of the furnace. As far back as 1879 the late Sir William Siemens designed a small crucible-furnace capable of melting a few pounds of steel on this principle, and the Stassano furnace is the best-known furnace of this type used for the smelting of iron and steel. It is shown in fig. 174. The furnace rotates round an axis inclined about 7° to the vertical. There are three electrodes, which nearly meet in the centre of the furnace, their distance being regulated by a hydraulic ram. A three-phase alternating current is used, and distributed between the three electrodes. The Stassano furnace is rotated by mechanism underneath the furnace during the operation of smelting, but this is not essential to this type of furnace. The furnace is lined with magnesia bricks, and there is provided a tap-hole for metal at the bottom of the furnace and a slag-hole at a somewhat higher level. The charge is fed through a hopper and inclined shoot to deliver below the electrodes. Furnaces of this type are now used commercially in the production of zinc, the volatilised metal being condensed in suitable chambers.

Electric furnaces are now receiving a large amount of attention, and there is no doubt that great advances will be made in this direction in the near future.

CHAPTER X.

THE SUPPLY OF AIR TO FURNACES.

Methods of producing Draught.—In every furnace it is necessary to conduct away the gaseous products of combustion to enable fresh air to enter and to give up its oxygen to the fuel. This passage of the fire-gases from the furnace and of the air to the furnace may be effected in two ways: first, by exhausting the products of combustion; and second, by forcing in air for combustion. In the former method a space containing rarefied air is formed in the furnace, and atmospheric air flows in from outside so as to preserve the equilibrium; whilst in the latter method the pressure in the furnace is greater than that of the air outside, and consequently the air and the fire-gases are forced out. Although the current is usually the same in both cases, the influence on the combustion may be different when the movement is effected by the compression or rarefaction of the air.

The exhaustion of the air is usually effected by means of chimneys. The chimney or stack may be regarded as a vertical pipe containing heated and expanded gaseous products of combustion. The column of gas within the chimney is, in consequence of the expansion due to heat, considerably lighter than a column of air of the same height at the ordinary temperature. The consequence is that, owing to the difference of weight, there is an excess of pressure of air under the grate, and movement ensues. This difference in the weight of the hot and cold columns is equal to the weight of the increase in volume that would be produced by heating the cold column of air to the temperature of the chimney. If the elongation thus produced be represented by h, the velocity of the movement $v=\sqrt{2gh}$; but h is dependent both on the height of the cold column of air and on the difference of temperature within and outside the chimney, whence it follows that theoretically the velocity of a current of gas within a chimney increases proportionately with the square root of the height and the square root of the difference of the external and internal temperatures, and that consequently the action of equal increments of height and temperature becomes continually smaller. But the action of a chimney does not depend so much on the velocity produced as on the weight of air supplied in a given period of time. The higher the products of combustion are heated, when they pass into the chimney the greater is their volume, and, with equal velocity, the less weight of gas would actually pass through the same chimney. The velocities, it has been shown, increase with the difference of the external and internal temperatures, but only in proportion to the square roots, whilst the relative weight of the gases decrease in direct proportion to the temperature by $\frac{1}{273}$ of the original volume for every degree Centigrade. There must therefore be a limit where the action of the chimney reaches its maximum, and it has been calculated that this maximum is attained when the difference of temperature amounts to 273°, or, in other words, when the external air is at the mean temperature and the chimney gases have a temperature of 300°. Similarly, it has been calculated that the quantities of air supplied to the chimney between 200° and 400° differ but slightly, so that for the chimney-draught these temperatures appear to be the most suitable, whilst for the utilisation of heat in the furnace the lower chimney temperature is obviously to be preferred; and even when the temperature of the chimney gases is only 100°, the quantity of air drawn in is to that drawn in by a chimney having a temperature of 300° as 7 : 8.

The amount of gas passing out of the chimney could be determined from the height and temperature of the shaft and the specific gravity of the gases if only the resistance given by friction to the gases in motion and the so-called "free section" were known. The term "free section" is applied to the sum of the areas of the interstices between the lumps of fuel on the grate. The smaller this free section is, the quicker is the motion of the air in it, and the more perfect the combustion, provided that the reduction in section is due to a diminution of the area of the grate, and not to undue clogging of the layers of fuel which, by increasing the friction, at once diminishes the action of the shaft, as the volume of air supplied is necessarily lessened. For this reason small grates give rapid combustion and large grates slow combustion with the same chimney. It has, however, previously been shown that a rapid motion of the air, in this case equivalent to rapid combustion, facilitates the production of carbonic anhydride, whilst a slow motion facilitates the production of carbonic oxide. As a rule, therefore, for the production of heat and for high temperature, rapid combustion on a small grate is to be preferred to slow combustion on a large grate.

The height of the stack must increase with (1) the rapidity of the combustion; (2) the height of the layer of fuel on the grate; and (3) the resistance to which the current is exposed in passing from the grate to the foot of the stack. On the other hand, the height of the stack must increase in inverse ratio to the temperature of the evolved gas.

For furnaces in which the combustion is not rapid, and in which there is but slight frictional resistance, as in furnaces from which the gases pass directly to the shaft, the height of the stack need not exceed 33 feet. Welding-, puddling-, and other furnaces in which the combustion is rapid require a shaft at least 50 feet in height if the gases pass into it at a high temperature; but if they are cooled on their way, and have great frictional resistance to overcome by being utilised, before they reach the shaft, for other purposes, as for heating steam-boilers, it is advisable to make the shaft 65 to 80 feet, or even 100 feet if the length of the flues is considerable, and if they are narrow and crooked.

A chimney is frequently arranged so as to be common to several furnaces, and in this the gases from all the furnaces unite. Its section is calculated on the assumption that the minimum velocity of the gases in the chimney (6½ feet per second) is not exceeded, even if only one of the furnaces be working and the others are cold. At the same time, in order to prevent an unduly decreased velocity when all the furnaces are at work, the common shaft must be made of considerable height, usually 130 to 165 feet. To ensure the successful working of chimneys of this kind, it is important that the up-currents should pass into the shaft in parallel directions, so as to prevent suction being arrested by the impact on each other by converging streams of gases. In order that cold air shall not be drawn into the shaft from a furnace that is not being worked, every flue passing from the furnaces to the shaft must be furnished with a damper.

The vertical projection of the interior of the shaft may be either of the same width above or below, or there may be a slight narrowing at the top. The tapering shape increases the stability of the shafts, especially when they are exposed to the action of storms. It has been proved theoretically that a slight divergence towards the top gives a better draught. The angle at which the sides are inclined to the perpendicular should be 0·5 to 1·5 degree.

Any cooling of the gases interferes with the draught. For this reason brick shafts are preferable to iron ones, and the interior should be made as smooth as may be, so as to lessen friction.

The first researches on chimney gases are due to Péclet, who published some analyses in 1828; but his results, and those of different experimenters who followed him, were open to the objection that the samples taken for analysis were only small fractions of the total gases in the flues, and, as they were not taken with sufficient frequency, they could not represent the mean composition. This grave defect was, however, remedied by Scheurer-Kestner in an elaborate research on the composition of the flue gases of boiler furnaces, which will always form the basis of future experiments in this direction.

A series of experiments conducted by this distinguished chemist and Meunier, in 1868, on the combustion of fuel in boiler-furnaces, showed the difficulty of burning fuel completely on the grate of a furnace; and the analyses of the gases made by them led to the conclusion that the products of combustion always contain unburned constituents, even in the case of a thin layer of fuel and an excess of air of more than 50 per cent.; that is to say, with volumes of 240 cubic feet of air for every pound of coal burnt, instead of 128 to 160 cubic feet. They also showed that the mean proportion of unburned hydrogen reached 20 per cent. of the total amount present. This points to the fact that hydrogen is more difficult to burn, even under favourable conditions, than carbonic oxide, and that with a thin layer of incandescent fuel the unburned carbon in the gas exists more often in the form of a hydrocarbon than in that of carbonic oxide.

In securing a representative sample of gas, the position of the flue from which the gases are withdrawn is by no means a matter of indifference. With a view to collect soot, it should, of course, be as near to the incandescent fuel as possible; but Cailletet has shown that the gaseous products from furnaces must not be collected immediately after being liberated from the fuel, for a current of gases from a mass of incandescent fuel may contain notably more carbonic oxide than the same gases do when cold—that is, during the cooling, combination of carbonic oxide and oxygen takes place.

In a series of tests made by the author[1] in connection with an exhibition opened with a view to abate the nuisance arising from smoke, 85 cases showed that the relation by weight between the carbon completely burnt to carbonic anhydride and that present in the form of hydrocarbons or carbonic oxide varies between the limits of 1000 : 4 and 1000 : 375. There were, however, only 9 cases in which a ratio of 1000 : 200 was exceeded, and but 3 in which the ratio was less than 1000 : 10.

In 17 cases given by Scheurer-Kestner this relation varied from 1000 : 10 to 1000 : 211, the result being mainly dependent on the amount of air introduced to effect the combustion. With reference to the hydrogen, it is to be observed that in these experiments the proportion of carbon completely burnt to carbonic anhydride to the hydrogen present, either in the free state or as hydrocarbons, varies from 1000 : 3 to 1000 : 16. The loss of carbon in the form of soot never exceeds 1 per cent. of

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[1] *Report of Smoke Abatement Committee*, London, 1882, in which volume there are references to the literature of the subject.

the fuel burnt, while the mean loss is probably between 0·5 and 0·75 per cent.[1]

In many cases it is important to be able to keep a record, and so be able to control the composition of waste gases; and within recent years a number of forms of apparatus have been devised for the automatic analysis of furnace gases, based upon the determination of the contained carbon dioxide.

The methods adopted may be divided into two classes—those depending on the specific gravity of the gases, and those in which the carbon dioxide is removed by absorption. The former include the Lux gas-balance,[2] Arndt's Oekonometer,[3] and similar apparatus devised by Pfeiffer,[4] Siegert, and Krell.[5] Since the specific gravity of the furnace gases is not only dependent upon the proportion of carbon dioxide present, but also upon that of the contained water vapour and unburnt gases, and is, moreover, variable with the pressure, results based upon this method of examination can only be regarded as approximate, and are not sufficiently accurate or reliable to substitute the ordinary analytical methods. The forms of apparatus in which the carbon dioxide is absorbed are more reliable, as their method of working is based upon the removal of the specific constituent, the percentage of which is required to be known. The forms of apparatus based on this principle include the "Ados" or "Sarco" apparatus,[6] the Simmance-Abady "Combustion Recorder,"[7] the apparatus of C. Jung,[8] that of H. J. Westover,[9] that of W. H. Porter,[10] the Uehling-Steinbardt "Gas Composimeter,"[11] and the Autolysator[12] of Stracho Johoda and Genzken.

Of these, the Ados and Simmance-Abady Combustion Recorder are the best known in this country. Both depend upon the absorption of the carbon dioxide by means of a solution of potassium hydroxide and the subsequent recording of the decrease in volume effected by the absorption, whereby an intermittent estimation of the carbon dioxide in the furnace gases is effected at successive short intervals.

Blowing-Engines.—The mechanical appliances employed for the production of a stream of compressed air are so varied in

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[1] For fuller information on this subject the student is referred to Gruner's *Traité de Métallurgie* and Ledebur's *Die Oefen*.

[2] Lux and Precht, Fischer's *Jahreseber.*, 1893, xxxix. 1205.

[3] *D. R. P.*, 70,829, 125,470, 129,163.

[4] *D. R. P.*, 78,612.

[5] *Verein deuts, Ing.*, 1888, xxxii. 1090 ; 1893, xxxvii. 595.

[6] *Ger. Pat.*, 160,288. *Zeit. angew. Chem.*, 1905, xviii. 1231.

[7] *Eng. Pat.*,18,680, 1906.

[8] *Chem. Zeit.*, 1905, xxix. 445.

[9] *U.S. Pat.*, 833,274, 1906.

[10] *Eng. Pat.*, 9540, 1906.

[11] *Eng. and Min. Journ.*, vol. vii. p. 608.

[12] *Zeit. Chem. Apparatenkunde*, 1907, ii. 57 ; *Journ. Soc. Chem. Ind.*, 1908, xxvii. 608.

their details that it is impossible to do more than allude to them, the construction and the principles involved falling more in the province of the mechanical engineer than in that of the metallurgist.

In early times the blast was obtained solely from leathern bellows, which were at first single-acting, and subsequently double-acting, but as leather soon becomes inflexible and brittle, it was found advisable to employ wooden bellows. In this way was evolved the box-blower, with single-acting movement of a piston. In the course of time cast iron was substituted for wood, and the iron blast-cylinder, one of the forms of blowing-engines still in general use, was obtained. In addition to this, for low pressures and large volumes of blast, fans and blowers are largely used.

A blowing-cylinder consists of a cast-iron cylinder fitted with a piston receiving a reciprocating motion from the crank-shaft of the engine. At every stroke, air is drawn into the cylinder on one side, and on the other compressed air is forced into a reservoir or into the blast-main. The interior of the cylinder is connected with the atmosphere on the one hand, and with the blast-main or reservoir on the other, by means of flap- or disc-valves fitted in the cylinder-covers. The piston is actuated by engines of the vertical direct-acting or of the beam-engine type, the former being now generally preferred. On the Continent the blowing-engines are frequently of the horizontal, direct-acting, condensing or compound class. The amount of blast required to be delivered is often very considerable, as is shown by the following examples:—

At the Dowlais Works in South Wales the blowing-engines[1] are worked with a boiler pressure of 100 pounds per square inch, and have two steam cylinders side by side, one 36 inches in diameter for high-pressure steam, and another, which is steam-jacketed and 64 inches in diameter, for low-pressure.

Connected with and directly underneath each steam cylinder is a blast cylinder 88 inches in diameter. The engines are designed to give a maximum pressure of 10 lbs. to the square inch, and working with a 5-foot stroke at 23 revolutions per minute, give 19,000 cubic feet of air per minute at atmospheric pressure.

They are capable of blowing 25,000 cubic feet of air per minute if necessary, and the pressure actually developed is over 5 lbs. to the square inch.

At the Barrow Hematite Steel and Iron Company's works[2] a set of 3000 horse-power quarter-crank blowing-engines are used. The two steam cylinders together form a compound engine, which can be worked as condensing or non-condensing. The steam

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[1] See T. M. Grant, "Notes on Blowing-Engines," *Journ. of the West of Scot. Iron and Steel Inst.*, vol. v. p. 128.

[2] *Journ. Iron and Steel Inst.*, 1903, ii. p. 628.

cylinders are 42 inches and 84 inches respectively in diameter, with a 5-foot stroke. The steam pressure is 150 lbs., and the normal speed is 50 revolutions per minute, which is equivalent to a duty of about 20,000 cubic feet of free air.

They can be worked at 80 revolutions per minute with a maximum pressure of 30 lbs. to the square inch.

For foundry purposes the blast is usually supplied by centrifugal fans or by blowers. The fan, although possessing the advantage of great simplicity, has but limited application, since it is useless when pressures exceeding about 6 inches of water-column are required to be produced. In such cases the Root's blower, or a machine of similar type, may be advantageously employed. It consists of an iron casing, in which are placed a pair of revolving cast-iron wafters driven by belts off pulleys, and making about 400 revolutions per minute, the smallest possible clearance being left between the two curved surfaces as they revolve. The blast is conveyed in air-tight riveted sheet-iron or steel pipes or *mains* of ample cross section to the hot-blast stoves.

As examples of more recently introduced forms of blowing-engines, gas-driven engines and steam turbines may be mentioned.

Large gas blowing-engines have been adopted with considerable success. The first blowing-engine worked by blast-furnace gas was erected at Seraing in 1899; it was of 600 horse-power, and was worked with unpurified gas.[1]

In recent years there has been a great development of the use of the surplus gases of the blast-furnace for the driving of gas engines to provide power, not only for the blowing-engines, but also for all purposes connected with ironworks, and this method is found to be more economical than the older methods using intermediary boilers, etc. In 1906 there were in work or in course of erection in Germany, in 41 smelting-works, no less than 349 gas engines, with an effective horse-power of 385,000, the great majority of these being worked with blast-furnace gas. One of the early difficulties met with in the use of blast-furnace gas in engines was the presence of dust and tar, considerable wear and tear resulting from the presence of gritty dust, owing to the want of efficient means of cleaning. The cleaning of the gases has therefore received a considerable amount of attention, and it is recognised that cleaning is also advantageous for that portion of the gas which is used in the hot-blast stoves. A. Sahlin[2] has described the methods used for cleaning the gases, and states that it should take place in three stages, viz.:—

1. The preliminary dry cleaning by means of dust-catchers, etc.
2. Further cleaning, so as to fit the whole of the gas for use in stoves, roasting-kilns, etc.

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[1] *Journ. Iron and Steel Inst.*, 1900, i. p. 109.

[2] *Ibid.*, 1905, i. p. 324.

This is accomplished by means of stationary cleaners, and then by coolers or scrubbers, with or without the addition of revolving washers. The stationary cleaners consist of a combination of cylindrical vessels in which the gas is led downwards with a rapid motion and upwards with a slow motion. In the scrubbers the gases pass upwards while a spray of water falls from the top, thus wetting the particles of dust and assisting their separation. The interior of the scrubbers may contain sieves, coke, bricks, etc., to increase the surface.[1]

3. The special cleaning of such part of the gas as is to be used for power purposes.

This final purification is effected by some type of centrifugal machine, such as that introduced by Theiren, shown in figs. 175 and 176.

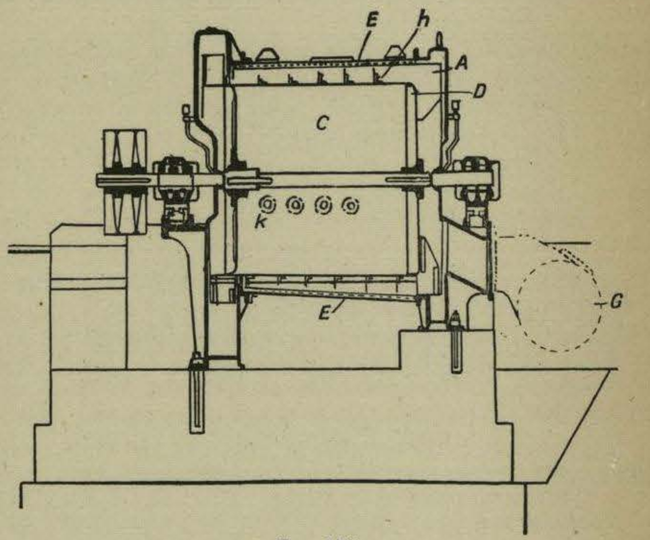

FIG. 175.

This consists essentially of a rapidly revolving water-tight drum D, fig. 175, with vanes set obliquely on its periphery. This drum is surrounded by an outer fixed casing, which forms the suction-chamber A. This casing is lined with coarse wire netting E, so as to give a rough surface, and the clearance between the edge of the vanes and the inside of the casing is only about a quarter of an inch. Water enters at the side of the apparatus at K, tangentially to the casing of the middle chamber C, and leaves the apparatus through the pipe G, shown in figs. 175 and 176. The gas is drawn in by the vanes *h*, and the coarse dust separates in the suction-chamber. By means of fans at each end of the drum D, the gas is then drawn through the space between the drum and the casing, the dust is projected against the spiral meshes of the grating E, while the water entering at the same time is also distributed over the surface of the grating. In this way the water is broken up and the dust efficiently removed. This apparatus is capable of cleaning a blast-furnace gas containing 4 to 5 grammes of dust per cubic metre down to 0·008 gramme per cubic metre, which is actually more free from suspended particles than is the surrounding atmosphere. This result is obtained with less than half a litre of water per cubic metre of gas. Although this apparatus requires more power than a slowly revolving cleaner, it is found to be more efficient, and to be specially suited for use where high purification is required.

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[1] *Journ. Iron and Steel Inst.*, 1906, iii. p. 45.

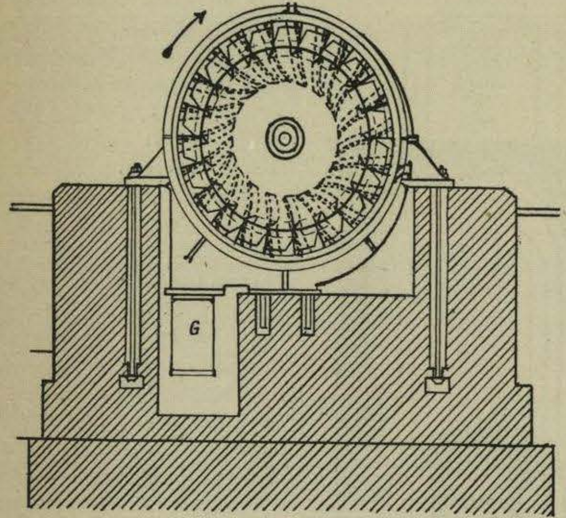

FIG. 176.

Steam turbines have been introduced in the Cleveland district and elsewhere; they are said to work economically and to give a uniform and steady air-blast. The use of a turbine blower in connection with ordinary reciprocating steam blowers is considered in some respects to be the ideal method of augmenting an existing blowing-plant. Turbines have the advantage of being cheaper and smaller than reciprocating blowers.

Hot-blast Stoves.—The temperature of combustion increases with the temperature of the air consumed up to the limits which are fixed by dissociation. Hot air economises in the blast-furnace a sum of *calories* equal to that which it brings, but if this heat has to be initially imparted to the air by the combustion of a fuel of equal value to that consumed in the furnace, it is evident that the economy will be at best but doubtful. In all cases the advantage of hot-blast will be in direct proportion to the cheapness of the fuel that is burnt in heating the blast. There is a great advantage when the waste heat of the furnace can be utilised in this way. By employing a fuel identical with that burnt in the blast-furnace it would appear, however, that there is still a distinct advantage due to the more perfect combustion of the carbon than is attained in the furnace, there being produced a greater proportion of carbonic anhydride as compared with that of carbonic oxide.

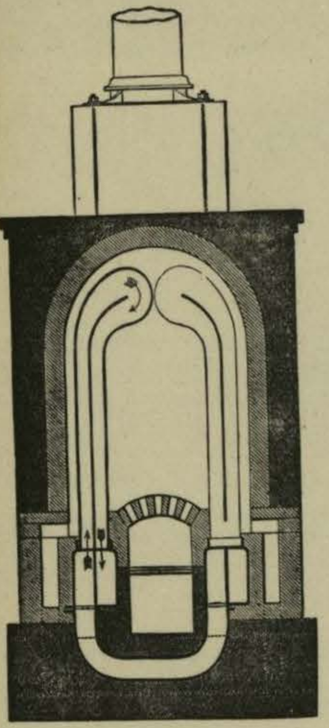
FIG. 177.

The apparatus in which the blast is heated before passing to the furnace was formerly heated by solid fuel, but now the waste gases from the furnace are practically always used. The first appliances for heating the blast date from 1828, when they were introduced by Neilson at Glasgow. This discovery, that 100 lbs. of coal burnt in heating the blast was able to save 300 or 400 lbs. of fuel burnt in the furnace, was received with disbelief, and ironmasters were very slow in availing themselves of one of the most important inventions which had been made in connection with the metallurgy of iron.

The cast-iron hot-blast stoves formerly used in metallurgical works may be referred to two types, both introduced at the same date. In 1833 Faber du Faur invented a hot-blast stove, consisting of sixteen cast-iron pipes united by semicircular bends, forming one long serpentine pipe enclosed in a chamber heated by the waste gases from the blast-furnace. It was placed directly above the throat of the furnace. The second type of iron hot-blast stove differed from the former in that the blast-current was split in its passage through the stove. It consisted of an oblong fire-brick chamber, containing a series of Λ-shaped cast-iron pipes, that connected two parallel horizontal main pipes embedded in the masonry on either side of the rectangular fire-place that extended throughout the stove.

A modification of this second type is the so-called pistol-pipe stove (fig. 177). In this case the arch is replaced by a single pipe divided longtitudinally, the division reaching nearly to the top, which is enlarged in the form of the stock of a pistol.

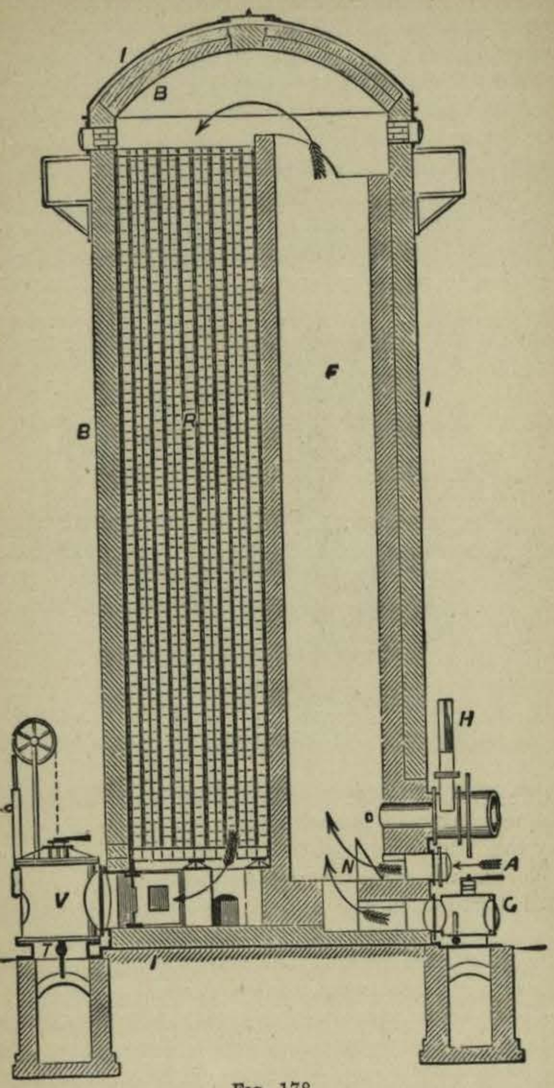

FIG. 178.

Two main types of regenerative hot-blast stoves are now employed. These are based on the principle of the intermittent absorption of heat by masses of fire-brick and the transference of the heat to the blast. The first stove of the first type was constructed by Cowper in 1860; it is similar in arrangement to a Siemens regenerator. It is enclosed, however, in an iron case so as to withstand the pressure of the blast. The first stove of the second type was constructed by Whitwell in 1865 for the Thornaby Works at Stockton. It is essentially a serpentine pipe-stove constructed of fire-brick.

The Cowper stove, which is represented in sectional elevation and plan in figs. 178 and 179, consists of a sheet-iron tower I, of circular horizontal section, closed with a dome-shaped roof B, and lined internally with fire-brick. A circular flame-flue, F, extends from the base to the dome, whilst the remainder of the stove is filled with fire-brick chequer-work, and forms the regenerator R. The waste gases from the blast-furnace pass in by the valve G, and are burnt at N, the necessary air for combustion entering by the valve A. The flame descends through the chequer-work and passes out by the chimney-valve V. In this way the brickwork becomes heated. The valves G, A, and V are closed, and cold blast, admitted through the valve C, is passed through in the reverse direction. It absorbs heat from the chequer-work, and is delivered as hot-blast by the valve H. The chequer-work is constructed of Cowper's honeycomb bricks. Two stoves are worked in conjunction, one being heated while the blast passes through the other. It is advisable to have a third in reserve. These stoves are 60 to 65 feet high, and 26 to 28 feet in diameter. Compared with pipe-stoves, the saving of fuel is about 20 per cent., and the increased make is also 20 per cent. An exact average of over 100 stoves shows the saving in fuel to amount to a little over 5 cwt. of coke per ton of iron.[1]

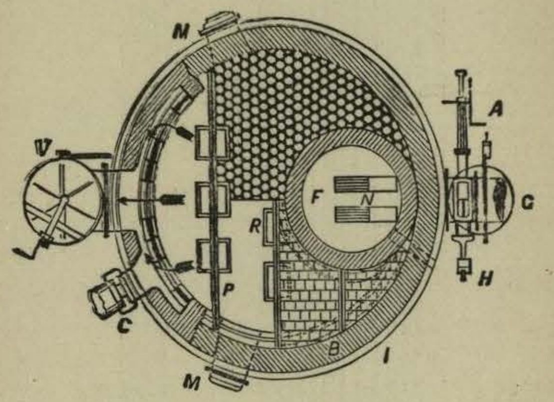

FIG. 179.

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[1] E. A. Cowper, *Journ. Iron and Steel Inst.*, 1883, p. 576.

The Whitwell stove[1] is shown in fig. 180. It is merely a brickwork serpentine pipe formed by vertical walls, and enclosed in a cylindrical case. The waste gases from the furnace enter at A and are burnt, air being admitted through the passages *a a*. The flame passes up and down the passages formed by the dividing walls, and escapes to the chimney by the passage C. When the stove is heated, the gas and chimney valves are closed, and cold blast is admitted at D, and passes out heated at B. The walls forming the regenerator consist of 5-inch brickwork. The older forms of Whitwell stove were 25 feet in height. Recently the height has been greatly increased, the largest size adopted being about 70 feet high and 25 feet in diameter. A domed top is also now used in place of the flat top as introduced by Whitwell.

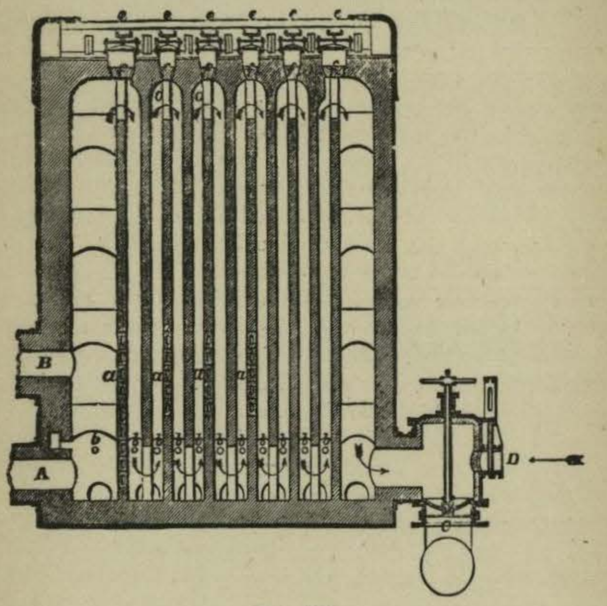

FIG. 180.

A number of modifications have been introduced in the construction of fire-brick hot-blast stoves; for example, the Ford and Moncur stove,[2] first introduced in Cumberland, has been designed chiefly to faciliate cleaning. For this purpose the upper edges of the bricks employed are dormer-shaped, to prevent the dust lodging; the stove is also divided into four separate parts by vertical partitions, so that when it is desired to clean out the

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[1] *Journ. Iron and Steel Inst.*, 1869, p. 206; 1871, ii. p. 217.
[2] *Ibid.*, 1896, i. p. 201.

dust, the blast is turned on to each section separately, and by proper release-valves the air is allowed to suddenly escape, and so carry away the dust, and it is claimed by this means that the stoves can be kept clean without the necessity of stoppages.

In the Gordon-Cowper-Whitwell stove, used largely in the Southern States of America, both the Cowper and the Whitwell systems are combined, while a separate chimney is provided to make each stove quite independent of the draught of the stack. It is claimed that these stoves have the advantage that gases which contain a considerable proportion of dust may be employed, while, owing to the fact that the latter part of the regenerative action is conducted by Cowper bricks, the gases are efficiently cooled, and a high temperature can be imparted to the blast.

In the Massick and Crookes stove[1] the regenerator is on the Whitwell principle, but arranged in what is known as a "three-pass" system; the main combustion-tube is placed in the centre of the stove, and the gases, after passing up the central tube, pass once down and once up through gas-passages similar in principle to those of the Whitwell stove, but arranged concentrically round the main combustion-tube. The products of combustion pass out at the top of the stove.

Dry Blast.—The question of the effect of the moisture contained in the air supplied to blast-furnaces has received very much attention during the last few years, and is certainly of considerable importance in many localities.

As long ago as 1799 Mr Dawson of Low Moor read a paper before a scientific society in York, pointing out the great difference in the moisture of the air going into the blast-furnace in the hot months of the year and in the winter months; and it is also interesting to note that the Duke of Devonshire, in his address delivered in 1869 at the inaugural meeting of the Iron and Steel Institute, mentioned, among the important problems which at that time either seemed to have found solution or still remained to be solved, the effect of moisture contained in the air of the blast, and varying at different seasons of the year. It was at one time thought that in hot-blast practice the introduction of water vapour would be advantageous, as the hydrogen produced by its decomposition is such a powerful reducing agent.

The question was considered at length by Sir L. Bell, who came to the conclusion, in his *Principles of the Manufacture of Iron and Steel*, that there is no advantage to be obtained by increasing the quantity of water vapour in the blast.

W. H. Fryer considered the effect of moisture in the air-blast before the Cleveland Institution of Engineers in November 1890, and stated that the effect of the moisture is to lower the temperature at the tuyères so that more fuel and greater engine-power have to be used, and the variations in the quantity of moisture

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[1] *Journ. Iron and Steel Inst.*, 1890, ii. p. 340.

cause constant variations in the working of the furnace and in the nature of the iron produced.

In the same paper Mr Fryer gave drawings and particulars of an apparatus for drying the air, at a cost of 4½d. per ton of pig-iron produced. This apparatus, which does not appear to have been used on more than an experimental scale, consisted of a cast-iron cylinder fitted with shelves, on which were placed lumps of dry calcium chloride which it was proposed to dry by heat after being used for a certain time; the apparatus was arranged so as to work continuously. Calorimetric calculations are given, based on data given by Sir L. Bell with regard to hot blast, and the reactions in the furnace, showing the losses due to the moisture in the blast. The results with dry blast at 10° C. and 485° C. are most interesting in view of recent developments, and are as follows:—

Temperature of blast	10° C.	485° C.
Increase of make of pig-iron per cent. . .	31·42	15·07
Diminution of power required for blast per cent.	67·50	15·71
Diminution of coke required in furnace ,,	21·51	12·01

In 1899 S. D. Mills[1] called attention to the necessity of using the driest air possible for supplying blast-furnaces. He had found great differences in the amount of moisture in the air inside and outside the engine-house on a cold day, and suggested that the buildings and engines should be arranged so as to take air directly from the exterior in preference to using the air in the buildings.

The application of dry blast to the manufacture of iron has been practically worked out by J. Gayley[2] who points out that the air used in the blast-furnace is by far the most variable element involved in the process; for whereas the raw materials used for the charge vary within about 10 per cent., the atmosphere, of which large quantities are used per ton of iron made, varies in its content of moisture from 20 to 100 per cent. from day to day, and often in the same day. The desiccation of the air used in blast-furnaces in such a way as to reduce its moisture to a small quantity and to keep it uniform must of necessity contribute in a marked degree towards the attainment of uniformity in the furnace operations.

With air containing 1 grain of water per cubic foot, there is passed into the furnace, for each 1000 cubic feet used per minute, practically 1 gallon of water per hour. A furnace of average size in the Pittsburg district consumes about 40,000 cubic feet of air per minute, which would pass into the furnace 40 gallons

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[1] *Journ. of the U.S. Association of Charcoal Iron Workers*, vol. viii. pp. 306–310.

[2] *Journ. Iron and Steel Inst.*, 1904, ii. p. 275; 1905, i. p. 256. See also *Amer. Inst. Min. Eng.*, Feb. 1906.

of water per hour for each grain of moisture contained in a cubic foot of air.

The results of observations of the amount of moisture contained in the atmosphere at Pittsburg are given by Mr Gayley in the paper mentioned above, which show that the amount varies from 1 grain per cubic foot on an exceptionally dry day in winter, to over 10 grains per cubic foot on an exceptionally humid day in summer. There would therefore, on these two days, enter the furnace 40 and 400 gallons of water per hour respectively.

After many preliminary experiments, Mr Gayley decided that the most practical method of desiccating the air was refrigeration by means of anhydrous ammonia. For this purpose an insulated chamber containing coils of pipe is used; this chamber is so located that the air for the blowing-engine is drawn through it at atmospheric pressure. The brine system of refrigeration is used, the ammonia machines for cooling the brine being of the compressor type. As the air passes through this chamber on its way to the blowing-engine the moisture present is condensed as water or as frost on the lower pipes, and as frost or ice only on the upper pipes. When the pipes have become covered with frost, the cold brine is shut off from several vertical lines of coil at once and warmer brine is passed through these pipes.

The frost is rapidly melted and the water formed run off; cold brine is then again run through the pipes which have thus been cleared of frost, and the refrigeration and desiccation again commences. For cooling the calcium chloride brine used in the refrigerators, brine tanks are used which contain twenty coils of pipes, consisting of an inner and an outer pipe, these coils being covered with the brine. The return brine from the refrigerating chamber flows into the top of the tank, is cooled by the ammonia expanding between the outer and the inner pipes, withdrawn by a pump and forced through the inner pipe (where it is cooled below 0° C.), and thence into the coils in the refrigerating chamber.

This system of brine refrigeration was used in order to minimise the risk of accidents which might occur should direct refrigeration by means of ammonia be used.

For thawing off the frost from the coils, these are divided into three divisions, and one of these is thawed off as above every day; in this way refrigeration is not interfered with. During the first run of the plant the water collected from the thawing of the frost averaged 2784 gallons per 24 hours.

It should be remembered that advantages accrue not only from the fact that a large amount of moisture is actually extracted, but also from the fact that the air used is practically uniform in moisture content, in spite of constant variations in the humidity of the atmosphere. The very first run obtained by Mr Gayley after the erection of the desiccating plant showed great saving in the fuel consumption, and also an increased burden.

The effect of thus cooling the blast is also to increase the effective capacity of the blowing-engines, owing to the greater density of the air.

The following figures given by Mr Gayley illustrate the differences obtained in the working of a furnace:—

	With Ordinary Blast.	With Dry Blast.
Product . . .	358 tons per day.	447 tons per day.
Coke . . .	2147 lbs. per ton.	1726 lbs. per ton.

B. Ossan[1] considers that dry blast is especially suited for a climate where the variations between day and night temperatures are considerable. In Europe, the changes are not so marked as at Pittsburg, and Ossan is of opinion that Gayley's methods would not show here a sufficient saving of fuel to pay a satisfactory return for the capital invested in the plant. By modifications in the plant, however, the cost could be much reduced, and it would be sufficient in most cases if a uniform humidity were maintained throughout the year without removing practically the whole of the moisture, as was done in the original Gayley's plant at Pittsburg.

J. E. Johnson, jun.,[2] has considered the relative cost of the different methods of air refrigeration, and is of the opinion that the use of a brine-circulating system, as used in Gayley's original plant, as a precaution against accidents, is unnecessarily expensive, whilst the substitution of the direct expansion of the ammonia would reduce the first cost, the labour and the power required. He also suggests the use of a two-stage method of refrigeration, one at, say, 36° F., and the second at 15° F., and also urges that there is no commercial gain by refrigerating at too low a temperature.

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[1] *Iron Age*, 1906, vol. lxxviii. p. 798.

[2] *Journ. Iron and Steel Inst.*, 1906, iii. p. 404.