Q. What are the details of construction of the Carpenter calorimeter ?

Referring to Fig. 16, the apparatus consists of the combustion chamber 15, which has a removable bottom. The chamber is supplied with oxygen for combustion through tube 23, the products of combustion being conducted through spiral tube 28, 29, 31. The tube ends in a hose nipple 30, from which a hose connection is made to a small chamber 39, attached to the outer case and provided with a siphon gauge 40. A plug, 41, with pinhole, is attached to the chamber for the discharge of gases. The siphon gauge indicates the pressure of the gases. Surrounding the combustion chamber is a larger closed chamber 1, filled with water and connected with an open glass tube with attached scale 9

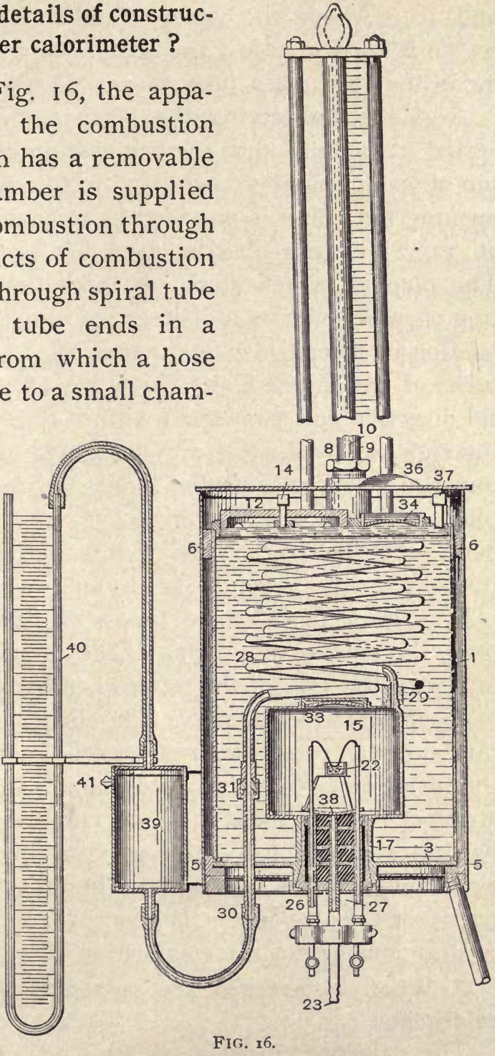


FIG. 16.

and 10. Above the water chamber is a diaphragm 12, which is used to adjust the zero level by means of screw 14 in the open glass tube at any desired point.

A glass for observing the process of combustion is inserted at 33 in top of the combustion chamber, at 34 in top of water chamber, and at 36 in top of outer case. An opening for filling is provided by removing the plug screw at 37, which can also be used for emptying if desired. The plug 17, which stops up the bottom of the combustion chamber, carries a dish 22, in which the fuel for combustion is placed, also two wires 26, 27, passing through tubes of vulcanized fibre, which are adjustable in a vertical direction and connected with a thin platinum wire at the ends. These wires are connected to an electric current and used for firing the fuel. On the top part of this plug is placed a silver mirror 38, to deflect any radiant heat. Through the centre of this plug passes a tube 23, through which oxygen passes to supply combustion. The plug is made of alternate layers of rubber and asbestos fibre, the outside only being of metal, which being in contact with the wall of the water chamber can transfer little or no heat to the outside. The instrument readily slips into an outer case, which is nickel-plated and polished on the inside so as to reduce radiation. It is supported on strips of felting, 5 and 6. The combustion chamber can be subjected to considerable pressure; however, 10 inches water pressure has usually been found sufficient. The capacity of the instrument is about 5 pounds of water, and is large enough for the combustion of 2 grams of coal.

Q. What advantages are possessed by the Carpenter calorimeter?

The calorimeter designed by R. C. Carpenter differs from other calorimeters by the provision made in the apparatus itself, for giving the calorific power of fuels almost direct in British thermal units, dispensing also with some of the objectionable features, such as the errors involved in the thermometer, the determination of the water equivalent of the calorimeter, correction for evaporation, radiation, and specific heats, thus enabling the operator to do his work quickly and accurately. This apparatus, shown in Fig. 16, is in principle a large thermometer, in the bulb of which combustion takes place, the heat being absorbed by the liquid which is within the bulb. The absorption of heat is proportional to the height to which a column of liquid rises in the attached glass tube.

Q. How may a copper-ball calorimeter, suitable for ascertaining smoke-box temperatures, be made?

At the Purdue University such a calorimeter is employed in locomotive tests, and is constructed as follows:

A piece of 1-inch steam pipe, threaded at one end, is screwed through the shell from the inside of the smoke box. It is set radially about 4 inches from the front tube sheet, and inclines from the centre of the smoke box downward. The threaded end passes through the shell a sufficient distance to receive a cap. The cap serves to close the end of the pipe, and also to carry a light rod, to the opposite end of which is attached a simple piston fitting loosely to the bore of the pipe. A copper ball, ⅞ inch in diameter, and a copper vessel suitably enclosed to prevent radiation, complete the outfit. In using the apparatus, the copper ball is inserted in the bore of the pipe, the piston applied below it, and both are pushed up the pipe until the cap at the lower extremity of the piston rod meets the lower end of the pipe. The cap is then screwed in place, closing the pipe and retaining the ball at the centre of the smoke box. Here it is allowed to remain from 40 to 60 minutes, after which interval it is assumed to have come to the temperature of the smoke box. The cap is then unscrewed and the piston quickly withdrawn, allowing the ball to roll down the pipe into the water contained in the copper vessel. From the known weight of the ball, the water, and the copper vessel, and from observed changes in temperature, the original temperature of the ball is calculated. The average result of three such determinations is assumed to be the temperature of the smoke box for the test.

Q. Is the amount of heat evolved by combustion in proportion to the amount of oxygen consumed?

In the erroneous belief that the amount of heat evolved on combustion was in proportion to the amount of oxygen consumed, Berthier determined the calorific power of fuel by burning it by the oxygen contained in oxide of lead, PbO, and ascertaining the weight of the resulting button of lead.

The calorific powers of various fuels as thus determined are as follows:

	Calories.	British heat units.
Air-dried wood with 20% H_2O	2,800	5,040
Charred wood	3,600	6,480
Wood charcoal with 20% H_2O	6,000	10,800
Dry charcoal	7,050	12,690
Peat with 20% H_2O	3,600	6,480
Dried peat	4,800	8,640
Peat charcoal	5,800	10,440
Average bituminous coal	7,500	13,500
Good coke	7,050	12,690
Coke with 5% ash	6,000	10,800
Air-dried lignite ... to	4,360 5,410	7,848 9,738
Hydrogen	34,462	62,032
Carbon burnt to CO	2,473	4,451

	Calories.	British heat units.
Carbon burnt to CO_2	8,080	14,544
CO, burnt to CO_2	2,403	4,325
Marsh gas	13,063	23,513
Olefiant gas	11,858	21,344

Q. What is the Berthier method of coal calorimetry?

The apparatus consists of gas furnace and crucible clearly shown in Fig. 17, which are so simple as to be self-explanatory. Berthier's method of coal calorimetry uses oxide of lead, PbO, as the source of oxygen. It requires only accurate weighing of the sample of fuel and an easily controllable fire for heating a clay crucible to a low red heat. There are no corrections for radiation and no delicate measurements of temperature to be made. These are apparently the great sources of error in the use of oxygen gas.

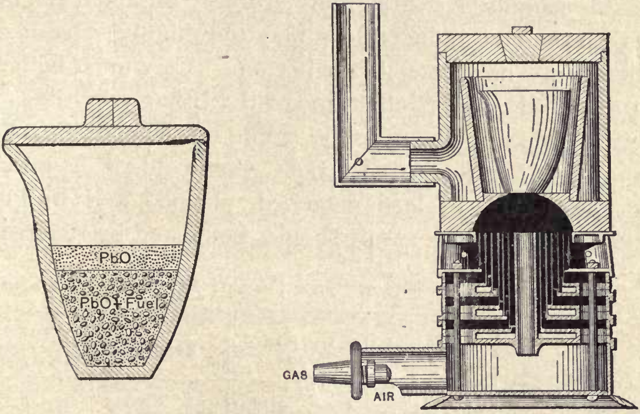


FIG. 17.

The heating power of fuels may be ascertained by mixing intimately 1 part by weight of the substance, in the finest state of division, with at least 20, but not more than

40, parts of litharge. Charcoal, coke, or coal may be readily pulverized; but in the case of wood the sawdust produced by a fine saw or rasp must be employed. The mixture is put into a close-grained conical clay crucible, and covered with 20 or 30 times its weight of pure litharge. The crucible, which should not be more than half full, is covered and then heated gradually until the litharge is melted and evolution of gas has ceased. At first the mixture softens and froths. When the fusion is complete, the crucible should be heated more strongly for about ten minutes, so that the reduced lead may thoroughly subside and collect into one button at the bottom. Care must be taken to prevent the reduction of any of the litharge by the gases of the furnace. The crucible, while hot, should be taken out of the fire and left to cool; when cold, it is broken, and the button of lead detached, cleaned, and weighed. The accuracy of the result should be tested by repetition.

TABLE 25.—COMPARISON OF OXYGEN AND LITHARGE METHODS.

Fuel.	Weight of Fuel, Grams.		Heating Power.		Results.		Probable Error per Cent.	
	Oxy.	Lith.	Oxy.	Lith.	Oxy.	Lith.	Oxy.	Lith.
Carbon from granulated sugar. Ash, 0.44%.......	....	2.18	Calibration.	14,640	Calibration.	All.		
	....	1.882		14,800		14,330	9 Det.	6 Det.
	....	1.879		14,550				
	....	2.767		13,920		1,2,3.6	± 2.6	± 0.76
	....	2.919		13,590		14,617		
	....	1.937		14,480				
Bituminous slack from West Virginia.......	1.310	3.197	14,720	11,420	14,620	11,470	± 1.1	± 0.14
	1.377	2.306	14,090	11,530				
	1.468	3.453	14,520	11,460				
	1.204	3.502	14,320	11,520				
	0.812	2.877	15,460	11,420				
Anthracite coal from Lehigh Valley......	1.328	2.4535	12,660	13,560	12,760	13,616	± 1.7	± 0.08
	1.372	2.3165	12,370	13,650				
	1.394	2.0000	12,520	13,604				
	1.538	2.0000	12,230	13,622				
	1.262	2.9675	14,000	13,643				

The purpose of covering the mixture of fuel and litharge in the crucible with a quantity of pure litharge is not only to prevent access of air to the fuel, but also to prevent the escape unoxidized of the more volatile portions of the fuel. And this covering of pure litharge must likewise be protected from the furnace gases. This apparatus is fully described in theoretical detail by C. V. Kerr, Trans. A. S. M. E., 1899.

Q. What is the calorific value of wood?

The large percentage of moisture in wood renders it unsuitable as fuel where high temperatures are required. The hydrogen present in wood is not available as fuel owing to the presence of oxygen, these two gases uniting to form water. Carbon is the only combustible available in wood for generating heat. This element is present in all woods, averaging about 50 per cent of the total weight when dry.

A cord of wood contains 128 cubic feet; its weight is about 2,700 pounds, or 21 pounds per cubic foot. 2.12 cords, or 2.55 tons of pine wood, were found to be equal to 1 ton Cumberland coal, 1 pound of the latter equalling 2.55 pounds of wood. In evaporative power the pine wood had but two-fifths of that of coal, equal to about 2½ pounds of water evaporated per pound of pine. This is much less than the results obtained by Prof. W. R. Johnson in 1844, who found that 1 pound of dry pine would, by careful management, evaporate 4.69 pounds of water.

The American Society of Mechanical Engineers, in their rules for boiler tests, assume one pound of wood to equal 0.4 pound of coal.

Q. How does wood compare with cotton stalks, brushwood, or straw as a fuel?

The evaporative values, given by John Head, for the following substances, when burnt in a tubular boiler, compare as follows:

Eight pounds of water evaporated by 1 pound good coal; 2 pounds dry peat; 2.25 to 2.3 pounds dry wood; 2.5 to 3 pounds cotton stalks or brushwood; 3.25 to 3.75 pounds straw.

Q. What is the calorific value of peat?

Very little use has been made of peat in this country, owing to the abundance, cheapness, and superior heating power of bituminous coal. Carefully conducted tests abroad show that peat, air-dried, containing not more than 14 per cent of moisture, has about one-half the evaporative power of good coal, and is superior to that of ordinary air-dried wood.

The calorific power of peat varies from 5,400 heat units for ordinary air-dried peat, to 9,400 heat units per pound when thoroughly dry. This corresponds to an evaporation, from and at 212° F., of 5.6 pounds of water for the former, and 9.79 pounds for the latter.

Q. What is the calorific value of lignite?

Freshly mined lignite contains an excess of moisture, to which is generally attributed its low heating power. The large amount of volatile combustible matter contained in lignite causes it to burn with a long smoky flame. The calorific value of lignites will vary from 6,500 to 11,000 heat units, and occasionally higher for the better qualities. This is equal to an equivalent evaporation from and at 212° F. of 6.73 pounds of water for the former, and 11.38 pounds for the latter.

Q. What is the calorific value of bituminous coal?

The calorific value of bituminous coal for the lower grades depends almost wholly upon the amount of its fixed carbon, the moisture and excess of oxygen operating against the efficiency of the fire as a whole; some of the lower grades of coal developing not more than 8,000 heat units, corresponding to an equivalent evaporation of 8.28 pounds of water from and at 212° F. per pound of coal.

The better grades of bituminous coal develop from 13,000 to 14,500 heat units per pound of coal, corresponding to an equivalent evaporation of 13.45 pounds of water for the former, and 15.01 pounds for the latter, both from and at 212° F.

A good average for the best varieties of bituminous coal is 13,600 heat units, corresponding to an evaporation of 14.08 pounds of water from and at 212° F. per pound of coal.

Q. What is the calorific value of coke?

The calorific power of coke should be very high, inasmuch as it is nearly pure carbon. Deducting the ash and other impurities, coke should yield 12,500 to 13,800 heat units per pound, which corresponds to an equivalent evaporation of 12.94 pounds of water for the former, and 14.28 pounds for the latter, from and at 212° F. per pound of coke.

D. K. Clark states that the best experience of the combustion of coke has been derived from the practice of locomotives. A rapid draught is required for effecting the complete combustion of coke, preventing the reaction which is likely to take place when currents of carbonic acid traverse ignited coke, and convert it into carbonic oxide. He showed by a process of mechanical analysis that the combustion of coke in the fire box of the ordinary coal-burning locomotive was complete. The total heat of combustion of one pound of good sound coke was found ordinarily to be disposed of as follows, when the temperature in the smoke box did not exceed 600° F.: 78.0 per cent in the formation of steam; 16.5 per cent by the heat of burnt gases in smoke box; 5.5 per cent drawback by ash and waste.

Q. What is the calorific value of anthracite coal?

Anthracite coals are principally carbon and ash. Excluding the moisture, there is not enough available hydrogen in the volatile matter to be of any heating value, after deducting the energy required to dissociate the volatile combustible from the fixed carbon. The volatile combustible may, therefore, be wholly neglected without sensible loss, and the coal treated according to its percentage of carbon.

Beaver Meadow, Carbon County, Pa., anthracite coal (Geol. Surv., Pa.).

Specific gravity, 1.55 = 96.88 pounds per cubic foot.

Fixed carbon	90.20	per cent.
Volatile matter	2.52	"
Earthy matter, ash	6.13	"
	98.85	"

Neglecting the 1.15 per cent loss in the analysis, we have as the calorific power of this fuel:

Carbon	.9020 × 14,544 =		13,119
Volatile matter	.0252 × 20,115 = 507		
Less	.0252 × 3,600 =	91 =	416
Total heat units			13,535

Then: $\frac{13,535}{966}$ = 14.01 pounds of water evaporated per pound of coal from and at 212° F.

CHAPTER IX.

STEAM GENERATION.

Q. What is the nature of the heat problem in a steam engine?

It is to convert the heat generated in the furnace by the combustion of fuel into the sensible motion of ponderable masses—a piston, fly wheel, etc.; and the degree in which it is possible for it to accomplish this (every imperfection and every source of loss eliminated) is the ratio which the difference of temperature of initial and exhaust steam (or its range) bears to the absolute temperature of initial steam; that is, $\frac{T_0 - T_1}{T_0}$, where T_0 is the absolute initial temperature, and T_1 the absolute final temperature.

Example: Suppose a locomotive takes steam up to the point of cut off at 120 pounds gauge pressure, to which we add the pressure of the atmosphere, 14.7 pounds = 134.7 pounds absolute pressure; its sensible temperature would be 350° F. and its absolute temperature 461° more, or $350° + 461° = 811°$. If this steam be exhausted under pressure a little greater than that of the atmosphere, say 15 pounds absolute, its sensible temperature would be 213° F., and its absolute temperature 461° more, or 674.° Now if $T_0 = 811°$, and $T_1 = 674,°$ we have:

$$\frac{T_0 - T_1}{T_0} = \frac{811 - 674}{811} = \frac{137}{811} = 0.169,$$

or say 16.9 per cent. That is, the range of temperature between initial and exhaust steam being 137° F., and the absolute initial temperature being 811° F., such a steam engine, on account of being obliged to let the steam go while it still has a temperature of 213° F. or 674° absolute, has within its reach, if it could save it all, only 16.9 per cent of the whole work contained in the initial steam in the form of heat. Such an engine will in fact yield about 6 per cent; and dividing this 6 per cent by the 16.9 per cent we have $\frac{6}{16.9} = .355$, or 35.5 per cent., as the ratio of usual engine performance to perfect performance of perfect heat engine under the above usual conditions. About two-thirds, then, of the heat work that may at least be striven for is usually lost (Hoadley).

Q. What is meant by the range of temperature in a steam engine?

It is the difference between the temperature of the steam entering the cylinder and the temperature of its exhaust. These temperatures should be expressed in terms of the absolute scale of temperatures, and not that of the ordinary thermometer.

Q. Does water conduct heat readily?

Water conducts heat very slowly from above downward. The effect observed is very different when, instead of applying heat at the upper surface, it is communicated to the under part, or to the bottom of a vessel in which liquid is contained. In this case the particles in immediate contact with the heat-giving body are expanded. This, by rendering them lighter than the succeeding ones, causes them to ascend; fresh particles succeed, and these rise in similar manner. Currents are thus determined in the liquid, and the whole mass is readily heated. This, however, is not a case of conduction from particle to particle; neither is it due to radiation, but it is the effect of *convection*—that is to say, the actual conveyance or distribution of the heated portion throughout the mass.

Q. What is the limiting difference in temperature between the heated gases in contact with a steam boiler, and the temperature of the steam within?

A common steam pressure in stationary boilers is 80 pounds by gauge, or 95 pounds absolute, the corresponding temperature being 324° F., which represents the cooling surface to which the hot furnace gases are exposed. It is probable that there can be no active transmission of heat from the gases without to the water within a boiler, with less than 75° F. difference of temperature. Pyrometer observations made by Hoadley, in the smoke box of a return tubular boiler, at all stages of the fire, satisfied him that in excellent boilers, well fired, having a ratio of heating surface to grate area as large as 36, the temperature of the escaping gases rarely, if ever, falls lower than 75° F. above the temperature due to the steam pressure, except when the fire doors are open and there is great and unusual excess of air admitted. Adding 75° to the temperature corresponding to 80 pounds gauge pressure, 324°, we have, say, 400° F. as the lowest practical temperature of escaping gases. This will be confirmed by the best practice under favorable conditions; and the actual temperature will range through a low average of 500° F. and a high average of 600° F. up to 800° F. or over.

Q. What is the latent heat of evaporation?

When water has been raised to a temperature of 212° F. in a vessel open to the atmosphere, the continued application of heat does not cause a further rise in temperature.

It will be observed that much more heat is required to evaporate a given quantity of water from and at 212° than was necessary to bring its temperature up to the boiling point.

The quantity of heat required to evaporate 1 pound of water from and at 212° has been experimentally shown to be equal to 966 British thermal units.

The total heat in 1 pound of steam at 212° F. is 1146 units, of which $212° - 32° = 180°$ are necessary to bring the water from the freezing to the boiling point; and 966 units of heat per pound of water are expended in doing the internal work of pulling the liquid molecules asunder, to which must also be added the exterior work of forcing back the atmosphere when the liquid becomes vapor.

The heat thus expended in the conversion of water into steam from and at 212° F., viz., 966 heat units per pound of water, and of which the thermometer gives no record, is the latent heat of evaporation.

Q. How may the latent heat in steam be proven by the quantity of water required for its condensation?

If the feed water and the water for condensation are 60° F., the water leaving the condenser at 120° F., the steam being condensed from 212° F., we have: Total heat in one pound of steam from water at $32° = 1{,}146$ heat units.

The water entering the boiler at 60° instead of 32°, there is a gain of $60 - 32 = 28°$, the heat expended being $1146 - 28 = 1118$ heat units. Subtracting the temperature of the injection from that of the discharge water we have: $120 - 60 = 60°$ difference. Then $1114 \div 60 = 18.63$ times as much water required to condense the steam as was evaporated to make it. In practice, 25 times is the usual allowance.

Q. Is the latent heat of evaporation wholly lost in steam engineering practice?

In the case of non-condensing engines exhausting directly into the atmosphere, the latent heat contained in the steam is lost; and this is the principal loss which occurs in the steam engine when considered as a heat engine.

In a condensing engine a partial recovery of this loss is had by the condensation of the exhaust steam, and consequent utilization of the pressure of the atmosphere upon the engine piston corresponding to the vacuum obtained, from which must be deducted the quantity of work expended in operating the air pump.

Q. What is meant by factor of evaporation?

A factor of evaporation is found by subtracting the temperature of the feed water above 32° F. from the total heat in steam above 32° F. at its pressure above vacuum, and dividing the remainder by 966, or the latent heat of steam at atmospheric pressure. It is commonly expressed by the formula:

Factor of evaporation $= \frac{H - h}{966}$, in which H and h are respectively the total heat in steam of the average observed pressure, and in water of the average observed temperature of the feed.

If we suppose water to enter a boiler at 70° F., the steam pressure to be 100 pounds by gauge or 115 pounds absolute, the factor of evaporation would be found thus:

The total heat in steam above 32° F. at 115 pounds absolute = 1185.

Temperature of feed, $70° - 32° = 38$.

Factor of evaporation $= \frac{1185 - 38}{966} = 1.187$

A table of factors of evaporation is here given for steam pressures by gauge from 60 to 200 pounds per square inch, varying by 10 pounds, together with feed water temperatures from 32° to 210°, varying by 10° F.

The use of the table will be illustrated in the solution of the following example:

Suppose a boiler to evaporate 9 pounds of water per pound of coal, the feed water entering at 70° F., the steam pressure to be 100 pounds by gauge, what is the equivalent evaporation from and at 212°?

The factor of evaporation corresponding to the steam pressure and temperature of feed water shown in Table 26 is 1.187, which multiplied by the pounds of water evaporated will be: 1.187 × 9 = 10.683 pounds of water per pound of coal.

TABLE 26.—FACTORS OF EVAPORATION.

Temp. of feed water. Deg. F.	STEAM PRESSURE BY GAUGE.														
	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
32	1.216	1.220	1.222	1.225	1.227	1.229	1.231	1.232	1.234	1.236	1.237	1.239	1.240	1.241	1.243
40	1.209	1.212	1.214	1.216	1.219	1.220	1.222	1.224	1.226	1.227	1.229	1.230	1.232	1.233	1.234
50	1.197	1.201	1.204	1.206	1.208	1.210	1.212	1.214	1.215	1.217	1.218	1.220	1.221	1.225	1.224
60	1.188	1.191	1.193	1.196	1.198	1.200	1.202	1.203	1.205	1.207	1.208	1.210	1.211	1.212	1.214
70	1.178	1.180	1.183	1.185	1.187	1.189	1.191	1.193	1.194	1.196	1.197	1.199	1.200	1.202	1.203
80	1.167	1.170	1.173	1.175	1.177	1.179	1.181	1.183	1.184	1.186	1.187	1.189	1.190	1.192	1.193
90	1.157	1.160	1.162	1.165	1.167	1.169	1.170	1.172	1.174	1.176	1.177	1.179	1.180	1.181	1.183
100	1.147	1.150	1.152	1.154	1.156	1.158	1.160	1.162	1.164	1.165	1.167	1.168	1.170	1.171	1.172
110	1.136	1.139	1.142	1.144	1.146	1.148	1.150	1.152	1.153	1.155	1.156	1.158	1.159	1.160	1.162
120	1.126	1.129	1.131	1.133	1.136	1.138	1.140	1.141	1.143	1.145	1.146	1.147	1.149	1.150	1.151
130	1.116	1.118	1.121	1.123	1.125	1.127	1.129	1.130	1.132	1.134	1.136	1.137	1.138	1.140	1.141
140	1.105	1.108	1.100	1.113	1.115	1.117	1.119	1.120	1.122	1.124	1.125	1.127	1.128	1.129	1.131
150	1.095	1.098	1.100	1.102	1.104	1.106	1.108	1.110	1.111	1.113	1.115	1.116	1.118	1.119	1.120
160	1.084	1.087	1.090	1.092	1.094	1.096	1.098	1.100	1.101	1.103	1.104	1.106	1.107	1.108	1.110
170	1.074	1.077	1.079	1.081	1.083	1.085	1.087	1.089	1.091	1.092	1.094	1.095	1.097	1.098	1.099
180	1.063	1.066	1.069	1.071	1.073	1.075	1.077	1.079	1.080	1.082	1.083	1.085	1.086	1.088	1.089
190	1.053	1.056	1.058	1.060	1.063	1.065	1.066	1.068	1.070	1.071	1.073	1.074	1.076	1.077	1.078
200	1.043	1.045	1.048	1.050	1.052	1.054	1.056	1.058	1.059	1.061	1.063	1.064	1.065	1.067	1.068
210	1.032	1.035	1.037	1.040	1.042	1.044	1.046	1.047	1.049	1.051	1.052	1.053	1.055	1.056	1.057

Factors of equivalent evaporation show the proportionate cost in heat or fuel of producing steam at any given pressure as compared with atmospheric pressure. To ascertain the equivalent evaporation at any pressure, multiply the given evaporation by the factor of its pressure, and divide the product by the factor of the desired pressure.

Each degree of difference in temperature of feed water makes a difference of .00104 in the amount of evaporation. Hence to ascertain the equivalent evaporation from any other temperature of feed than 212°, add to the factor given as many times .00104 as the temperature of feed water in degrees below 212°. For other pressures than those given it will be practically correct to take the proportion of the difference between the nearest pressures in Table 27, adapted from table published by Babcock & Wilcox Company.

TABLE 27.—FACTOR OF EQUIVALENT EVAPORATION AT 212° F.

Total pressure above vacuum in pounds per square inch.	Factor of equivalent evaporation at 212°.	Total pressure above vacuum in pounds per square inch.	Factor of equivalent evaporation at 212°.
15	1.0003	90	1.0350
20	1.0051	95	1.0362
25	1.0099	100	1.0374
30	1.0129	105	1.0385
35	1.0157	110	1.0396
40	1.0182	115	1.0406
45	1.0205	120	1.0416
50	1.0225	125	1.0426
55	1.0245	130	1.0435
60	1.0263	140	1.0453
65	1.0280	150	1.0470
70	1.0295	160	1.0486
75	1.0309	170	1.0502
80	1.0323	180	1.0517
85	1.0337		

Q. What is meant by total heat in steam?

The total heat in steam includes the sensible temperature of the steam above 32°, plus the latent heat of evaporation corresponding to the pressure under which the steam is generated.

TABLE 28.—PROPERTIES OF SATURATED STEAM, PRESSURE, TEMPERATURE, VOLUME AND DENSITY. (Haswell's Table.)

Pressure per square inch, pounds.	Pressure in mercury, inches.	Temperature, degrees.	Total heat from water at 32°.	Volume of one pound, cubic feet.	Density, or weight of one cubic foot, pounds.
1	2.04	102.1	1112.5	330.36	.003
5	10.18	162.3	1130.9	72.66	.0138
10	20.36	193.3	1140.3	37.84	.0264
14.7	29.92	212	1146.1	26.36	.03802
20	40.72	228	1150.9	19.72	.0507
25	50.9	240.1	1154.6	15.99	.0625
30	61.08	250.4	1157.8	13.46	.0743
35	71.26	259.3	1160.5	11.65	.0858
40	81.43	267.3	1162.9	10.27	.0974
45	91.61	274.4	1165.1	9.18	.1089
50	101.8	281	1167.1	8.31	.1202
55	111.98	287.1	1169	7.61	.1314
60	122.16	292.7	1170.7	7.01	.1425
65	132.34	298	1172.3	6.49	.1538
70	142.52	302.9	1173.8	6.07	.1648
75	152.69	307.5	1175.2	5.68	.1759
80	162.87	312	1176.5	5.35	.1869
85	173.05	316.1	1177.9	5.05	.198
90	183.23	320.2	1179.1	4.79	.2089
95	193.41	324.1	1180.3	4.55	.2198
100	203.59	327.9	1181.4	4.33	.2307
105	213.77	331.3	1182.4	4.14	.2414
110	223.95	334.6	1183.5	3.97	.2521
115	234.13	338	1184.5	3.8	.2628
120	244.31	341.1	1185.4	3.65	.2738
125	254.49	344.2	1186.4	3.51	.2845
130	264.67	347.2	1187.3	3.38	.2955
135	274.85	350.1	1188.2	3.27	.306
140	285.03	352.9	1189	3.16	.3162
145	295.21	355.6	1189.9	3.06	.3273
149	303.35	357.8	1190.5	2.98	.3357
150	305.39	358.3	1190.7	2.96	.3377
155	315.57	361	1191.5	2.87	.3484
160	325.75	363.4	1192.2	2.79	.359
165	335.93	366	1192.9	2.71	.3695
170	346.11	368.2	1193.7	2.63	.3798
175	356.29	370.8	1194.4	2.56	.3899
180	366.47	372.9	1195.1	2.49	.4009
185	376.65	375.3	1195.8	2.43	.4117
190	386.83	377.5	1196.5	2.37	.4222
195	397.01	379.7	1197.2	2.31	.4327
200	407.19	381.7	1197.8	2.26	.4431

At atmospheric pressure we have: 212° F., the sensible temperature of steam; 966 heat units, the latent heat of evaporation. Then

212 − 32 = 180
Latent heat = 966

Total heat in one pound of steam = 1146 heat units.

The amount of heat absorbed in vaporization, or rendered latent by each pound of water in its conversion into steam, varies according to the pressure at which the steam is generated, being greatest at atmospheric pressure and decreasing as the steam pressure increases. For example:

At 100 pounds gauge pressure or 115 pounds absolute we have a corresponding temperature of 338° F. The latent heat of vaporization at this temperature and pressure is 876 units of heat per pound of water evaporated. We have then:

Temperature of the steam 338 − 32 = 306
Latent heat of evaporization = 876

Total heat in steam = 1182 British thermal units.

A result which varies slightly from that given in Table 28. As the tabular numbers are those obtained by direct experiment, they are to be followed in all cases.

Q. What is the effect of the withdrawal of heat from steam?

When heat is withdrawn from steam it condenses to form water, and the same quantity of heat necessary to produce the steam reappears in the water used to condense the steam, and bring it back to the original temperature of the feed water. This property is made use of in steam heating, where steam of very low pressure is made to give up its heat through the sides of the radiating coils, the water of condensation returning to the boiler at a temperature approximating the boiling point, depending somewhat on the details of the piping.

Q. What is meant by evaporation per pound of combustible?

Evaporation per pound of combustible is the net evaporation per pound of coal after making due allowance for the ashes and the unburnt coal falling through the grates.

Suppose 1,000 pounds of coal be fed to the furnace and evaporated 8,500 pounds of water, this would be an evaporation of 8.5 pounds of water per pound of coal. If 130 pounds of ashes remain after the combustion of the coal, we have: $1{,}000 - 130 = 870$ pounds of combustible, evaporating 8,500 pounds of water. The evaporation would then be: $8{,}500 \div 870 = 9.77$ pounds of water per pound of combustible.

Q. How may water evaporated per pound of coal be converted into equivalent evaporation from and at 212° F. per pound of combustible?

Taking a case from actual practice in which: Steam pressure by gauge, 95 pounds; feed water entering boiler, 138° F.; bituminous coal; coal fed to the furnace deducting moisture, 6,817 pounds; ashes, 859 pounds; total combustible, 5,958 pounds; water evaporated per pound of coal, 9.04 pounds; water evaporated per pound of combustible, 10.34 pounds.

Example 1. What is the equivalent evaporation from and at 212° per pound of coal?

Ninety-five pounds gauge pressure = 110 pounds absolute.

Heat units in steam 110 pounds absolute pressure from water at 32° = 1183.5 (see Table 28).

The water entering the boiler at 138° instead of 32°, there is a gain of $138 - 32 = 106°$.

Then: $1183.5 - 106 = 1077.5$ units of heat.

$$\frac{\text{Heat units in steam}}{\text{Latent heat of evap.}} = \frac{1077.5}{966} = 1.115, \text{ a multiplier.}$$

$9.04 \times 1.115 = 10.08$ pounds of water evaporated from and at 212° per pound of coal.

Example 2. What is the equivalent evaporation from and at 212° per pound of combustible?

Proceed as above to obtain a multiplier, then the product of the water evaporated per pound of combustible into the multiplier will be the answer, thus: $10.34 \times 1.115 = 11.54$ pounds of water evaporated from and at 212° per pound of combustible.

Q. What is meant by an equivalent evaporation from and at 212° F.?

Evaporation from and at 212° F. takes into account the latent heat of evaporation. The rise in temperature of the feed water in the boiler proceeds regularly with each increment of heat received by it, until the temperature 212° is reached, at which point the water continues to receive heat, but records no rise in temperature until 966 units of heat have been absorbed per pound of water, after which the thermometer begins to record higher temperatures corresponding to the pressure of steam.

In making computations from and at 212° the process is divided into three parts:

1. Heat required to bring feed water up to 212°.
2. Heat required to convert one pound of water at 212° into steam at 212° = 966 units.
3. Heat in steam at 212° F., or 1,146 units, to that corresponding to the steam pressure.

As water freezes at 32° F. this temperature is always to be deducted from the temperature of the feed.

The equivalent evaporation from and at 212° is found by dividing the total heat in the steam by 966, which gives a multiplier by which the weight of water actually evaporated per pound of coal is to be multiplied. For example:

A boiler evaporates 8½ pounds of water per pound of coal from feed water at 75° F., the steam pressure being 100 pounds by gauge or 115 pounds absolute. What is the equivalent evaporation from and at 212° F.?

Referring to Table 28 we find the total heat required to generate one pound of steam from water at 32° under a pressure of 115 pounds absolute is 1184.5 heat units. The water entering the boiler at 75° instead of 32°, there is a gain of $75 - 32 = 43°$. Then: $1184.5 - 43 = 1141.5$ units of heat; $\frac{1184.5}{966} = 1.182$, the multiplier; $8.5 \times 1.182 = 10.05$ pounds, the equivalent evaporation from and at 212° at atmospheric pressure.

Q. How may the equivalent evaporation from and at 212° be estimated, when only the total heat of combustion of the fuel is known?

When the total heat of combustion of one pound of the combustible is known, the equivalent evaporation from and at 212° may be determined by dividing the number of heat units required to convert water at 212° into steam at atmospheric pressure.

Example: Suppose a bituminous coal to have developed by calorimeter test 13,200 heat units per pound, what would be the equivalent evaporation from and at 212°? $\frac{13,200}{966} = 13.67$ pounds of water, at atmospheric pressure.

Q. What is the object in reducing evaporative results to an equivalent evaporation from and at 212°, at atmospheric pressure?

Equivalent evaporation from and at 212° F., at atmospheric pressure, has been accepted by engineers as being at once the readiest, most convenient, and most intelligible basis yet suggested for estimating the comparative evaporating power of different kinds of fuel. It represents the weight of water which would have been evaporated by each pound of fuel had the water been both supplied and evaporated at the boiling point corresponding to the mean atmospheric pressure.

Q. What is the ordinary rate of evaporation per pound of small anthracite coal when burnt in horizontal tubular boiler furnaces?

The ordinary rate of evaporation per pound of small anthracite coal, from feed water at 60° F., under 80 pounds gauge pressure, say 324° F., is placed by Hoadley as being in general below 8 pounds. Indeed, 8 pounds of dry steam is a fair result; 8.25 is a good result; 8.5 pounds very good; and 9 pounds about the best attainable, being rather over 10,000 thermal units, which corresponds to 69 per cent of the full calorific power of the carbon, and is for coal consisting of 83.33 per cent of carbon a high result.

Q. What is the available heat of combustion?

The available heat of combustion of one pound of any fuel is that part of the total heat of combustion which is communicated to the body, to heat which the fuel is burnt; the water in a steam boiler, for example. The theoretical heat of any fuel is easily determined, its proximate or elementary analysis being known; but the actual available heat can be determined only by a series of more or less elaborate experiments or trials in actual use.

The disposition of the heat generated in the furnace of a steam boiler of the ordinary horizontal tubular form set in brickwork, and provided with a special air-heating arrangement which lowered the temperature of the flue gases to about 213° F., and raised that of the air supplied to the furnace about 300° F., was ascertained by Hoadley to be as follows:

	Per cent.
Waste in flue gases including evaporation of moisture in coal and heating vapor in air when these losses are not separately given	5.04
Evaporating moisture in coal	1.55
Heating vapor in air	.18
Imperfect combustion	1.44
Radiation and heat not otherwise accounted for	4.00
Heating and evaporation of water	87.79

The high efficiency here given is due in great part to the recovery of heat from the escaping gases and the preheating of air entering the furnace, as well as the unusual care and skill exercised during the test. These results are in percentages of the total amount of heat accounted for in heating and evaporating water in the boiler, and are fully one-third greater than obtains in good ordinary practice.

CHAPTER X.

STATIONARY FURNACE DETAILS.

Q. What is the efficiency of a furnace?

The efficiency of a furnace for a given sort of fuel is the proportion which the available heat bears to the total heat generated in the furnace. By furnace is meant not merely the chamber in which the combustion takes place, but the whole apparatus for burning the fuel and transferring heat to the body to be heated, including ash pit, combustion chamber, flues, and chimney.

Q. What losses occur in a furnace by which its efficiency is lowered?

The heat generated in a furnace can never be wholly utilized. Heat, like water or steam, must flow from a higher to a lower level in order to become available, and in any such transfer there are always losses, among which occur:

Loss due to radiation of heat from the sides of the furnace.

Loss occasioned by difference of temperature between the escaping gases and that of the atmosphere necessary to produce natural draught.

Loss by the waste of unburned fuel falling through into the ash pit.

Loss by imperfect combustion—that is, by the formation of carbonic oxide instead of carbonic-acid gas.

Loss by excess of air passing through the furnace, doing no useful work.

Q. How is the efficiency of a steam boiler measured?

In steam boilers the efficiency of the furnace is measured by the pounds of water evaporated per pound of coal burned on the grate, under known conditions. The efficiency is expressed in a percentage indicating how nearly the actual performance attains to the theoretical. If the latter be expressed by 100, the efficiency will always be a less number.

Suppose a coal is known to contain 13,100 heat units by calorimeter test, the equivalent evaporation from and at 212° F. would be 13,100 ÷ 966 = 13.56 pounds of water per pound of

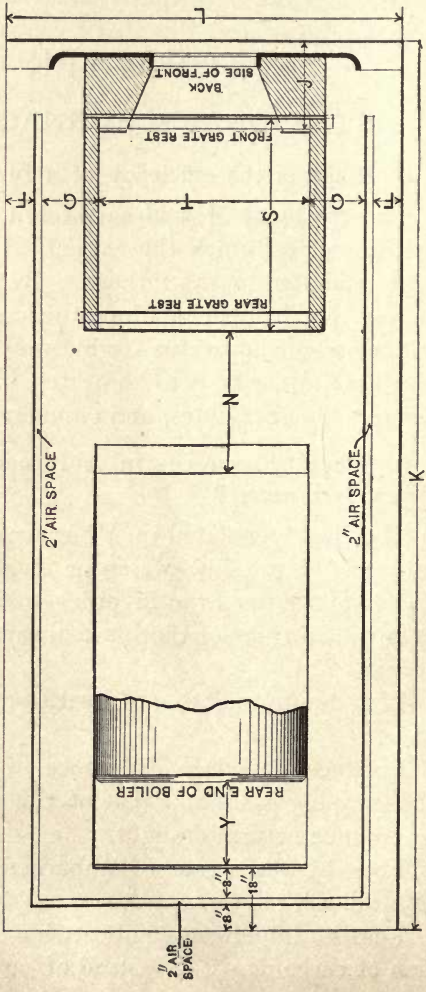
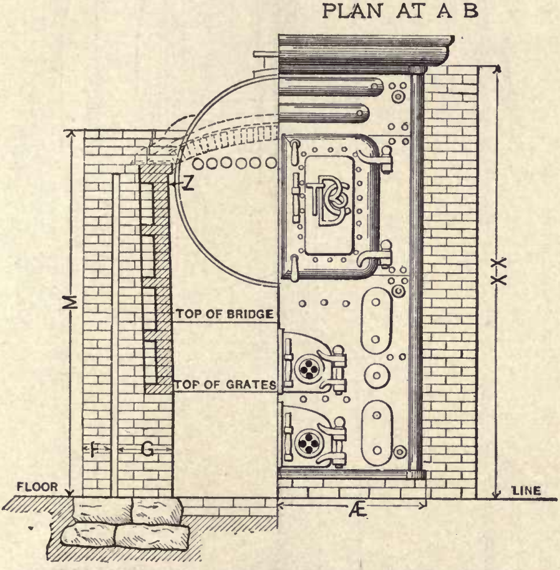


FIG. 18.

coal. By actual test 9.25 pounds of water are evaporated per pound of coal. We then have:

$$\text{Efficiency } \frac{9.25 \times 100}{13.56} = 68.22 \text{ per cent.}$$

The loss of heat in this case amounts to 31.78 per cent of the total heat generated in the furnace. This loss, which is largely unavoidable, may be accounted for as on page 215.



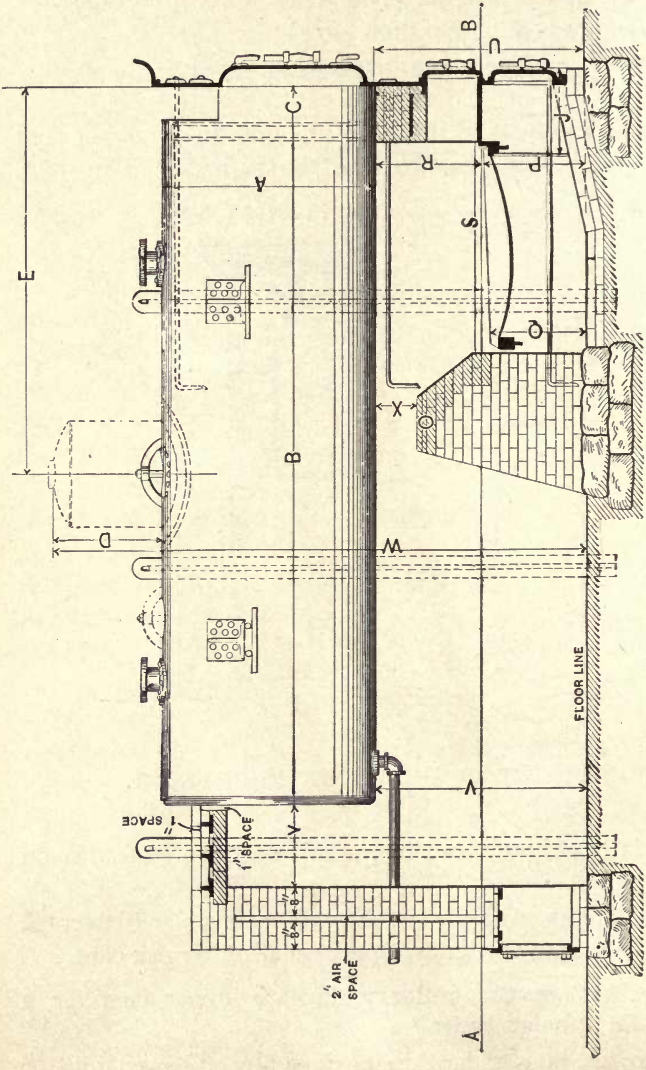
HALF SECTION AND ELEVATION OF FRONT.

FIG. 19.

Good boilers, properly set and well managed, will average nearly the same efficiency, approximating 65 per cent.

Q. What are the ordinary furnace dimensions for a horizontal tubular boiler?

There are no standard dimensions for boiler settings or



LONGITUDINAL SECTIONAL ELEVATION.

FIG. 20.

TABLE 29.—RETURN TUBULAR BOILER SETTING (THE BIGELOW COMPANY).

Diameter of boiler.	Length of curtain sheet.	Thickness of outside side walls.	Thickness of inside side walls.	Thickness of front wall at bottom.	Width of walls over all.	Height of walls from top of floor.	Thickness of bridge wall at bottom.	Thickness of bridge wall at top.	Floor line to top of grates at front.	Floor line to top of grates at rear.	Top of grates to under side of boiler.	Length of furnace.	Width of furnace.	Top of floor to under side of boiler at front.	Top of floor to under side of boiler at rear.	Top of floor to top of flange on dome.	Top of bridge wall to under side of boiler.	Space in rear between boiler and wall.	Space between boiler and walls at side.	Height of front.	Width of front.
A	**C**	**F**	**G**	**J**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**	**T**	**U**	**V**	**W**	**X**	**Y**	**Z**	**XX**	**Æ**
Inch.	Inch.	Inch.	Inch.	Inch.	Ft. In.	Ft. In.	Inch.	Inch.	Inch	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Ft. In.	Inch.	Inch.	Inch.	Ft. In.	Ft. In.
36	11	8	12	19½	6– 8	7– 0	32	15	25	23½	26	36	36	51	50½	9– 1	10	20	2	7– 9	4– 6
42	12	8	12	19½	7– 2	7– 7	36	15	27	25½	26	42	42	53	52½	10– 1	10	20	2	8– 6	4–10
44	12	8	12	19½	7– 4	7–10	36	15	27	25½	26	48	44	53	52½	10– 5	10	20	2	8– 6	5– 0
48	14	8	12	21½	7– 8	8– 0	36	15	30	28	26	48	48	56	55½	11– 2	10	20	2	9– 0	5– 0
50	14	8	12	21½	7–10	8– 1	36	15	30	28	26	48	50	56	55½	11– 6	12	20	2	9– 2	6–10
54	14	8	12	21½	8– 2	8– 6	36	15	30	28	28	54	54	58	57½	12	12	22	2	9–10	7– 1
60	16	8	16	23½	9– 4	8–11	40	15	30	28	30	60	60	60	59½	12– 8	12	24	2	10– 6	7– 6
66	17	8	16	25½	9–10	9– 8	40	15	33	31	30	66	66	63	62½	13–11	14	28	2	11– 3	8– 1
72	18	8	16	27½	10– 4	10– 1	40	15	34	32	30	72	72	64	63½	14– 6	14	30	2	11–10	8– 7
78	18	8	16	27½	10–10	10– 6	40	15	34	32	30	78	78	64	63½	15– 6	14	30	2		
84	20	8	16	27½	11– 4	10–11	40	15	34	32	30	84	84	64	63½	16	14	30	2		

furnaces; the practice varies as between East and West, and between anthracite and bituminous fuels. A very good design is shown in Fig. 20 in sectional elevation. This design is by the Bigelow Company, New Haven, Conn. A plan is shown in Fig. 18 and a half front elevation and half section is shown in Fig. 19.

The bottom of the front should set up 5 inches (2 bricks) above the floor level. Front edge of moulding on bottom of front should set back 2 inches from front edge of brick work. Both of these details are shown in Fig. 20. All measurements given in Table 26 are based on the front being set as stated above. Ash pits under the grates should slope down from bottom of ash door to floor level. The front wing brackets on the boiler should rest directly on the wall plates so that all the expansion will go to the rear, provision being made for this longitudinal movement by rollers placed between the rear wing brackets and the wall plate underneath.


FIG. 21.

The inside walls in this design taper, beginning at the top of the grates and extending to a line 4 inches under the bracket, giving a space of 2 inches between the side of boiler and inside of wall, as shown at Z in Fig. 19. The inside wall should close in to the boiler on a line $2\frac{1}{2}$ inches (1 brick) under the brackets. The outside and inside walls have a 2-inch air space between them. Headers should be run from wall to wall, say, every 18 inches, but not tied together. Fire brick in the furnace should be laid with a course of headers every five or six courses, so that portions of the wall can be easily taken out and repaired. Boilers should be covered on top with some non-conducting material; if with a brick arch, an air space of 2 inches should be left between the boiler and the brick work. The arch tee bars for back connection should be lined with fire brick laid endwise before the bars are placed in position, as in Fig. 21.

Q. What are the details of construction of Kent's furnace for steam boilers?

This design of furnace, shown in longitudinal sectional elevation in Fig. 22, is intended especially for furnaces which use bituminous coal, lignite, peat, tan bark, or other fuel which contains large quantities of tarry or gaseous matter, and which in burning distils a large amount of combustible gases.

The fire chamber, built of brick, extends out in front of the boiler; in it the fuel is burned, either on the ordinary grate bars, or by any one of the numerous stokers now in the market. A bridge wall is provided at the end of the grates, over which the gaseous products of combustion pass on their way to the heating surfaces of the boiler. Two wing walls are built parallel to and at some distance in the rear of the bridge wall, as shown in Fig. 23. A gas-mixing chamber is thus formed between the bridge and wing walls. The combustion chamber is the next into which the gases travel from the passage between the wing walls. In this chamber are several piers of fire brick projecting in front of the wall at the rear of the combustion chamber. The remaining details of the setting are those of the Babcock and Wilcox boiler, and readily understood.

In the operation of this furnace, with ordinary grates and with bituminous coal or other gaseous fuel, the alter-

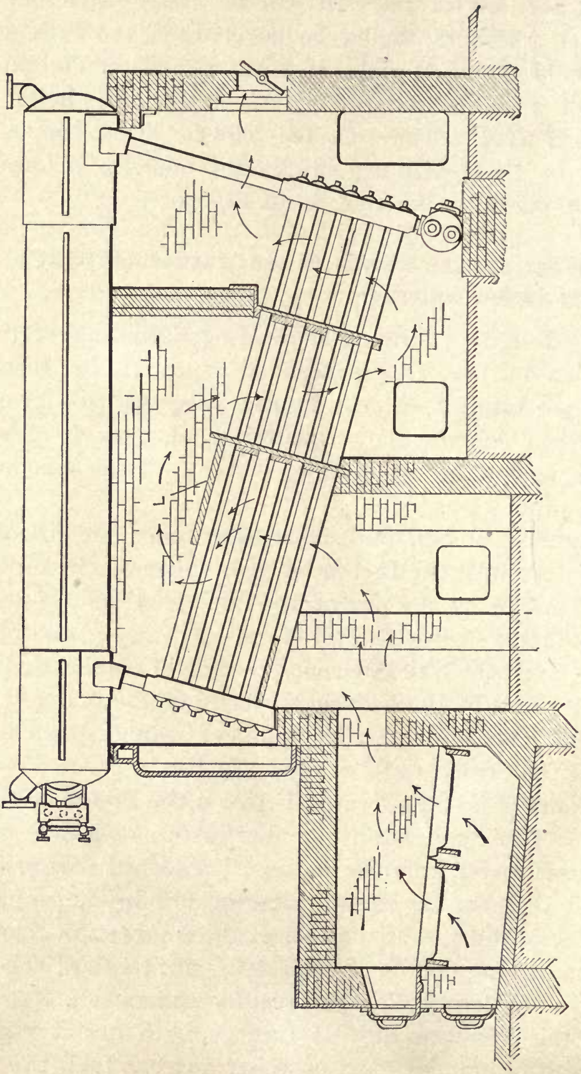


FIG. 22.

nate method of feeding coal is preferred—that is, the fresh coal is spread alternately on the right and left sides of the grate, an interval of some minutes of time elapsing between the feeding on the right and on the left side. Immediately after fresh coal is put on one side of the furnace dense smoky gases arise from it, which in the ordinary boiler setting would pass out of the chimney unburned, since in the ordinary setting there is no means provided for mixing with them an abundant supply of highly heated air; but in this furnace such air is supplied through the bed of partially burned and very hot coal and coke on the other side of the grate. The two currents, one of cool smoky gas arising from the fresh coal on one side of the grate and the other of clear and very hot gas con-

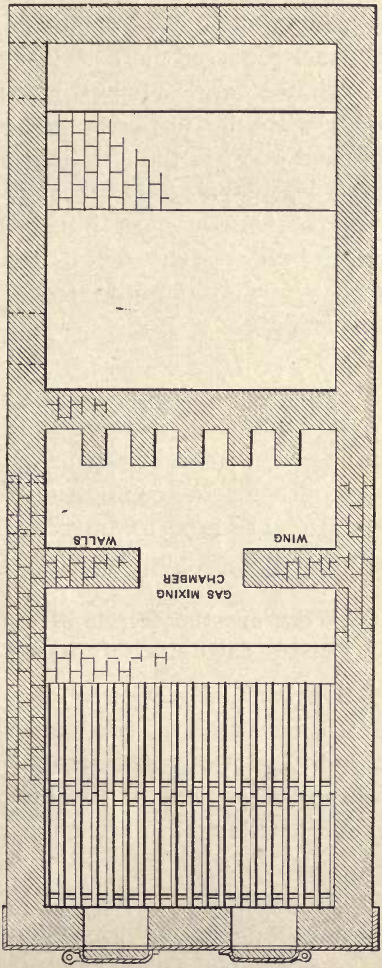


FIG. 23.

taining a large excess of air, pass together over the bridge wall and are compelled by the wing walls to change their direction and to mix together in the gas-mixing chamber and in the contracted vertical passage between the wing walls. The combustion of the unburned gas is further rendered more certain and complete by passing through the large combustion chamber, whose walls, together with the fire-brick piers, are in a highly heated state and perform the functions of a regenerative furnace—that is, they absorb heat from the burned gases at such times as they are most intensely heated, and radiate or give up heat at such times as the gases are not so hot, as during the first minute after feeding fresh coal, when there is a great excess of freshly distilled and rather cool gases.

By this means complete combustion of the smoky gases is secured in the combustion chamber when reasonable care is used by the fireman, and the resulting thoroughly burned products of combustion are then in the right condition to be allowed to traverse the gas passages through the tubes and give up their heat to the boiler.

Q. What are the details of construction of the O'Brien and Pickles down-draft furnace?

A longitudinal section of this furnace is shown in Fig. 24. It consists, in common with down-draft furnaces generally, of two grates, an upper and a lower one; the raw fuel being fed to the upper grate where it burns, the draft passing in through openings in the upper fire door, down through the fuel on the upper grate, and under the inner manifold shown immediately over the bridge wall. This manifold has communication with the boiler by the elbow and connections clearly shown. On top of the inner manifold is a fire-brick partition closing the space between it and the boiler, and compelling the draft to flow downward.

The front manifold is placed directly under the front end of the boiler, and between it and the inner manifold are tubular grates, through which water circulates from one manifold to the other.

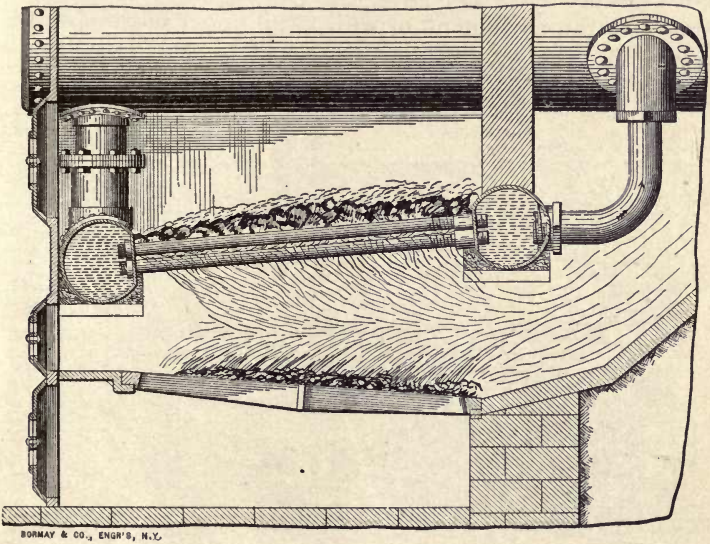


FIG. 24.

Any fuel that falls through the upper grate is caught by the lower one, upon which it burns, the draft passing in through the lower or ash-pit door, up through the grate and beneath the inner manifold. The grate bars for the lower series are of the ordinary pattern, the spaces being much finer than obtain in the upper series.

Q. What is the construction and operation of the Babcock and Wilcox automatic stoker?

This is an endless-chain grate stoker. It is shown in perspective in Fig. 25, wholly withdrawn from the furnace. The grate is made up of a series of short cast-iron bars linked together and engaging sprockets at the front and rear, by the movement of which the upper portion of the grate is carried constantly forward. The coal is fed through a hopper of the full width of the grate, and the depth of the layer is regulated by a door which can be lifted or lowered. The coal is ignited near the front and is carried slowly backward, the speed of the grate being adjusted so that the time of travel is sufficient for the complete combustion of the fuel, the ash and refuse being carried over at the back end and falling into the ash pit. A fire-brick arch at the front end of the furnace facilitates the coking of the fresh fuel as it enters, and the combus-

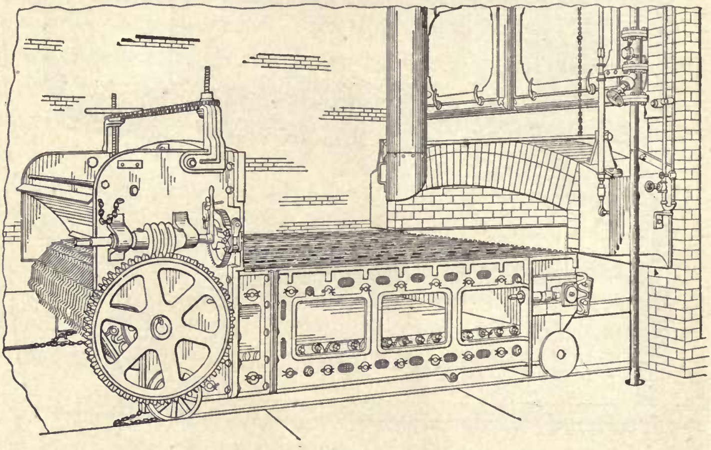


FIG. 25.

tion of the volatile gases evolved. The apparatus as a whole is mounted on wheels running on rails placed on the sides of the ash pit, and can be drawn out clear of the boiler for inspection or repairs, or to give room when necessary to replace furnace linings.

Q. What is the construction and operation of the Roney mechanical stoker?

This stoker is shown in connection with a horizontal tubular boiler setting in Fig. 26 and in detail in Fig. 27.

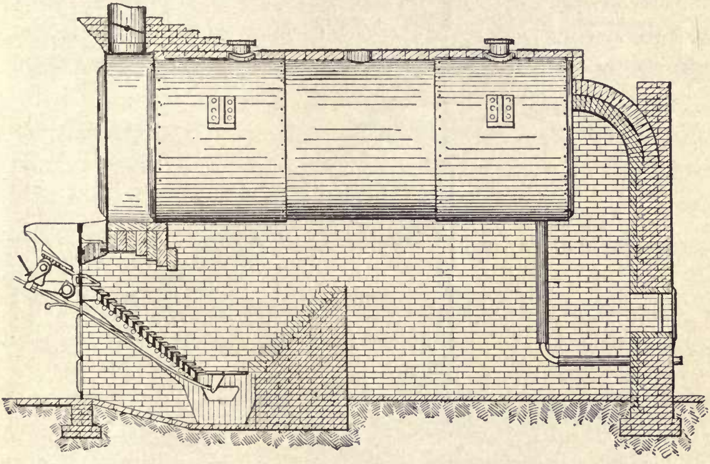


FIG. 26.

It consists of a hopper for receiving the coal, a set of rocking stepped grate bars, inclined at an angle of 37° from the horizontal, and a dumping grate at the bottom of the incline for receiving and discharging the ash and clinker.

The coal is fed on to the inclined grates from the hopper by a reciprocating pusher, which is actuated by the agitator and agitator sector. The grate bars rock through an arc of 30°, assuming alternately the stepped and the inclined position. They receive their motion from the rocker bar and connecting rod, and these, with the pusher, are actuated by the agitator, which receives its motion through the eccentric from a shaft attached to the stoker front under the hopper. The range of motion of the pusher is regulated by the feed wheel from no stroke to full stroke, and the amount of coal pushed into the furnace adjusted, according to the demand for steam. The motion of the grate bars is similarly regulated and controlled by the position of the sheath-nut and lock-nuts on the connecting rod. Each grate bar is composed of two parts: a vertical web provided with trunnions at each end, which rest in seats in the side bearers, and a fuel

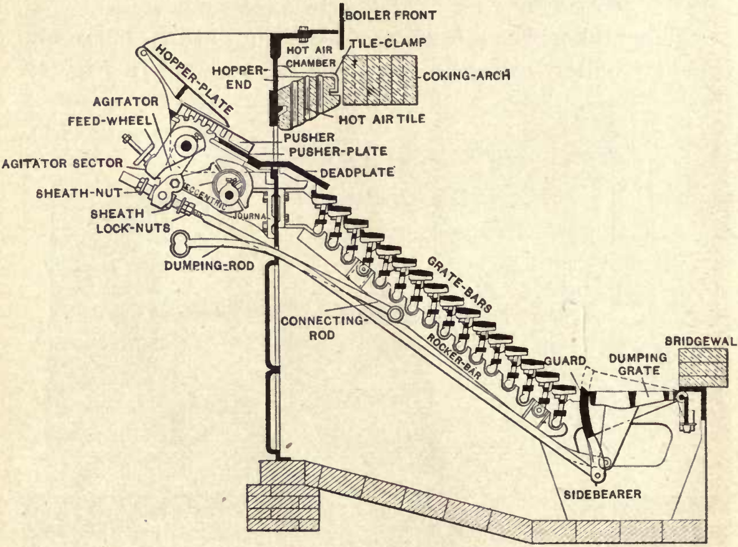


FIG. 27.

plate ribbed on its under side, which bolts to the web. These fuel plates carry the bed of burning coal, and being wearing parts are made detachable to facilitate repairs. The webs are perforated with longitudinal slots, so placed that the condition of the fire can be seen at all times without opening the doors; and free access had to all parts of the grate to assist, when necessary, the removal of clinker.

For bituminous coal a coking arch of fire brick is sprung across the furnace, covering the upper part of the grate and forming a reverberatory furnace and gas producer, whose action is to coke the fresh fuel as it enters and release its gases. These, mingling with the heated air supplied in small streams through the perforated tile above the dead plate, are quickly burned in the large combustion chamber above the bed of incandescent coke on the lower part of the grate.

Q. What is the construction of the Wilkinson automatic stoker?

Three views are shown of this stoker, Fig. 28 being a front view, Fig. 29 the furnace view, Fig. 30 a sectional

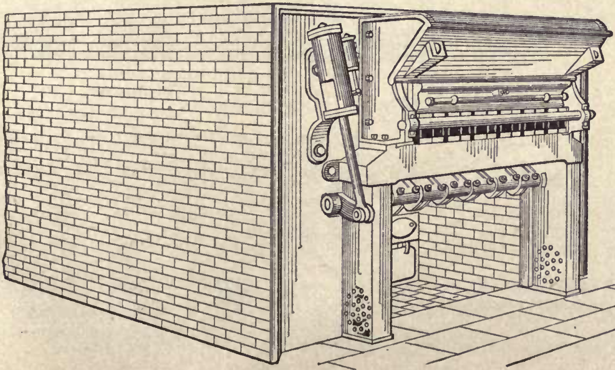


FIG. 28.

elevation, to which has been added a *résumé* of the process of combustion. The grate bars are hollow, as shown in Fig. 30. They are placed side by side and inclined toward the bottom of the furnace at an angle suited to the repose

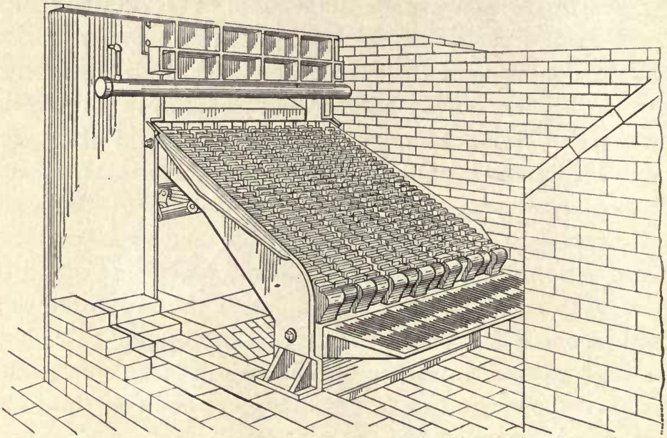


FIG. 29.

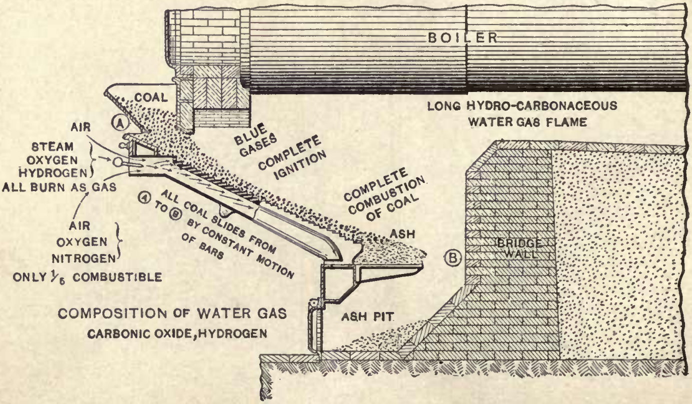


FIG. 30.

of the fuel, and they are so constructed as to admit of sufficient air through the fire to the combustion chamber. The lower ends of these grates slide upon and are supported by a cast-iron box. This box has finger grates, about 15 inches long, secured to its rear face. Throughout the inclined length of each grate is cast a succession of steps. Through the rise of each step a vent of about ¼ × 3 inches is provided to admit air through the fire to the combustion chamber. A continuous back and forth motion is given the grates for the purpose of maintaining a uniform thickness of fire by a gradual descent of the fuel from the top to the bottom of the grate, depositing the clinker and ash on the stationary grate shown projecting from the cast-iron box forming the lower bearing bar at the ash pit. The accumulated ash is pushed off this stationary grate into the ash pit by the reciprocating motion of the bars, to be removed in the usual manner.

The blast is saturated steam through a nozzle of $\frac{1}{16}$-inch diameter, giving an induced current of air controlled by a regulating valve.

The motor for operating the grates may be either hydraulic or steam attached to each stoker, or a small engine may be employed for operating several stokers.

Q. What are the details of construction of the Ayres and Ranger mechanical stoker?

This stoker is shown in connection with the flue of an internally fired boiler in Fig. 31; a front elevation is shown in Fig. 32. This stoker belongs to the class known as coking stokers. The coal is fed into the hopper shown at the front end of boiler; at the bottom of this hopper is a series of propeller-shaped blades joined to and radiating from a sleeve mounted on a shaft, which is caused to rotate intermittently at any desired speed; and by these the coal is propelled through an opening in the furnace, on to an inclined guide plate, and from this upon a perforated dead plate below, and by this means the coal is equally distributed across the front of the furnace, forming a bank or ridge of coal to be there coked, and to be then carried by moving fire bars to the back of the furnace. The fire bars are so arranged that every other one is stationary; the moving bars are actuated by a cam or other device by which an up-and-down vertical movement may be imparted to the front end of the bars. This cam in continuing its movement then engages the end of the moving bar and pushes it in the direction of the arrow, Fig. 31. The end of the bar being tapered rides up on the roller at the rear of the furnace, and thus raises that end of the bar. By the return motion of the cam the bar is brought back to its normal position. This continual motion of the mova-

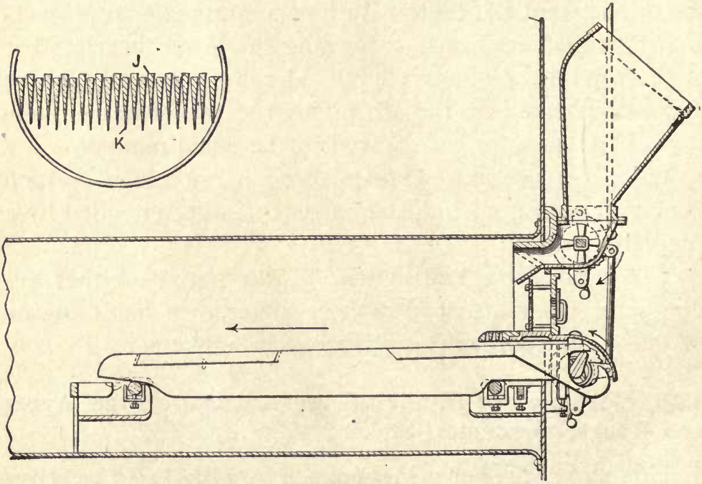


FIG. 31.

ble bars carries the fuel gradually from the front to the rear of the furnace. It also serves to break up the clinkers, clear the air spaces, ultimately depositing the exhausted portion of the fuel into the ash or clinker pit at the end of the bars in the usual way.

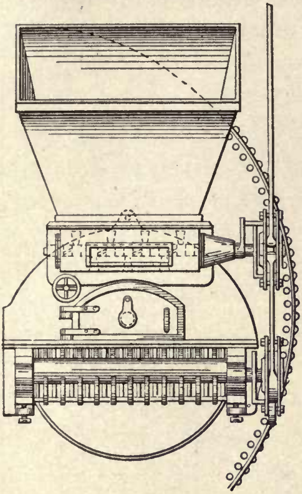


FIG. 32.

Q. What are the principal details of the Murphy furnace ?

A cross-sectional elevation of the Murphy self-feeding furnace is shown in Fig. 33. The grate bars are arranged on opposite sides of the furnace chamber and incline downwardly toward the centre, the fuel being introduced at the top and fed down toward the middle, in which there is a device for mechanically removing the clinkers. A fire-brick arch spans the combustion chamber. A coal magazine is located at each side of the furnace and is provided with discharge openings and coal pushers. The latter have a reciprocating motion imparted to each by a rock shaft, rack, and pinion.

The inclined grate surface is composed of stationary and movable grate bars, alternately placed. The upper ends of the stationary grate bars abut against a compensating plate, which permits the bars to expand readily with the heat. The movable grate bars are connected to vibrating levers, from whence they derive their motion. In connection with this motion the movement of the rock shaft imparts motion to the coal pushers in a manner to feed the coal just in proportion to the requirements of the furnace.

The crushing and removal of the ashes and clinkers is effected by a clinker bar at the bottom of the grates. The clinker bar is provided on the outside with teeth which extend spirally around the bar, and the approximate inner edges of the grate bearers are provided with similar teeth to aid in crushing the clinkers when the clinker bar is rocked.

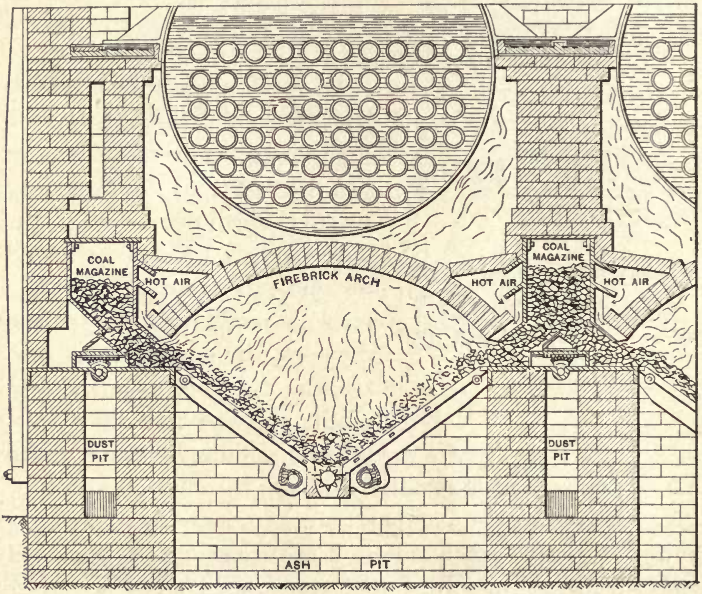


FIG. 33.

The furnace is especially adapted for the use of small sized bituminous coal and slack, which is put into magazines at the side of the combustion chamber. Air is admitted through a register at the front, passes through flues up over the arch, and there takes up heat from the front, arch, and arch plate, passing down through the small openings in the arch plate to the coking fuel. It is claimed that this furnace has a coking capacity sufficient to feed 50 pounds of coal per square foot of grate per hour.

On the side of a battery of boilers is placed an engine with proper gearing for operating a reciprocating bar across the outside of the entire front, and to which all the working parts are attached by links.

Q. What is the construction and operation of the American stoker?

This stoker belongs to the not very numerous class of underfeeding devices. The illustration Fig. 34 shows it in longitudinal section, and Fig. 35 in cross-sectional elevation. The stoker consists of a coal hopper, a conveyor pipe, a screw conveyor, a coal magazine under the furnace level, a wind box, and a reciprocating piston motor with a ratchet-feed attachment for operating the screw conveyor. The rate of feeding coal is controlled by the speed of the motor, this being effected by the simple means of throttling the steam in the supply pipe to the motor.

The coal is fed into the hopper either by hand or by overhead conveyor mechanism. It descends of course into the receptacle below, in which is contained the screw which conveys it into the magazine in the furnace proper. The continuous supply causes the coal thus fed to overflow on both sides, and spread upon the side grates, shown in Fig. 35. As the fresh coal approaches the fire in its upward course it is slowly roasted or coked. The gases released from the coal mingle with the incoming air through the tuyeres and are burned, leaving only the incandescent coke for delivery on the side grates.

The non-combustible ash and clinker is deposited on the side grates by the constant upward feeding of the coal. One open grate against each wall admits air mixed with

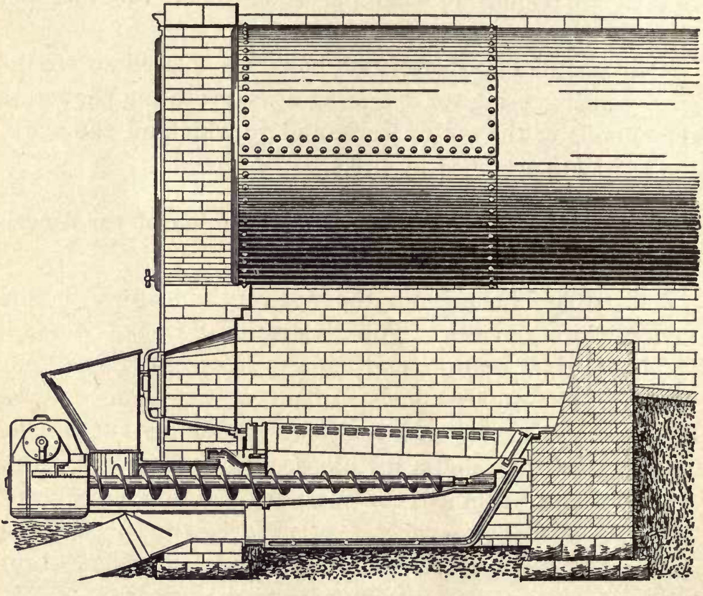


FIG. 34.

the exhaust steam from the motor, which serves to prevent the clinker sticking to the walls. To clean, a slice bar is run along over the grate, the clinker raised and drawn out with a hook. The central part of the fire is never disturbed, as the constant feeding does all the stoking necessary. The fire doors are never opened except when cleaning.

This stoker requires a blower for supplying the air necessary for combustion, the air pressure varying from 1 to 1½ ounces, depending upon the quality of fuel and depth of fire. The latter is ordinarily from 14 to 18 inches thick above the tuyere blocks.

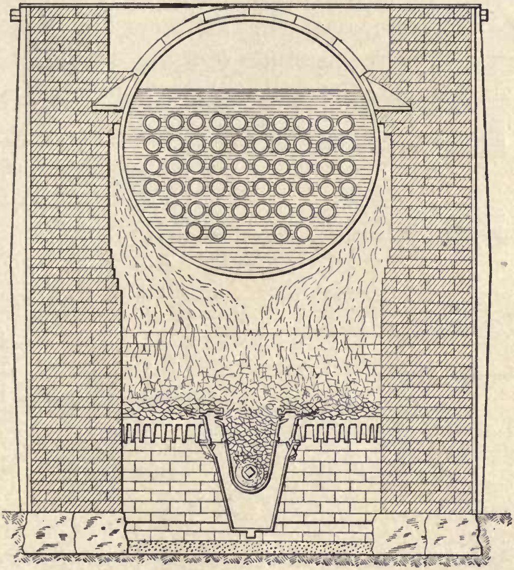


FIG. 35.

Q. What is the construction and operation of the Jones underfeed mechanical stoker ?

This stoker is shown in sectional elevation in Fig. 36, and in cross section on the line A–B in Fig. 37. The stoker consists of a steam cylinder or ram, with a coal hopper, outside of the furnace proper; a retort or fuel magazine inside the furnace, on the sides of which are placed tuyere blocks for the admission of air. The retort also contains at its lowest point an auxiliary ram or pusher which causes the coal to be evenly distributed. This pusher is in a position where the fire never reaches.

The retort is first filled with coal, on a level or a little above the tuyere blocks. The fire is then started along each side of the retort, the air chambers reaching to the tuyere blocks being opened. As soon as the fire is well under way, the air chamber opening is closed and the blower started; the fire will then be built up very rapidly.

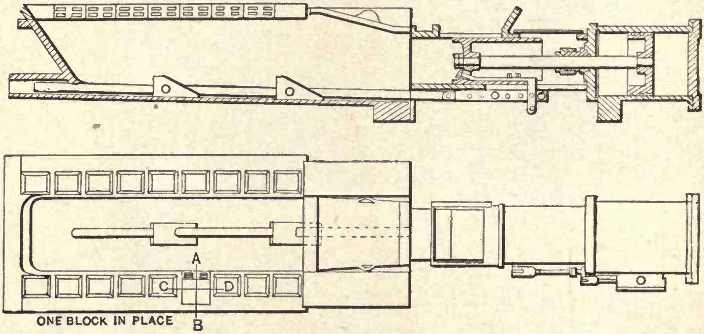


FIG. 36.

Coal being in the hopper, and the ram plunger on its forward stroke, when more coal is needed the plunger is shifted back by moving the lever, coal then falls in front of the plunger, steam is admitted to the cylinder and the plunger forced forward, pushing the coal into the retort. Coal is pushed into the retort as needed to replenish that consumed.

Air at low pressure is admitted into the air chamber and through the tuyere blocks, over the top of the green fuel in the retort, but under and through the burning fuel; the result is that the heat from the burning fuel over the retort slowly liberates the gas from the green fuel, this gas being thoroughly mixed with the incoming air before it passes through the burning fuel, resulting in a bright, clear fire, free from smoke. The retort being air tight from below, and the fuel being in a compact mass, the air moves upward and combustion takes place only above the air slots. The retort is thus kept cool and not subject to the action of the fire. The incoming fresh fuel from the retort forces the resulting ash and clinker over the top of the tuyere blocks on to the side plates, from which they can be easily removed at any time without interfering with the fire in the centre of the furnace.

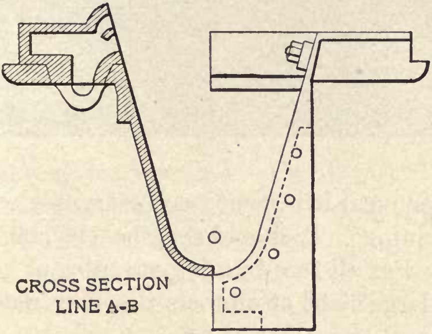


FIG. 37.

Q. What is the construction of the McClave grate?

This grate is shown in Fig. 38, which represents the shaking movement, and Fig. 39, which represents the cut-off movement. The shaking movement is adapted for breaking up a soft coal fire when it cakes, or to remove fine ashes from a hard coal fire when there is but little or no clinker formed. In this movement there is no increase of openings during the operation, the bars keeping equidistant from each other in their travel from the normal position downward and return.

The cut-off movement is used principally for fine anthracite fuel, such as culm, buckwheat, and pea coal. Small anthracite fuels should not be shaken or stirred up in any manner until it becomes necessary to give the fire a thorough cleaning. It should then be cleaned as quickly as possible. For all free-burning varieties of coal that do not produce large slabs of clinkers this movement removes the clinkers and ashes from the bottom of the fire quickly and thoroughly without opening the fire door.

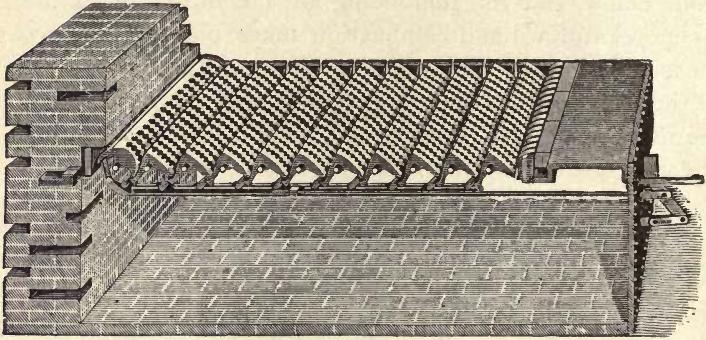


FIG. 38.

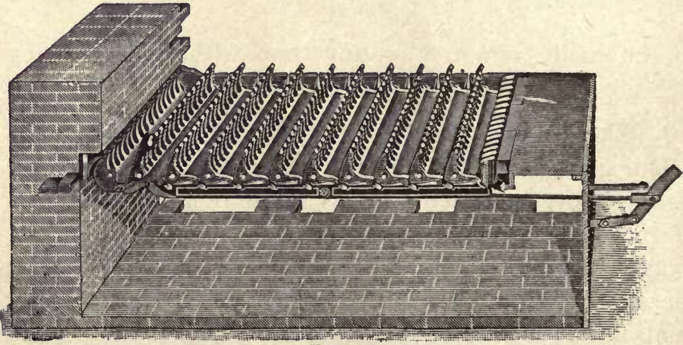


FIG. 39.

Single lever connections are used for grates less than 5 feet in length, and the width of the grates is generally made in two or more rows. To clean a fire when the fuel clinkers badly, the unconsumed fuel of one row can be shoved over on the other row, and with the full cut-off movement the clinkers and ashes can be cut down into the ash pit; then shove all the unconsumed fuel on to the clean row of bars and cut the clinkers down the same as before; then redistribute the unconsumed fuel over the whole grate.

Q. What are the details of construction of the Fisher apparatus for feeding bagasse to steam boiler furnaces?

The feeding of bagasse to a boiler furnace by Fisher's method is shown in Fig. 40, which consists of an inclined chute down which the bagasse is fed. At the lower end and near the furnace front is a roller having radial blades, which roller is driven by any suitable mechanism. Between this roller and the furnace front is a perforated steam or air-blast pipe extending across the chute. There is attached to the furnace front a pivoted door extending over both the perforated blast pipe and bladed roller. A second door is hinged to the one just referred to and is adapted for closing the chute. These doors fit in between the sides of the chute, and thus being practically air tight prevent the escape of any sparks which might otherwise fly out from the mouth of the furnace.

The bagasse after being discharged upon the chute slides down to the bladed roller, which is constantly rotating and which feeds the bagasse along over the perforated pipe, from which latter let it be supposed there is escaping a blast of air or steam under pressure. As the material passes over this perforated pipe, the blast of air or steam escaping therefrom lifts the material and scatters it in all directions over the furnace grate, thus rendering it impossible for any large mass of the material to fall in one spot and there retard combustion. Besides the function of

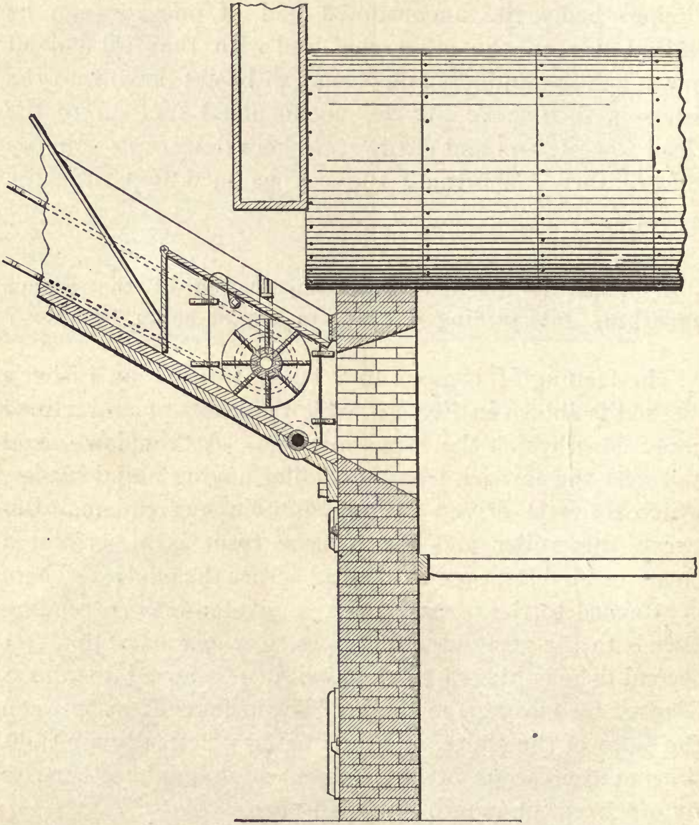


FIG. 40.

scattering the finely divided particles of the fuel over the grate bars the blast of steam or air will create a better draft in the furnace, and thus materially assist combustion.

Q. What are the details of construction of Heggem's boiler for burning straw?

This boiler is particularly adapted for agricultural use, and is of the usual portable type; but the object of the present design is that the boiler shall be capable of burning alternately either straw or solid fuel, as may be desired,

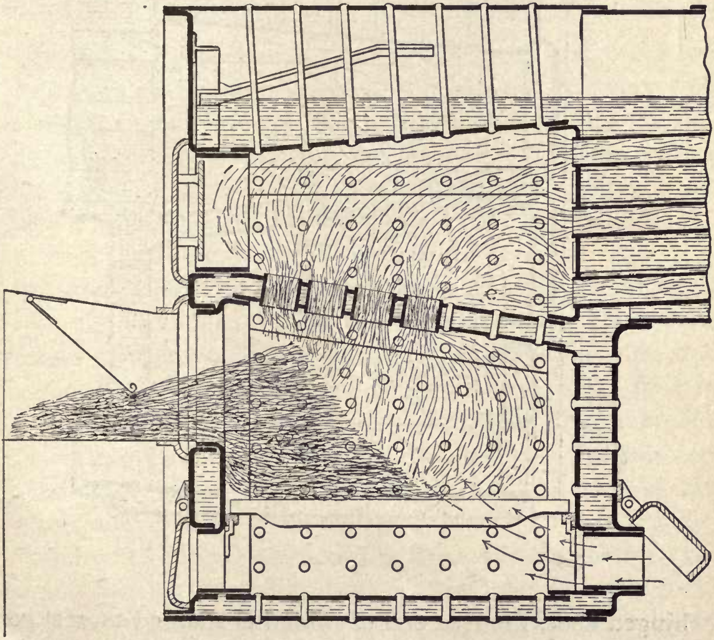


FIG. 4

the fire box being provided with a draft apparatus that may be made applicable in each case for the particular fuel burned. This boiler is shown in sectional elevation in Fig. 41, and shows the arrangement of dampers when using straw as fuel, in which case a funnel is fitted to the usual fire-door opening; this funnel being provided with a hinged door, the free end of which is adapted to rest continually against the straw as it is forced into the fire box. The damper under the barrel of the boiler being raised, as shown in the engraving, causes the draft to flow into the fire box, as indicated by the arrows, causing the

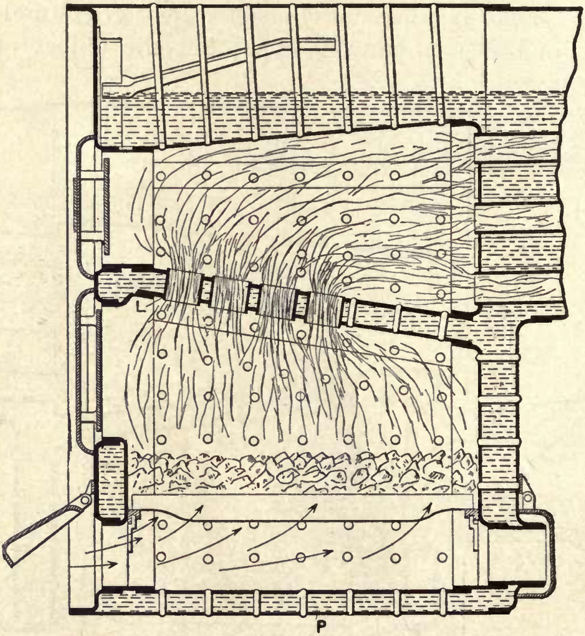


FIG. 42.

straw to burn at the ends, as it is forced in through the funnel.

Fig. 42 shows the same boiler with the straw-feeding funnel removed, the regular fire door in place, the closing of the damper under the barrel of the boiler and the opening of the damper or ash-pit door under the fire door, and the use of coal as fuel.

Q. What are the details of construction of the Allen and Tibbitts apparatus for feeding comminuted fuel to furnaces?

A vertical section of a steam boiler furnace showing the apparatus in operation is given in Fig. 43. The operation consists in spraying the fine particles of fuel into the furnace by means of rapidly revolving distributing rollers. On the circumference of the rollers are provided ribs, which are fixed in diagonal lines from the middle to the ends of the rollers. These rollers are given rapid revolving motion, and are designed for throwing the fine fuel into the furnace by their centrifugal force. There is a rotary vertical spiral conveyor enclosed in a pipe and stepped in the bottom of a coal supply pit in the floor in front of the furnace. At the top of this pipe are branch pipes leading from the head of the vertical pipe and extending over and communicating with the interior of the boxes containing the revolving rollers, by which the fuel is delivered into the furnace in a shower or spray in the upper part of the combustion chamber, so that the particles will catch fire in transit and be consumed or partly consumed before falling upon the fire floor, the draft being through the grated doors, thus avoiding the opening of the doors for feeding purposes. In instances when the fire dust is used no grate bars need be employed in the floor; but as a general rule, when the coarser grades of fuel are used, grate bars should be used for providing a draft upward into the fire.

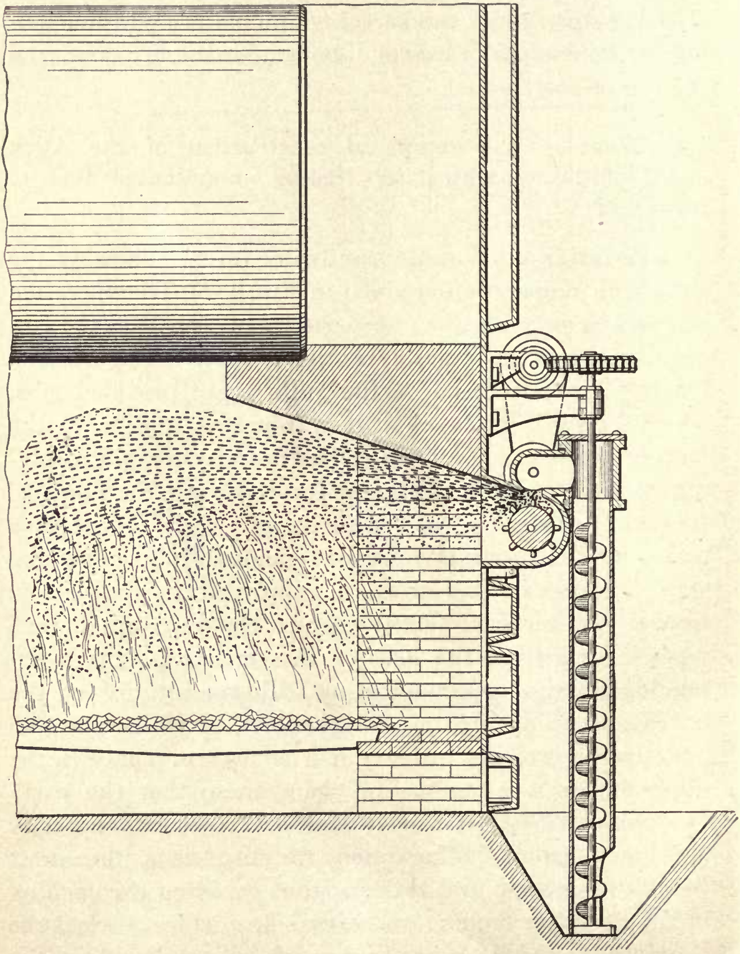


FIG. 43.

Q. What are the details of construction of the Rogers apparatus for feeding fine fuel?

This apparatus is designed for feeding fine fuels, such as rice hulls, cotton hulls, sawdust, etc. A cross-sectional elevation of a boiler furnace with the apparatus also in section is shown in Fig. 44. This apparatus consists of a hopper placed at the side of the furnace and near the front end of the boiler, a steam blast pipe, and a nozzle for distributing the fuel over the grate. This nozzle is made with one straight side placed parallel to the boiler front; the opposite or rear side is formed obliquely toward the bridge wall. A sliding gate opens or closes communication between the hopper and the furnace. For the purpose of superheating the steam used in the blast nozzle, its supply pipe passes along the side of the boiler, to the rear and return, thence into the discharging pipe.

The fire may be started in the furnace in any approved way and with any desired fuel. The sliding gate is then opened, as is also the steam cock, whereupon the hulls or sawdust resting in the hopper and chute are caused by the suction of the steam blasts to discharge through the nozzle into the furnace, over the fire bed in thin sheets, in the manner illustrated in the engraving. Should the supply become excessive, the sliding gate and steam cocks are closed. When the gate is closed, no back blast through the hopper can occur, and danger from fire in the hopper or chute will be prevented at such times as the feeder may not be in use.

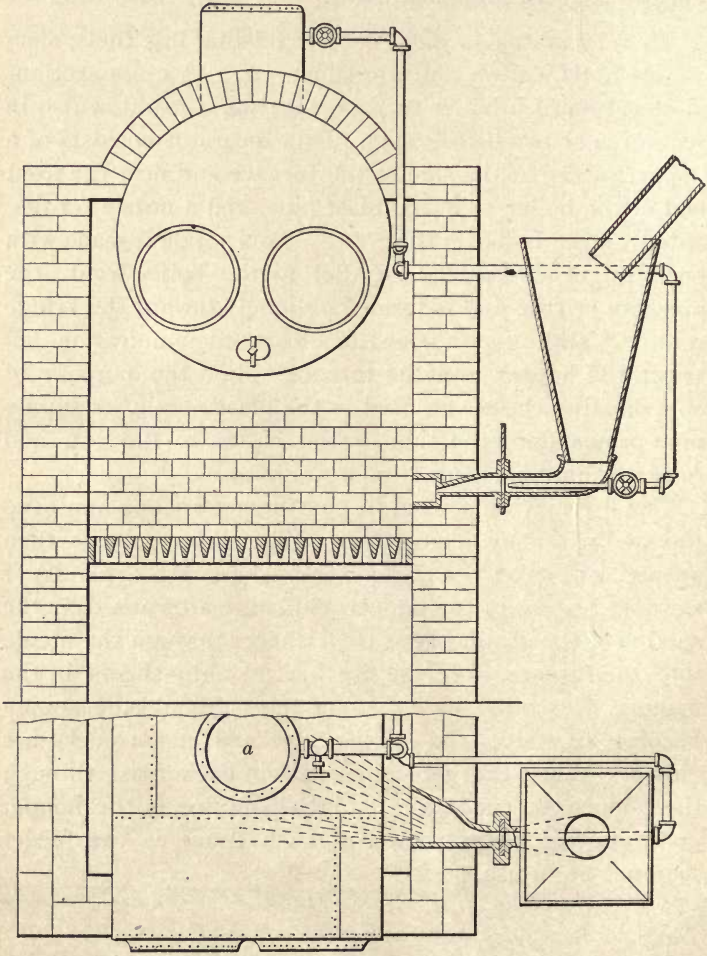


FIG. 44.

CHAPTER XI.

LOCOMOTIVE FURNACE DETAILS.

Q. What are the ordinary limitations of a locomotive fire box?

The width of the fire box is limited to the distance between the frames inside of the driving wheels; the necessary outside clearance; and the thickness of the two water legs from out to out. The inside width will be about 41½ inches. The length of the fire box will depend somewhat upon the size and type of the boiler and the arrangement of the axles for the driving wheels; in general, this length is limited to about 10 feet.

Q. What are the objections to a long fire box?

Mainly the inconvenience occasioned in firing, as the proper distribution of coal by means of a hand shovel, through an opening some 12 x 16 inches, to a point 10 feet distant, is one requiring great skill. In the case of caking coals, the longer the fire box the more difficult is the task of breaking up the fire through the fire door opening.

Q. What are the advantages of large grate area?

It lowers the rate of combustion, and thus permits the use of inferior grades of fuel which could not be economically employed in locomotives having a small ratio of grate area to total heating surface.

For locomotives of great power, a large grate surface is essential, even under the highest economical rates of combustion, and for this reason boilers with an extended grate surface, such as the Wootten, become more or less a necessity.

Q. What is the rate of combustion in locomotive boiler practice?

The rate of combustion will vary with the type and size of locomotive, the contour of the railroad, the weight and speed of trains, etc. From 80 to 125 pounds may fairly represent ordinary practice, but the extreme limit to economical combustion appears to be about 150 pounds per square foot of grate surface per hour; a higher rate of combustion is apt to lift the coal from the grates and loss of efficiency occurs.

Q. What is the special function of the fire-brick arch in locomotive fire boxes?

The supplying of fuel in a locomotive fire box is an intermittent operation; consequently, the temperature of the fire is constantly changing from high to low, depending upon the quantity of fresh fuel laid upon the fire. The fire-brick arch gets white hot by reason of its position over the fire; this stored-up heat assists in driving out the volatile combustible matter in the fuel; as there is almost always an excess of air passing through the fire, the gases driven off by the combined heat of the fire and the incandescent fire-brick arch are raised to a very high temperature while in intimate contact and mixture, combustion ensues under the most favorable conditions for completeness, economy, and high temperature. The products of combustion are then diverted to the rear of the fire box, where a change of direction is necessary before passing forward toward the tubes.

By its use the combustion of bituminous coal is improved, smoke is prevented, cinder sparks are arrested, the flame and gases from the fire are cleaner, that is, carry less soot and impurity, the dragging of the fire is reduced, and the fuel is, therefore, used in a more economical manner than in the ordinary fire box.

Q. What is the usual construction of the brick arch in locomotive fire boxes?

The brick arch consists usually of fire-brick tiles laid on tubular bearing bars. Fig. 45 shows one form of construction in which the tubular bearing bars are secured to the tube sheet at one end, the other end being secured to the crown sheet. There is a water circulation through these pipes which prevents their burning out in the furnace. Another design is shown in Fig. 46, in which the tubular bearing bars extend the whole length of the fire box, the water connection being such that a constant circulation is had. The fire-brick tiles extend across the fire box from side to side; the arch is lowest next the tube

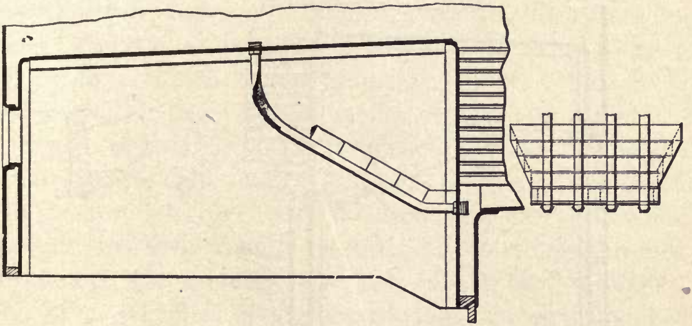


FIG. 45.

sheet, and inclines upward as it approaches the rear end of the fire box; the length of the arch and angle of inclination vary with the size of the fire box, but the rear end must always be high enough properly to feed and care for the fire.

Another method of construction is to build a curved arch across the fire box from side to side, as shown in Figs. 68 and 69.

Q. Does the brick arch cause leaky flues?

This question, raised by M. D. Corbus, in *Locomotive Engineering* (January, 1900), is accompanied by the statement that practice has demonstrated positively in some locomotives that a brick arch in a fire box causes the flues to leak, beginning directly after the arch is put in, and the engine does hard labor. The arches as described by him are in three pieces, placed lengthwise in the fire box and resting on four plugs screwed into the side sheets. The brick is cut away next the flue sheet and side sheets, to allow cinders and fine coal to drop down to the grates;

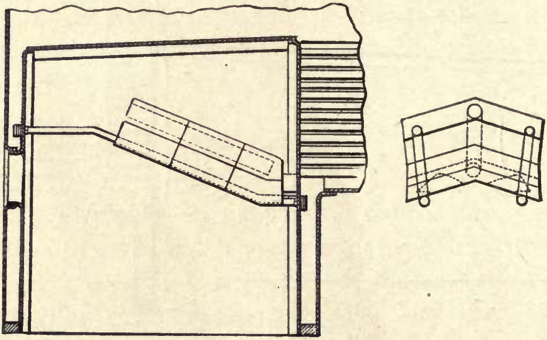


FIG 46.

only about 6 inches of each corner of the arch rests against flue sheet, from 6 to 10 inches below the flues.

In replying to the above, George B. Nicholson, through the same journal, asks: What causes flues to leak? Is it not a too rapid expansion and contraction of the metals of the flue sheet and flues? Then will a brick arch cause this expansion and contraction? Suppose an engine with a brick arch to be fired up and gradually heated to the working point, the heat of the fire box probably being between 2,000° and 2,500° F. The brick arch attains and will hold this temperature for a considerable time after the fire has been knocked out of the engine. Now this brick arch, representing an almost fixed number of heat units, is placed within from 4 to 6 inches of the flues and flue sheet; there is nothing about this that is likely to cause an undue variation in the temperatures of either. The real reason is that the fire is not maintained under the flues as it should be, quite frequently getting into such a condition that cold air is drawn rapidly through the grates and up through the flues; the flow may last but a few seconds, still long enough considerably to reduce the temperature of the metals; it is then cut off by the application of a shovelful of green coal when the great, almost permanent heat of the arch will cause the temperature to rise much more rapidly than would be the case in waiting for the coal to ignite, and the heat of the fire cause the change. This, being repeated from time to time, starts the flues to leak; the engine is brought in, the arch knocked out and condemned, when the trouble was not the arch, but in the method of firing.

If brick arches are put in with just enough space between the arch and flues to permit of the free circulation of the gases, and at the same time not to allow the opening to become blocked with cinders, and high enough that a good fire can be kept under them with reasonable ease, a decided improvement in steaming qualities will be secured, as well as lessened fuel consumption and increased life of the flues.

Q. What kind of grates are commonly supplied locomotive fire boxes?

The present practice is confined almost wholly to shaking grates, because of the facility afforded for cleaning the fire on the road, and for dumping the contents of the fire box at the end of the trip.

Q. What is the construction of the tubular water grate?

The water grate consists of tubes extending from the tube sheet in the fire box to the opposite sheet at the rear, as shown in Fig. 47. These water tubes are placed side by side across the width of the fire box with such interval between them, for air space, as shall best adapt them for the fuel to be used; they usually incline slightly, to give

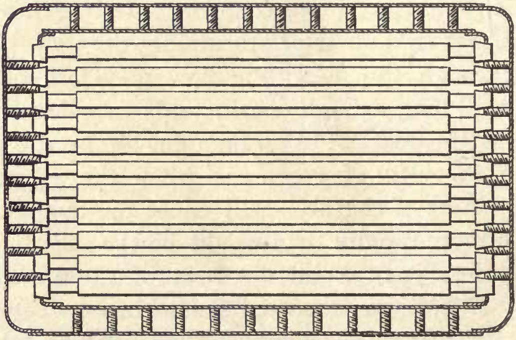


FIG. 47, A.—Plan.

better circulation than when laid horizontally. The circulation of water through these tubes prevents their burning out, unless they become filled with scale, which is a not infrequent occurrence.

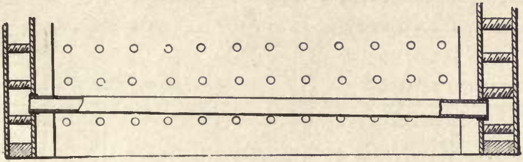


FIG. 47, B.—Longitudinal Section.

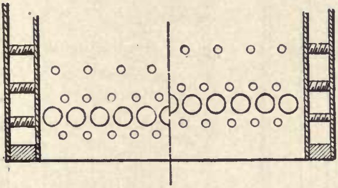


FIG. 47. C.—Cross Section.

Q. What are the ordinary details of a locomotive firebox grate?

For coal-burning locomotives the grates in use include the plain grate bars with drop plate for the removal of ashes, etc., at the end of the run; such a grate is shown in Fig. 48, in which 1 represents the grate bars; 2, a dead plate; 3, the end holder; 4, the drop plate; 5, the drop-plate handle; 6, the drop-plate handle supports; 7, the drop-plate shaft; 8, the drop-plate shaft bearing.

Shaking grates are now in very general use in locomotive practice. The ordinary details are much the same for all grates, but there is a wide diversity in minor details. Fig. 49, from Grimshaw's "Locomotive Catechism," shows the salient points of shaking-grate mechanism as ordinarily applied to locomotives, in which 1 represents a series of grates, each consisting of a central bar with fingers passing each other, with suitable air space between,

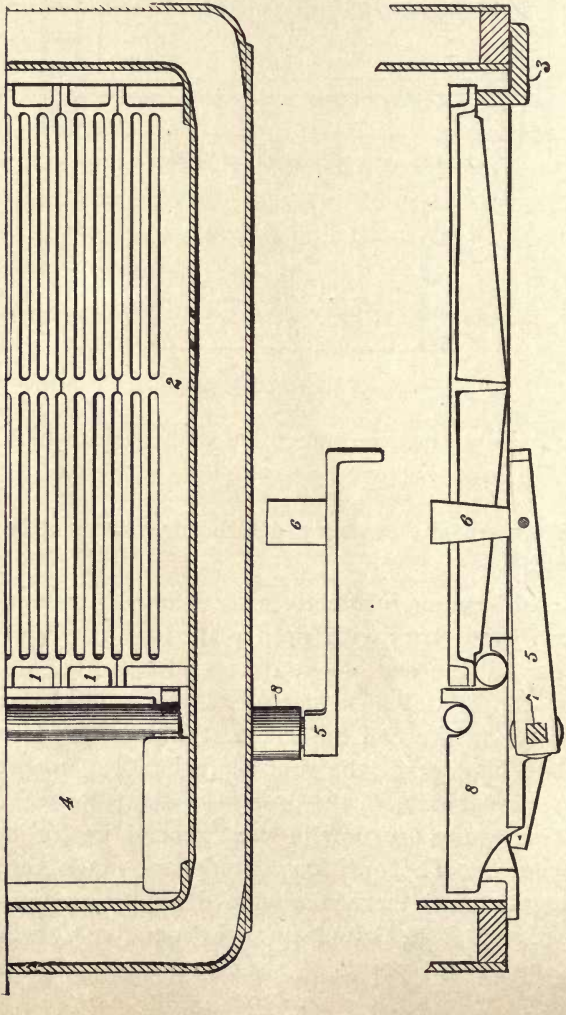


FIG. 48.

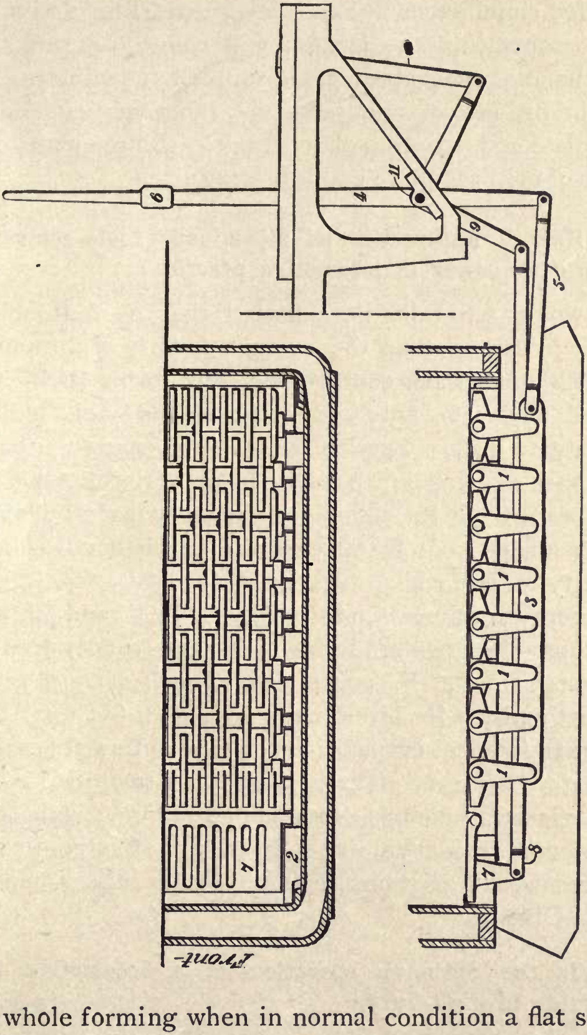


FIG. 49.

the whole forming when in normal condition a flat surface for the fuel; 2, the frame carrying the rocking grates; 3, a connecting bar by which all the rocking-grate bars are operated simultaneously; 4, a lever extending up into the cab for operating the grates; 5, a connecting link; 6, a lever handle, removable; 7, a drop plate to facilitate cleaning the fire box of unburned fuel, ashes, and clinkers; 8, drop-plate rod; 9, drop-plate crank; 10, drop-plate crank handle; 11, drop-plate crank bearing.

Q. How do anthracite and bituminous coals compare in evaporative power in locomotive practice?

It would naturally be expected that as anthracite is richer in carbon than the average quality of bituminous coal (82 and 58 per cent, respectively, being the mean of several analyses), anthracite coal should yield a higher evaporative duty. Service trials, however, prove that the difference existing is wholly in favor of bituminous coal, fully bearing out the assertion frequently made by firemen, that a tender load of soft coal will go further than a like quantity of hard coal.

Recent experiments on the N. Y., L. E. and W. R.R., with high-class modern locomotives, gave evaporative rates from and at 212° F. per pound of coal, of 5.68 for anthracite and 7.2 for bituminous.

The theoretical evaporative power of anthracite coal containing 82 per cent of carbon and 7.4 per cent of volatile matter is 15.25 pounds, from and at 212° F., while that of bituminous coal containing 58 per cent of carbon is about 12 pounds, due allowance being made for other component parts (Dixon).

Q. Is the ordinary operation of a locomotive boiler favorable to high duty?

The operation of a locomotive boiler militates against a high duty; its exposure to constantly changing atmospheric conditions cannot but be a fruitful source of loss, and the remarkable differences of opinion with regard to boiler proportions, grates, and draft appliances, prove that some boilers, at least, do not have a fair chance to perform their functions in an economical manner. The efficiency of a well-designed bituminous coal-burning boiler may be taken at: $\frac{7.2 \times 100}{12} = 60$ per cent, which, considering the disadvantages under which it labors, is a creditable figure (Dixon).

Q. What evaporative performances are had of locomotive boilers in practice?

From a number of locomotive tests made, rather to test the coal than to test the locomotive, evaporations are shown, according to W. O. Webber, from 6½ to 8½ and 9 pounds of water per pound of combustible, and the fuel consumed per square foot of grate surface 90 pounds, and running from there to 136 pounds. These engines were small; one on which most of the tests were made was an engine with a fire box only 3 feet wide by 5 feet long, with a boiler 42 inches diameter, 114 2-inch flues, 2½ inch exhaust nozzle. Engine 15″ x 22″, and only 740 total square feet of heating surface. The standard American locomotive will develop on an average a horse-power for each 27 pounds of water evaporated when not overloaded; the evaporation under ordinary conditions will run from 5½ to 6½ pounds of water per pound of coal.

Q. What are some of the practical results of single-shovelful firing?

Mr. Angus Sinclair's observations while riding on locomotives on the B., C. R. and N. Ry., where firing tests were being made, was that the coal was broken to small lumps, and the fireman kept up the necessary supply of fuel in the fire box by putting on a single shovelful at a time. When the engine with a long freight train was pulling hard on a long grade, the coal thrown into the fire box averaged 5 shovelfuls per mile, each containing about 18 pounds of coal, which was 90 pounds to the mile. On the level it was about 5 shovelfuls for every two miles. The fire always looked clear and bright, and all the engines steamed admirably. The engineer always filled up the boiler well going into a station, and then shut off the injector for a few minutes in starting, to let the fireman make up a good fire. As soon as the train was going the engineer hooked up the engine as far as he could to avoid tearing the fresh fire to pieces. When the engine was running for a grade, a fairly heavy fire was gradually put upon the grates, and it was maintained during the heavy pull; but was made up by single shovelfuls, or, at most, two shovelfuls at one time. There were no special smoke-preventing appliances used; the fire boxes were supplied with a brick arch, but no means were employed to admit air above the fire.

Q. Is there a saving in coal by light firing in locomotive practice?

Mr. Fred McArdle, an engineer on the B., C. R. and N. Ry., writes that the single-shovelful method of firing has brought about a great saving in coal, making less work for the fireman, and more pleasant for the engineer. The engine is not popping off continuously while standing at stations. The cab and train are not smothered in dense black smoke from the time the engine is shut off until the train is again started. Prior to the time that light firing was adopted passenger engines were fired with three to five shovels of coal to a fire; the same engines are now fired with one shovel of coal to a fire, and at no time exceeding two, and they only when starting away from stations and going over heavy grades. At the present time engines are running from 155 to 250 miles without taking coal, and savings of 2 to 3½ tons of coal are now effected on each round trip. The trains are from 3 to 6 coaches; engines 15 x 24 to 17 x 24 inches. Through freight engines on all divisions are 18 x 24 — 6 wheel connected, fired with one and two shovels to a fire, rarely throwing out black smoke between stations; they run 96 to 105 miles with one tank of coal. These trains save 2 to 4 tons of coal each round trip over the former method of firing.

Q. What is the best method of firing a locomotive?

Referring again to Mr. McArdle's communication, he made the excellent suggestion that to make a success of light firing the engineer and fireman must work together. The fireman should carry a clean, light fire, keeping the fire thin enough for plenty of air to be admitted for combustion. This he cannot do if his engineer, in starting, allows his lever to remain at full stroke for a quarter of a mile before he begins to cut it back. Under such conditions the fireman with a light fire would have very little fire left in his box by the time the train had moved half its length.

Under the old method of firing, a shovelful of coal was put in each corner of the box, and one or two down in the centre; that method of firing has been demonstrated to be a mistake, as they now fire the same engines with one or two shovels of coal at a time.

Q. What are the noticable improvements in connection with light firing and boiler repairs?

Mr. Henry Raps, foreman boilermaker for the B., C. R. and N. Ry., reports freer steaming qualities; longer life and more uniform wear of brick arches; a decrease in the number of burned and broken grates; a decrease in the number of bent and broken ash-pan dampers and their fastenings; a fewer number of stopped-up flues; a longer life of nettings and stacks; the total absence of burned smoke arches and extensions, and the non-accumulation of cinders in the front end.

Q. What is the direct saving upon the brick arches by light firing?

On account of fires not being so thick in light firing, there is not as much liability to throw coal against the arch. As there is less fire to clean out at the end of the trip, there is less danger of the arch being struck by the clinker bar; for these reasons brick arches last longer. A comparison may be instituted thus: 51 brick arches applied to locomotives under the old method of firing averaged 7,863 miles per arch.

Forty-five brick arches under the single-shovelful method of firing averaged 9,703 miles per arch, a gain of more than 23 per cent.

The average cost, including maintenance, of one arch under the old method of firing was $6.41; an average cost of $8\frac{15}{100}$ cents per 100 miles. The average cost, including maintenance, of one arch under the light firing was $4.61; an average of $4\frac{75}{100}$ cents per 100 miles.

Q. What are the principal furnace details of the Wootten boiler?

Previously to the invention of the Wootten boiler by

John E. Wootten, in 1877, it had been the general practice to make the fire boxes of locomotives of a width determined by the distance between the inner faces of the opposite driving wheels; Wootten's invention consisted in increasing the area of the grate by arranging the fire box and grate above and extending them laterally over the driving wheels, without raising the body of the boiler to any material extent. Figs. 50 and 51 are reproductions of the original patent office drawing, in which it will be seen that the fire box A laterally overhangs the driving wheels B, B′; the grate D also overhangs the wheels and extends across the interior of

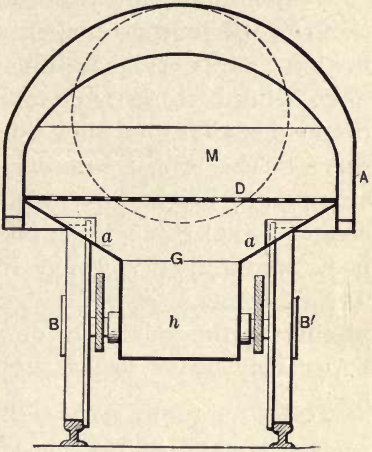


FIG. 50.

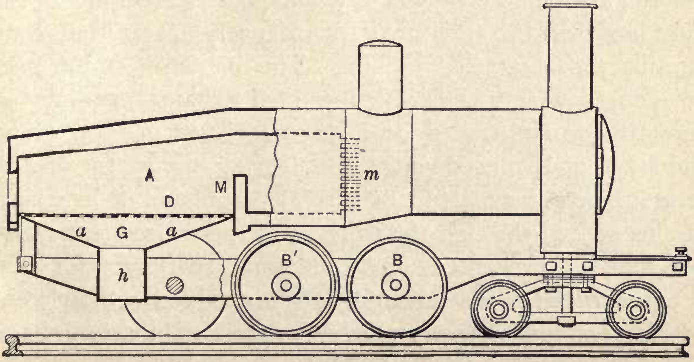


FIG. 51.

the fire box. The ash pan G collects the ashes and directs them into the receptacle *h*.

A bridge wall M extends across the fire box or combustion chamber and may be either a water space or made of fire brick; this bridge wall plays an important part, for the grate being necessarily elevated, a corresponding elevation of the body of the boiler would be demanded in the absence of the bridge, in order that the tubes *m* might be at a proper height above the grate, to prevent the direct escape of fuel through the tubes, and this elevation of the body of the boiler would render the boiler topheavy. The arrangement of the bridge wall, as shown, permits the placing of the tubes low down so that the body of the boiler may be as low as usual, and, therefore, not topheavy.

Q. What advantages were attained by the fire box designed by Wootten?

Important advantages are attained by the increased grate-bar area due to the lateral extension of the fire box. The fuel can be consumed in comparatively thin layers more gently and economically, and with less injury to the fire box than the thick mass of intensely heated fuel in an ordinary contracted fire box. The increased grate area dispenses with the usual contracted exhaust opening for creating an artificial draft, a larger exhaust opening being adopted, and, consequently, the tearing up of the fuel in the fire box is avoided, the forcible expulsion of hard particles of fuel through the tubes, and the consequent waste of fuel, is prevented, and the usual spark-arrester dispensed with; these advantages are attained without rendering the locomotive topheavy by the combination of the laterally extended fire box with the bridge M.

Q. Was the combination of bridge wall and combustion chamber adhered to in the Wootten boiler?

In 1886, Wootten patented another fire box in which the combustion chamber, which formed so prominent a feature in the original patent, was dispensed with, and a bridge wall only employed; this design in one of several forms is shown in Figs. 52, 53, and 54, and consists of a fire bridge located wholly within the fire box and supported

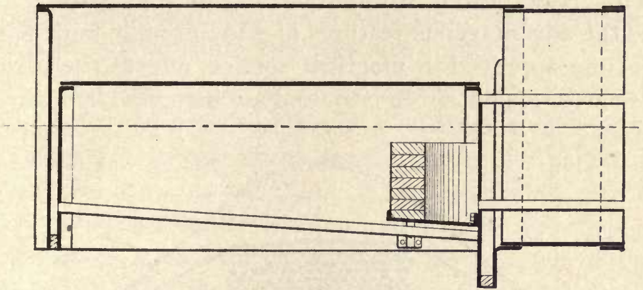


FIG. 52.

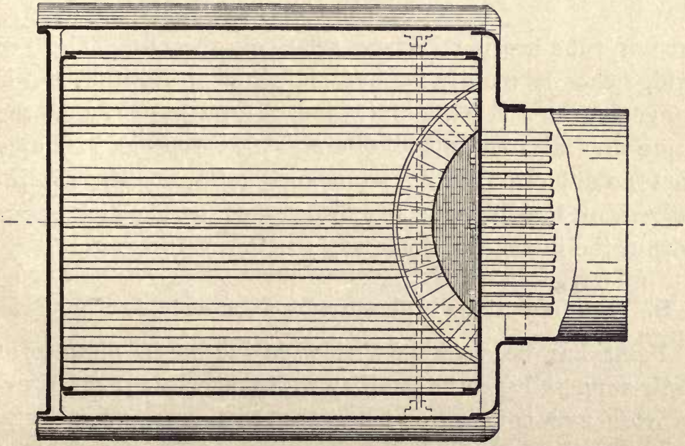


FIG. 53.

above the grate in such relation to the tube sheet as to form a space or chamber in the rear, which is closed at the bottom and open at the top, for the free passage of the products of combustion from the fire box to the tubes.

This later design, while retaining to a substantial degree the advantageous features of wide fire-box boilers, by this time approved in practical service, affords the advantages of a reduction in cost and an increased amount of area of tube-heating surface relatively thereto. The fire bridge can be readily applied and fitted in position and is conveniently accessible for renewal and repair, and the grate area attainable in boilers of this type is so ample that no objection results from such curtailment as is involved in locating the fire bridge and combustion space within the fire box and above a portion of the grate.

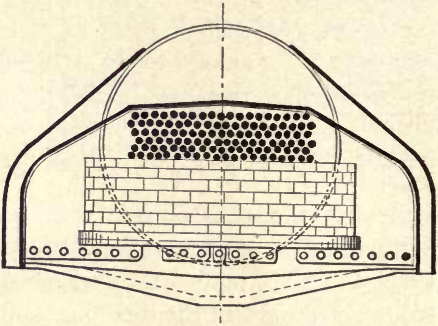


FIG. 54.

Q. What are the disadvantages of a wide fire box?

Fault has been found with wide fire boxes because of their supposed greater liability to leakage by reason of expansion and contraction; but the real reason for leaky joints, broken stay bolts, etc., which caused much annoyance with the earlier Wootten fire-box designs, was due rather to the flat surfaces and other defects in the general design, than is traceable to large grate area, apart from other considerations.

Q. What advantages are claimed for the division of the wide fire box into two separate furnaces?

In many instances, especially where the fuel employed is of low grade, free burning, and contains a considerable percentage of hydrocarbons tending to evolve smoke, the use of two furnaces has been deemed desirable, provided it can be accomplished without undue expense or complication of construction, or incidental curtailment of grate area to any objectionable degree. Two furnaces permit of a better system of alternate firing, and thus reduce the intensity of smoke when burning bituminous coals of low grade, than is the case with a single fire box under ordinary conditions.

Q. What are the general details of the fire box of the Barnes locomotive boiler?

This boiler is of the wide fire-box type, in which a laterally extended fire box and a combustion chamber are provided. At the rear end of the combustion chamber is a water wall, which is open at the bottom to the water space in the waist below the combustion chamber, and extends a sufficient distance above the bottom of the combustion chamber to serve as the forward boundary wall of the bed of fuel on the grate (see Fig. 55). The interior of the fire box is divided into two separate and independent furnaces, by a central longitudinal water wall, which is closed at bottom by a water-space bar, and at its front end is open at bottom to the waist of the boiler and to the

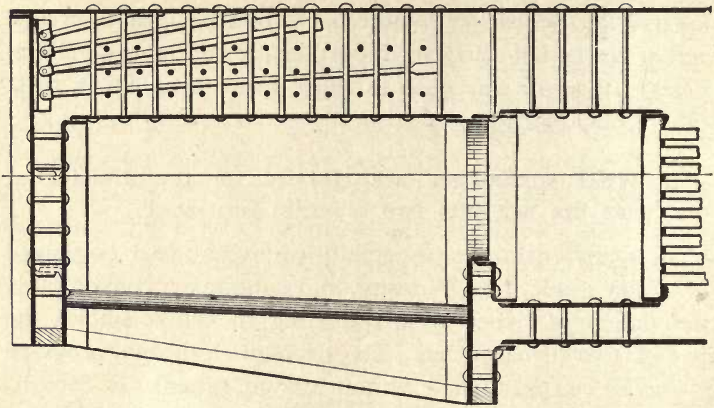


FIG. 55.

water wall above referred to, Fig. 56. In the case of a double combustion chamber, as in Fig. 57, the central

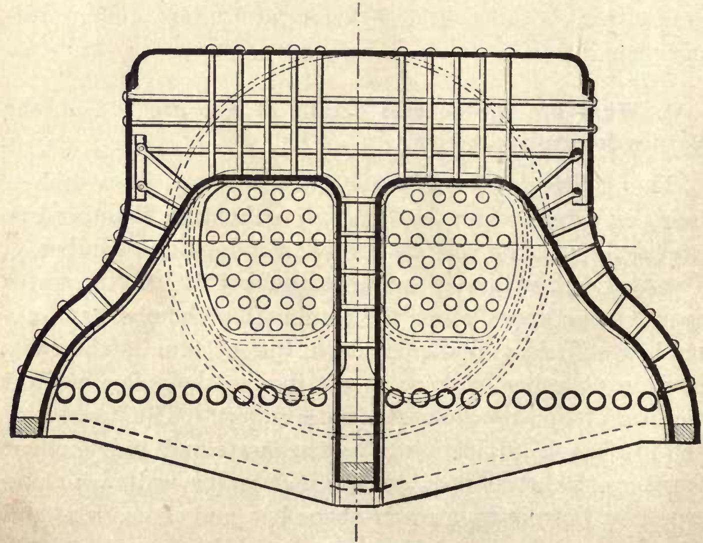


FIG. 56.

water wall is open to the waist at both top and bottom. The side sheets of the water wall, in the middle of the furnace, are connected at their upper ends to the crown sheets of the furnaces, or may be made integral with the crown sheets as shown in the engraving. Fig. 57 shows in plan the double combustion chamber, and Fig. 58 a single combustion chamber common to both furnaces. A

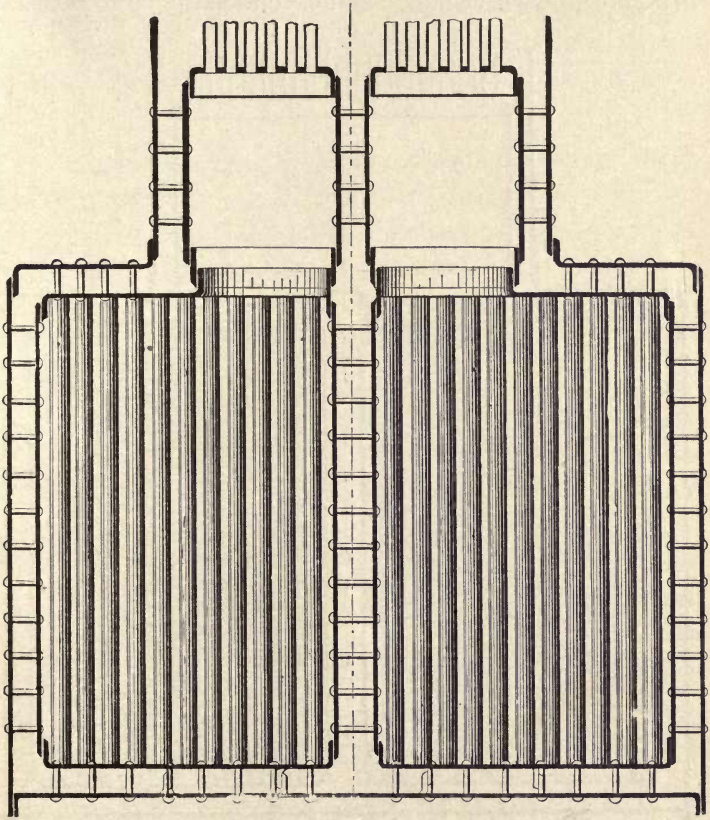


FIG. 57.

material increase of fire-box heating surface is provided by the central water wall. By the use of the two independent furnaces, the fire may be kept in better condition than is practicable with a single and exceptionally large furnace.

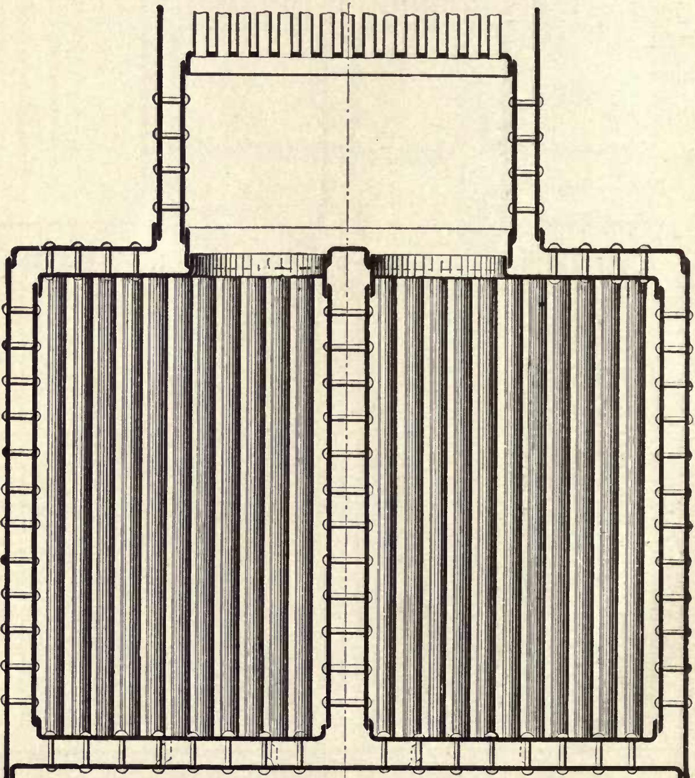


FIG. 58.

Q. What is the best modern practice in the means adopted to increase the production of steam by increased draft in locomotives?

Mr. C. H. Quereau, Denver and Rio Grande R.R., obtained data for the Sixth Session of the International Railway Congress, from the Motive Power Departments of railroads owning some 15,000 out of more than 36,000 locomotives in use in the United States, Canada, and Mexico; these results are given in the following ten questions.

Q. What evaporative results are had in average locomotive practice?

Coal, with evaporative results varying from 10.76 to 3.10 pounds of water per pound of coal, is the almost universal fuel, though in the West, where the quality of the coal is poor and the cost high, fuel oil is used successfully.

Q. What is the present tendency as between single or double exhaust pipes?

The single exhaust pipe is evidently the preference of most roads and apparently is displacing the double pipe. There has been a very decided shortening of the length of the pipe during the past ten years, notwithstanding that the average diameter of the smoke box must have increased in the same period. Because of the very general adoption of this change and the considerable amount the pipes have been shortened, it seems reasonable to assume that it must have been noticeably beneficial.

Q. What is the most efficient form of exhaust tip?

The tip shown at *b*, Fig. 59, is essentially that recommended by the Master Mechanics' committee. That 60 per cent of the roads reporting use this form as standard is presumptive evidence that it is the most efficient form. The tips, *c* and *d*, vary but little from *a* in the shape of the exhaust and the absence of a shoulder, which must produce back pressure. If these are classed with *b*, the result is that 84 per cent of the tips have no shoulder. A reasonable interpretation of these facts is that tips with shoulders are less efficient than those without. There is one advantage in the shouldered tip; namely, that it will not gum up by the accumulation of oil from the exhaust.

There are good reasons for the extensive use of the single exhaust tip, which presupposes the use of a single exhaust pipe. The following table gives the areas in square inches of different tips:

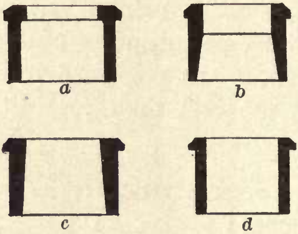


FIG. 59.

AVERAGE EXHAUST TIPS.

Cylinders.	Single.		Double.	
	Diameter.	Area.	Diameter.	Area.
17 × 24 in.	4¼ in.	14.2 sq. in.	3⅛ in.	7.7 sq. in.
18 × 24 "	4½ "	15.9 "	3⅜ "	8.9 "
19 × 24 "	4¾ "	17.7 "	3⅜ "	8.9 "
20 × 24 "	5 "	19.6 "	3⅜ "	8.9 "
20 × 26 "	5 "	19.6 "	3½ "	9.6 "

The area of the single exhaust tip is shown to be roughly twice that of the double tip. It is reasonable to assume that each is as large as it can be made, and produces a satisfactory amount of steam under service conditions; also that two cylinders exhausting alternately through a single tip will meet less resistance, hence produce less back pressure, than the same cylinders exhausting each through a separate tip half the area of the single tip; hence, that the single tip is more efficient than the double. This conclusion would be unwarranted unless it had been shown that with the single exhaust pipe and tip and a partition of the proper height between the exhausts, the exhausts from one cylinder do not interfere with those from the other. The use of a bridge or bar in the exhaust tip is universally condemned, except as a temporary expedient.

Q. What is the best form of stack?

The cast-iron choke, or tapered stack, is the choice of 80 per cent of the roads reporting, and growing in favor.

There is also an increasing tendency to reduce the diameter of the stack, the cylinders remaining the same. The diamond stack is standard on but one railroad system, and it is a significant fact that two roads, which at one time were under the control of the system on which the diamond stack is standard and inherited it, have begun to discard the diamond stack for the tapered design. From these facts it seems reasonable to conclude that experience has shown the diamond stack to be less efficient than either the straight or taper form. With the diamond stack the exhaust steam cannot escape in a direct line because of the cone, and the netting area through which the gases must escape is less than with either of the others.

There appear to be no rules for varying the stack dimension for different sizes of cylinder. It is evident that the rule given by the Master Mechanics' committee concerning the best relation between the stack and the exhaust tip has had considerable influence. See Fig. 66.

Q. What is the function of the diaphragm in the smoke box?

The chief function of the diaphragm, which is used only with straight or tapered stacks, is to regulate the distribution of the draft through the flues and grates. They are used incidentally to extinguish and break the sparks coming through the flues. The Michigan Central has increased their efficiency in this respect by lining the surfaces of the baffle plates against which the sparks strike with steel netting, having 2½ x 2½ meshes per square inch, and wire 0.109 inch in diameter. These functions apply both to the diaphragms wholly back of the exhaust pipe and to those extending in front of the exhaust pipe. The advantage claimed for the latter over the former is their action in sweeping practically all the cinders from the smoke box. The Chicago Great Western has found that the diaphragm when extending forward of the exhaust pipe causes excessive wear to both this and the steam pipes.

Q. What advantages are to be gained by the use of draft pipes?

The use of draft pipes with extension front ends has increased considerably during the past few years. There can be little reason for doubt, judging by the reports, that their use materially increases the draft, which must result in increasing the efficiency of the exhaust by allowing an increase in the diameter of the tip and the consequent reduction in back pressure. On the other hand, there is no doubt that this advantage is accompanied by occasional delays for lack of steam, due to the petticoat pipes working out of adjustment or becoming warped by heat. Such delays are frequently due to poor designs, and more frequently to carelessness on the part of roundhouse men whose duty it is to adjust these parts, but a certain amount of such careless work can never be entirely obviated, because of the class of men to which this work must almost necessarily be intrusted. Again, it is entirely probable that a considerable number of these delays are not known to the heads of the motive power departments.

Q. What is the object in the smoke-box extension of locomotives?

The original purpose for which the extended front end was designed was to serve as a receptacle for cinders (see Fig. 63). That it is not very efficient in accomplishing this end was shown by the results of a test with the mounted locomotive at Purdue University. The locomotive tested had 17.5 square feet of grate area, and a front end 52 inches in diameter by 64 inches long, including the extension; cylinders, 17 x 24 inches; exhaust tip double, each 3 inches in diameter. The average speed in miles per hour was 25, and the duration of the test six hours, making it equivalent to a run of 150 miles. As the locomotive was mounted on wheels controlled by friction brakes, and did not move in relation to the earth, the opportunities for making accurate observations and measurements were all that could be desired. The results showed that 75 pounds of sparks were retained in the front end at the end of the run, while 294 pounds had passed through the stack.

The fact that sixteen out of twenty-five roads reporting have shortened their extensions an average of 17 inches in the past ten years shows quite conclusively that experience has demonstrated it does not accomplish the end for which it was designed, or that the gain in draft by shortening is more valuable than the original purpose.

Q. Does the efficiency of draft appliances in locomotives vary with locality or with quality of fuel used?

The statement has frequently been made that draft appliances which have been proved by extended experience and experiments to be the best adapted for a given quality of coal or section of the country do not, and will not, prove at all adapted for similar classes of coal in other sections, and that it is necessary to use entirely different designs. This seems an unreasonable proposition.

The sole purpose of the draft appliances is to produce a vacuum by means of which the necessary oxygen for the combustion of the fuel is provided, and properly to distribute this. The primary source of the forced draft necessary with locomotives is the force of the exhaust steam, and the most efficient design of draft arrangements is that which will produce the required vacuum with the least loss of power, that is, with the least back pressure. Assuming that such a design has been devised and its efficiency established, it follows that it must be the most efficient whatever the locality in which it may be used, and whatever the grade of coal, and the only reasonable change in the design which should be allowed is to increase or decrease the vacuum to meet the necessities of the case by increasing or decreasing the back pressure.

No claim is made that this most efficient arrangement has been designed, but it seems reasonable to believe it is within the range of possibility, and when designed should be universally the most efficient. For instance, it having been shown that the shorter the front end, the more efficient the exhaust jet is, this remains true the world over, no matter what the fuel or other conditions may be; as the most efficient method of regulating the back pressure has been shown to be by means of the tip, any design which fails to make the area of the tip less than that of every section between it and the cylinder must be faulty, wherever used.

Q. What conclusions were reached by Mr. Quereau regarding the means adopted to increase the production of steam by increased draft?

This topic naturally falls under two heads. The producing of the vacuum, and the distribution of the draft:

The Production of the Vacuum.

1. The most efficient means of producing the vacuum are evidently those which accomplish the result with the least back pressure in the cylinders.

2. These can best be determined with a locomotive on a testing plant where the conditions can be made those of regular service.

3. The proper basis for determining efficiency is that which compares the cause, back pressure, with the result, vacuum, and conclusions drawn solely from the vacuum obtained are of doubtful value.

4. The steam passages from the cylinder should be of ample proportions.

5. The exhaust pipe passages should gradually contract from the bottom to the tip, without abrupt curves.

6. The area of the opening through the tip should be less than that of any section between it and the cylinder.

7. The exhaust pipe should be single, with a partition but little if any higher than 13 inches, and the total

height as short as possible consistent with easy curves in the pipe and a proper arrangement of the netting, providing the height is not less than 19 inches.

8. The steam passage in the exhaust tip should be of the shape shown at *b*, Fig. 59.

9. Crossbars in the tip lessen the efficiency of the exhaust jet.

10. The front end should be as short as possible.

11. With front ends more than 60 inches in diameter, double draft pipes increase the efficiency, but careful designing and thorough workmanship are necessary to prevent them from warping and working out of adjustment. If they become displaced they are worse than useless.

12. With properly designed draft pipes it is probable that the greater the distance from the exhaust tip to the base, or choke, of the stack the greater the efficiency.

13. Either the taper or straight stack is more efficient than the diamond stack.

14. Probably the taper stack is somewhat more efficient than the straight, when the proportions of each are the best for any given case, because of the more easy approach and exit afforded the gases by the former.

15. The correct rules for the most efficient stack proportions are still open to question.

16. The theory of the adjustable exhaust tip is admirable, but the results of experience have been that those designs tried so far soon become inoperative. To be permanently successful a design should be automatic and beyond the control of the engineman—connected with the reversing gear, for instance.

17. As far as practicable the plane of the netting should be at right angles to the currents of gases passing through it, so as to offer as little resistance as possible.

18. The area of the openings through the netting should be greater than that through the flues, when possible.

The Distribution of the Draft.

So far as known there are no published results of the most efficient arrangement of diaphragm plates or draft pipes, so that conclusions concerning them are largely matters of opinion or personal experience.

19. With diamond stacks the distribution of the draft is best accomplished by the use of draft, or petticoat, pipes.

20. With extended front ends and straight or taper stacks the baffle plates are almost entirely depended on for regulating the distribution.

21. It seems entirely probable that with the extended front end a design may be developed which will leave out the baffle plates and depend entirely on draft pipes for the distribution of the draft, and that such a design would be more efficient than those which depend on the baffle plates.

Q. What conclusions were reached by Mr. Quereau regarding the means for preventing fires caused by sparks from the stack?

The following conclusions follow, in numerical order, the answers to the previous question:

22. The extended front end is of little practical use as a receptacle for cinders.

23. The baffle plates and netting should be so designed as to extinguish the sparks, break the cinders up, and then discharge them into the open air.

24. Systematic and competent inspection of front end arrangments, especially the netting, at regular intervals,

in connection with a permanent record showing the condition at the time of inspection and the repairs made.

25. The use of fire guards made by ploughing two or three furrows as far from the track as possible, and then burning over the ground between the tracks and furrows.

Q. What is the best method for utilizing the heat of exhaust steam in locomotives?

Mr. Quereau concludes that:

26. American practice has not yet developed a successful design for this purpose, though two roads are making the attempt.

27. The exhaust from the air pump is being successfully used by a number of roads to heat the water in the tender.

28. Because of the fact that most American locomotives are equipped with injectors, instead of pumps, for feeding the boiler with water, and that the injectors will not work with feed water hotter than about 120° F., it seems probable that the maximum benefits of heating the feed water by means of the air-pump exhaust will not be derived till the control of the temperature of the feed water is made automatic. Experiments with this end in view are being made.

Q. What are the details of construction of the Strong locomotive fire box?

The corrugated fire box adopted for the Strong locomotive boilers is a somewhat radical departure from the designs which have long been employed in locomotive construction. By reference to Figs. 60, 61, 62, it will be seen that there are two corrugated furnaces, which, by means of a junction piece, lead into a single corrugated combustion chamber, the latter terminating in the back tube sheet, from which the tubes proceed forward, as in the ordinary locomotive, to the smoke box.

The ordinary soft-coal burning boiler 52 inches in diameter has about 900 stay bolts, but this boiler has none whatever. There is not a rigid connection between the inner and outer parts of the boiler, and only two connections of any kind between the ends, the functions of which are to support the inner shell; there is nothing whatever to resist expansion and contraction, and thus hurtfully act upon the material. The corrugations doubtless contribute to freedom of movement, but even if they do not the

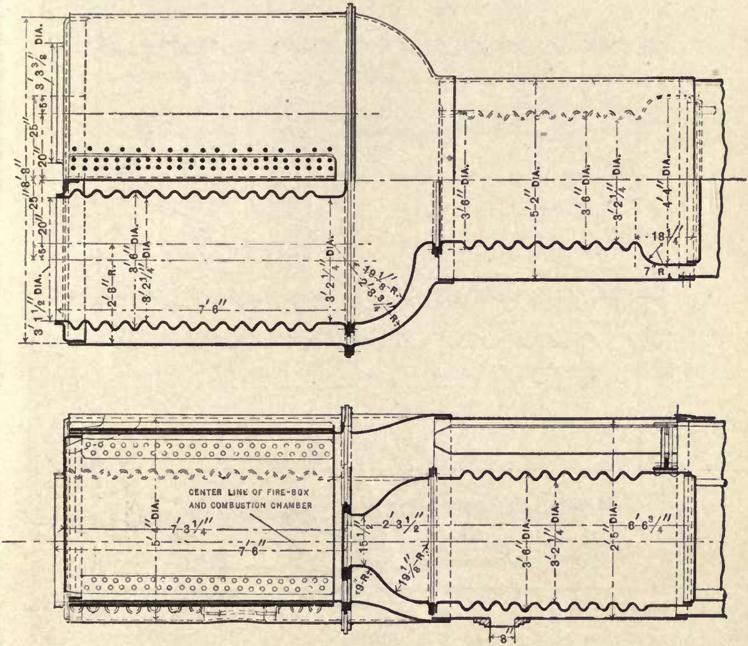


FIG. 60.

plates of the outer shell have the usual opportunity to buckle.

The crown sheet, being the upper half of a cylinder, easily parts with scale which may form upon it, and in this respect is in direct contrast with the common, flat horizontal crown sheets covered with bolts and crown bars, which are a sufficient means of anchoring all scale which forms upon the sheet, and equally efficient means of preventing inspection and cleaning. The crown sheet of this boiler is accessible from end to end; an inspector can crawl all over it, examine every portion, and remove any scale or dirt which may have lodged upon it. The cir-

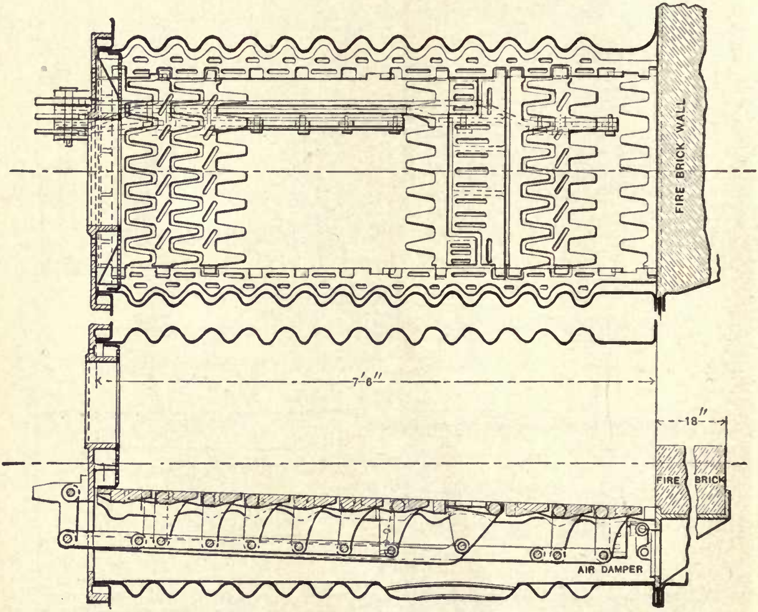


FIG. 61.

culation of water is entirely unimpeded; the water under the fire box is free to rise without any obstruction whatever.

The inner shell has no joint which is in contact with the fire, except that connecting the back tube plate and combustion chamber, which does not differ from common practice. The life of this boiler, as shown by actual experience, is three to four times that of the ordinary stayed boiler with the same surface, proving that the construction is not only theoretically correct, but practically in advance of boilers of the ordinary type.

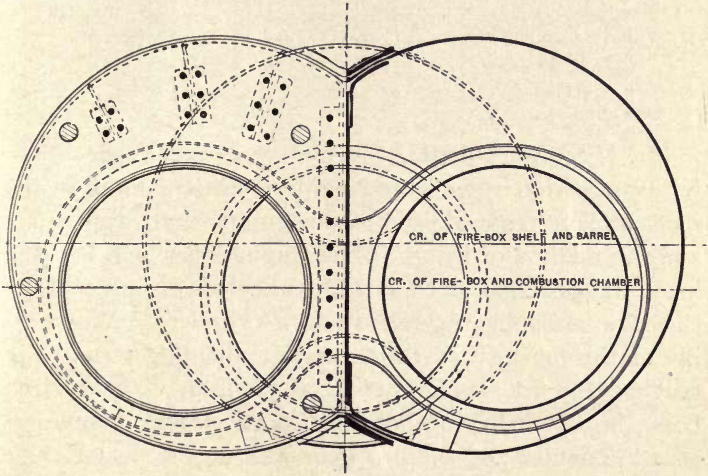


FIG. 62.

By the system of double furnaces with alternate firing, almost absolute perfection in combustion is secured, with total absence of smoke and almost total absence of fire from the stack, as a very light draft can be used, steaming freely with 2½ to 3 inches of vacuum, while the ordinary locomotive would require under the same conditions of working from 8 to 12 inches.

Q. How is the smokeless combustion of bituminous coal carried out in practice?

The smokeless combustion of bituminous coal is being very successfully carried out in locomotives on the Southern Pacific Railway, burning a coal known as Castle Gate, mined in Utah, analzying as follows:

Moisture	2.15	per cent.
Volatile combustible	39.10	"
Fixed carbon	50.75	"
Ash	7.40	"
Sulphur	.60	"

Mr. J. Snowden Bell, a locomotive expert, made a careful examination into all the conditions which obtain in that road, both as regards fire-box design and draft appliances, and the method of firing. The engine on which Mr. Bell made his observations was a 10-wheeled Schenectady, of the 1800 class, having 20 x 26 inch cylinders. When riding on the engine up a 108-foot grade, hauling 6 passenger coaches, the fire was kept clear and bright, without either being heavy or having holes in it; steam was maintained at 180 pounds, and the fire door was never closed. Mr. Bell says he never saw a soft-coal burning engine, either on a level or on a grade, which could be compared as to freedom from smoke; the light and frequent firing which was practised was, in his opinion, the correct and intelligent one, and involved less fatigue on the fireman than the ordinary heavy firing.

Mr. H. T. Small, superintendent motive power of the above road, contributes detail drawings of all the mechanical features which contribute to this result, as applied especially to 12-wheel, 22 x 26 inch locomotives.

Q. What are the details of the front ends of locomotives, Southern Pacific Railway?

The interior arrangement of front ends, shown in Figs. 63 and 64, is also practically the same as recommended by the Master Mechanics' Association in 1896, and is giving satisfactory results. It has been adopted as standard by the Southern Pacific, notwithstanding that it is necessary to use 7 x 7 mesh netting, and during the dry summer months 8 x 8 mesh netting in engines running through the valley district. The exhaust pipe and nozzle for the twelve-wheeler class are given in Fig. 65.

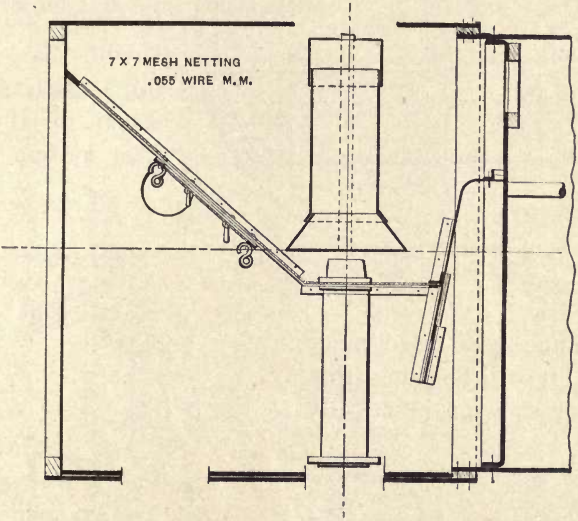


FIG. 63.

The standard cast-iron stack and saddle (Fig. 66) are used on several classes of engines, and the results obtained in service are entirely satisfactory. Although incorrect in theory, it has been fully demonstrated that it is really un

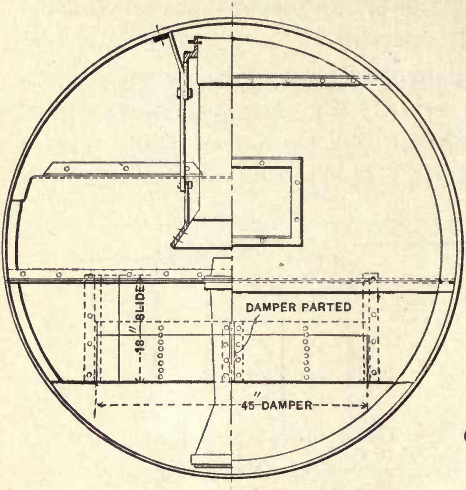


FIG. 64.

necessary to incur the expense of maintaining a special pattern of stack for each class of engines, and as a matter of fact the Southern Pacific has only three patterns of stacks for the entire system, and these have been used since 1890. It will be noted that the stack shown is practically

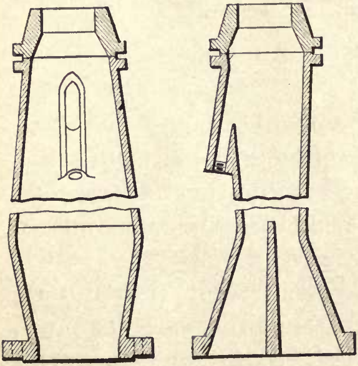


FIG. 65.

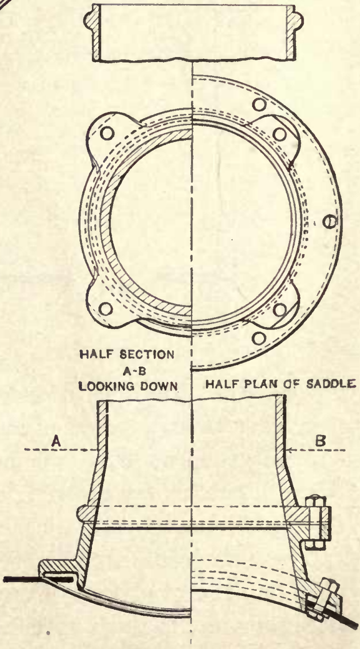


FIG. 66.

the same as that recommended by the Master Mechanics' Association in 1896.

Q. What are the details of furnace door on locomotives, Southern Pacific Railway?

The furnace door (Fig. 67) is used on all coal-burning engines, the door proper being in two sections. The upper section, commonly called the "trap," is left open continually while the engine is working, and through this opening, which is 6 x 15 inches for the large engines, the fireman charges coal into the fire box. It will be noted that the deflector, projecting through the door and opening into the fire box, is adjustable to any angle desired; it so guides the air admitted through the "trap" as to best aid combustion, and its proper position is determined very readily by the enginemen. It also serves as a check on

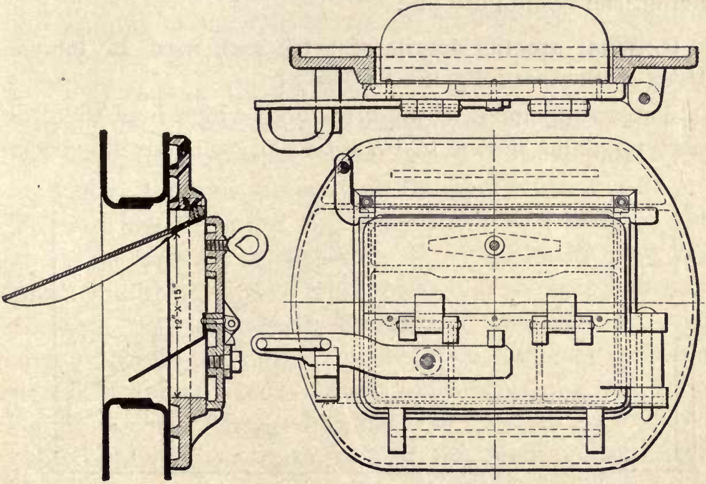


FIG. 67.

firing with large lumps of coal, or large amounts of coal regardless of size.

The small fire-door opening was a novelty to Mr. Bell, as it will be to others, but is obviously an excellent feature, and this, with the thorough and uniform distribution of air and support of fuel by Mr. Heintselman's latest design of grate, an effective ash pan, and proper front-end arrangements, are clearly the factors to which, with good firing, the results are due.

Q. What are the details of brick arch used in locomotives of Southern Pacific Railway?

The arrangement of the brick arch which is of the ordinary type and shown in Figs. 68 and 69 needs no special

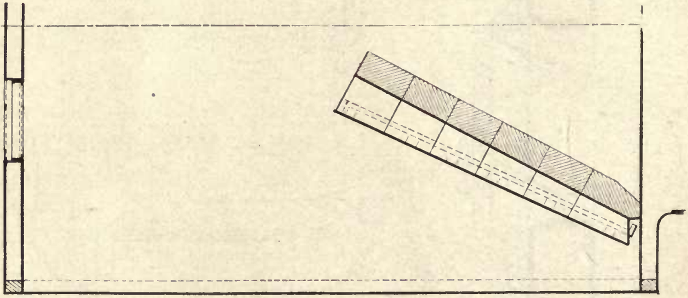


FIG. 68.

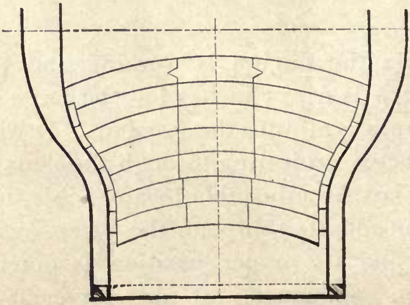


FIG. 69.

mention, excepting that it is considered an important factor, and helps to produce perfect combustion and economy in fuel consumption.

Q. What are the details of grate used in locomotives on Southern Pacific Railway?

The improved finger grates and bearings shown in detail in Fig. 70 are novel, as is also the manner of hanging the grates from the fire-box sheets. It will be seen that the hanging of the side bars is so arranged as to compensate for the expansion and contraction of the grate bars, and by means of the collar at the end of each trunnion bearing the grates are held central at all times, keeping the air spaces equally divided between the fingers. The air spaces through the body of the grate bar and fingers serve to distribute the air to the fire more evenly, and at the same time the thickness of the metal in the body and fingers is reduced to a minimum. The fingers being detachable, they can readily be removed and replaced when change of air openings or spaces between fingers is desired to suit different kinds of coal; or, in case any number of fingers become damaged in any way they can be replaced, thereby saving the remainder of the grate. The fingers are applied to the grate bars in the rough, or just as received from the foundry.

Q. What are the details of ash pan used on locomotives of the Southern Pacific Railway?

The general arrangement of the self-dumping ash pan (adapted to twelve-wheelers) operated by compressed air is shown in Fig. 71, and the application of air valves to the sides of the ash pan is shown in Fig. 72; these side valves are also worked by compressed air. This style of ash pan is considered an important improvement, and has resulted

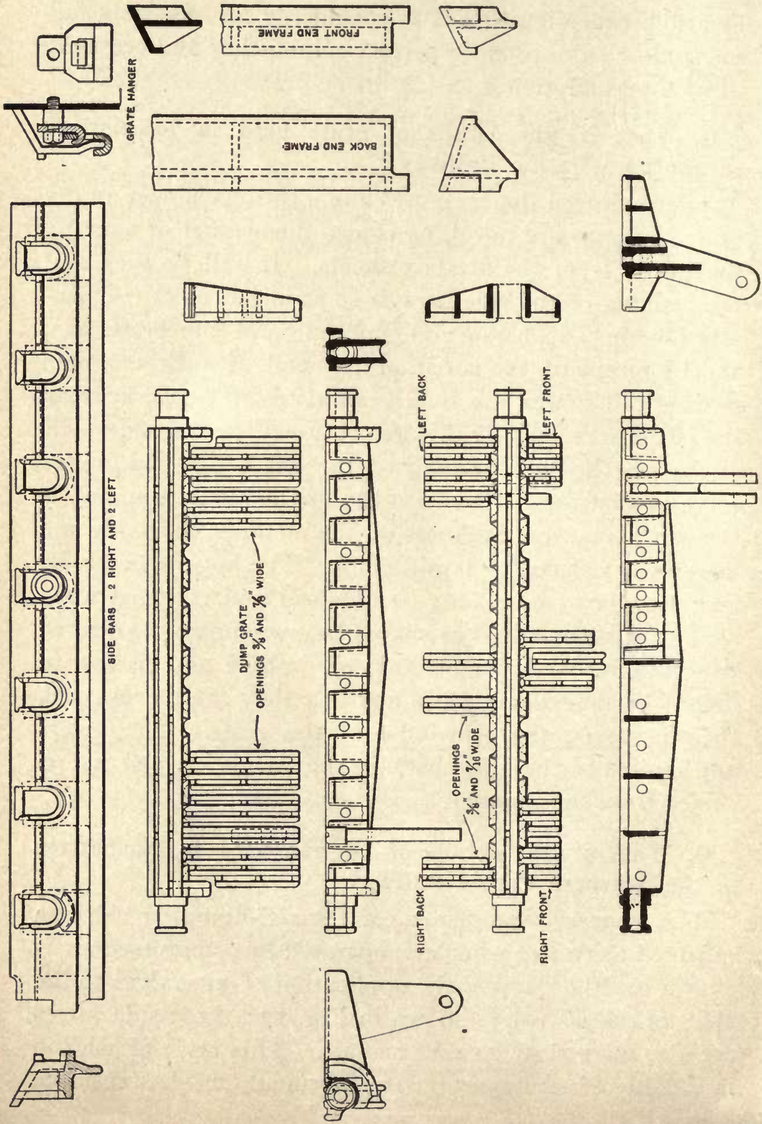

GRATE HANGER
FRONT END FRAME
BACK END FRAME
SIDE BARS - 2 RIGHT AND 2 LEFT
DUMP GRATE
OPENINGS 3/8" AND 7/8" WIDE
LEFT BACK
LEFT FRONT
OPENINGS
3/8" AND 7/16" WIDE
RIGHT BACK
RIGHT FRONT

FIG. 70.

in a saving of fuel and a saving in labor and delays to trains on account of cleaning. The side dampers distribute the draft through the grates evenly, whereas, in former arrangements with only end dampers, the draft was excessive through the centre of the grate and insufficient at the sides and ends. Clinkers no longer form on the sides of the fire box, and the fireman is always free to shake the grates, knowing that the ash pan will not become filled up, as the new pans can be dumped in a few seconds by a single movement of a valve. Therefore a light fire can always be carried, and there are no delays for cleaning. With former styles of ash pans where the fireman removed the ashes with a hoe, trains were sometimes delayed on this account as long as thirty minutes. The new ash pans are so arranged that there is no chance of sparks dropping, and when drifting down grades all the dampers, if required, can be closed with one movement of the air valve, or the openings can be partially closed to suit the conditions.

Q. What facts are given in the daily report of the Travelling Fireman on the Southern Pacific Railway?

One thing contributing to the success of the Southern Pacific in burning bituminous coal is the daily report made by the Travelling Fireman. This is of value in keeping the head of the department posted as to whether the work of firing is being properly attended to. The blank used for this report gives the number of the train, date, names of the enginemen, and between what stations the report covers. The questions are well designed to bring out any failures of the men or machinery, and are as follows:

Kind of coal, and was it broken to suitable size?

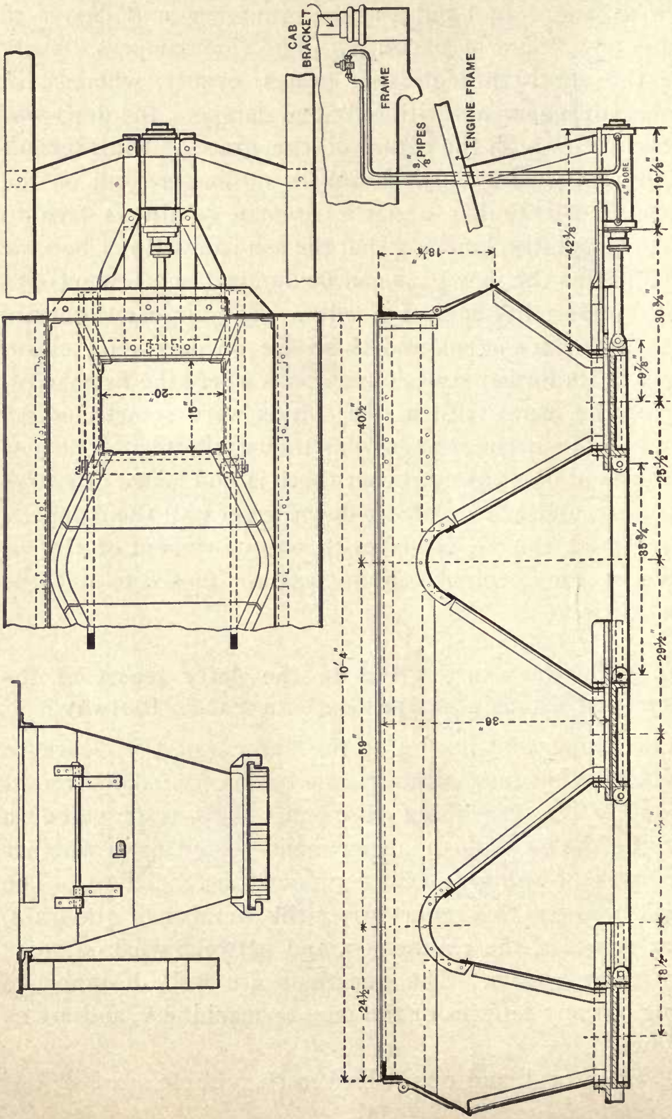

CAB BRACKET
FRAME
ENGINE FRAME
3/8" PIPES
4" BORE
19 1/8"
42 1/8"
18 1/4"
30 3/4"
9 7/8"
25 1/2"
35 3/4"
29 1/2"
18 1/2"
20"
15"
40 1/2"
59"
10'-4"
24 1/2"
36"

FIG. 71.

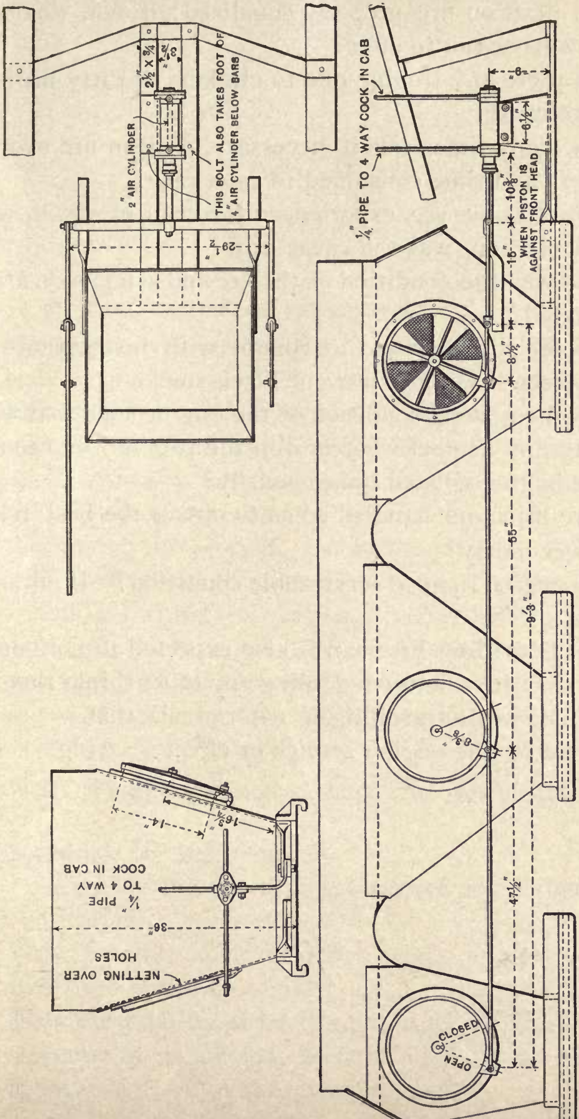

2½" X ¾
3½"
2" AIR CYLINDER
THIS BOLT ALSO TAKES FOOT OF 4" AIR CYLINDER BELOW BARS
29½"
¼" PIPE TO 4 WAY COCK IN CAB
6"
6½"
10⅜"
15"
WHEN PISTON IS AGAINST FRONT HEAD
8½"
55"
9'-3"
8⅜"
47½"
CLOSED
OPEN
14"
16¾"
16⅜"
¼" PIPE TO 4 WAY COCK IN CAB
36"
NETTING OVER HOLES

FIG. 72.

Was draft on fire properly equalized; if not, what suggestions have you to offer?

Was there any trouble due to clinkers or dirty fire? If so, state cause.

How many times was it necessary to clean fire over the division; and time consumed in each case?

If any trouble was experienced for want of steam, what, in your opinion, was the cause of it?

What was the condition of the fire and ash pan on arrival at terminal?

Was fireman disposed to comply with instructions and practise economy, and prevent black smoke?

Was the general condition of the engine such that would indicate any neglect whatever on the part of the fireman?

Was engine slipped unnecessarily?

Were injectors handled so as to obtain the best results in fuel economy?

Was engine in good serviceable condition? If not, state defects.

The Travelling Fireman is also expected to note on the report or write a letter regarding any other things that may be noticed while travelling or at terminals, that in any way would better the engine service or effect a saving.

PART II.

HYDROCARBON OIL AS A FUEL FOR LOCOMOTIVES.

Q. Is oil used as fuel in locomotives?

It has long been in use in the Russian oil fields; it has been tested experimentally near the Pennsylvania and Ohio oil fields; and has been used for fuel for several years past on the Pacific coast. The Southern California Railroad began burning oil in 1894, and have used it more or less ever since. Various minor changes have been made with a view to improve the process; but in the main the arrangement has been about the same for the last three or four years; and according to *Locomotive Engineering*, about all their engines burn oil now. The Southern Pacific Company also burn oil in some of their locomotives. The oil burners being easily removable, they burn either oil or coal according to the relative prices of the two fuels.

Q. What advantages are claimed for petroleum as a fuel?

It is claimed for petroleum:

1. That its heating power is greater per pound than that of any solid fuel.

2. That it permits of continuous firing in a closed furnace, free from drafts of cold air.

3. That the quantity of heat required to maintain a constant pressure of steam may be controlled by the simple adjustment of a valve in the oil-supply pipe.

4. Absence of débris; there being no ashes or clinkers left in the furnace.

5. That the fire is not only easily started, but can be instantly discontinued without loss of fuel.

Q. What is petroleum?

Petroleum is a natural hydrocarbon oil; in its widest application, the term covers all the mineral oils found in this country. It is of a dark-brown color, having a greenish tinge. In specific gravity the crude oil averages about 0.8, with variations of .025 on either side; equivalent to 50 pounds per cubic foot.

The composition of crude oil is by no means constant, but it will approximate closely:

Carbon	84	per cent.
Hydrogen	14	"
Oxygen	2	"
	100	"

The theoretical heating power of oil by this analysis would be:

		Heat units.
Carbon	.84 × 14,544 =	12,217
Hydrogen (available)	.1375 × 62,032 =	8,529
Total heat units	=	20,746

The evaporating equivalent of which would be 21.47 pounds of water from and at 212° F. per pound of oil.

Q. What is the calorific value of petroleum?

The heating power of crude oil is greater than the refined oil, and when employed as a fuel it is the crude oil that is commonly used except locally, where the thick oily residuum from the refineries is used; which is always with good effect, when the furnace details are properly adapted for burning it.

The calorific power of crude oil approximates the following:

	British thermal units.
Pennsylvania, light	17,933
Ohio, heavy	18,718
West Virginia, heavy	18,324
West Virginia, light	18,401

An oil averaging 18,500 heat units per pound would yield an equivalent evaporation of 19.15 pounds of water from and at 212° F.

The boiler plant at the World's Fair, Chicago, was supplied with crude oil from the Lima, Ohio, district for fuel. The quantity of petroleum used for firing the main boiler plant was upward of 31,000 tons, and the work done was stated to have been 32,316,000 horse-power hours, or about 2.1 pounds of oil per horse power per hour.

Q. What is the calorific power of refined mineral oil?

A commercial product known as "mineral seal" yielded upon analysis:

Carbon	83.3	per cent.
Hydrogen	13.2	"
Oxygen, nitrogen, and loss	3.5	"
	100.0	"

This oil has a density of 40° Baumé, which corresponds to a specific gravity of .83. The flash test was 266° F., and the fire test 311° F. It is a pure mineral oil. The calculated heat units are:

		British thermal units.
Carbon	14,500 × .833 =	12,079
Hydrogen	52,370 × .132 =	6,913
		18,992

The average result obtained by experiment is 18,790 heat units, which is 1.1 per cent lower than the value calculated from the analysis (Jacobus).

Q. What success has attended the use of liquid fuel as auxiliary to coal for locomotive engines?

Experiments made in England, on the Great Eastern Railway, have been quite successful in the use of liquid fuel as an auxiliary to coal in locomotive engines. The fluid used is tar, and to it is added a certain proportion of green oil which was also obtained from the works where the tar was produced, the cost being about 3 cents per gallon. Each of the 12 or 14 engines, it appears, used about 12 pounds of coal and over a gallon of oil, which is equal to about 11 pounds fluid fuel per train mile as against 34 pounds of coal. The relative cost of the combined material is rather less than coal, but the value of the oil injector is seen to special advantage on gradients where an extra supply of steam is required.

Q. What success has attended the burning of the heavy residuum obtained by the distillation of bituminous shale?

Not much attention has been given to the distillation of oil from bituminous shale in this country. Some lignites, for example those found in Ouachita County, Ark., have been experimentally dealt with; the lignite was soft enough to be cut with a knife, solid, heavy, compact, of a bluish-brown color, disintegrating by exposure to the atmosphere. It consisted of:

Fixed carbon	34.50	per cent.
Volatile matter	60.50	"
Ash	5.00	"
	100.00	"

When distilled in an iron crucible, the first product that came over was gas having a feeble odor of sulphurous acid and burning with a tolerably bright flame. The gas was soon accompanied by ammoniacal water, a yellowish oil, and a waxy product which when condensed had the consistency of lard and the color of beeswax. The last products which came over were lubricating oil and paraffin. The products of this distillation were:

Coke	37.83	per cent.
Watery solution containing sulphurous acid, organic acids, and ammonia	34.32	"
Crude oil	12.16	"
Gas and loss	15.69	"
	100.00	"

From this analysis 2,000 pounds of lignite would yield 35.40 gallons of crude oil.

Crude residue, not unlike the above, left after extracting oil from bituminous shale, was applied for heating purposes at the Forth bridge. In appearance this residue resembled butter, and would not burn upon the application of a lighted match. By melting it and forcing it in jets with superheated steam against previously heated fire-clay surfaces with an induced current of air, it burned freely and developed great heat.

Q. What changes are necessary to convert a coal into an oil burning locomotive?

To change from coal to oil fuel on the Southern California Railroad the grates are taken out, and a cast-iron plate is placed 4 to 6 inches below the mud ring, extending over the entire space under the fire box. This plate has three openings for air to come up into the fire box, 9 x 15 inches, one of these air openings being in the middle of the fire box, one near the front end, and one near the back end. The plate is protected from the heat of the fire above by a covering of fire brick. The ash pan and dampers are left the same as a coal burner. The sides of the fire box are also protected from the direct force of the intense heat by a fire-brick wall about 5 inches thick, which comes up to the flues in front, up above the flare of the fire box on the sides and to the bottom of the door at the back. There is a brick arch extending across the fire box from side to side, reaching back pretty well toward the door, just the same as in a soft-coal burner. Some of the engines also have a narrow arch just under the door, which serves to keep the intense heat from the door ring.

The atomizer which separates the oil into a fine spray and blows it into the fire box is located just under the mud ring, pointed a little upward, so the stream of oil spray and steam would strike the opposite wall a few inches above the bottom, if it was to fly clear across the box. Deep fire boxes have the atomizer at the back end of the box, while the shallow and long fire boxes have it located at the front end, pointed back. The shallow boxes have the same arrangement of side walls that the deep ones have, but the arch is put in differently. Some of them have three small arches extending from side to side, but clapping over each other from front to back, so as to divide the current of flame and heat into several parts, and thus distribute it over the long, shallow box more evenly. A good deal depends on the size and position of the arch, which has the same effect on the steaming of an oil burner that the diaphragm in the front end has on the draft of a coal burner. No air is admitted above the fire of the atomized oil.

Q. How are the atomizers constructed for burning oil on the Southern California Railroad?

The atomizers, one for each engine, are of brass, 12 inches long, 4½ inches wide from side to side, and 2 inches thick from top to bottom, divided into two parts by a partition in the middle. Steam comes into the bottom part, heats the atomizer, and issues through a slit $\frac{1}{32}$ by 4 inches. The oil flows into the top part of the atomizer over the hot partition, and on running out of the front end is caught by the steam issuing from the slit in the bottom part, and is sprayed into the fire, which, when the engine is working, is a mass of flame, fitting the fire box under the arch, and most of the time the whole box.

The supply of steam and oil to the atomizer is regulated by the fireman from the cab, the handles for the steam and oil supply valves being placed where he can have his hands on them when on his seat box. Before the oil is fed into the atomizer it passes through a small heater made of brass, having a steam pipe through it; this steam pipe also leads to a coil in the bottom of the oil tank to warm the oil so it will flow easily. The oil on the Pacific coast is not at all like the fuel oil from the Indiana and Lima fields. Some of the oil has a generous portion of thick stuff like asphaltum in it, so it does not flow very easily; while other kinds are thin as water and almost as clear. The oil tank is located in the pit of the water tank, usually assigned for coal.

Q. How is the oil supplied to the burner under pressure?

An air pipe leads from the main reservoir to the oil tank, with a reducing valve similar to the one used in the air-signal line, but with a different spring box, so as to bring the air pressure down to 4 pounds, which is maintained in the oil tank, at which pressure the oil comes out freely. Self-closing valves are provided to shut off the flow of oil in case of accident.

Q. What size of exhaust nozzle is used when burning oil?

It is about the same size as is used when burning good coal. Frequently no changes are made in the front end except to take out the netting; others have a low nozzle and petticoat pipe put in instead of high nozzle and a diaphragm or apron.

Q. Are oil fires smokeless?

An oil fire requires as careful attention as does soft coal to render its combustion smokeless. The fireman and engineer must work coincidently to get the best results. Every time the engineer changes his lever or throttle the fireman must change his fire. He must keep his eye on the water in the boiler, must know the road, etc.—in fact, a good fireman on an oil-burning locomotive must keep his eyes open, for he can make or waste more for the company than he could on a coal burner.

Q. What is the effect of the products of combustion of an oil fire upon the tubes of the boiler?

The products of combustion from an oil fire make a sticky deposit in the flues, which soon coats them and interferes with the steaming. To cure this difficulty, the fireman sticks a long funnel through a hole in the fire-box door, made for that purpose, and gives the flues a dose of about four quarts of sand, which is drawn through the flues and scours them out.

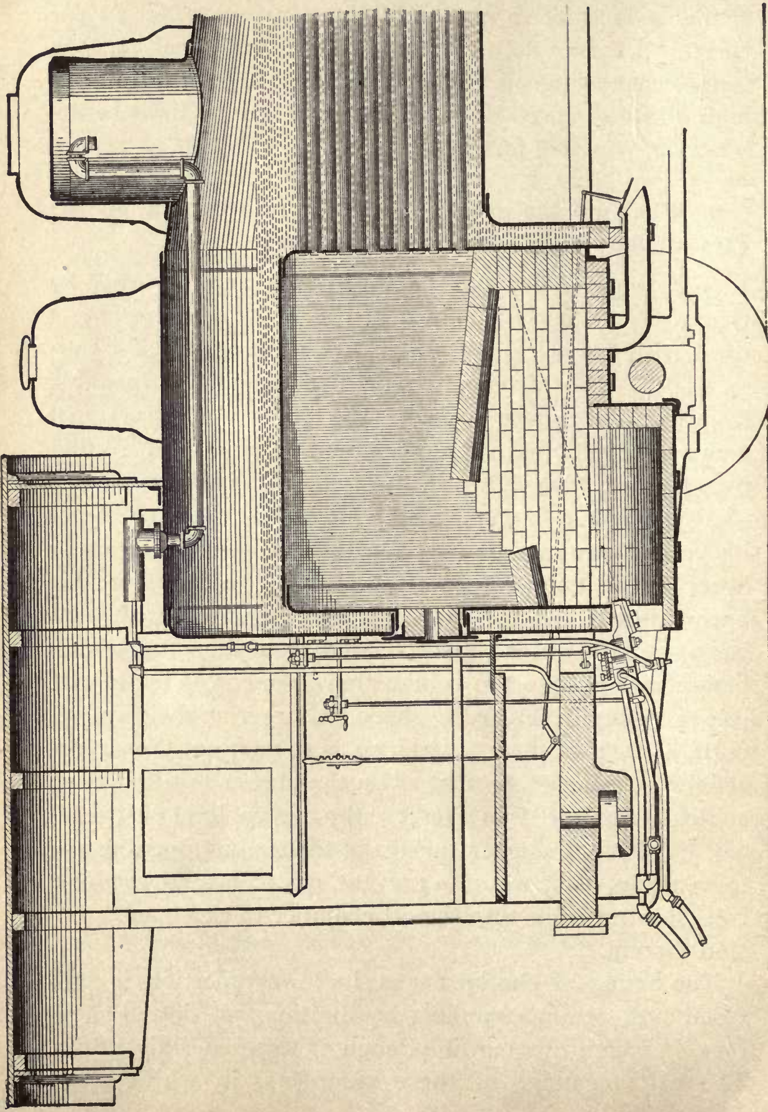
Q. What is the relative cost of oil and coal as a fuel in locomotive practice?

In California coal is high priced; good coal at Los Angeles costs $6.50 to $7.50 per ton; oil costs about $2 per ton less. With coal at $4.80 per ton it is profitable to change a locomotive into an oil burner, with oil at $1 per barrel. Engines do not steam as freely with coal, so they cannot make as good time or handle as large a train at as high a rate of speed. There is apparently no limit to the steaming power of an oil burner.

Q. What are the general details of construction of the Prescott burner for liquid hydrocarbons?

A locomotive fire box equipped with an oil burner by George W. Prescott is shown in Fig. 73. The fire box is lined with fire brick, and fitted with front and back arches as shown. An air-supply pipe with damper, adjustable from the cab, is also shown. Fig. 74 is a plan sectional view of a double burner provided with a central oil-receiving chamber, also shown in Fig. 75. This oil chamber is located inside a larger chamber in which water or steam under pressure may be used for the purpose of raising or lowering the temperature of the oil. The casing of this burner is rectangular in shape, and provided with exit passages, into which the oil is fed from the oil chamber before passing into the combustion chamber. These exit passages are irregular in shape or larger at their induct portions than at their outlets, so as to contract the supply of oil at the outlet, so that when the burner is tilted at an angle, as indicated in Fig. 75, the upper level of the oil will be above the upper surface of the contact opening and form a trap, as it were, to prevent gas or heated products from flowing back into the oil chamber to cause an explosion therein.

The casing of the burner at its lowest portion is provided with steam chambers having tapered, slotted openings, in which are movably mounted tapered slide valves. The exit openings of these chambers, in which these



BORMAY & CO., ENGR'S, N.Y.

FIG. 73.

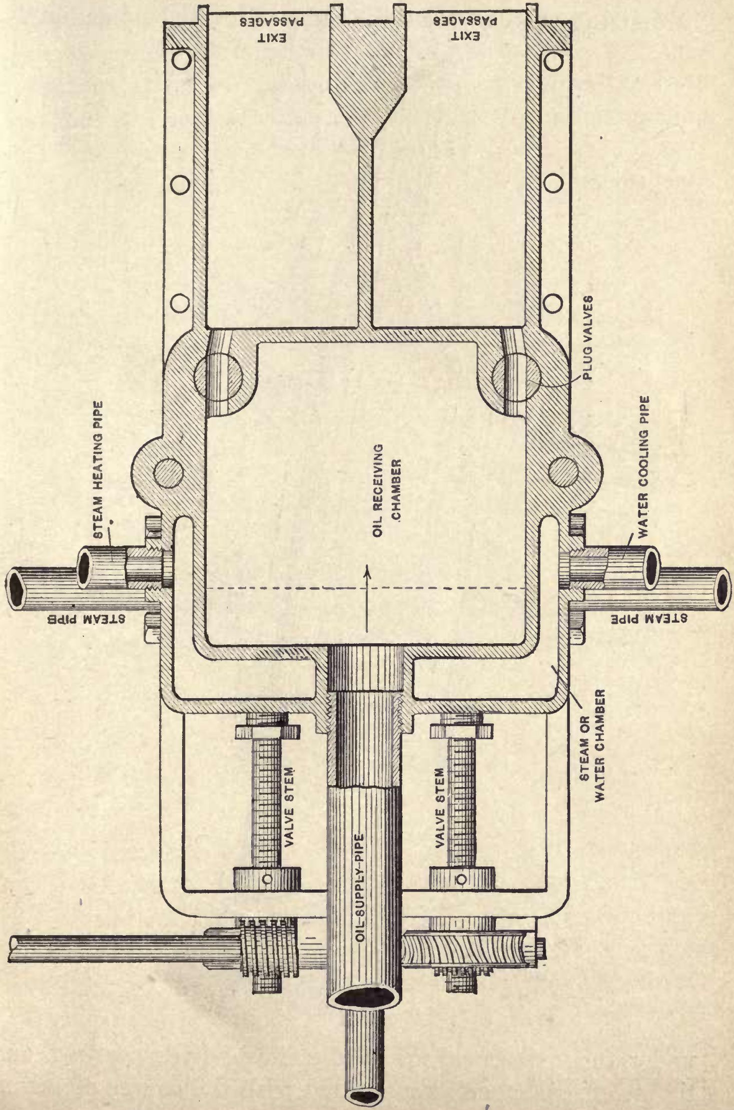

EXIT PASSAGES
EXIT PASSAGES
PLUG VALVES
STEAM HEATING PIPE
OIL RECEIVING CHAMBER
WATER COOLING PIPE
STEAM PIPE
STEAM PIPE
STEAM OR WATER CHAMBER
VALVE STEM
VALVE STEM
OIL-SUPPLY-PIPE

FIG. 74.

"atomizing valves" are arranged, are located immediately

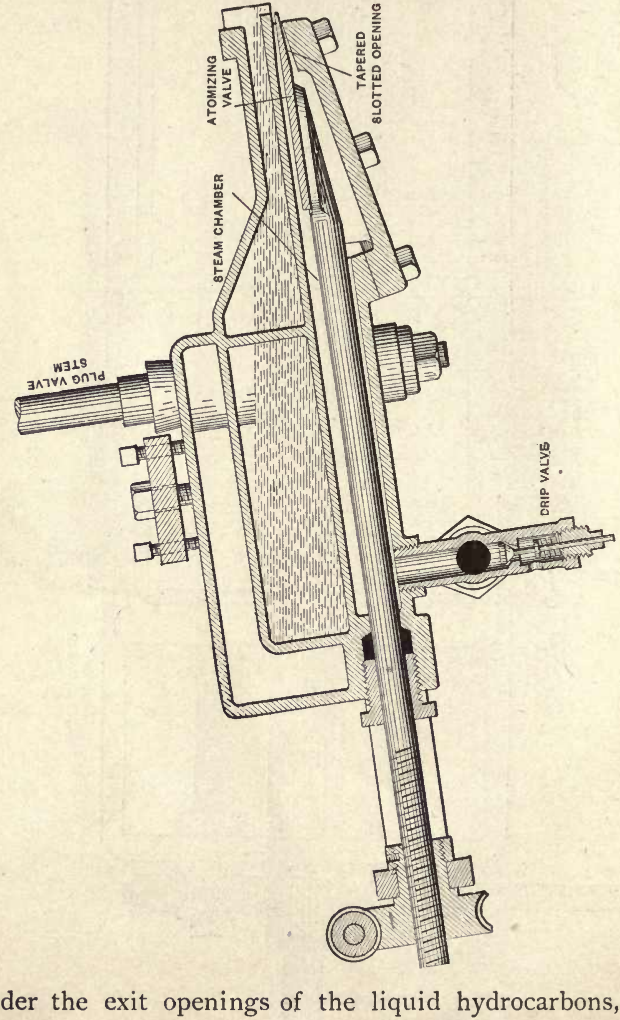


FIG. 75.

under the exit openings of the liquid hydrocarbons, and the steam chamber is connected with the source of steam under pressure, so that when the valves are opened steam under pressure contacts with the liquid hydrocarbon immediately, atomizes the same, and drives it into the fuel chamber with sufficient force to meet the incoming atmospheric air and promote combustion.

The steam-supply chamber in which the valves are located is connected by means of a pipe with the source of steam supply, so that steam under pressure may be furnished the casing to atomize the oil. The steam-supply pipe is fitted with a drip valve, the parts of which are so arranged that when steam under sufficient pressure is furnished to the chamber the drip valve is kept closed; but as soon as the pressure is lowered sufficiently, the valve is opened by means of the tension spring and the water of

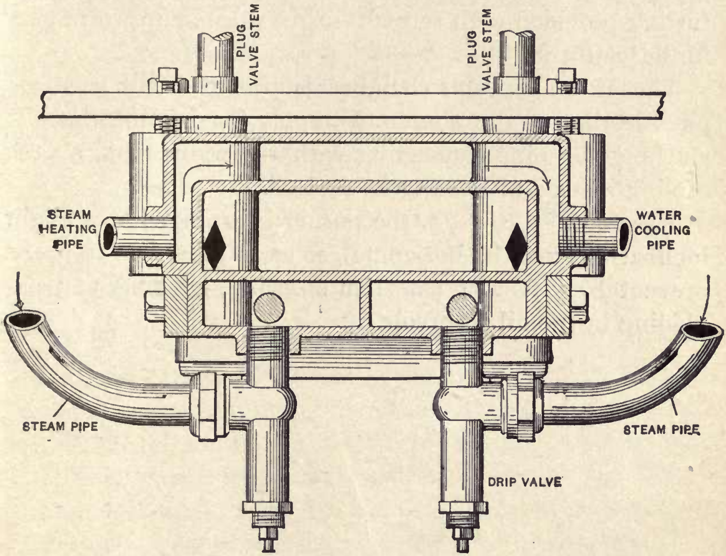


FIG. 76.

condensation allowed to drip out and empty the chamber and the pipe.

The plug valves shown in Fig. 76 govern the supply of oil to the burner, and can be operated from the cab, either independently or simultaneously.

Each atomizing valve in the burner is provided with a stem that projects out of the rear end of the casing, and further provided with screw threads, worm, and worm gear for adjustment.

The steam or water chamber is provided with a steam pipe, leading to the source of supply for heating the oil; and another pipe connecting with the water tank, should cooling instead of heating be desired.

As shown in Fig. 73, the burner is arranged at a slight inclination from the horizontal, so as to provide a trap and prevent back flow of gas from entering, igniting, and exploding in the oil reservoir.

CHAPTER XII.

CHIMNEYS AND MECHANICAL DRAFT.

Q. What service does a chimney render in connection with a steam-boiler furnace?

It is the means generally employed for the purpose of maintaining a draft of air through the body of burning fuel in the furnace. Its effectiveness is due to that quality which it possesses of maintaining an unbalanced pressure between the interior or combustion chamber of the furnace and the atmospheric pressure without.

Q. What is the cause of draft in steam-boiler furnaces?

Furnace draft is caused by the difference in weight or pressure of the column of cold air outside of the chimney, and the weight of the column of heated gases within it. Air and gases, when heated, expand in volume, and become less dense than for equal volumes at a lower temperature; this difference in density is the draft-producing quality of heated gases.

Q. How does this unbalanced pressure originate in a chimney, and how is it maintained?

The unbalanced pressure originates in the fact that hot gases occupy a larger volume for a given weight than cold gases. As there is no exit for the hot gases generated in the furnace except through the chimney, a current is at once established in that direction. By reason of the height of the chimney above the furnace, and the fact that it is filled with gases of higher temperature, and consequently of less density than that of the air outside of the chimney, an upward current of hot gases will be maintained so long as any unbalanced pressure exists between the outside and inside of the chimney.

Q. What is the rate of increase in volume for different temperatures of gases escaping by the chimney?

Let us suppose that 18 pounds of air pass through the furnace per pound of coal; we then have $18 + 1 = 19$ pounds of gases. If the temperature of the air flowing into the furnace is 68° F., its volume will be 241 cubic feet; if the temperature of the escaping gases be 572° F., the volume will have been increased to 471 cubic feet, a difference of $471 \div 241 = 1.95$ times increase in volume of the hot gases over that of the cold air, a ratio approximately of 2 to 1.

TABLE 30.—VOLUME OF ESCAPING GASES IN CUBIC FEET PER POUND OF COAL BURNED. (Rankine.)

Temperature.	POUNDS OF AIR PER POUND OF COAL.		
	Twelve pounds, cubic feet.	Eighteen pounds, cubic feet.	Twenty-four pounds, cubic feet.
32° F.	150	225	300
68	161	241	322
104	172	258	344
212	205	307	409
392	259	389	519
572	314	471	628
752	369	553	738
1,112	479	718	957
1,472	588	882	1,176
1,832	697	1,046	1,395
2,500	906	1,359	1,812

As the lighter gases are confined to the chimney they rise to the top by reason of their lesser gravity, and within certain limitations the higher the chimney and the higher the temperature of the escaping gases the stronger or more intense will be the draft.

Q. How is the area of a chimney determined for a given boiler plant?

This detail in steam engineering has been practically fixed by Ishewood's experiments, and further corroborated by observations extending over many years, including all kinds of fuel, and in connection with almost every imaginable furnace contrivance, grates, etc.

It is a common practice to make the area of the chimney bear some relation to the grate surface, although the latter does not bear, in practice, a fixed relation to the boiler-heating surface; and not always to the quantity of fuel to be burned, nor to the rate of combustion.

After a series of elaborate experiments Mr. Ishewood fixed upon ⅛ of the grate area as being the best proportion for draft area, and this recommendation holds good for both hard and soft coal at ordinary rates of combustion.

In practice the sectional areas of chimneys will be found to vary between $\frac{1}{6}$ and $\frac{1}{10}$ of the grate surfaces to which they may be attached; the latter proportions being for very large plants and in connection with unusual height of chimney.

The area of chimney may be based upon the quantity of coal burnt. Up to 1,000 horse power the most satisfactory chimneys are those in which from 1½ to 2 square inches of chimney area are had for each pound of coal burnt per hour. If, say, 600 pounds of coal are supplied a steam-boiler furnace per hour, we have:

600 × 1.5 = 900 sq. in., or 34 in. diameter.
600 × 2 = 1,200 " " 39 " "

In which case a 36 or 40 inch chimney would probably be selected.

Q. How is the height of a chimney determined?

In the larger cities the height of a chimney is often determined by the height of buildings in the immediate vicinity; city chimneys are often, for this reason, much higher than necessary for the mere purpose of securing proper draft.

Where there are no local restrictions governing the height of a chimney, those for small powers, say 30 H. P. and less, the height may be 50 to 60 feet; for 100 H. P. the height may be 70 to 90 feet; and for 1,000 H. P. 150 feet in height will be found ample for draft purposes.

A rule sometimes met with would fix the height at 25 times the internal diameter of the chimney; this is a good rule for a few sizes, but it will not apply to all diameters. Small chimneys must have a certain height to get sufficient draft to burn the fuel. The height of large chimneys is kept down to reduce cost of construction. The following heights come within the range of good practice:

A 2-foot	chimney	 70	feet high	= 35	diameters.
" 3	"	 90	"	= 30	"
" 4	"	 100	"	= 25	"
" 5	"	 120	"	= 24	"
" 6	"	 130	"	= 21.67	"
" 7	"	 140	"	= 20	"
" 8	"	 150	"	= 18.75	"

Q. In estimating chimney draft where should the chimney measurement begin?

Draft properly begins at the level where the air passes through the fire, and not at the level of the ground at the base of the chimney.

Q. What is the best temperature for chimney draft?

The ordinary limit of temperature for escaping gases from steam boilers is approximately 100° F. above the temperature of the steam. If steam is being generated at 100 pounds pressure by gauge, the corresponding temperature would be $338° + 100° = 438°$ F., the lowest temperature for the escaping gases. On the other hand, the maximum temperature would be about 584° F., because at that temperature the gases are about one-half the density of the atmospheric air. The best working temperature will be found to lie between these two limits.

Q. What is meant by intensity of draft?

Intensity of draft denotes the velocity of flow of air through the furnace. Intensity is secured by height of chimney, by high temperature of escaping gases, or both combined. Anthracite coal requires a greater intensity of draft than is necessary for bituminous coal, and it is for this reason chimneys for the latter coal can be 15 to 20 per cent lower than for anthracite. The intensity of draft for anthracite coal will vary from ¾ to 1 inch of water; for bituminous coals, ⅜ to ⅝ inch of water will suffice.

Q. How may the intensity of chimney draft be estimated?

Intensity of chimney draft is usually measured in inches of water. Suppose a chimney to be 150 feet high and the temperature of the escaping gases 600° F., the temperature of the atmosphere 75° F., the draft in inches of water may be found thus: To the sensible temperature 600° and 75° we must add the absolute temperature 460° F.; then:

$$150 \times \frac{460° + 600°}{460° + 75°} = \frac{159000}{535} = 297 \text{ feet}; 297 - 150 =$$

147 feet, the motive column. Water is 820 times heavier than air, we have then: $\frac{820 \times 297}{147} = 1656$, which expresses the relation of weight as compared with water.

If we divide the motive column by this amount we have $\frac{147}{1656} = .0887$ foot. Then $.0887 \times 12 = 1.064$ inch, say $1\frac{1}{16}$ inches of water by draft gauge, or the height of a column of water lifted by the action of a chimney corresponding to the height and temperature above given.

The above example may be regarded as an extreme case; a much lower set of conditions are here given:

Suppose a chimney 100 feet high, escaping gases 500° F., atmosphere 60° F., what will be the draft in inches of water?

$$100 \times \frac{460° + 500°}{460° + 60°} = \frac{96000}{520} = 184 \text{ feet.}$$

$184 - 100 = 84$ feet. The motive column.

Then: $\frac{820 \times 184}{84} = 1796$, the ratio of weight as compared with water.

Dividing the motive column by this ratio: $\frac{84}{1796} =$ .0467 foot.

Then $.0467 \times 12 = .560$ inch of water, or about $\frac{9}{16}$ inch.

Q. Why is maximum economical chimney temperature taken to be about 584° F.?

Chimney temperature is for draft purposes only; draft increases with the temperature of the gases in the chimney; from 32° to 300° F. the draft augments very rapidly, from 300° to 750° the draft varies but little, and then gradually diminishes in intensity with higher temperatures.

An ordinary steam pressure for high-grade, triple-expansion engine is 185 pounds by gauge, or 200 pounds absolute; the temperature of which is 382° F., to which we add 100° for excess temperature, difference of hot gases over that of the steam = 483° F.

The best draft is had when the density of gases within and without the chimney is as 2 to 1. Suppose an average air temperature of 62° F., the absolute temperature would be $62° + 460° = 522°$; the best draft would be $522° \times 2 = 1{,}044°$ absolute, or $1{,}044° - 460° = 584°$, the temperature of the gases in the chimney.

Q. What rule governs the proportions for chimneys as given in Table 31?

Proportions for chimneys from 20 to 90 horse power are for a single boiler and furnace in which the grate area is assumed to be 9 times that of the tube area for the smallest horizontal tubular boiler, diminishing to 7 times the tube area for the largest boiler. A commercial horse-power rating approximating 15 square feet of heating surface per horse power is assumed for all boilers included in the above grouping.

For chimneys from 100 to 1,000 horse power, the dimensions are suited to two or more boilers set in a battery and working together; a horse power in this portion of the table is based on 4 pounds of coal per horse power per hour.

The rate of combustion is assumed to be 12 pounds per square foot of grate surface per hour. The proportion of grate to chimney area varies from $\frac{1}{7}$ for the 100 horse-power boiler to $\frac{1}{10}$ for the 1,000 horse-power boiler.

TABLE 31.—CHIMNEY DIMENSIONS FOR STEAM-BOILER FURNACES FROM 20 TO 1,000 HORSE POWER.

Horse power.	Grate area, square feet.	Coal per hour, pounds.	Area of chimney, square feet.	Diameters round chimney, inches.	Height for—	
					Bituminous coal, free burning, feet.	Small anthracite coal, feet.
20	12	....	2.02	20	50	60
30	14	....	2.28	20	55	65
40	17	....	2.91	24	55	70
50	23	....	3.67	26	60	70
60	24	....	3.80	27	60	75
70	29	....	4.35	28	65	80
80	34	....	4.88	30	65	85
90	38	....	5.00	30	70	90
100	40	400	4.76	30	70	90
150	50	600	6.82	36	75	95
200	67	800	8.69	40	80	100
250	83	1,000	10.64	44	85	105
300	100	1,200	12.50	48	85	105
350	117	1,400	14.18	51	90	110
400	133	1,600	16.00	55	90	115
450	150	1,800	17.65	57	90	115
500	167	2,000	19.25	60	95	120
550	183	2,200	20.65	62	95	120
600	200	2,400	22.22	64	100	125
650	217	2,600	23.65	66	100	125
700	233	2,800	25.01	68	105	130
750	250	3,000	26.32	70	105	135
800	267	3,200	27.61	72	110	135
850	283	3,400	28.82	73	110	140
900	300	3,600	30.00	74	115	145
950	317	3,800	31.67	76	115	145
1,000	333	4,000	33.33	78	120	150

Q. How may the draft of a chimney be modified?

If the chimney draft is sluggish it may be increased by means of a specially contrived blower exhausting upward in the chimney as in Fig. 77. In small boiler plants, and especially where a sheet-iron stack is employed, the exhaust pipe from a non-condensing engine is quite frequently led into the stack, the pipe turned upward, and terminating in a contracted orifice; the size of the latter being usually determined by local conditions.

Excess of draft may be controlled by means of a damper, placed between the exit of the gases from the boilers, and the chimney. In small boiler plants, and especially those having a sheet-iron stack, the damper is commonly placed either in the breeching or in the stack itself.

Q. What is the construction of the argand steam blower?

This blower, as made by James Beggs & Co., is shown in section in Fig. 78, and one method of applying it through a side wall of a boiler furnace is shown in Fig. 79. The blast is regulated to suit the requirements of any furnace by means of a globe valve in the steam-supply pipe. Should the small holes in the argand ring become clogged with loose scales from the steam pipe or other cause, they can be cleansed with a bent wire (hook shaped), when steam is turned on full force.

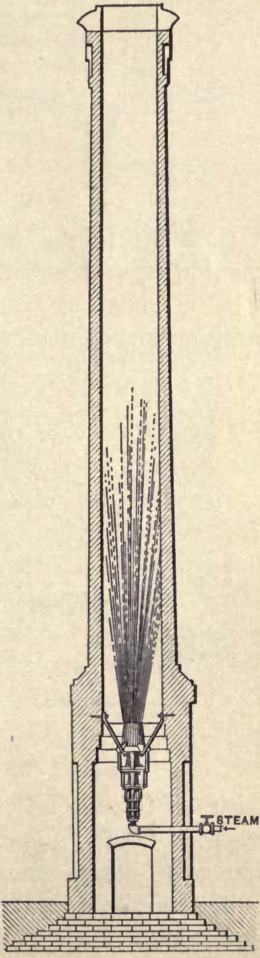


FIG. 77.

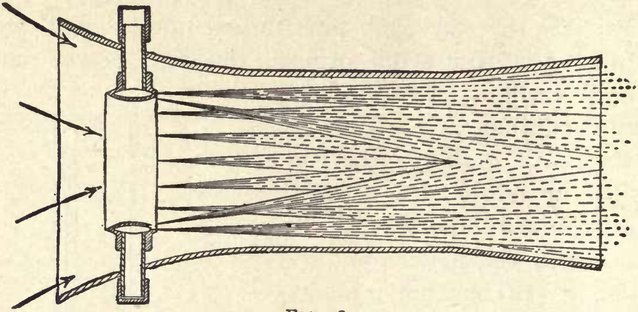


FIG. 78.

Q. What is the best location for a steam blower in connection with a boiler furnace?

It is generally conceded by those who have given the subject special attention that a blast furnished by undergrate combined air and steam blowers, properly proportioned, is better adapted to burn the smaller anthracite fuels than either a strong natural draft or a draft produced by a jet or jets in the stack.

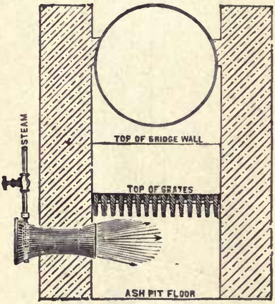


FIG. 79.

Both of the latter methods so relieve the pressure on the upper surface of the fire that the unconsumed gases escape into the stack before they have time to ignite, whereas with the forced draft a pressure is produced between the uptake and the upper surface of the fire which retards the gases long enough for them to ignite, whereby the boiler can be heated more effectively than by the radiant heat alone which is emitted from the incandescent carbon and radiated against a small portion of the heating surface only. Then, again, the steam has a mechanical effect, in that it keeps the clinkers soft and porous, so that the blast will readily pass up through the entire bed of fuel uniformly, instead of being forced to pass between solid clinkers wherever it can find an opening, as is the usual case with a fan blast, for an all-air blast tends to form the clinkers into compact slabs, through which the air cannot pass.

Another mechanical effect of the steam is that it moistens the fine ashes in the lower strata of the fire, which keeps them from being blown up into the burning surface to choke it by filling the interstices between the particles of fuel.

Q. What special preparation of fuel is recommended in connection with a steam-jet blower in the ash pit?

In all cases where anthracite culm is used for fuel, it should be sprinkled with water before putting it on the fire, not so as to make it sloppy and heavy, but just enough to make the dust adhere to the particles of small coal. Anthracite screenings from coal yards should be treated in the same manner, and if they have lain out in the weather for any considerable length of time, it will be found advantageous to mix them with about one-fifth their bulk of bituminous slack, where it is available.

A very simple yet very important feature in burning fine fuels successfully, where the argand blowers are used to furnish blast, is to close the damper in the chimney, or stack, to a point where the burning gases will not blow out through the fire door when opened, for where there is a strong chimney or stack draft in connection with the undergrate blowers a large percentage of the gases escape without igniting. Therefore one should not fail to so regulate the damper that the largest possible volume of gaseous flame may be produced in the furnace. Where the chimney draft is weak, it may be necessary to keep the damper wide open, but it has been found that in the majority of cases it is not only beneficial, but absolutely essential, to regulate the dampers as described in order to produce the best results.

Q. What is mechanical draft?

This name is commonly applied to any system of pressure or exhaust fans driven by a separate mechanism, by which, in the case of a blower, a current of air is forced through the fire; or by exhaustion of the products of combustion by means of a vacuum created by a revolving fan placed beyond the uptake or in the breeching leading to the chimney. In either case the air needed for combustion is supplied the fire through mechanical means and not by natural draft.

Q. What are the ordinary methods of application of mechanical draft?

The commonest method is by means of a centrifugal fan, or fan blower, by means of which the air needed for combustion is forced through the fire. The air supply in stationary boiler practice is usually forced into an air-tight ash pit, and as there is no other escape for the air it is forced through the fuel, and thus becomes a "forced" draft. Another method, frequently employed on steamships, is to make the fire-room air tight and force the air into it at such pressure and in such volume as may be needed for the combustion of the fuel.

A typical arrangement of the B. F. Sturtevant Company's steam fan for the production of under-grate-forced draft is shown in Fig. 80. The fan discharges the air

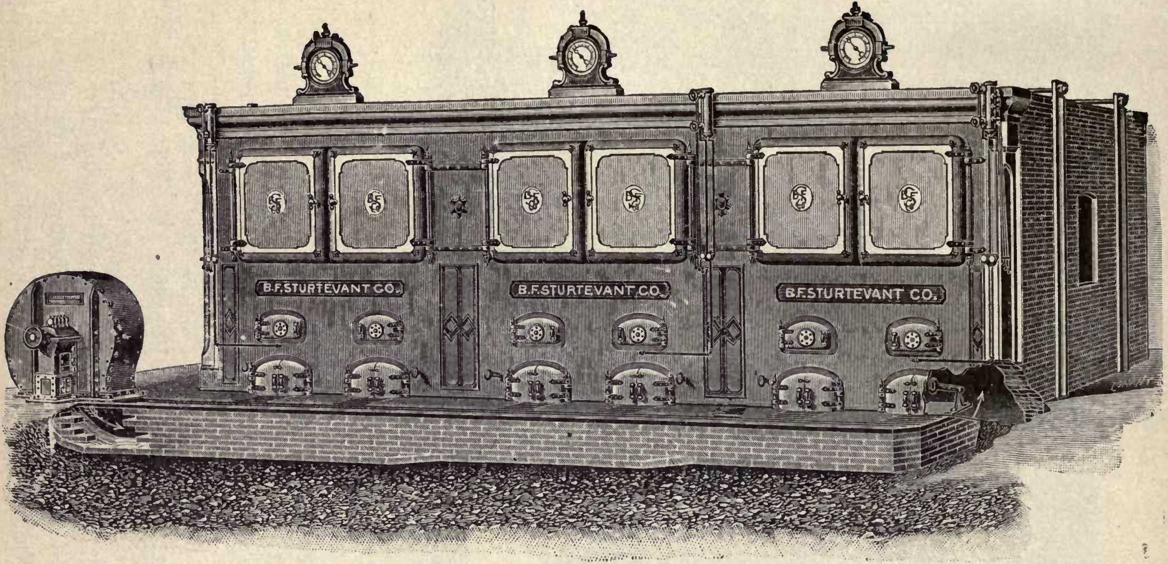


FIG. 80.

into an underground-brick duct extending along the front of the battery of boilers. From this duct smaller branches, two to each boiler, extend to the ash pits, to which the air is admitted in the requisite amount through ash-pit dampers of the type shown in Fig. 81. There is thus maintained within the ducts and ash pits a pressure greater than that of the atmosphere by an amount dependent upon the speed of the fan, which may be regulated at will.

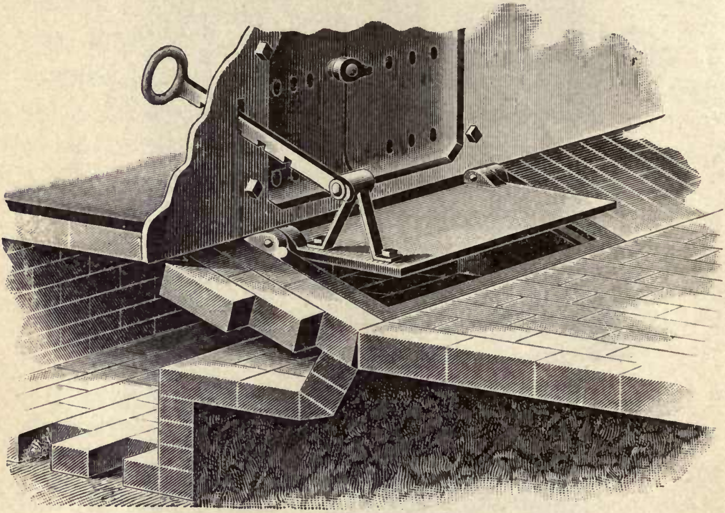


FIG. 81.

Q. What objections are there to the closed ash-pit system?

An objection to the direct introduction of air under pressure by means of a pipe in the bottom of or through one side of a closed ash pit, is found in the failure properly to

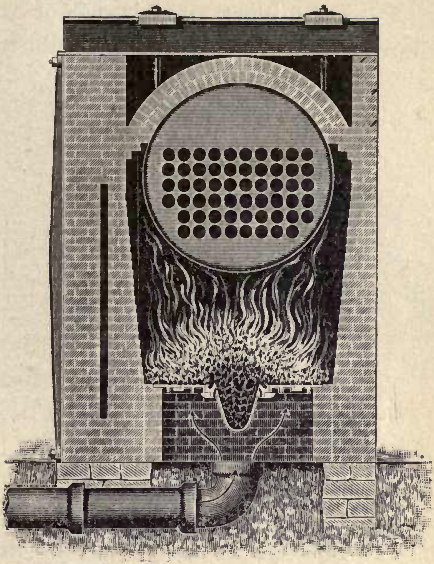


FIG. 82.

distribute the air in the ash pit (see Fig. 82), resulting in unequal combustion, localizing the heat in certain portions of the grate, and producing blow-holes in others.

The air pressure in the ash pit, being in excess of that of the atmosphere, necessitates keeping the ash-pit doors closed; this pressure also causes all leakage to be outward. The tendency is, therefore, to blow the ashes out of the ash pit, and the flame, smoke, and fuel out of the fire doors.

Q. How may the objections to the closed ash-pit system be overcome?

So far as the localization of the combustion is concerned it may be overcome by deflecting the air entering the ash pit by means of a damper as shown in Fig. 83. This device, by the B. F. Sturtevant Company, insures a thorough distribution of the air throughout the ash pit before it rises to the grate. The air duct is in this case constructed within the bridge wall, there being one or more dampers for each boiler. The amount of opening is regulated by the handle shown in the engraving.

A hollow-blast grate is one of the devices for equably distributing the air and stimulating draft in connection with mechanical draft apparatus. The Gordon hollow-blast grates in combination with a Sturtevant fan are shown in Fig. 84. The grate bars are cast hollow, and have suitable openings adapted for burning coal, coal ref-

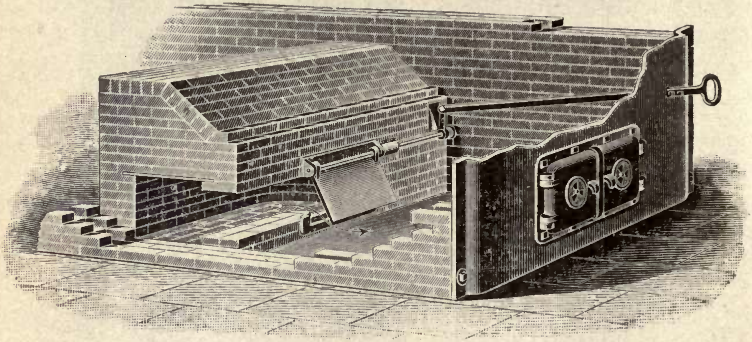


FIG. 83.

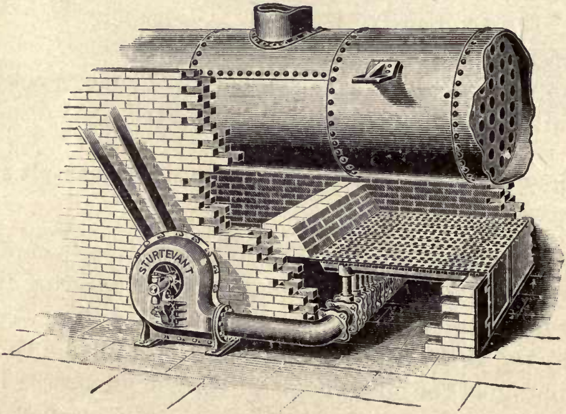


FIG. 84.

use, bagasse, tanbark, etc. The main blast pipe enters the ash pit through one of the side walls; suitable tubes connect the blast pipe, and the grate bars above, thus establishing an air connection between the two.

Q. What is the induced system of draft?

The induced suction or vacuum method for obtaining a suitable draft for furnace combustion consists in the introduction of an exhausting fan in the place of a chimney. The fan serves to maintain the vacuum which would exist if a chimney were employed, and its capacity can be made such as to handle the gases which result from the processes of combustion. As the draft is thus rendered practically independent of all conditions except the speed of the fan, it is necessary to provide only a short outlet pipe to carry the gases to a sufficient height to permit of their harmless discharge to the atmosphere. In practice the capacity of an induced draft fan, as measured by the weight of air or gases moved, necessarily varies with the temperature of the gases it is designed to handle. Therefore the density, which varies inversely as the absolute temperature, should enter as a factor in all such calculations. The simplest arrangement for an ordinary boiler plant consists in placing the fan immediately above the boiler, leading the smoke flue directly to the fan-inlet connection, and discharging the gases upward through a short pipe extending just above the boiler-house roof.

The induced draft system is, on the whole, better subject to control than the other systems; its leakage is always inward, avoiding inconvenience from flame and smoke at the fire doors, it lends itself readily to control by the dampers which may be introduced for the purpose.

An induced-draft plant is shown in Fig. 85, consisting of 4 Manning boilers, each boiler containing 180 tubes 2½ inches in diameter, 15 feet long; fire box 6 feet in diameter, 28.27 square feet of grate surface, and 1,823 square feet of total heating surface for each boiler. The economizer contains 192 tubes, 4⅝ inches in diameter; the square feet of heating surface is 2,304. The two Sturtevant fans have a somewhat novel arrangement, whereby a relay is provided and the floor area occupied is reduced to a mimimum. Each fan has a wheel 7 feet in diameter, and driven by direct-connected engine. By means of an arrangement of dampers, the gases may be caused to pass through the economizer, and thence to either one or both fans, whence they are discharged through a short, vertical stack. The experimental results obtained furnish an interesting commentary upon the relations between fan speed, volume moved, pressure created, and horse power required. Up to a certain speed the natural draft of the short stack is equal to, or actually exceeds, that created by the operation of the fans; but when the draft produced by the fans exceeds that which the stack is capable of creating, the additional work is thrown upon the fans, and the power increases practically as the cube of the number of revolutions.

Q. What is the proper kind of fan for use in connection with a mechanical draft apparatus?

Two types of fans exist. The first, known as the disc or propeller wheel, is constructed on the order of a screw propeller, and moves the air in lines parallel to its axis, the blades acting on the principle of the inclined plane. The second, or fan blower proper, consists in its simplest form of a number of blades extending radially from the

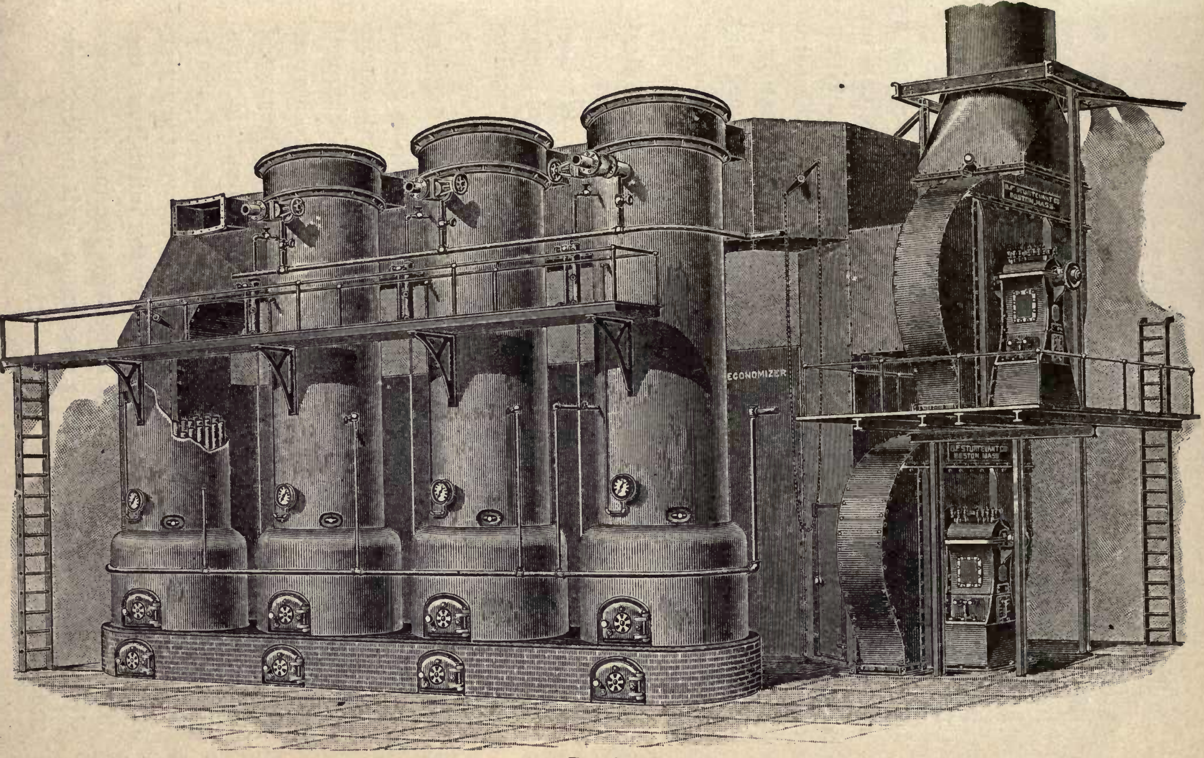


FIG. 85.

axis, and presenting practically flat surfaces to the air as they revolve. By the action of the wheel the air is drawn in axially at the centre and delivered from the tips of the blades in a tangential direction. This type may be simply designated as the centrifugal fan, or, more properly, as the peripheral discharge fan.

The propeller or disc fan is practically useless as a means of draft production. The desired results can be secured only by the use of the peripheral discharge type.

Theoretically there should be a difference in the form of wheels designed for creating pressure and creating a vacuum; practically the distinction between a blower and an exhauster is one of adaptation rather than of construction.

Q. What are the advantages claimed for mechanical draft?

The advantages claimed may be summarized, for land requirements as distinguished from marine, in that by its introduction greater economy in the first cost or running expense of a steam plant may be secured.

As compared with chimney draft, a chimney requires certain fixed and practically unalterable conditions for its location and erection, and is only to a limited extent adaptable to changes in its requirements. Mechanical draft apparatus may, on the contrary, be adapted to a great variety of conditions, such as accommodation to restricted space; or it may be placed in any convenient location and not necessarily in the fire or engine rooms.

Perfect control may always be maintained over the action of mechanical draft. With a chimney the intensity of the draft is least when the fire is low; with the fan it is possible instantly to produce the maximum draft under these conditions.

Climatic conditions do not affect mechanical draft; it can be made as strong in summer as in winter, and on a muggy day as on one that is bright and clear.

Increased rates of combustion are readily had by means of mechanical draft, and the capacity of a boiler largely increased at any time to suit temporary or permanent conditions.

The burning of cheap and low-grade fuels is best accomplished by means of a mechanical draft.

The prevention of smoke, usually a mere incident to the application of mechanical draft, has sometimes been a purpose sufficient in itself to warrant its installation, not that a direct saving in cost of fuel is had, but that cheap and low-grade fuels may be used in localities where smoke-prevention laws are enforced. This is on the assumption that the furnace is properly designed, and the introduction of a fan blast merely insures rapid combustion.

The utilization of waste heat in gases by the use of an economizer is practicable only in the case of a chimney when the escaping gases are of a comparatively high temperature. When the draft is produced by a fan, the draft is independent of the temperature of the gases, the conditions then are favorable for utilizing the heat which is unavoidably lost in the case of a chimney. The saving in fuel which may be accomplished under working conditions by the combined use of mechanical draft and economizer has been experimentally shown to range between 10 and 20 per cent.

CHAPTER XIII.

SPONTANEOUS COMBUSTION.

Q. What is meant by spontaneous combustion?

Spontaneous combustion means self-ignition; it is a name given to fires which have their origin in the heat generated by chemical action, or by the rapid oxidation of the substances thus ignited. The spontaneous combustion of coal is due to the chemical action set up between the carbon constituents and the atmospheric oxygen which is absorbed by coal; the volume of oxygen so absorbed depends upon the surface exposed and the porosity of the coal; the chemical action evolves heat, and when this heat is confined it results in a constantly increasing temperature, and this accelerates the process of oxidation.

Q. What is the probable action set up in spontaneous combustion between the coal and the oxygen of the atmosphere?

The surface of each particle of coal is active in attracting and condensing the atmospheric oxygen, and the oxygen so absorbed is largely rid of the dilutent nitrogen and, therefore, is better fitted for the process of oxidation which begins slowly, but at once. In this process two actions are set up: first the combination of oxygen with what is called the disposable hydrogen in the coal to form water; secondly, the combination of oxygen with the carbon, forming carbonic acid gas, and heat is evolved as the result of both actions. In the initial stage it is not sensible, nor is it apparent as in the case of iron, where visible rust indicates the process. When this heat is subjected to the cooling effect of the atmosphere, or when it can be conducted from its source, no danger is to be apprehended; but where the evolved heat is not so conducted or cooled, as in the case of a mass of fine coal, the temperature will rise and continue with accelerated rapidity as the ignition point is approached (Howard).

Q. How much oxygen will coal absorb?

It has been experimentally determined that certain English coals absorbed twice their own volume of oxygen, and in a pulverized state this absorption equalled 2 per cent of its own weight.

Q. What is Richter's theory regarding the spontaneous combustion of coal?

The theory worked out by Richter is that two of the constituent elements of bituminous coal, viz., the carbon and the hydrocarbons, have a strong attraction for atmospheric oxygen, and under ordinary conditions this absorption of oxygen will be in proportion to the surface exposed, to the porosity of the coal, and to the temperature of the mass.

Q. Have experiments been made to prove the correctness of Richter's theory?

The absorption of oxygen by, and chemical combination with, pulverized bituminous coal is known to occur, and approximately under the following conditions:

At a low temperature the action is slow; but it rapidly increased when 100° F. was exceeded. Powdered coal has been known to fire in a few hours at a steady temperature of 250° F. Under ordinary conditions, however, the absorption was in proportion to the surface exposed, to the porosity of the coal, and to its temperature.

Q. To what element in the coal is spontaneous combustion generally attributed?

Sulphur was once believed to be the real cause of spontaneous combustion in coal, for the reason, probably, that if it is present in the coal it is in the form of pyrites, and this was associated with a well-known fact that heaped-up pyrites in shale, when wetted, often cause the combustion of the pile. The sulphur theory received the support of the noted Swedish chemist Berzelius.

Q. What are the objections to the sulphur theory in the spontaneous combustion of coal?

It is objected to because it does not account for the numerous cases of the spontaneous combustion of coal in which sulphur is not present. The investigations of Dr. Percy in England and of Dr. Richter in Germany showed that the sulphur theory did not account for all the discovered facts.

Coals almost free from sulphur have been observed to be dangerous, and others heavily charged with it comparatively safe. Further the sulphur theory does not account for the ignition of charcoal, or of oily waste, nor of wool when saturated with animal or vegetable oils and subjected to favoring temperatures.

Iron pyrites, or disulphide of iron, is the only sulphur compound found in coal which by oxidizing under favorable conditions will gradually develop heat sufficient to make self-ignition a possibility. Sometimes, however, the pyrites will rapidly oxidize, and at others it will remain unchanged for a long period. The recent conclusions seem to point out that pyrite is merely accessory to the trouble, in that through oxidation it lowers the point of ignition in the surrounding mass of coal, and in the process it swells, causing disintegration of the lumps, and consequently increases the absorbing surface of the coal. The temperature of ignition of sulphur is 482° F., whereas coal requires from 700° to 900° F.

Q. Can the safety of coals as regards spontaneous combustion be determined by analysis?

The difference between safe and unsafe coals cannot be determined by proximate or ultimate analysis. It is the deep mass of small and fine coal that constitutes the danger; and coals of a firing tendency are dangerous, some at one depth of pile and some at another.

Q. How does carbon spontaneously ignite?

Carbon in a finely divided state has the power of condensing oxygen within its pores; now, to condense a gas, force is consumed and heat is produced. In the fire syringe, a piece of tinder is set on fire by the heat evolved by the condensation of the air. When charcoal condenses oxygen heat is liberated, and, if the charcoal is freshly burned, the rapidity of the action will produce such an amount of heat as to cause the chemical combination of the oxygen and carbon, when, of course, combustion takes place with evolution of light and heat. The initial temperature of the action is here due to the sudden squeezing together of the gaseous molecules, for if the air be admitted to the freshly burned charcoal by slow degrees no combustion takes place.

Q. Is wood liable to spontaneous combustion when placed against or in close proximity to hot surfaces?

The fact that a hot steam pipe will char and eventually ignite wood is well known to fire-insurance inspectors. The application of moderate heat to wood dries up its juices, renders it brittle, and ultimately causes its complete disintegration and combustion if air is supplied, though the process is exceedingly slow. At the ordinary temperature of the air, oxygen has so little action upon wood that it is practically indestructible.

Q. How should permanent woodwork passing through large masses of bituminous coal be protected?

By covering the woodwork with sheet iron well painted to protect it, as iron also suffers from oxidation.

Q. Does the presence of wood in a pile of coal affect favorably or otherwise the conditions leading to the spontaneous combustion of coal?

It is a well-established fact that the presence of wood in a pile of coal, whether present as loose chips or as forming supports, contributes materially to the fire risk. The surfaces of the wood through a process analogous to dry distillation become charred and converted into charcoal or tinder. The tendency to oxidation which carbon and carbon compounds, existing in such a substance as charcoal, possess, is favored by the condensation of oxygen within its pores, whereby the intimate contact between the carbon and oxygen particles is promoted. Hence the development of heat and the establishment of oxidation occur simultaneously, the latter is accelerated as the heat accumulates, and chemical action is thus promoted, and may, in course of time, proceed so energetically that the carbon or carbo-hydrogen particles may be heated to the igniting point.

Q. Does the height of a pile of coal contribute to spontaneous combustion?

The higher the pile of coal the greater is the fire risk, especially if the coal is very fine. It is a matter of general observation that when fires break out on shipboard, they originate directly under the main hatchways, or under the coaling chutes, or in the middle or near the bottom of a deep cargo.

Q. Is coal liable to spontaneous combustion when placed against or over hot surfaces?

So long ago as 1852 Graham pointed out that the tendency of coals to spontaneous ignition is increased by a moderate heat. In one case coal had taken fire by being heaped for a length of time against a heated wall, the temperature of which could be easily borne by the hand. In another, coal ignited spontaneously after remaining for a few days upon stone flags covering a flue, of which the temperature never rose beyond 150° F. Examples are sufficiently numerous to fully establish the fact that masses of coal exposed to even a moderate heat become hazardous as a fire risk.

Q. Will small bodies of coal ignite spontaneously?

Coal in small quantity and in a cool place never ignites spontaneously; it does not, therefore, follow that all the conditions leading up to spontaneous combustion are absent, only that one of them, and that an all-important one, the means of accumulating heat, is absent, since the barriers interposed to its escape are not sufficiently close-fitting.

Q. What would be the effect of forcing air into a body of coal as a means of preventing spontaneous combustion by forced ventilation?

When air is forced into a body of coal more or less oxidation occurs, followed by a rise in temperature, the heat present or liberated by its increased oxidation is absorbed by the coal, fresh supplies of air being continually forced in, passes over and around the oxidizing surfaces of the coal becoming hotter and hotter, the air itself becomes heated, and all the conditions for combustion obtain, which, if once begun, continue more and more rapidly with each increment of air supply.

Q. Is wet coal more liable to spontaneous combustion than dry coal?

Water does not assist in the spontaneous combustion of coal except where pyrites are concerned. There is much misunderstanding as to the part played by water in the changes leading to spontaneous combustion. The water itself is not decomposed, as some have imagined. The heat evolved during the combustion of hydrogen and oxygen to form water (62,000 heat units) must be supplied before they can be again torn apart, so that so far from water being a producer of heat, it is likely to be a consumer.

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