

The Low Temperature Carbonization of Coal*

A Review of Its History, Theory and Practice

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THE question of the low temperature carbonization of coal is not a new one; the disadvantages of bituminous coal as a fuel have been recognized from very early times, and as far back as 1656 Evelyn described in his diary a "project by Sir John Winter of charring seacoale, to burn out the sulphure and render it sweete." The resulting "cinders" made a "cleare pleasant chamber fire, depriv'd of their sulphure and arsenic malignity."

In 1681 a patent was taken out by Becker and Serle for the production of pitch, tar and smokeless fuel from coal, while the Earl of Dundonald took out in 1781 a patent for making pitch, tar, oils, cinders, etc., from coal.

The early literature of the gas industry, from 1792 onwards, teems with references to low temperature carbonization, but the gas engineer's desire for the utmost yield of gas from his coal led to the adoption of higher and still higher temperatures, until to-day the highest possible temperatures compatible with the nature of the retort are universally used in this industry.

From the point of view of the gas industry, with gas as the primary product, this choice has been thoroughly justified by the results obtained and the same thing can be said of the coking industry, where a hard metallurgical coke is the main desideratum.

Neither gas coke nor metallurgical coke, however, is an ideal substance for use as a domestic fuel, and in the modern sense of the term, the idea of low temperature carbonization is the outcome of attempts that have been made to produce a smokeless fuel from bituminous coal.

In this sense, low temperature carbonization can be said to date from 1890, when the late Col. Scott Moncrieff suggested the withdrawal of the charge from gas retorts when half the usual quantity of gas had been evolved, with the idea of using it as a domestic fuel. It was found, however, that the only result was the production of a partially coked layer on the outside of the charge with an inner core of practically raw coal.

A more feasible suggestion was made in the same year by Parker, who proposed (Eng. Pat. 67, 1890) to produce a smokeless fuel by passing steam, water gas, or coal gas, superheated to a temperature of 600° to 650° C., through a mass of coal in a retort. The idea of using an inert gas as a heating medium is an excellent one, but it failed in this as in subsequent attempts owing to the peculiar nature of the phenomena connected with the carbonization of coal at these comparatively low temperatures.

In 1906, Parker took out his famous master patent (Eng. Pat. 14,365, 1906) for the production of "Coalite" by heating coal in the presence of steam to a temperature not exceeding 800° F. A number of retorts were tried, details of which are given in a series of patents taken out between 1906 and 1911. The first proposal was to use D shaped retorts about 5 ft. wide, 7 ft. long, and 16 in. high, the coal being placed in a layer not more than 6 in. thick.

Coal which melted under heat was treated in tapering cylinders about 10–12 in. in diameter, one end being perforated to allow the escape of the gases produced, or it was heated in completely filled tubes of not more than 6 in. in diameter.

These experiments failed, however, and the next step was to use a narrow vertical retort of oblong cross section, which again was replaced by bunches of vertical tubes, each tube being from 4 to 6 in. in diameter, and each separate battery of tubes being connected by means of a separate pipe with the hydraulic main. In the later patent, these tubes were provided with slots by means of which communication was established between adjacent tubes, so that if one of the tubes became temporarily choked, the gas evolved could pass up the other.

This gradual alteration in the design furnishes an interesting commentary upon the difficulties experienced by the Coalite company, and these proved so great, that despite the assistance of some of the best scientific brains of the country, and the expenditure of large sums of money, the process failed to satisfy commercial requirements.

The Coalite failure, however, served one good purpose—it created a popular interest in coal carboniza-

tion, it showed the need that existed for a free-burning smokeless fuel, and cleared up many obscure points in coal carbonization.

A considerable amount of work has since been performed on low temperature carbonization, both from a scientific and a technical standpoint, and whilst commercial success has yet to be realized, a number of the problems involved have proved capable of solution on a semi-commercial scale.

The question of commercial success by any system capable of general application is not an easy one. The process of coal carbonization itself is a most complicated one, and it is rendered still more complex by the wide differences that exist between different coals.

CONSTITUTION OF COAL

The whole phenomena of coal carbonization at low temperatures are intimately bound up with the constitution of the coal that is treated, and, in the solution of the problem, the most important requirement is a clear understanding of the nature of the coal itself. Unfortunately this is extremely difficult to obtain by purely chemical methods. The brilliant researches of Wheeler and his collaborators have established the fact that coal contains two classes of substances, *viz.*:—Resinous substances derived from the resins and gums of the vegetation from which the coal was originally formed, and cellulosic or "humic" compounds derived from the cellulose of the original vegetation. Some of the conclusions of Wheeler and his co-workers are still the subject of debate, but the following distinctive properties of these two classes of substances are agreed to by most of the workers in this field.

Cellulosic or "humic" compounds:—(1) Are infusible. (2) Yield very small quantities of liquid distillates on being heated, these consisting chiefly of phenolic compounds. (3) Are insoluble in chloroform.

Resinous substances:—(1) Have a low melting point. (2) Yield a large proportion of liquid products on distillation, these consisting below 500° C. chiefly of paraffins, naphthenes, and members of the olefine series. (3) Are soluble in chloroform, phenol, pyridine, and certain other solvents. (4) Leave on heating to 500°, a pitch which acts as a binding constituent in the formation of coke.

At first sight, it might seem possible to consider all coals as being made up of varying proportions of resinous and cellulosic or humic material, and that the properties of any coal would depend essentially on the relative proportions of these two substances that it contains. Such a constitution would, however, by no means account for the differences found in different coals. In the first place, neither resins nor cellulose contain sulphur and nitrogen, and the organic sulphur and nitrogen compounds of coal would still require a place in the essential constituents of the coal. Secondly the properties of non-coking cannel and spore coals could not be reconciled very easily with a constitution based only on resinous and humic substances.

It is therefore essential to widen our ideas of the constitution of coal to include substances other than these two, or else to broaden the terms to include substances widely differing both in constitution and in properties. Unfortunately, purely chemical methods have exhibited very serious limitations in the examination of the exceedingly complex mixture of substances contained in coal, and a clearer conception of the rational constitution of coal can probably be gained much more easily by a combination of chemical and microscopical methods.

The pioneer work of Lomax, followed by the researches of Stopes, Hickling, and others in this country, of Renault and Bertrand in France, and of White, Jeffreys and Thiessen in America have thrown considerable light on the constitution of coal. It is impossible to go into their researches in detail, but essentially, in the light of the microscopic examination of coal sections, coal can be regarded as being made up of varying proportions of humic matter, resinous substances, and cuticular substances, the last-named embracing spores, spore cases, etc. (including probably the so-called algæ noted by Bertrand and Renault in cannel), and the resistant cuticles of the original vegetation. To these can probably be added the nitrogenous and organo-sulphur compounds in the coal which presumably would have been derived from the cell contents of the parent vegetation.

It is impossible in this paper to discuss the latter substances in detail, but, from the point of view of carbonization it is of considerable importance to gain an idea of the nature of the cuticular material in coal. At first sight, it would seem probable that this would be resinous in character; under the microscope it appears as a bright yellow substance resembling very closely the resinous particles in the coal, but so far as the author is aware, the small amount of work that has been performed in this direction seems to indicate that cuticular matter in general is non-resinous in character, or at any rate, if it is resinous, it differs in many important respects from the customary resinous constituents.

In an unpublished paper read by Lomax before the Manchester Geological Society in 1914, it was shown that spore coals were non-coking in character, and this was confirmed by Lomax and the author in an examination of the Lantern Seam of the South Rhondda Colliery. This seam is highly resinous in its general character; when distilled at temperatures of 500° to 550° C., it swelled, fused, and gave a considerable proportion of liquid distillates that were not phenolic in character. When the seam was examined in detail, however, it was found that those portions which were made up of spore coals were non-expanding, non-fusible, and, except in places where resins were clearly evident, non-coking in the customary sense of the term. It appears likely therefore that the cuticular ingredients of coal are non-resinous. On the other hand, they have properties that are different from the purely humic constituents. Spore coals, even though they are non-coking, yield a large proportion of paraffin compounds on distillation at low temperatures, and this fact, together with their resistance to decay, seems to indicate a non-cellulosic origin.

Unfortunately, very little detailed work has been done as far as the investigation of the cuticular portions of living plants is concerned, but apparently they consist of cellulose combined with fatty and waxy compounds of very high molecular weight. Such a composition would account for the properties possessed by spore coals, but the exact nature of the residual product as it exists in coal has yet to be determined.

THEORY OF THE COKING PROCESS

As far as the coking property of coal is concerned, the predominant factor is undoubtedly the proportion and character of the resinous constituents that it contains. Parr and Olin (Bulletin 60, University of Illinois) as the result of a study of the low temperature distillation of Illinois coals, put forward the following hypothetical conditions as being necessary for the formation of coke:—(1) There must be present certain substances which have a definite melting point; (2) the temperature of decomposition of these substances must be above the melting point; (3) when the compounds that satisfy the first and second conditions are unsaturated, it is possible by subjecting them to oxidation so to lower the temperature of decomposition that the second condition is no longer fulfilled, in which case coking will not occur. These hypotheses seem to agree very well with the known data concerning the coking process, and, while the phenomena involved are exceedingly complicated, a fair idea can be obtained with their aid of the reactions that take place within the coking chamber.

It is necessary at the outset to distinguish between high and low temperature carbonization. In the former case, not only is the reaction complicated by secondary reactions taking place between the liquid and gaseous products at temperatures above 700° C., but there is a considerable physical difference in the structure of the resulting coke product. The secondary reactions of the liquid and gaseous products have already been very ably dealt with, and it is therefore advisable in these notes to consider only those factors that are involved in the production of coke.

As far as coke formation is concerned, the use of a high temperature simplifies the process considerably and actually reduces the number of factors that have to be considered in large scale operations.

When a charge of bituminous small coal is introduced into a coking chamber the walls of which are maintained at a temperature of say 1000° C., the outer layers become rapidly heated until, at a temperature of 300° to 400° C., they soften owing to the fusion of the resinous substances. The temperature rises too

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rapidly for this condition to last very long, however, and gas begins to be evolved, the evolution increasing rapidly as the temperature rises, until finally the portions nearest the wall solidify. Gas still continues to be evolved from the solidified portion, and continues in fact until the coke reaches the temperature of the walls, and even then, at 1000° C., there is still left a small quantity of volatile matter which could only be expelled by raising the temperature considerably.

Meanwhile the adjacent layers towards the centre of the oven have attained the pasty stage, and gas begins to be evolved which passes principally through the porous, solid, outer layers to the wall of the oven. (Cf. Lewes, "Carbonization of coal," Young, J. Gas Lighting, 1912, 119, and Evans, J. Gas Lighting, 1913, 587.) A small amount possibly given off from the inner portion of the pasty mass, may pass upwards through the central core of raw coal, but this quantity would not be very great. As the gases pass through the outer solid coke, the hydrocarbons are decomposed to a certain extent with the formation of carbon which is deposited on the outer layers, thus forming a stronger, harder coke.

Essentially the coking process resolves itself into the formation of a pasty zone, which, fairly rapidly at first, but afterwards with continually decreasing speed, travels towards the centre of the oven. The rate of advance of the zone depends on the temperature of the oven walls and the thickness of the charge. The higher the temperature, the more rapidly does the fused zone pass towards the centre of the oven. In the later stages of the carbonization the rate of progress becomes very slow. It has been shown by Simmersbach, that in a coke-oven 20 in. wide, the centre of the charge remained at a temperature of 10° C. for 2 hours after charging, then rose to 100° and remained there for 13 hours, while even after 20 hours the temperature was only 410° C. (cf. Ramsburg and Spear, J. Franklin Inst., Apr., 1917).

As the coking process continues, the coke becomes fissured along lines perpendicular to the walls of the oven, and finally when the fused zones reach the centre of the oven, the resistance of the outer layers becomes greater than the resistance towards the centre of the charge, and a considerable proportion of the gas evolved passes up the centre of the charge, the coke dividing into two distinct masses.

LOW TEMPERATURE CARBONIZATION

In its main essentials, the process of low temperature carbonization proceeds along similar lines to the above, but several of the factors involved are so intensified that a radical alteration in the design of the oven is necessary for the process to be carried out on anything like a commercial scale. The following notes summarize the main differences:

(1) The low temperature (450°—550° C.) of the walls of the oven reduces enormously the rate of transmission of heat through the charge, or in other words, it reduces the velocity of the zone of fusion. For this reason, a thickness of four to five inches is the maximum that can be treated in stationary charges within economical limits of time. This factor brings in its train the following results:—(a) The capital outlay is increased owing to the increase in the number of units, (b) labor charges are necessarily increased, (c) the space taken up by the plant is increased, and (d) the maintenance cost is increased.

(2) The resistance of the fused zone to the passage of gas is enormously increased as the temperature diminishes. It has been estimated by O. B. Evans (J. Gas Lighting, 1913, 587) that the resistance offered to the passage of gas at 540° C. is about 7 times greater than at 700° C. Owing to this extremely high resistance, if for any reason the outer zone becomes choked, the gas accumulates in the charge to such an extent that serious gas pressures are developed. In several cases the author has found that when dealing with resinous coals, the gas escapes from the central portion of the charge not in a direction at right angles to the containing walls, but parallel to them, so that the resulting coke appears as if it were built up of extremely thin layers. This seems to indicate that in low temperature carbonization, the outer layers are much more resistant to the passage of gas than is the case in high temperature carbonization.

(3) The time during which the coal is in a state of semi-fusion is considerably prolonged.

In the case of high temperature carbonization the time-temperature gradient is rather steep, and the interval of time during which the coal is in a state of fusion is comparatively short. In the case of low temperature carbonization, however, this period is considerably prolonged and owing to this prolongation of

the pasty stage, with the high pressures that are induced in the coal mass, the cell cavities in low temperature coke are considerably larger than is the case with high temperature coke. This produces ultimately a considerable expansion in the coke, an expansion often great enough in the case of some resinous coals and with well filled retorts to choke up the gas outlet completely. With such coals a considerable space must be left in the retorts to allow room for expansion, and the economic efficiency of the process is thus seriously affected. Further, the coke becomes porous and friable.

(4) Any free space left at the top of the coal charge increases the amount of air that is left in contact with the coal. This exerts a most deleterious action when the coal is carbonized at low temperatures and results in the formation of a friable, powdery coke.

It is evident that the low temperature carbonization of bituminous (coking) coal involves the solution of a number of problems many of which are of a most conflicting character. The records of the Patent Office contain a number of attempts to solve these problems and of these, three main classes can be distinguished, *viz*:—

(1) The use of externally heated, intermittently charged retorts.

(2) The use of intermittently charged retorts, internally heated.

(3) Continuous processes in which the coal charge is carried forward by automatic means through a retort which may be heated either externally or internally, or by a combination of both methods.

Externally heated retorts. The various types of "Coalite" retorts are on the whole typical examples of low temperature retorts. Their failure was due to the lack of detailed knowledge regarding the constitution of coal, and also to the difficulty of adapting the system for carbonization on a commercial scale. The Coalite trials proved one thing very clearly, however, and that was the necessity of carbonizing the coal in layers as thin as was compatible with commercial requirements. This result is achieved in a very simple manner by the Tozer retort of the Tarless Fuel Company. In this retort, the coal is charged in concentric layers, so arranged that no layer is more than 4—5 in. thick. It is obvious that much larger charges can be got into the same space than in the coalite process, the coal can be charged much more rapidly, labor charges for handling are reduced, and the heating of the retorts can be made very uniform.

The retorts are used in conjunction with Simpson's process for heating coal under a vacuum of from 20 to 26 in. of mercury. The use of such a high degree of exhaustion has certain obvious advantages. The oxygen left in the retort after charging is reduced to a minimum, the liquid and gaseous products would be removed very rapidly from the retort and possibly distillation would be effected more readily. The influence of the vacuum on the quality of the coke produced is not clear. Porter and Taylor state (Tech. Paper 140, U. S. Bureau of Mines) that Pittsburgh bituminous coal yielded a light, inferior, porous coke when slowly heated at atmospheric pressure, but at a pressure of less than 30 mm. it produced a dense coke. The reason for this is not very clear, but apparently the use of a vacuum produced a decrease in the tenacity of the tar film.

On the whole a vacuum process offers certain advantages over those carried on at atmospheric pressure; but on the other hand, from a commercial standpoint it has certain disadvantages which are obvious to workers familiar with coal carbonization on a large scale. These can be summarized thus:—(1) Increased capital outlay; (2) increased power consumption; (3) difficulty of avoiding leakage (this would be a difficult matter under works conditions, especially when working on a big scale with unskilled labor in a colliery district liable to subsidence).

Taking the Tarless Fuel process as a whole, it is attractive in many respects, but it has yet to prove its capacity for satisfying commercial requirements on a big scale.

A process that has attracted considerable attention is that carried on by the Barnsley Smokeless Fuel Company. This differs in many essential aspects from customary low temperature practice, and it might perhaps be briefly dealt with. In the first place the Barnsley retorts are made of fireclay instead of cast iron, the usual material used in low temperature retorts. Cast iron is certainly not an ideal material; its disadvantages were early recognized by the gas industry and led to its substitution by clay retorts. In the Barnsley plant vertical retorts of rectangular cross section are used which are somewhat wider than those used in most low temperature processes. In these (Eng. Pat. 108,200) four varying zones of heat were

maintained, the lowest being at a temperature of about 450° C., the next 500°, the next 550°, etc., whilst finally, in the free space at the top of the charge, a temperature of 900° to 1200° C. was maintained. In this space was suspended a grid made of some suitable material (metal, metal oxide, fireclay, or carbon) so that the gaseous compounds of distillation were subjected over as great an area of contact as possible to the temperature necessary to convert the paraffinoid tars to aromatic hydrocarbons.

The author has had no experience of this plant, but from purely theoretical considerations the chances of success would be small if the above temperatures were adhered to. In the first place, the retorts are wider at the bottom, so that the zones maintained at the lowest temperatures are actually wider than those at higher temperatures. Thus the top portions would be carbonized such sooner than the lower portions, so that assuming that the lower layers could be carbonized in economic limits of time (which is doubtful) the result would be the formation of a mass of coke of very uneven quality, the lower layers spongy and porous, whilst the top layers would probably be difficult to burn. It is also difficult to see how the dangers of a serious accumulation of gas could be avoided in the lower portions, and the conditions in this respect would probably be worse even than in the "Coalite" retorts. However, the author has had no experience of the process and it would be interesting to learn something of the results that have been obtained.

A number of other examples of low temperature retorts could be given, but, taking them as a type, they possess the following disadvantages, arising mainly from the necessity of having to work with charges of coal that are neither too wide nor too high. The number of units must be considerably greater than is the case in high temperature practice, and this involves increased capital outlay, increased labor charges, increased repair costs, and a lowering of the general economic efficiency of the plant.

Internally heated retorts. In this type the coal charge is heated by the actual passage through it of inert gas preheated to a temperature sufficiently high to carbonize the charge. On purely theoretical grounds, this proposal is extremely attractive. The bulk of the time occupied in present systems of carbonization is taken up in heating the innermost layers of the coal, and if these could be heated from the outset considerable economies in time could be effected. A considerable number of attempts have been made to carbonize coal by passing through it a current of inert gas heated to a temperature of from 400° to 600° C., and Parr and Olin (Bull. 60, Univ. of Illinois) had some excellent results on a small scale by this method.

As far back as 1890, Parker (Eng. Pat. 67, 1890) proposed to pass steam water-gas or some other suitable gas superheated to 500°—600° C., with a view to making smokeless fuel, and a number of other inventors have followed along similar lines. In the case of bituminous (resinous) coals, the old difficulty arises that when the coal reaches the pasty stage it becomes impervious to the passage of the gas, but there seems to be no reason why the method should not be used for shales, cannel, or for coals that are not fusible.

The results obtained by McLaurin with a process of this type (this J., 1917, 620) are extremely interesting. As would be expected, cannel coal proved to be quite easy to work when carbonized by means of a stream of hot producer gas, but it was also found that Cadder coking coal if screened came out of the retort in the same shape and same size as it was put in. McLaurin suggests that this is due to the slow heating to which the coal was subjected and that under those conditions it did not intumescence. If this condition is applicable to all coals, it opens up possibilities of an extremely interesting character. The author, however, has not found it possible to repeat this result with the highly resinous coals of South Wales, except under conditions in which oxygen was present in the heating gaseous medium. The effect of oxygen when coal is carbonized at low temperatures has already been discussed, and the author is inclined to believe that the small quantity of oxygen which would be present in the hot producer gas in McLaurin's experiments played as important a part as the slow heating. A typical analysis of the producer gas gave 0.9% of oxygen, so that there seems to be every reason for believing that the coal was carbonized in an atmosphere containing a small proportion of this gas, an idea which is confirmed by a study of the properties of the tars obtained.

Another proposal of this type is that given by Lamplough (Eng. Pat. 108,343, 1917), the heating medium in this case being steam.

On the whole, internal heating seems to offer con-

siderable possibilities in the treatment of shales, canals, and possibly certain types of coal if carefully screened, but as McLaurin and others have found, difficulties would arise in the carbonization of fine coal in this way. There is perhaps one point that would need consideration, and that is, if a small proportion of oxygen were systematically introduced into the heating gas, what would be the effect upon the tars produced? These apparently would have a similar composition to the old Jameson tars, which were produced under conditions theoretically analogous to those existing in McLaurin's process.

Continuous processes. The third class of retort which has been proposed for the low temperature carbonization of coal is that in which the coal is carried forward through the furnace by means of a conveying system.

The Archimedean screw has been suggested as a suitable carrier for quite a long time. A most interesting anticipation of one of the most modern of these systems is given in Patison's Eng. Pat. 569, 1873, in which coal, shale, or other fuel is carried through a heated retort by means of a worm conveyor. For low temperatures—with a high oil yield—the inventor proposed to use a cast iron retort, but for high temperatures he suggested the use of a fireclay furnace.

The well-known Del Monte system differs only slightly from this system, but it had one innovation, and that was in the use of a screw mounted on a hollow shaft, which was heated internally by a row of jets from a central gas pipe. Further, the coal was subjected to a fractional distillation, one end of the retort being maintained at a considerably lower temperature than the other. This retort again could be used for wood, shale, lignite, or peat, but with coking coals, the swollen pasty mass which was produced completely prevented the working of the screw.

It seems difficult to believe that any system which involves the stirring up of the coal in any way can be used for bituminous coals, and for that reason, it is doubtful whether a continuous system on the lines of the Woodhall-Duckham or the Glover-West retorts can be used for the low temperature carbonization of these coals, except perhaps under conditions already touched upon.

On the other hand, there seems to be no reason—apart from those connected with engineering difficulties—why the coal should not be conveyed through a furnace by some system in which the coal itself is not stirred.

A system of this type that has been worked with some degree of success is that introduced by Pringle and Richards. In this the coal is carried by means of an endless conveyor through a retort the temperature of which is maintained at about 500° C. The conveyor itself is fitted with compartments so as to subdivide the coal into a number of separate small charges each of which is rapidly heated to the desired temperature. The coal itself is undisturbed in its passage through the retort, and leaves as a porous semi-coke which is an excellent domestic fuel. This process as yet has only been worked on an experimental scale; the obvious difficulties are of an engineering character and whether or not they can be overcome on a large scale plant remains to be proved.

A system of this type seems to offer several advantages for low temperature carbonization; temperature control could be readily effected, labor charges would be low, and by suitable engineering methods the rather heavy capital outlay and high maintenance and repair costs which would probably be inherent in this particular system could be reduced to a limit which would make it a commercial proposition.

A number of other proposals could be given, but as yet, not one of them has been tested on a commercial scale. As far as the author can see there does not seem to be any overwhelming difficulties in the way of the low temperature carbonization of shales, lignites, canals, etc., whilst for resinous coals, success will probably be attained only by an individual study of the coals it is desired to treat, accompanied possibly by a suitable preliminary treatment which will give a final product of sufficient solidity and strength to withstand customary conditions of handling and transport. In this connection the briquetting of the coal either before or after carbonization will have to receive very serious consideration. The main considerations in this direction are economic in character and in the present artificial conditions prevailing in the coal market it would be extremely difficult to estimate the commercial possibilities of such a combination.

Economics of low temperature carbonization. An attempt might, however, be made to review from a general standpoint the financial possibilities of low temperature carbonization, and this perhaps is all the more necessary because of the extravagant estimates

that are periodically issued from certain sections of the financial press. In this connection it must not be overlooked that there are many coals which are almost unusable in the raw state, and in some cases even there are whole coalfields in which the coal is of such quality that under the economic and geographical conditions prevailing in their immediate vicinity they are commercially unworkable. Several such cases have been brought to the author's notice in which a well designed system of low temperature carbonization would result in the economic salvation of the coalfield. Disregarding for the present these exceptional cases, there remain two or perhaps three main directions in which the adoption of low temperature carbonization has been strenuously advocated.

The first is in the treatment of cannel coal. From a technical standpoint this does not appear to present any very serious difficulties, and the question practically resolves itself into a commercial one. The matter has already been fully treated recently ("A New British Oil Industry," Craig, Perkin, Berry, and Dunstan, J. Inst. Petrol. Tech., Apr., 1918) and need not be discussed here. In this case, however, the utilization of the residue is the factor upon which the success or failure commercially depends. The method usually suggested is to gasify the residue in producers of the Mond type and recover the ammonia produced (see Paton, Iron and Coal Trades Review, Mar. 22, 1918, and "Fuel Economy," paper read before Birmingham Section, Inst. Elect. Eng., 1917). Technically such a process would be ideal, especially if the carbonization and gasification could be performed in one plant as proposed by McLaurin (this J., 1917, 620) or Wollaston (Eng. Pat. 111,964, 1918); there is one point which needs to be emphasized, the necessity for considering the Haber process as a factor in the reduction of price of ammonium sulphate after the war. It is estimated by the Barrett Company of New York, that the production of ammonia from this process alone amounted in 1917 in Germany to a quantity equivalent to over 1,000,000 tons per annum of ammonium sulphate. The world demand for this fertilizer is increasing rapidly, and there is every prospect of a still further increase during the next few years, but with a competitor of this magnitude in the field, there is every need for caution in considering the claims of the recovery producer against the cheaper and technically more efficient non-recovery producer.

There is one other point that can be only briefly dealt with, and that is the relation of the gas industry to low temperature carbonization. In the author's opinion, the gas engineer, to whom gas is the main and primary product, is quite justified in adhering to high temperatures in general practice. The yield of gas in low temperature carbonization is far too low to make it attractive to the gas engineer, and with humic coals this small quantity is seriously contaminated with carbon dioxide. Further, to attain a total yield comparable with present practice, the capital outlay would be considerably increased, the space required for the plant would be very much greater than in present practice, and the labor costs (per 1000 cub. ft. of gas) would be enormously increased.

There are of course advantages in favor of low temperature practice, but in view of the standardized conditions prevailing in the gas industry, with works already cramped for space in many cases, and with heavy capital charges on plant already installed, it is extremely difficult to see where its advantages come in. Gas coke is certainly not an ideal product either from a domestic or an industrial standpoint, but by suitable preliminary treatment of the coal used, even this can be made an excellent free-burning product; and if the market conditions allow, the gas engineer can always erect additional plant for this purpose. Apart entirely from any preliminary treatment, however, the uses of gas coke are rapidly extending and before long it should cease to be the drug on the market that it has been in the past.

Taking everything into consideration, the gas engineer is well advised in rejecting low temperature carbonization as being unsuitable for the purpose of producing gas in as great a quantity and of as high a quality as possible.

High-Speed Steel for Milling Cutters, Taps and Reamers

WHILE tungsten high-speed steel has been used for some years for probably nine-tenths of all turning, planing, and slotting tools, it has been employed for a much smaller percentage of milling cutters, taps, reamers, etc. This small use is partly due to the difficulty of hardening tools with fine edges, for to obtain the best efficiency, tungsten high-speed steel requires hardening

at from 1,250 to 1,350 degrees C. As the manufacture of munitions calls for the most efficient tools of all kinds, experiments were made by Darwin & Milner, of Sheffield, England, to find a steel that, without tungsten, would possess the hardness of the so-called high-speed steels. As a result, it was discovered that the addition of cobalt to chromium-carbon steel produces a most satisfactory tool with a hardening temperature of only 1,200 degrees C.; in fact, if this is exceeded, the tools give poorer results. Hardening for practically all applications is said to be satisfactory when the tool is allowed to cool naturally in still air, free from drafts. This new alloy, known as "cobalt-crom," has been found especially suitable for milling cutters, twist drills, reamers, taps, and forming tools, and for machining gun-metal and yellow metals, as well as for high-endurance drawing and blanking dies, lathe centers, shear blades, airplane and automobile engine valves, and all gages and instruments that must resist abrasion. In one test, it was possible to cut for a half day with carbon-steel saws without regrinding; for two days with tungsten high-speed steel saws; and for four days with cobalt-crom saws.—*Machinery.*

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