(*Paper No. 4202.*)

“Recent Developments in By-Product Coking.”

By GEORGE BLAKE WALKER, M. Inst. C.E.

WHEN the Author's previous Paper¹ was presented, about 17 years ago, the subject of By-Product Coking was somewhat new in this country, although great progress had been made abroad, especially in Belgium and Germany. Since then a complete revolution has taken place in coking practice in England. By-product ovens have very largely taken the place of old beehive ovens; scarcely any of these have been built recently, and they are destined ere long to pass into the limbo of superseded appliances. The change has been of a far-reaching character, and the details of construction of the leading types of coke-oven show a distinct tendency to uniformity.

The three most noticeable improvements in all modern retort coke-oven plants are:—

- (1) Better distribution and heating of the combustible gases, so as to ensure a more equal temperature in all parts of the oven-walls.
- (2) Separate supply of air for combustion to all the numerous burners.
- (3) “Direct recovery” of sulphate of ammonia.

All the leading types of oven are excellent, and preference is largely a matter of individual opinion. The numbers in the United Kingdom are given on p. 105.

Among the benefits obtained from by-product coking which have

¹ “By-Product Coke Ovens,” Minutes of Proceedings Inst. C.E. vol. cxlii, p. 308.

Type of Oven.	1910	1911	¹ 1912	¹ 1913	1914	1915
Beehive	16,037	14,301	13,833	13,167	9,210	7,521
Coppée	1,991	1,904	1,900	1,926	² 1,538	² 1,343
Simon-Carvès . .	1,140	1,244	1,141	1,402	1,354	1,766
Otto Hilgenstock .	1,025	1,118	1,283	1,597	1,589	2,034
Semet-Solvay . .	1,055	1,107	1,128	1,107	1,134	1,251
Koppers	507	656	757	814	916	1,241
Simplex	334	240	240	275	428	486
Collin and Huessener	294	244	355	419	479	575

latterly become of importance in new fields of usefulness, the following may be mentioned:—

- (a) Utilization of surplus gases from coke-ovens for power-generation in gas-engines.
- (b) Production of illuminating gas for cities.
- (c) Supply of gas in bulk in lieu of steam for power-generation and for manufacturing and metallurgical purposes.
- (d) Production of benzol and toluol for explosive purposes and for motor traction.
- (e) Tar products.
- (f) Expansion in the production of sulphate of ammonia for fertilizing purposes.

These important developments have, in consequence of the war, drawn public attention to the best means of utilizing fuels, and the recovery-plants demand consideration quite as much as the ovens themselves. Much also has been achieved in the improvement of mechanical arrangements in connection with coke-ovens, such as the preparatory washing, and the compressing of the charge of coal, and the quenching and loading of the coke.

The objects aimed at in all recent ovens are:—

- (1) More intense and better equalization of heat in all parts of the oven-walls, in order to burn off the charge more quickly and uniformly.

¹ These figures are taken from report of Chief Inspector of Mines for 1914, and published in *The Gas World*, 5 February, 1916, p. 18.

² "It is assumed that these figures include also some Coppée non-recovery ovens, and that the decrease is in respect of these, since it is known that additional Coppée by-product ovens were started in 1915." (Footnote from *The Gas World*, 3 March, 1917, p. 19.)

(2) Equalization of the pressure of the gas between the ovens and the heating flues.

(3) Reduction in the time of coking, whereby a larger output of surplus gas, coke, and by-products is obtained from a given number of ovens, and reduction in the cost of coke-making, etc.

(4) Good means of inspection of the heating-flues.

(5) Facility of regulation.

(6) Increased yield of ammonia and benzol.

(7) Reduction of quantity of gas required for heating the ovens by the use of regenerators.

The retort coking systems may be divided into two classes, namely, that in which by-products are not recovered, and that in which they are.

In the first method the gases of distillation are conducted, without the separation of the tar and ammonia, into the oven-flues where they are utilized for burning the charge contained in the oven, and afterwards to fire boilers or heat furnaces.

In the second method the ovens may be either of the waste-heat or of the regenerator type, the tar and ammonia being separated and the purified gases used for other purposes. In the waste-heat ovens upwards of 80 per cent. of the gas is burned in the oven-flues. In the regenerator type 40 to 50 per cent. of the gas driven off during the burning of the charge of coal is used for heating the oven-flues, and the balance (60 to 50 per cent.) is available either for heating boilers, or for supplying gas to gas-engines, or for town-lighting, etc. To a large extent collieries can utilize for their own purposes the surplus gases which are obtainable from the coking processes after recovery of by-products. Till recently the heating of boilers was considered the simplest and most advantageous way of using the waste gas. As a rule Lancashire double-flued boilers have been considered most suitable, but water-tube boilers have also been adopted in some cases, and are more efficient where good water is available.

The temperature at which the gases from coke-ovens can be conducted to the boiler-flues varies with both the class of oven and the relative position of the oven and the boilers. It is obvious that the closer the boilers can be to the ovens, the less heat is lost by radiation.

The following particulars of modern ovens are intended to draw attention to their salient features without going into details which can easily be obtained by those interested. Some of the claims made by the inventors as to special points in the design have

been admitted, with the desire of dealing with their respective merits quite impartially. The illustrations have in most cases been supplied by the builders.

TYPES OF MODERN OVENS.

The name of Evence Coppée must always be associated with the history of the retort type of coke-oven. As early as 1861 he introduced an oven (without recovery of by-products) which possessed the feature of the long narrow chamber which has since been generally adopted. About 20,000 of these ovens were built in early days. The Coppée oven as built to-day is of modified design, and

Fig. 1.

the results obtained are not inferior to those of its more youthful rivals. The heating-flues in the oven-walls are vertical, and grouped in five compartments, each containing six flues. These six flues are again sub-divided into two sections of three flues each (*Fig. 1*). A special feature of this design is that the direction of the flame can, if desired, be reversed in any of the five compartments independently (*Fig. 2*), and the temperature of the various parts of the oven walls can be kept equable. This tends to greater durability and tightness of the walls. The Coppée Company state that—

“in most systems of regenerator ovens the air for combustion is heated by passing through the whole or a portion of the regenerator according to the position of that particular oven in the battery, that is to say, the air supplied to

the ovens at the far end of the battery has become fully heated by passing through the whole of the regenerator, while the air supplied to the ovens at the opposite end has only just entered the regenerator and is consequently only slightly heated. By the special arrangement of the regenerator in the Coppée oven, however, the air is made to pass through the whole of the regenerator, and is thus heated to a uniform temperature before entering the flues of any oven. This is most important as it conduces materially to the uniform working of the ovens."

Fig. 2.

The general arrangement of the regenerator flues of these ovens is shown in *Fig. 3*.

The Simon-Carvès oven was described in the Author's previous Paper,¹ where it is spoken of as a horizontal flue oven.

Although ovens with horizontal flues are still built by this firm, they have latterly built a large number with vertical flues. The design of the horizontal-flue oven has been modified to some extent, and the present design gives excellent results.

In the ovens with vertical flues the Simon-Carvès design follows the early type of Hoffmann oven, but an improvement was intro-

¹ Minutes of Proceedings Inst. C.E., vol. cxlii, p. 312.

Fig. 3.

COPPÉE REGENERATIVE BY-PRODUCT OVEN.

duced, when the principle of having only one point of combustion, and the distribution of the flame throughout the different vertical flues was abandoned, and a separate supply of gas was admitted at the bottom of each flue, ignition taking place at that point. The supply of air and gas to each flue is through pipes, as shown in *Fig. 4*, and it can be separately regulated from a position outside

the oven in the open air; this has distinct advantages, as the person regulating is not exposed to any great heat.

Referring to *Fig. 4*, the gas is brought in by the pipe (1), and alternately fed by means of gas taps (2), through the distributing boxes (3) and (3a), provided with the necessary taps from which run the gas channels (4), (5), (6), (7) and (8), leading into sections (9),

(10), (11), (12) and (13), these being correctly proportioned to give the required supply of gas to each set of vertical flues.

This gas meets the air at point (14), about the level of the sole of the oven, where combustion takes place. Referring to *Fig. 4a*, the air for combustion, after traversing the regenerator (14), rises through the ducts (15), into the distributing chamber (16), feeding the compartments (20), (21), (22), (23) and (24) through the horizontal channels (17) and (18) and two other parallel channels

Fig. 4a.

placed alongside, and shown at (29) and (30) on *Fig. 4b*, representing a transverse section through the oven.

These compartments correspond with the gas sections (9), (10), (11), (12), (13), and are connected to them by the openings (15) before-mentioned. The supply of air which is allowed to pass along the horizontal channels is regulated by dampers (25) inserted in these channels, through openings (26) in front of the oven, which are closed with removable plugs.

The regulation of the gas, and the air required for its combustion, is thus entirely effected by the operator from the outside of the ovens; and, after the final regulation is effected, the taps and openings can be sealed to prevent anyone else tampering with them.

The gas is supplied alternatively to either side of the oven by a set of three-way gas taps (2), one to each oven, actuated by the same winch by which the reversing of the air through the

Fig. 4b.

regenerator chambers is effected, and which is placed at the end of the battery. In this design the distance traversed by the flame is the minimum practicable, as it passes simply up to the flues in one half of the oven and down in the other. It is found in practice that a balance is practically maintained between the pressure in the coking chamber and that in the flue.

It is almost impossible and would be invidious to decide between the best half-dozen designs where there are so many excellent

points. The practical test is the shortness of the burning-time which will yield a thoroughly-burnt coke. This depends on the heat produced in the heating-flues, which again is affected by the heating of the air required for combustion. In the Otto ovens a temperature of $1,200^{\circ}$ to $1,400^{\circ}$ C. is obtained, and where the boilers are close to the coke-ovens the waste-heat gas arrives at

Fig. 5.

KOPPERS SYSTEM OF REGENERATORS.

the boilers at rather over $1,000^{\circ}$ C. The width of the oven is an important factor in connection with quick burning. An oven 1 foot 6 inches wide will burn off sooner than an oven 1 foot 8 inches wide, and this again more quickly than one of 1 foot 10 inches or 2 feet. It follows that on account of the high temperature employed specially refractory bricks must be used for the oven-walls. Although there are excellent fire-clays in the United Kingdom, much

has yet to be learned from the Continent as to the preparation of the clay before firing. The burning of a charge of 7 to 8 tons of coal in 24 hours may be regarded as the objective, and this has been achieved by several systems—notably the Koppers oven. In this oven the gas and air for combustion are separately distributed

on each side, and along the whole length of the oven. Each oven-wall contains thirty vertical flues, and as there is a gas-jet in each flue, each oven is heated at sixty points. The gas-supply is regulated by the size of the aperture in the tuyere, and the air-supply by slides; so that exactly the right proportion of gas and air to produce uniform heating can be obtained. The tuyeres can be withdrawn and changed from the top of the oven.

The distinguishing feature of the Koppers regenerator oven lies in the employment of separate regenerative chambers for each oven (*Fig. 5*), so that every oven is entirely independent of its neighbour. The air for combustion leaves the regenerators at a temperature of $1,000^{\circ}\text{C}$.

The special feature of the "Simplex" (Fabry-Linard) system is that the ovens work in pairs. One oven in each pair is in full distillation, while the other oven is burnt off and ready to be drawn (*Figs. 6 and 7*). If this regularity in charging and drawing

Fig. 7.

CROSS SECTIONS.

Scale: 1 Inch = 12 Feet.

FEET 10 5 0 10 FEET

"SIMPLEX" (FABRY-LINARD) REGENERATOR OVEN.

is secured, a constant supply of gas is continuously available for burning in the heating-flues. The gas-burners are arranged on the top of the oven, and they are therefore not likely to be blocked by particles of firebrick, etc., which may have dropped to the bottom of the flue. The regulation of the gas for each oven is effected by means of a cock, and, when once this is correctly set no further attention is required.

The principle of this process is that the combustion of the gas is effected gradually in three more stages, so as to make it take place slowly, but simultaneously at different points of the flue, fresh gas

being introduced at each stage, so that the whole of the oxygen has been consumed before the products of combustion leave the oven.

METHODS OF CHARGING OVENS.

Up to 25 years ago coke-ovens were invariably charged by means of hopper trucks, which were emptied into ovens by charging-holes in the top. This method was attended with the disadvantages that the charge was loosely packed, and the oven was not completely filled.

In 1885 an invention was patented for putting the coal to be coked into an iron box, of the same shape as the coke-oven, and having for its bottom a movable floor which could be pushed into the oven, carrying the charge. At first the charge was stamped by hand, but in 1903 a mechanical arrangement of iron stamper (*Fig. 8*) was patented. The earlier stamping-machines had only one stamper, but later Messrs. Meguin and Company introduced a second stamper, in order to increase the efficiency of compression. It is claimed that an average increase of 12 per cent. in the output is obtained by the adoption of stamping; but this is not always the case. With rich coals the yield from uncompressed coal is equal to that from compressed, but with lean coals compressing is of great advantage. The charging-box of the compressor is filled from an overhead hopper containing the washed coking-coal, or by hopper tubs. The coal-storage bins should be as close as possible to the coke-ovens, so that the coal can be delivered to the charging-machine by simple means, and with the minimum of labour. When the storage-hopper is not in line with the ram track the filling of the charging-machine can be accomplished by passing it under a bridge carrying a conveyer. It may also be charged from an aerial ropeway, or by other means.

Coke made from stamped coal is denser than coke made from coal simply charged loose into the ovens. It is stated that the crushing strength of coke made from Saar coal has been increased from about 1,140 lbs. to 1,990 lbs. per square inch by the introduction of the stamping process, thus rendering the coke more capable of bearing the weight imposed upon it in the blast-furnaces. The time occupied in charging is greatly reduced, and therefore the oven-walls do not suffer from contact with the cold outer air for more than a very few minutes.

The moisture content in the stamped coal can be kept as low as 10 per cent., which is considerably lower than in the case of coal which has not been pressed. The amount of steam generated in

the process of carbonization is also diminished, and the absorption of heat in evaporating the water is considerably less.

When the process of stamping is complete, the cake or loaf of stamped coal can be pushed forward into the oven by the sliding

floor of the machine. The width of the loaf is kept about an inch less than the width of the oven so that none of the coal may be rubbed off in the process of pushing it into the oven. As soon as the charge has been introduced into the oven, the door next to the charging-machine is closed, leaving only a space sufficient for the

iron floor to be withdrawn, which is done without delay. As soon

Fig. 9.

SEMET-SOLVAY COKE-OVEN, WITH DARBY QUENCHER.

as this operation is completed the charging-machine returns to the storage-hopper to receive another charge. The coke is discharged

when ready by a pusher, driven by steam or by electricity, on to the bench between the ovens and the railway-sidings, which is somewhat wider than the length of the oven.

Benches were formerly always made level, only having a fall sufficient for drainage, because the slacking of the coke had to be done with jets of water from hoses directed upon it by the benchmen. Since the introduction of quenching-apparatus (*Figs. 9 and 10*) fixed close to the mouth of the oven, the quenching is effectually done within a width of about 5 feet, and the bench itself is made to slope at a sharp angle, so that the coke falls and breaks into lumps. If the quenching is fairly complete, the coke is allowed to lie on the sloping bench till it is cold. If the coke is still red-hot, jets of water from hoses are played upon it. At the foot of the slope the progress of the sliding coke is stopped by gates, by opening which the coke may be allowed to slide either into wagons, or on to a conveyer-belt running longitudinally along the bench-front, or into an iron hopped truck or car running in a subway, which conveys it to a screening-plant, where it is separated into large coke for blast-furnace use, and the smaller coke known as breeze. This car was introduced by the Semet-Solvay Company, and is generally known as the Solvay quenching-car. Such a car, by Messrs. Vaughan and Dymond, of Newcastle-on-Tyne, is shown in *Fig. 11*.

Messrs. Coulson and Company, of Spennymoor, were one of the first firms to make electrically-driven charging-cars in this country (*Fig. 12*). They are of various capacities, those constructed to hold about $8\frac{1}{2}$ tons having three hoppers. By means of a Renold chain, the motor drives a counter-shaft between the hoppers, resting in bearings fixed on the bottom of the frame car. The travelling-axle is actuated by two gear-wheels.

Fig. 10.

Fig. 11. *Fig. 12.*

The Coppée Coke Oven Company's three-hopper car is driven by a 20 HP. motor. The machine rests on roller bearings, holds 9 tons of coal, and can charge fifty ovens in 12 hours.

The Schalke Ironworks, Gelsenkirchen, build a charging-car with conical hoppers which ensures a good discharge of the washed coal.

Special designs of cars have been made so as to clear the hydraulic main and gas-pipes from the top of the ovens, where these have been arranged in the middle of the ovens. Some coke-oven engineers consider it detrimental to the output of by-products to place the gas-collecting mains on one side of the ovens. The gases should, of course, be got rid of as quickly as possible to prevent decomposition of the by-products, and therefore the course of the gases should be as short as possible.

A car suitable for existing coke-ovens has been designed by Messrs. Coulson and Company, Spennymoor. It can be adapted to most existing plants, irrespective of the position of the collecting main. Each charge-hole is supplied by a separate car. The current is obtained through overhead trolley wires. A catch on the level of the rails engages with a lever suspended from the motor, and a car started from the bunker will run by gravity to the oven to be charged where it is stopped. The attendant, having sent off all three cars, follows and reverses the motor, thus sending the wagons back again to the hopper.

DIRECT-RECOVERY SYSTEMS.

The direct recovery process is a marked advance on the old system, both as regards the larger proportion of by-products obtained and the cost of operation. It is obvious that costs will differ in every case, owing to special circumstances, the efficiency of a particular plant, and the proportion of gas to be treated. Comparisons made with particular plants can therefore only be regarded as representing actual results in the case of such a plant, and experiments carried out with different plants give somewhat different results. The Tables given on pp. 124-127 of an English and a Continental plant illustrate this, and the figures, having been ascertained in both cases by competent investigators, will be found to give a substantial indication of the relative costs of the two systems.

The Table on pp. 124–125 is from a Paper by Mr. J. Christopher.¹

The Table on pp. 126–127, by Mr. C. Heck,² of Alsdorf, Germany, gives the cost of working direct, semi-direct, and old recovery processes, and will be found useful in making comparisons with the costs of any existing plant.

RECOVERY OF BY-PRODUCTS FROM COKE OVENS.

It will have been seen from the description of the various types of coke-ovens chiefly in use that they all approximate closely to one another, and differ mainly in the details of the methods adopted for securing the most regular and intense heating of the oven-walls. In recent years, however, modifications have been largely introduced in the method of dealing with the gases for the recovery of by-products.

The former process, briefly described in the Author's previous Paper, which is now being spoken of as the "Indirect" process, has been largely superseded by what is called the "Direct" process for the recovery of sulphate of ammonia, of which there are four systems.

The pioneer in the direct extraction of ammonia from coal-gas (as in so many other branches of the coke-oven industry) was Mr. F. Brunck, who in 1903 attempted to pass the hot gas from the coke-ovens directly into a bath of sulphuric acid. This invention, however meritorious, did not achieve success owing to the fact that the tar contained in the gas was deposited in the saturator, and a dirty salt was produced. Much trouble was also experienced owing to the effect of certain gases on the saturator. Brunck then introduced an apparatus with a mechanical separator for separating the tar from the hot gas, but found it impossible to remove the tar thoroughly from the gas at such a high temperature. It was then sought to reduce the temperature of the gas to facilitate the extraction of the tar; but difficulty was experienced with the saturator, as the gases were at too low a temperature to permit of sulphate being formed. For these reasons Brunck's system was finally abandoned.

Mr. Heinrich Koppers, of Essen, soon afterwards turned his attention to this question, and as a result of his experiments a more successful system of direct recovery was devised. He succeeded in

¹ "Journal of the Society of Chemical Industry," vol. xxxii (1913), p. 115.

² *Glückauf*, 1913, p. 443.

overcoming the difficulties previously experienced with the tar, and obtained a good white salt. There are two alternative processes. In one the separation of the tar is effected at a temperature a little above dew-point, and the gases are conducted directly into the saturator, the liquor in the latter being maintained at a temperature which allows of the production of sulphate by the application of external heat. In the other process the gases are cooled to atmospheric temperature for the complete extraction of tar and then subjected to superheating before delivery to the saturator. The latter method has proved the more successful, and has been largely adopted.

Fig. 13, p. 128, is a diagram which represents the latter process. The hot gas direct from the ovens enters the coolers B, where its temperature is reduced to about 25°C . The gas is then drawn by an exhaustor C, by which it is delivered to the tar-extractor D. After having been freed from the tar, the gas is led into the reheater A, where it becomes heated to a temperature of about $50\text{--}60^{\circ}\text{C}$. The heated gas is then conducted along the main F direct to the saturator E, in which the ammonia gas is extracted owing to absorption in sulphuric acid, and is recovered in the form of sulphate. The saturator is of the totally enclosed type, and the sulphate is continuously removed therefrom by means of an injector, working with either steam or compressed air. The salt is delivered on to a collecting table and thence into a centrifugal dryer L, where it is completely freed from mother-liquor.

The products of condensation, which are extracted in the cooling and tar-eliminating operations, are drawn off from the condensers, tar extractors, etc., and are conveyed into a separating-tank H, where the tar and ammoniacal liquor separate owing to their different densities. The tar flows into the storage-tank I, and the liquor into the storage-tank J. The liquor is pumped to the ammonia still G, where the ammonia is driven off by steam and lime in the usual way. The vapours of distillation are conducted from the still and are delivered into the main F, where they mix with the heated gas, and the whole then passes into the saturator.

An important feature of this process is that no live steam is required, either for distilling the liquor to liberate ammonia or to reheat the gas after cooling and tar-extracting. For both these purposes the exhaust steam from the engines driving the exhaustors is more than sufficient.

COMPARATIVE WORKING COSTS, ETC., OF VARIOUS TYPES OF AMMONIA RECOVERY PLANTS.

500 Tons Coal per Day, Moisture 10 per Cent.

	Water Absorption.	Semi-Direct.		Direct.	
		With Benzol Recovery.	Without Benzol Recovery.	With Benzol Recovery.	Without Benzol Recovery.
A. Effluents.					
Total liquor from :—					
1. Moisture in coal	50	50	50	50	0
2. Water of formation	13	13	13	13	0
3. Water added in scrubbers	50	0	0	0	0
4. Steam added in stills	28 "	16 "	16 "	nil	nil
Total effluent	141 " (Limey)	79 " (Limey)	79 " (Limey)	63 " (Clear)	nil
B. Thermal Losses :—					
1. Gas cooled to	25° C.	25° C.	50° C.	25° C.	80° C.
2. Water vapour in gas	Condensed	Condensed	Condensed	Condensed	Not condensed
3. Liquor to be heated from 25° to 100° C.	113 tons	63 tons	63 tons	nil	nil
Equivalent of heat (1)	0·422	0·422	0·282	0·422	0·112
units lost, calculated (2)	4·347	4·347	4·347	4·327	nil
to tons of coal per day (3)	1·089	0·607	0·607	nil	nil
Total	5·858 tons	5·376 tons	5·236 tons	4·769 tons	0·112 tons

C. Plant :—									
1. Exhausters	1	1	1	2	2	2	2	2	2
2. Air condensers, etc.	20	20	20	20	20	20	20	20	nil
3. Water	4	4	4	4	4	4	4	4	2 tar washers
4. Scrubbers	3	nil	nil	nil	nil	nil	nil	nil	nil
5. Ammonia stills.	1 for 113 tons	1 for 63 tons	1 for 63 tons	1 for 63 tons	1 for 63 tons	1 for 63 tons	1 for 63 tons	1 for 63 tons	nil
6. Superheater	1	nil	nil	nil	nil	nil	nil	nil	nil
7. Saturators	2 (a)	2 (larger than a)	2 (larger than a)	2 large	2 large	2 large	2 large	2 large	2 large
8. Settling pools	for 141 tons	for 79 tons	for 79 tons	for 79 tons	for 79 tons	for 79 tons	for 79 tons	for 79 tons	nil
9. Purifiers	2	nil	nil	nil	nil	nil	nil	nil	nil
Total cost (comparative)	£7,800	£5,600	£5,300	£5,700	£5,600	£5,700	£5,700	£5,600	£3,600
D. Working costs :—									
1. Steam for exhausters	s. d. 19 3	s. d. 19 3	s. d. 19 3	s. d. 19 3	s. d. 19 3	s. d. 19 3	s. d. 19 3	s. d. 19 3	s. d. 38 6
2. Water in scrubbers	2 0	nil	nil	nil	nil	nil	nil	nil	nil
3. Pumping liquor	2 0	1 0	1 0	1 0	1 0	1 0	1 0	1 0	nil
4. Steam for stills	42 0	24 0	24 0	24 0	24 0	24 0	24 0	24 0	nil
5. Interest on "C"	21 4	15 4	14 6	15 7	14 6	15 7	15 7	15 7	9 10
Total daily cost (comparative)	86 7	59 7	58 9	55 1	58 9	55 1	55 1	55 1	48 4

											Direct Process.	Semi-Direct Process.	Old Process.
A	Coal coked per hour	.	.	.	.	.	.	.	.	.	33·3	33·3	33·3
B	Liquor produced per hour	.	.	.	.	.	.	.	.	.	0·3	6	12
C	Power used for exhausters	.	.	.	.	.	.	.	.	mm. water gauge	900	750	500
1	"	.	.	.	.	.	.	.	.	HP.	70	58	39
2	"	.	.	.	.	.	.	.	.	"	12	12	12
3	"	.	.	.	.	.	.	.	.	"	5	..	..
4	"	.	.	.	.	.	.	.	.	"	2	3	7
5	"	.	.	.	.	.	.	.	.	"	3	3	3
6	"	.	.	.	.	.	.	.	.	"	92	76	61
7	"	.	.	.	.	.	.	.	.	"			
	Total power consumed	.	.	.	.	.	.	.	.	"			
D	Steam used in distilling liquor, per hour	.	.	.	.	.	.	.	.	Tons	0·075	1·5	3
1	"	.	.	.	.	.	.	.	.	"	0·025	0·1	..
2	"	.	.	.	.	.	.	.	.	"	0·050	0·05	0·05
3	"	.	.	.	.	.	.	.	.	"	0·150	1·65	3·05
4	"	.	.	.	.	.	.	.	.	"			
	Total steam used per hour	.	.	.	.	.	.	.	.	"			
E	Value of power and steam used :—												
	Case 1.—Electric driving and live steam used for heating and distilling. Assuming that 1 HP. on plant = 1 kilowatt on switchboard = 7 kilogrammes steam to turbo-generator.												
1	Steam used for driving, per hour	.	.	.	.	.	.	.	.	Tons	0·644	0·532	0·427
2	"	.	.	.	.	.	.	.	.	"	0·150	1·650	3·050
3	"	.	.	.	.	.	.	.	.	"	0·794	2·182	3·477
4	"	.	.	.	.	.	.	.	.	"	1·588	4·364	6·954
5	"	.	.	.	.	.	.	.	.	"	13,900	38,100	60,900

Case II.—Using exhaust steam in turbines :—

F	Case II.—Using exhaust steam in turbines :—											
	1	Steam used for all purposes per hour	.	.	.	.	.	.	Tons	0·150	1·65	3·05
	2	Power recovered from (1) 25 kilogrammes steam = 1 HP.	.	.	.	.	.	.	HP.	6	66	120
	3	Remaining HP. to be generated (C 7 above)	.	.	.	.	.	.	"	86	10	..
	4	Steam required to produce this HP. per hour	.	.	.	.	.	.	Tons	0·602	0·07	..
	5	Total steam used per hour	.	.	.	.	.	.	"	0·752	1·720	3·05
	6	Value at 2 marks per ton of steam per hour	.	.	.	.	.	.	Marks	1·504	3·440	6·10
	7	" " per year	.	.	.	.	.	.	"	13,150	31,000	53,400
G	1	Value of cooling water (1 cubic metre = 0·08 mark)	.	.	.	.	.	.	Marks per year	..	4,200	8,400
	2	" sulphuric acid (1 ton = 30 marks)	.	.	.	.	.	.	"	105,000	105,000	105,000
	3	" lime (1 ton = 15 marks)	.	.	.	.	.	.	"	500	1,100	2,200
	4	" other materials, etc.	.	.	.	.	.	.	"	3,500	3,500	3,500
	5	Total value of materials	.	.	.	.	.	.	Marks per year	109,000	113,800	117,100
H	1	Wages and salaries	.	.	.	.	.	.	Marks per year	35,000	35,000	35,000
J	1	Working costs in Case I. above	.	.	.	.	.	.	Marks per year	157,900	186,900	213,000
K	1	Working costs in Case II. above	.	.	.	.	.	.	Marks per year	157,150	179,800	205,500

The gas passes out of the saturator by the main K, by which it is conducted back to the ovens and other points where required. In cases where benzol is required to be recovered from the gas, it is necessary for the gas to be cooled down after leaving the saturator.

In America, at the ovens of the Indiana Steel Company, Gary, a charge of $12\frac{3}{4}$ tons of coal, consisting of a mixture of 80 per cent. Pocahontas and 20 per cent. Klondyke district, is completely burnt off in 16 hours, thus giving a capacity of $19\frac{1}{2}$ tons of coal per oven per day under normal working-conditions.

With regard to by-products, the yields obtained from a number of these plants in this country average: sulphate of ammonia 1.5 per cent. of the weight of coal carbonized; tar 5 per cent.; and benzol $2\frac{1}{2}$ to 3 gallons per ton of coal. At one plant, a yield of 1.62 per cent. of sulphate was obtained for a considerable period. The salt produced is white and quite free from all trace of tarry matter.

[THE INST. C.E. VOL. CCV.]

K

SIMON-CARVÈS DIRECT-RECOVERY PROCESS.

In the Simon-Carvès process the hot gases from the ovens are freed from tar by passing them first through a "cyclone" and then through a centrifugal extractor (*Fig. 14*). The gas enters the upper portion of the cyclone at a determined velocity, through an inlet placed at a tangent. The gas whirls round the sides of the vessel, and the tendency towards a gradually diminishing velocity is counteracted by the conical shape of the lower part of the apparatus. The tar is deposited on the sides of the inverted cone and flows out through a sealed drain-pipe. The gas leaves the cyclone through a central pipe, taken through the top cover, and passes on to the dynamic centrifugal separator which revolves at a peripheral speed of 200 feet per second. The fine particles of tar coagulate into drops; these are thrown against the casing of the separator, and drain to the bottom. It is claimed that by this double centrifugal process all traces of tar are removed from the gas, which is drawn through an exhaustor into the saturator, where the ammonia combines with the sulphuric acid and forms ammonia sulphate. After leaving the saturator the gases, which are still hot, are cooled for the extraction of benzol and are conducted to the ovens and burnt in the flues, any surplus being passed to the gasholder where it is available for power purposes.

OTTO-HILGENSTOCK DIRECT-RECOVERY PROCESS.

The hot gases leaving the ovens carry with them the tarry constituents, which are partly precipitated in the mains and are only prevented from causing obstructions by a flow of hot tar in which they are absorbed. When the temperature of the gases has dropped to 100° C. or thereabouts by natural atmospheric cooling, they are drawn through a conical orifice in which they are subjected to a spray of fine tar. This eliminates the tar-fog, and the gas is sent on in a clean condition. The temperature of the gas leaving the sprayers is usually between 65° C. and 77° C., the exact temperature depending on the moisture contents of the gas. The clean gas now passes to the exhaustors, which revolve at about 2,000 revolutions per minute, and which force it through the saturators. The ammonia of the gas combines therein with the sulphuric acid, forming sulphate.¹

¹ Further particulars are contained in a Paper by O. Rau, "Progress in the Recovery of By-products." Report of the International Congress of Mining and Metallurgy, Düsseldorf, 1910.

According to tests made by Mr. R. Peel at New Brancepeth Colliery, the gas-pressure in the hydraulic main averages 0·2 inch water-gauge, the suction on the main before the tar-sprays is equal to 1 inch of water-gauge, and before the exhauster, 4 inches of water-gauge. The pressure between the exhauster and the saturator is equal to 23 inches of water-gauge, and after the saturators, 4 inches. The average temperatures (Centigrade) are:—

Hydraulic main	225°	After exhauster	66°
Before tar-spray	86°	In saturator	67°
After „	58°	After saturator	58°

“SIMPLEX” RECOVERY SYSTEM.

The hot gas from the coke-ovens is conducted by the main suction-pipe to the tar scrubber. A branch pipe from the suction-pipe main dips into the tar-pit to collect any tar that may be condensed in the suction main.

In the tar scrubber the temperature of the gas is brought to about 15° C. above that of its water dew-point. This cooling is effected by passing the gas through wooden tiers, the whole surface of which is regularly and continuously washed with tar at a temperature of 75° to 80° C. At the same time the gas is deprived of its tar fog and is sufficiently purified to pass through an acid lye of ammonium sulphate, without detriment to the latter. The tar scrubber is fed by the pump with a regular supply of tar drawn from the tar storage-tank and distributed by a rotary distributor. The temperature of the tar-pumps in the tar scrubber is regulated by a valve which allows more or less hot tar from the receiver to mix with the cold tar from the storage-tank. The hot gases from the tar scrubber are then conducted to the tar separator. This is constructed with a series of vertical tubes through which the gas is passed. A special cap is fixed on the top of each tube having tangential slots through which the tar-laden gas is drawn. These slots give a fast rotary motion to the gas which causes it to impinge on the inside periphery of the vertical tubes, the separated tar flowing down into a tar-well at the bottom. The gas, thus freed from the tar, is drawn through smaller vertical tubes at the bottom of the main tubes, the space between the two being effectively sealed to prevent any escape of gas by way of the tar well. A rotary tar-distributor is arranged over the caps covering the tops of the vertical tubes for the purpose of keeping the tangential slots and tubes clean. In order to regulate the velocity of the gas through the tubes a certain number of blank

caps are provided, which enable regulation to be effected. The gas from the tar-separator is exhausted by a centrifugal exhauster and forced through the saturator, wherein it is deprived of its ammonia and a corresponding quantity of sulphate of ammonia is produced. The small quantity of liquor, which sometimes condenses along with the tar, contains some chloride of ammonia, and is therefore concentrated in a small gas-fired boiler and subsequently crystallized in the form of ammonium chloride, which is dried and sold at a more remunerative price than the sulphate of ammonia.

The advantages of the plant described above may be summarized thus:—

(1) The recovery of the sulphate of ammonia is performed without the use of condensers, coolers, or scrubbers.

(2) The results obtained are equally good in summer and in winter, as they do not depend on the cooling and scrubbing of the gas, and no loss of ammonia can occur.

(3) No cooling-water for condensers is required.

(4) No noxious effluent whatever is produced, whether or not benzol be recovered.

(5) The labour and supervision involved in the working of the plant are less than with the scrubber process.

(6) The plant is simple in design and not more expensive to maintain than that for the scrubber process.

POWER-GAS.

The use of coke-oven gas for power purposes at collieries is certain to make rapid progress. Up to the present time colliery-managers have scarcely realized that a considerable supply of power from by-product coke ovens was available. In some cases there is a disposition to build waste-heat ovens and use the whole of the gases, after they have heated the ovens, under boilers. There is, perhaps naturally, a very great reluctance on the part of most colliery-managers to scrap existing steam plant which is serviceable, although it may be far from economical; and the tendency seems to be in favour of introducing steam turbines to generate electricity, especially where exhaust steam can be utilized. "Mixed-pressure" turbines, running on exhaust-steam during the day and on live steam at night, have been introduced at collieries in large numbers. From the point of view of actual heat-efficiency the advantage is clearly in favour of the gas-engine and the regenerator type of oven: but the varying circumstances of collieries modify this

conclusion to some extent, inasmuch as at most pits there is a quantity of unsaleable fuel available. There can, however, be no doubt that such inferior material could be gasified in gas-producers, with results far more advantageous than if it were burned under boilers. Frequently, with bad fuel, it is necessary to use forced draught, and in any case the labour bill for firing and cleaning out boilers is heavy as compared with that for charging and dealing with the ashes from gas-producers. This, however, is foreign to the subject of the utilization of coke-oven gas.

It is interesting to compare the amount of power which can be obtained by raising steam with waste heat from non-regenerator ovens and using it in steam engines, and by using the surplus gases from regenerator ovens in internal-combustion engines. The quantity of gas available depends of course on the quality and composition of the coal and the efficiency of the ovens, but a coal containing 30 per cent. of volatile constituents, and yielding not less than 10,000 cubic feet of gas per ton, may be taken as representative.

In a battery of fifty modern by-product ovens, each having a capacity of 10 tons of damp coal, and burning off in 30 hours—say $5\frac{1}{2}$ charges burnt per week—2,750 tons of coal per week would be carbonized. If these are “waste heat” ovens without regenerators there will be sufficient waste heat at about 800° C. to fire six Lancashire boilers (say 30 feet by 8 feet), which would evaporate, say, 500 gallons of water per hour, and produce steam in non-condensing engines to the extent of about 250 HP. each, or 1,200 HP. in all. In addition to this there would probably be some, but not very much, surplus gas which could be used in gas-engines.

If the ovens were of the regenerator type the heat would be absorbed from the waste gases in passing through the regenerators, and would be of little value for steam-raising. The highly heated air for combustion in the heating-flues of the ovens effects a great economy in the quantity of gas required for carbonization and leaves a considerable surplus for use in internal-combustion engines. As much as 60 per cent. of the scrubbed gas is sometimes available, but 40 per cent. is a very moderate proportion; 2,750 tons of coal at 10,000 cubic feet per ton give 27,500,000 cubic feet of gas 40 per cent. of which is about 11,000,000 cubic feet. Reckoning

11,000,000
$\frac{30 \text{ feet of gas per horse-power-hour in gas-engines}}{30 \times 168}$

= 2,182 HP., or nearly double the amount obtained by steam-raising.

Of course, these figures are exceedingly rough, but they are fairly representative of results obtained in actual practice. If the gas was used in gas-engines whose consumption was only 20 cubic feet of gas per horse-power-hour, the advantage over steam would be 50 per cent. more, and probably such a consumption as 20 cubic feet per horse-power-hour will soon be common practice.

The calorific value of coke-oven gas varies with the analysis of the coal, but is usually somewhere between 400 and 450 B.Th.U. per cubic foot. This high value was a source of great trouble in gas-engines in the early stages, but experience has enabled the makers to strengthen the weak parts, and now the internal-combustion gas-engine running on coke-oven gas can be regarded as reliable. Coke-oven gas and the exhaust-steam turbine have in recent years very greatly assisted in the production of secondary power in collieries, which is becoming so much more necessary as mines become much more extensive than formerly and as thinner seams are being worked.

The following comparison of the relative value of coke-oven gas burnt under boilers and producing steam to be used in turbines, with live gas employed directly in gas-engines, is obtained from a continental source.¹

Assuming a battery of 120 ovens, charged daily with $6\frac{1}{2}$ tons of coal each, and yielding 4,236 cubic feet of surplus gas per ton of coal (i.e. for the battery of 120 ovens 137,700 cubic feet per hour), with a mean calorific value of 442 B.Th.U. per cubic foot there are 6,086,400 B.Th.U. per hour for disposal.

With a heat-consumption of 11,800 units per horse-power-hour, it is possible with gas-engines to produce about 5,150 H.P. measured on the switchboard.

Comparing this with the use of waste gases under boilers, and assuming a steam-pressure of 142 lbs. per square inch with 590° F. superheat at boilers, and 70 per cent. efficiency, the steam produced will be, say, 36,300 lbs. per hour: deducting 10 per cent. for condensation, etc., leaves 32,670 lbs. of steam to drive two steam turbo-dynamos (950 kilowatts each), which will produce 2,575 H.P. measured on the switchboard.

The first cost of a gas-engine plant to produce 5,150 H.P., including three engines, each of 1,260 kilowatts, and buildings, may be put down at about £33,000, and the cost of producing current at 0.064*d.* per kilowatt-hour.

¹ Messrs. Haniel & Lueg, Düsseldorf.

The cost of boilers and steam plant to produce 2,575 HP. (1,895 kilowatts) may be put down at £25,000, and the cost of producing current at 0·093*d.* per kilowatt-hour. Therefore, with coke-oven gas, the gas-engine supplies electrical energy 31 per cent. cheaper (93 : 64 : : 100 : 69) than can be done with the steam-turbine supplied with steam from boilers heated by the waste gases from coke-ovens.

The annual monetary profit from the gas-engine plant, as compared with the steam-turbine plant, is estimated by Messrs. Haniel and Lueg to be about £3,500 in favour of the gas-engine plant, irrespective of the value of the gas. But if the calorific value of the gas is calculated, and taking 6*s.* per ton as the value at the pit of common boiler-coal, then the gas utilized, on the basis of its calorific value, would add £6,700 to the advantage of the gas-engine plant.¹

¹ As an illustration of the use of surplus coke-oven gas at a colliery, the following figures taken from the coke-oven gas-engines at Wharnccliffe Silkstone Colliery, near Barnsley, may be of interest.

The plant consists of 5 engines (2 Stockport, 1 Mather and Platt, 1 National and 1 Robey), which latter acts as a spare and handles the week-end load. The total rated horse-power of the five engines is 2,000, but they are run at about three-fourths load.

Two Stockport vis-a-vis gas-engines, two cylinders 20 inches diameter by 30 inches stroke running at 128 revolutions per minute and driving air-compressors by ropes.

Horse-power for the two engines	300
Load factor (percentage)	92·3
Hours per week in operation	135
Horse-power hours per annum	1,950,000
Equivalent units per annum	1,454,700
Gas consumption in cubic feet per annum	53,188,000

	Cost per Annum.			Cost per Unit.
	£	s.	d.	d.
Stores and renewals	210	0	0	0·035
Attendance	276	5	0	0·046
Overhauling labour	124	0	5	0·020
Oil	37	19	0	0·006
Gas at 2 <i>d.</i> per 1,000 cubic feet	484	18	0	0·080
10 per cent. interest on £3,682	368	6	5	0·061
Totals	£1,501	6	5	0·248

Checking the above cost per unit in the bulk we have

$$£1,501 \ 6 \ 5 = \frac{360,317d.}{1,454,700 \text{ units}} = 0·248d. \text{ per unit,}$$

The yield of surplus gas is greater in proportion for a large than for a small battery of ovens, but even with a small battery there should be a fair surplus, provided the ovens are in good order.

One Mather and Platt 2-cycle double-acting gas-engine having one cylinder 20 $\frac{1}{2}$ inches diameter by 34 inches stroke running at 102 revolutions per minute and driving the ventilating fan by ropes.

Horse-power rated	300		
Load factor (percentage)	78·3		
Hours per week in operation	161 $\frac{1}{2}$		
Horse-power hours per annum	1,973,504		
Equivalent units per annum	1,472,250		
Gas consumption in cubic feet	59,184,000		
	Cost per Annum.		Cost per Unit.
	£	s. d.	d.
Stores and renewals	160	15 10	0·026
Attendance	214	16 6	0·035
Overhauling labour	41	2 10	0·007
Oil	23	15 0	0·004
Gas at 2d. per 1,000 cubic feet	493	4 0	0·080
10 per cent. interest on £3,726	372	12 0	0·061
Totals	£1,306	6 2	0·213

Cost per unit taken in the bulk

$$= £1,306 \ 6 \ 2 = \frac{313,514d.}{1,472,250 \text{ units}} = 0·213d. \text{ per unit.}$$

One National vertical tandem gas-engine having four cylinders 23 $\frac{1}{2}$ inches diameter and four cylinders 22 inches diameter by 24 inches stroke running at 200 revolutions per minutes direct coupled to a 700 kilowatt direct-current generator.

Rated horse-power of engine	1,000		
Load factor (percentage)	59·3		
Hours per week in operation	137		
Units generated per annum (metered)	3,097,900		
Gas consumption " " in cubic feet	123,916,000		
	Cost per Annum.		Cost per Unit.
	£	s. d.	d.
Stores and renewals	408	19 1	0·032
Attendance	312	18 2	0·024
Overhauling labour	265	4 0	0·021
Oil	101	1 0	0·008
Gas at 2d. per 1,000 cubic feet	1,032	12 8	0·080
10 per cent. interest on £7,842	784	4 0	0·061
Totals	£2,904	8 11	0·226

Cost per unit when taken in bulk

$$= £2,904 \ 8 \ 11 = \frac{697,067d.}{3,097,900 \text{ units}} = 0·226d. \text{ per unit.}$$

The above overhauling labour includes such labour as cleaning purifiers, etc.

It has just been stated that 120 regenerator ovens should produce surplus gas for 5,000 HP., or 42 HP. per oven. During the miners' strike in Yorkshire in April, 1914, it was found possible to work a battery of fourteen Simon-Carvès ovens, at Wharnccliffe Silkstone Colliery, and to obtain surplus gas to the extent of 300 HP., which is just half the above figure (21 HP. per oven). The difference between the results is of course due to the fact that the quantity of surplus gas from a small unit is much less than from a large unit. Also the ovens at Wharnccliffe Silkstone Colliery were intentionally run very slowly as the supply of coal was limited.

COKE-OVEN GAS FOR LIGHTING.

The application of by-product coke-ovens for supplying lighting-gas to cities and rural districts has been growing in Germany during the past decade, especially in the neighbourhood of Essen, where a company has been formed for supplying purified gas to that city and surrounding towns as far as 70 miles away. An interesting article on the development of this application of the surplus gases appeared in *The Times Engineering Supplement*, December, 1913, and the plan has also been described by Mr. Dorey Ford in a Paper read before the Institution of Mining Engineers.¹ Coke-ovens are now being built by gas-companies, e.g., at Vienna and Birmingham, with a view to produce a metallurgical coke, and at the same time an equal yield of gas and residuals. The earliest installation on a large scale was in connection with the supply of lighting- and power-gas to the city of Boston, U.S.A., where at the Everitt works there were erected, in 1901, one hundred coke-ovens specially for this purpose; and the number has since been increased. These works were described in a Paper read before the International Engineering Congress in Glasgow, 1901, by Mr. F. Schniéwind, the Engineer of the plant.

It is claimed that very considerable economies can be secured by producing gas for lighting purposes in coke-ovens—i.e., large retorts—as compared with producing it in a large number of comparatively small retorts, as is the present practice. Mr. G. Stanley Cooper, in a Paper read in February, 1914, before the London Junior Gas Association, pointed out that the advantages of bulk carbonization may be summarized thus:—

¹ Transactions of the Institution of Mining Engineers, vol. xlvii, p. 207.

(a) The labour-costs are reduced considerably, owing to the fewer charging and discharging operations.

(b) Coke-breeze and low-grade fuel may be used for heating the ovens.

(c) A good metallurgical coke, and a superior tar are produced in coke-ovens designed for town-lighting purposes where none of the gas from the ovens is used for heating them.

The gas for heating is producer-gas obtained from a Kerpely producer, which is of the revolving grate type. At Birmingham, Mond producers have given excellent results. The charging of the ovens can be done in the daytime, and thus they are all closed and producing gas during the time when the greatest quantity is required. The ovens are charged and drawn every 24 hours.

In Western Germany the use of coke-oven gas for lighting is making great strides. In Rhineland and Westphalia, Wesel, Mülheim on the Ruhr, Velbert, Wulfrath, Barmen, etc., take nearly 1,000 million cubic feet of gas per year. Essen, Oberhausen, Osterfeld, Bottrop, Gelsenkirchen, Herne, Bochum, Castrop, Witten, etc., take 1,872 million cubic feet annually; and there are other towns supplied from coke-ovens. The price paid by municipalities for coke-oven (purified) gas is under 9*d.* per 1,000 cubic feet.

The Paper is accompanied by tracings and lithographs from which the Figures in the text have been prepared.