"SOME PHYSICAL PROPERTIES OF COKE;
THE SIGNIFICANCE OF
(a) THE VOLATILE MATTER CONTENT
AND OF
(b) THE PARTICLE SIZE OF THE COAL".

The author desires to record his indebtedness to the late Professor Thomas Gray, Professor W. M. Cumming and Dr. G. S. Cruickshanks for their assistance during the course of these investigations. He also wishes to express his appreciation to Professor Cumming for the facilities for carrying out much of the experimental work which he kindly granted in his laboratory at the Royal Technical College, Glasgow. He should also like to thank his employers, The Scottish Coke Research Committee firstly, for the opportunity of carrying out this work and secondly for their co-operation especially in the large scale blending experiments and the open grate, domestic stove and boiler tests.

"Some Physical Properties of Coke:
The Significance of (a) the volatile matter content and of (b) the particle size of the coal."

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by

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"Some Physical Properties of Coke: The Significance of (a) the volatile matter content and of (b) the particle size of the coal".

Introduction

Since its introduction, coke has played an ever increasing role in industry. It was early discovered that the quality of coke made from various coals differed widely and users of coke gave preference to certain types which were found to give the best results in practice. It has therefore always been the desire of the coke makers to provide a better coke and a very great amount of work has been carried out to this end.

Rapid progress has been made in the methods of the manufacture of coke. The value of the bye-products obtained during the carbonisation of coal was soon realised and improvements in the methods of the coking of coal have resulted in greater yields of these bye-products being obtained. The magnitude of the progress made may be realised from the fact that in the early days of coke-making, all the bye products and a part of the coal were required to provide the heat necessary for carbonisation, while today, when coal is coked by modern methods, only 40-50% of the gas obtained is required to supply the heat necessary for the coking of the coal, the remainder/

remainder of the gas and the other bye-products being available for other purposes.

A much more rapid rate of carbonisation is now obtained by the use of higher flue temperatures and improved oven construction.

The improvements in the method of carbonisation have been introduced chiefly to provide a cheaper product, but the quality of the coke has not been allowed to deteriorate.

It has long been recognised that coke intended for use in the blast furnace and cupola should primarily be as strong as possible. The blast furnace trials recorded by Evans - (Gas World, 1926, vol. 84, Jan. 2, coking section, 9, 14) and later those carried out by Marshall and Wheeler (Journ. Iron and Steel Inst. 1933, No. 1) have shown conclusively the detrimental effect which breeze has on the performance of coke in the furnace. The production of small coke from the time it leaves the screens at the coke ovens until it arrives at the stock level of the furnace is caused chiefly by the various drops to which it is subjected.

In many countries and Scotland is no exception, those seams of coking coals giving the best cokes are becoming worked out and it is imperative that every effort should be made, not only to increase the number of coals from which metallurgical coke can be made but also to find methods whereby the quality of the coke made from these inferior coking coals can/

can be improved.

With this end in view many experimenters have been investigating the effects of the conditions of manufacture on the nature of the coke produced from coking coals.

It has been found possible by blending various coals to make good metallurgical coke from coals which individually would not give usable cokes. By this means the quality of coke produced from certain coals has not only been improved but the number of coals from which coke may be made has been enlarged.

We are indebted chiefly to Audibert and Delmas and Foxwell for the greatest contributions to our present knowledge of the effects of the heat treatment of coking coals.

Audibert and Delmas (Fuel, 1926, 5, 229, 1927 6, 131, 182, 1929, 8, 232) made a noteworthy study of the softening and swelling propensities exhibited by certain coals when heated. The method they developed is described as follows:

"Finely powdered coal is compressed into a cylinder of 60 mm. length and 6-7 mm. diameter and having an apparent density of 1.2 gm./c.c. The coal pellet is placed in a copper tube of slightly greater internal diameter than the diameter of the pellet. A glass rod drawn out at one end is placed on the cylinder of coal. The rod is almost counterpoised/

counterpoised X and any displacement of the rod is measured by a pointer attached in front of a scale. The dilatometer tube containing the pellet is placed in a heating bath ..... The whole apparatus is maintained in an upright position."

The coal pellet was heated progressively at various rates and starting at a temperature which varies according to the kind of coal and the rate of heating, the following phenomena were observed:-

The coal softens and flows tending to fill up the free space of the dilatometer tube. At a certain temperature the coal intumesces, the temperature and degree of intumescence again varying according to the kind of coal and the rate of heating used.

As a result of their study of the "Mechanism of Coking" Audibert and Delmas suggested certain experiments to determine a method by which a coal may be made suitable for coking by adding to it a suitable amount of a correcting coal. By means of the dilatometer test just described the coals were first divided into two classes, easily or difficultly fusible. The coals belonging to the one class were blended with those of the other. The optimum mixture was found to be approximately that which just begins to intumesce at the given rate of heating (i.e. the rate obtaining in the coke oven which/

X the glass rod should be weighted to give a load of 50g. on the coal pellet (Davies and Wheeler, Fuel, 1931, 10, 100).

which is usually about 1°C/min.) and a few crushing tests on coke pellets made from mixtures varying slightly in composition to this approximately optimum blend sufficed to find the most suitable blend.

Foxwell, in his study of the "Plastic state of Coal" (Fuel 1924, 3,122) used a different method for the determination of the plastic range of coking coals.

The coal is heated in a wrought iron tube of about 1.6 cm. internal diameter. The tube is carefully packed with graded firebrick and has a device for preventing the coal from flowing and thus causing a variation in the length of the plug. The tube is placed in an electric furnace, the temperature of which is raised at the desired rate. At about 300°C gas is caused to flow from a graduated gas holder through the tube. The gas flows through the coal, the pressure required to cause the flow being measured on a gauge. A head of water of about 5,000 mm. is used to force the gas from the gas holder. The rate of gas flow used was about 20 c.c./min. when the gauge pressure was zero. Readings of temperature and pressure and the volume of gas space in the gas holder were taken every minute.

In addition to the information thus obtained the rate of evolution of gases and vapours (calculated to N.T.P.) from the coal when heated at the same rate of rise of/

of temperature is required. This was determined by an independent experiment.

The resistance to gas flow was indicated by symbol "m," which was defined as the pressure required in mm. of water to force 1 c.c. of gas per min., measured at N.T.P., through a centimetre cube of the material maintained at t°C.

It was shown that when a coking coal was heated, at a certain temperature which varies with the nature of the coal, the value 'm' became higher than theory demanded and as the temperature was raised continuously, 'm' increased rapidly, reached a maximum and finally decreased to a low value. This abnormality in the value of the resistance coincides with the temperatures between which the coal is in the plastic state. The resistance becomes great when the coal becomes plastic and the interstices between the particles of coal are filled up. The faster the rate of heating the greater is the resistance and the higher the temperature at which the resistance becomes very low. The temperature at which the first perceptible increase in resistance occurs is however independent of the rate of heating.

A plastic curve is obtained for each coal by plotting the resistance to gas flow against the temperature. The general shape of the curve, the maximum value of the resistance and the total resistance (area of the curve) are different/

different for each coal and moreover, at any given rate of heating they are characteristic for each coal. Non-coking coals and coals which do not coke sufficiently to enable them to be used in a coke oven, show either no increase of resistance or at most only a few mms. water gauge and the same is true of a small number of coking coals.

Foxwell was unable to discover any clear relationship between the coal properties he examined and the qualities of the cokes produced. He states that (Fuel 1924,3,375),

"there is little or no agreement between the coking index or the percentage of gamma compounds in the coal and its coking properties, when carbonised in the coke oven. There is likewise no numerical agreement between the area of the plastic curve and the quality of the coke, but this is not to be expected, for the plastic curve gives a picture of the manner in which coking proceeds rather than a measure of the coking power."

It was found by the author that in all plastic range determinations except those when poor coking coals were heated at a slow rate (1°C/min.) that a very short period after the coal became plastic the tube became blocked. Foxwell, (Fuel, 1924,3,125) found that only in a few cases did the tube become blocked and no gas passed through the coal. The pressure of the system increased since the water

continued/

continued to flow into the gas-holder at a rate decreasing from the initial value of 20 c.c./min. The pressure of the system continued to increase until a point shortly after the end of the "plastic range" of the coal when the rate of flow of gas through the coal increased to a value greater than the rate of flow of the water into the gas-holder. Since the maximum pressure obtained varies for each coal a difference will result in the actual stage of the coking process at which gas will again flow through the tube. This difference is, however small since the pressure decreases very rapidly at first.

The areas of the "plastic curves" described by Foxwell are therefore dependent on the plastic ranges of the coals and these were determined by a very simple apparatus, a modification of that used by Foxwell.

This brief account of some of the work carried out to examine the physical changes which coking coals undergo when heated is sufficient to show the important influence of the plastic range of the coal on the physical properties of the coke made from it.

There must of course be other factors which have an important bearing on the physical properties of the resultant coke.

Rose, (Fuel, 1926,5,562) has drawn attention to the connection between the total volatile matter content of a coking coal and the nature of the coke obtained from it.

He/

He states that coals containing high percentages of volatile matter give highly fissured cokes, while those having low volatile matter contents give blocky cokes with comparatively few fissures.

Now, since the fissuring of a coke takes place during the period subsequent to the plastic range of a coal, the degree of fissuring should be related to the percentage of volatile matter evolved during this period. Accordingly, it was thought that by comparing the volatile matter contents of the coals after heating to the temperature of the end of their plastic ranges and the physical properties of the corresponding cokes, a more accurate correlation could be obtained.

CHAPTER I

METHODS OF EXAMINATION OF COALS, BLENDS AND COKES.

1. Preparation and Carbonisation of Coals and Blends

(a) Full scale oven tests

For the preparation of cokes from straight coals the normal methods of carbonising at each particular coking plant were adopted.

The following procedure was taken in the case of the large scale blending tests recorded:

The non-coking blending material was crushed finely in a pan mill and then intimately mixed in the mill with an equal quantity of the coal. The required quantity of this 50% blend was then shovelled from a wagon into the front of the wagon of washed, uncrushed coal, as it was being slowly emptied, by tipping, into the boot of the crusher elevator. The elevator was then started and the blend was conveyed to the Carr disintegrater and from there to an empty hopper. The blend was carried by a belt conveyor to the stamper box where it was stamped and charged in the usual way.

(b) Experimental oven tests

Large scale blending tests are expensive and tedious

and/

and in order to expedite this work a small experimental oven was erected at one of the coking plants.

The oven, hopper and ram are shown in Figs. 1 and 2.

The experimental oven is rectangular in cross-section, 14 in. wide, 6 ft. long and 3 ft. high and carbonises a charge of 7 cwts. of coal. The oven setting is 6 ft. 2 in. wide, 8 ft. long and 5 ft. 3 in. high.

The oven is heated on each side by a set of two horizontal flues 9 in. high and 6 in. wide. The gas and air are introduced into a combustion chamber 6 in. high and 6 in. wide, placed below each set of flues. The top of the combustion chamber is 6 in. below the level of the sole of the oven. The products of combustion pass along the lower horizontal flue, at the end of which more gas and air enter and the mixture burns along the upper horizontal flue and from there to the waste heat flue of the bench of large scale ovens. The amount of gas and air admitted and thus the flue temperature can be varied at will.

The oven has two doors which are connected by wire ropes, passing over pulleys to balance weights, to facilitate the raising of the doors for discharging the coke. One of the doors is provided with a levelling door.

The coal is charged from a hopper, having the same capacity as the oven, through a charging hole of 12 ins. diameter, placed in the centre of the oven.

The/

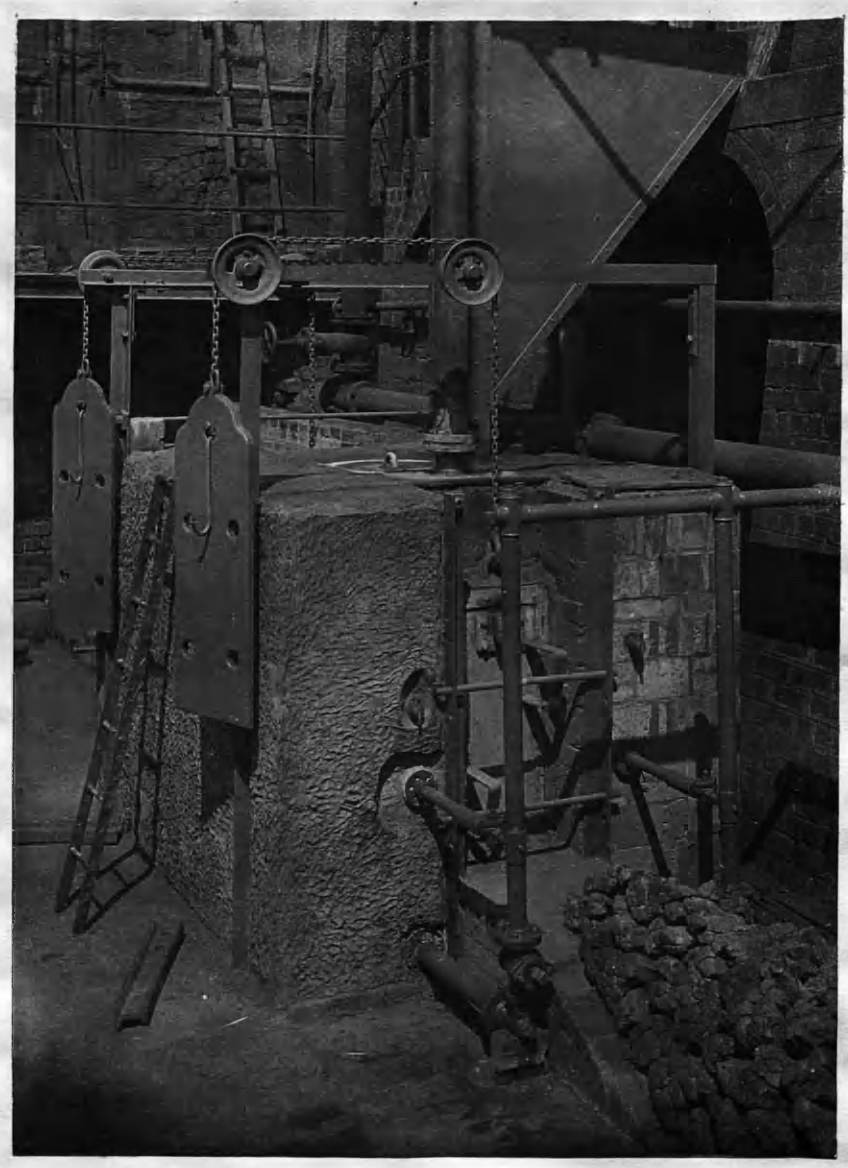


FIGURE 1 - Experimental Oven.

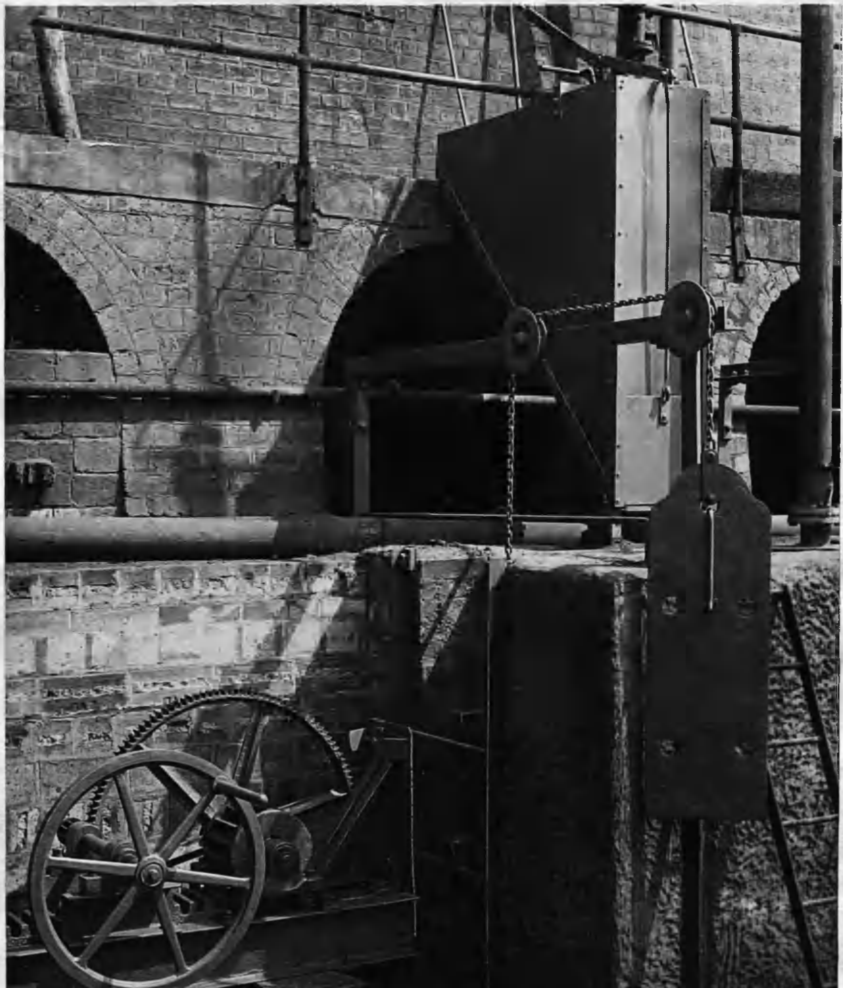


FIGURE 2 - Experimental Oven showing Hopper and Ram.

The products of carbonisation are led into the atmosphere through a vertical pipe 12 ft. long and 4 in. diameter, placed 2 ft. from the coke side of the oven.

The coke is discharged, by means of a hand ram, on to the hearth, where it is quenched by means of a hand hose.

About 7 cwt. of each blend was mixed by repeated coning of the mixture, and carbonised in the experimental oven.

(c) Bag Tests.

When it was desired to compress the blend before charging, it was found convenient and satisfactory to coke the blends in bags placed in the normal oven charge.

About 260 lb. of each blend were coked in this way. The dimensions of the bag filled with the blend were 36 in. x 22 in. x 16 in. The bags were wired and brushed over with fireclay. Each bag was placed in the stamper box 5 ft. from the coke side, after one third of the charge had been stamped. The cake was then completed in the usual way and charged to the oven.

2. Sampling of Coal

(a) Full scale tests

A sample of about 1 cwt., taken in equal quantities at regular intervals, as the crushed, washed coal, was being charged into the charging cars or into the cake box, was considered to be/

be a representative sample of the coal in each oven charge. The total sample was thoroughly mixed. A sample of about 3 lb. was taken for the determination of the moisture in the charge and the bulk sample air-dired to facilitate mixing. The sample was then reduced by coning and quartering until a sample of 7 lb. remained. This sample was crushed to pass a 20's mesh I.M.M. sieve reduced to 8 oz. and crushed to pass a 60's mesh I.M.M. sieve.

(b) Experimental oven tests

A sample of 7 lb. was taken from the 7 cwt. oven charge and reduced in the manner described above.

(c) Bag Tests

A 7 lb. sample was taken from the well mixed blend used in the test and reduced in the usual manner.

3. Analyses of Coals and Blends.

(a) Screening Analyses

The 7 lb. samples of each coal and blend were screened using square mesh sieves having the following apertures, ½in., ¼in., ⅛in., 1/10th in., 1/40th in., and 1/120th in.

(b) Proximate Analyses

The air-dried laboratory sample, ground to pass a 60's

mesh/

mesh I.M.M. sieve was used for the proximate analysis of each coal, which was carried out using the following standard methods:-

(i) Moisture

1-2 gm. of the finely powdered sample are heated at 105°C for 1 hour.

(ii) Volatile Matter

1 gm. of coal is heated for 7 min. in a platinum crucible closed by a well fitting lid and placed in a nichrome wire triangle. The temperature of the bottom of the crucible should be 925°C ± 25°C. The platinum crucible should have the following dimensions:-

965° ±5

Diameter at base 24-25 m.m. ; height 35-40 m.m.

(iii) Ash

1-2 gm. of coal are heated at 750°-800°C in an oxidising atmosphere in a muffle furnace until constant weight.

(c) Agglutinating Value - Gray-Campredon Method.

The weight of sand which can be bound into a coherent mass by unit weight of coal is determined by heating 25 gm. of a mixture of coal and sand in various proportions in a covered platinum crucible.

The crucible should have the same dimensions as that used for the determination of the volatile matter.

The sand used should pass a 40's mesh and be retained on a 50's mesh I.M.M.sieve.

The/

The crucible is placed on a nichrome wire triangle, so adjusted that the bottom of the crucible is 1 cm. above the top of a Meker burner (diameter of grid is 3 cm.). The temperature of the bottom of the crucible should be approximately 1,000°C.

The crucible containing 25 gm. of the mixture of sand and coal is heated for 7 min. and cooled. A loosely fitting smooth cork is placed on the surface of the coked mass and a shallow porcelain dish placed bottom up on the top of the cork. The whole arrangement is inverted and the crucible removed.

The maximum ratio of sand to coal in the mixture which gives a coherent mass, capable of bearing a 500 gm. weight, the proportion of loose powder being less than 5%, is adopted as the agglutinating value.

4. Determination of the Degree of Expansion of Coking Coals

This determination was carried out in a similar manner to that described by Audibert (Revue de l'Industrie Minérale, 15 Mars, 1926).

The general arrangement of the apparatus is shown in Fig. 3.

The bath consists of a monel metal tube 12 in. long and $2\frac{3}{4}$ in. diameter, which contains a mixture of equal parts of potassium and sodium nitrates. The bath is placed in an electric furnace and the temperature may be varied as desired. A dilatometer tube 12 in. long and $\frac{5}{8}$in. internal diameter, having a flange/

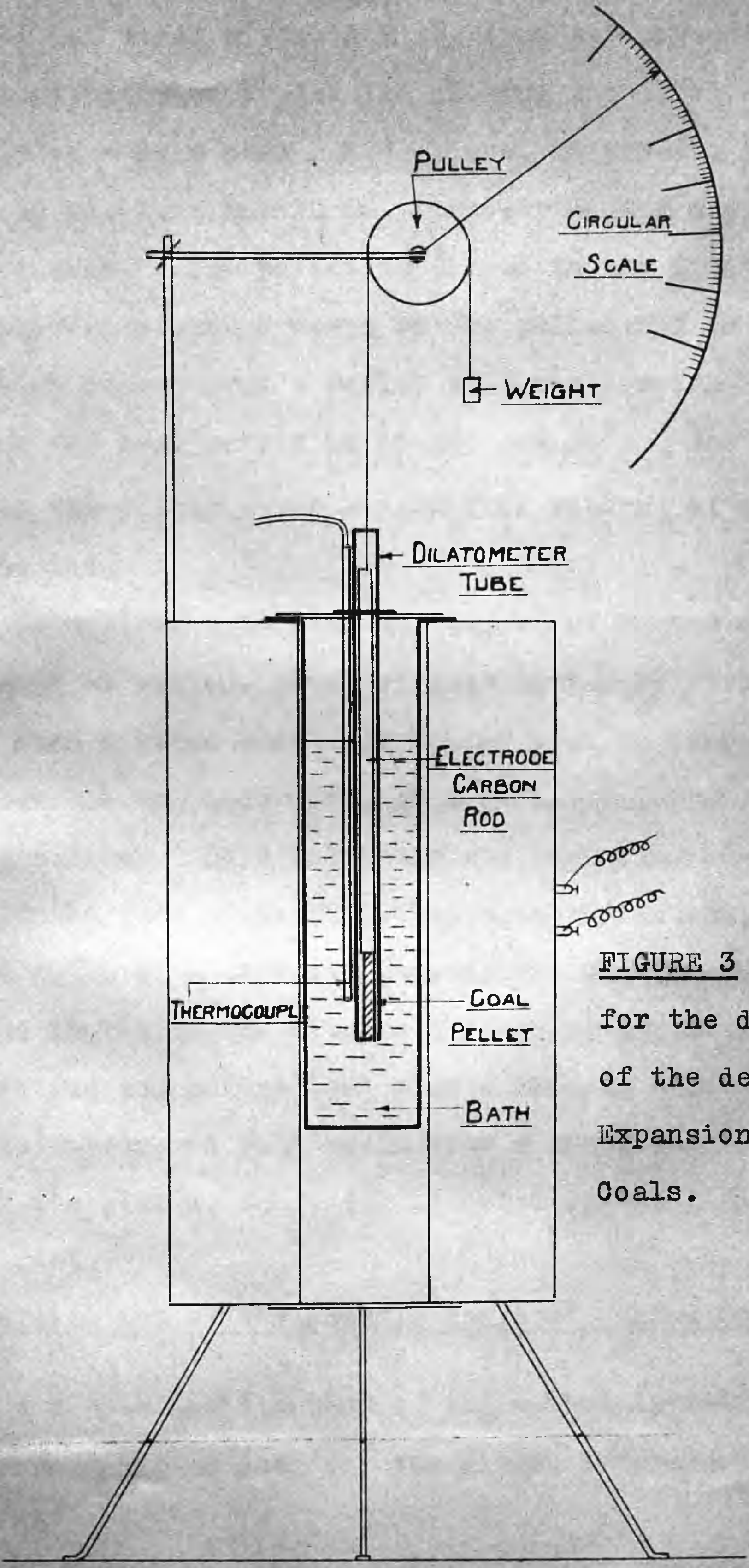


FIGURE 3 - Apparatus for the determination of the degree of Expansion of Coking Coals.

a flange, 1 in. wide, situated 2 in. from the top, is supported in a vertical position by the lid closing the bath. The coal, ground to pass a 60's mesh I.M.M. sieve, is pressed into a cylinder, 50 mm. long and 12 mm. diameter having a density of 1.1 gm. per c.cm. The pellet is placed in the dilatometer tube. A rod of electrode carbon rests on the pellet and is connected by a cord, which passes over a pulley to a small weight. The total pressure on the coal pellet is 40 gm. per cm^2. The pointer attached to the pulley gives a magnified reading of the displacement of the rod.

Using this apparatus the degree of expansion and the plastic range at various rates of heating may be obtained.

When a given sample of coking coal is heated at a given rate, the carbon rod undergoes, at a definite temperature, a descending motion. This indicates the beginning of the plastic range. If the rate of heating chosen is sufficiently rapid, the carbon rod will, at a definite temperature undergo an ascending motion, the degree of the displacement being dependent on the rate of heating and on the coal sample chosen. On further heating the carbon rod will again show a small descending motion. The end of the plastic range is indicated by the piston ultimately coming to rest.

5. Determination of the Plastic Range of Coking Coals

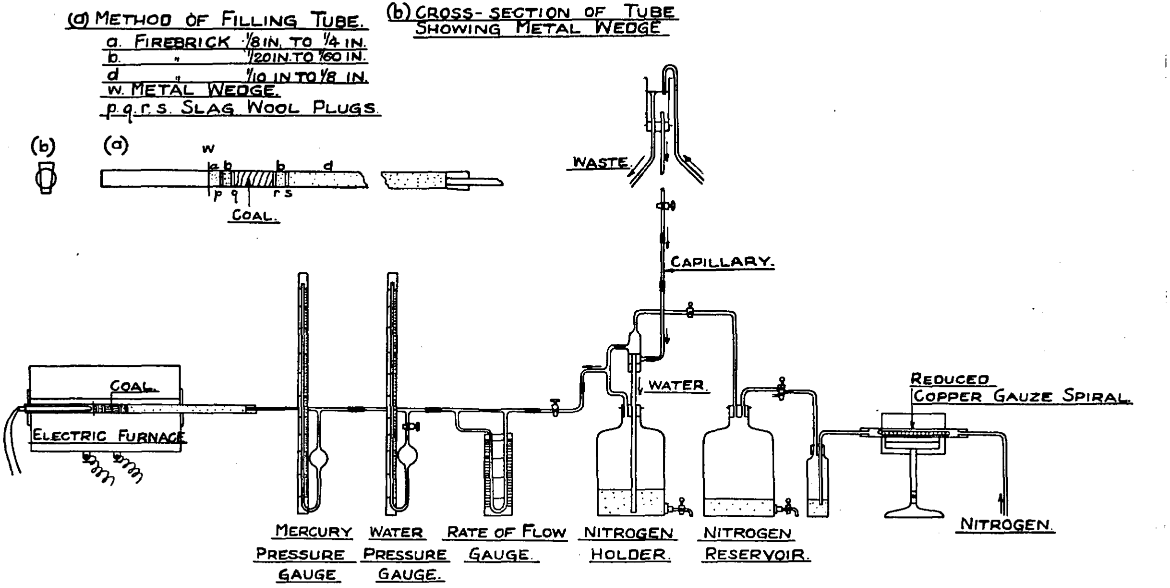
A simple modification of the method devised by Foxwell has been developed and used for the direct determination of the plastic/

plastic limits of coking coals.

The apparatus employed for this determination was similar to that used by Foxwell to determine the pressure required to force gas, at a rate of 1 c.cm. per min., through a plug of coal 1 cm. long, at any given temperature, (Fuel, 1924, 3,122). The essential difference was the addition of a differential pressure gauge, by means of which the rate of flow of gas through the system could be obtained directly at any given temperature.

Using Foxwell's method, it was necessary to carry out an independent experiment to determine the rate of evolution of gas from the coal and then from observations of the rate of flow of water into the gas holder and the pressure of the system it was possible by an involved calculation to find the rate of flow of gas through the coal at a given time.

The general arrangement of the apparatus is shown in Fig. 4. The method of filling the tube was the same as that described by Foxwell and is shown in Fig. 4(a). A steel tube of $\frac{3}{8}$in. internal diameter was used. It had saw cuts at the top and bottom at W, making two slots through which passed a metal wedge. This wedge served to counteract the expansive force of the coal and prevented it from flowing. A head of water of about 12 ft. forced nitrogen through the coal, a constant head being maintained by means of an apparatus devised by Gray (J.S.C.I., 1928 xlvii, 187T), A capillary tube was placed/



X FIGURE 4 - Apparatus for the Determination of the Plastic Range of Coking Coals

X taken from Davidson, "Fuel in Science and Practice", 1930,9,489.

placed in the water supply tube and the restriction adjusted to give a rate of flow of nitrogen of about 20 c.c./min. when the pressure gauge reading was zero.

The coal to be examined was ground to pass through a sieve of $\frac{1}{4}$in. square mesh. The tube, packed as shown in Fig. 4(a) was placed in the electric furnace and the temperature raised rapidly to 250°C. At this temperature the nitrogen flow was started and the external resistance adjusted to give the desired rate of heating. The pressure in the system and the rate of flow of nitrogen were noted at intervals of 5°C.

The change of the coal to the plastic state was accompanied by an increase in the pressure of the system and a decrease in the rate of flow of nitrogen through the coal. Usually the tube became completely blocked up and for a time no nitrogen passed through the coal. A negative reading of the differential pressure gauge was often obtained, indicating that some of the gas evolved by the coal was passing into the nitrogen holder. The pressure was allowed to increase to a given value, 12 cm. of mercury, at which point the water flowing into the nitrogen holder was cut off. Due to the evolution of gas by the coal, the pressure in the system increased very slowly. The end of the plastic range was accompanied by a sudden drop in the pressure of the system, this drop being observed from the reading of the pressure gauge. At the same time the rate of flow gauge gave a positive reading which increased rapidly.

In/

In some cases the tube never became completely blocked up and nitrogen passed through the tube throughout the experiment. This occurred when poor coking coals were heated at a relatively slow rate, for example at 1°C/min. In these cases the temperature of the end of the plastic range was taken as that point at which the rate of flow of nitrogen, after decreasing to a minimum value, began to increase.

The end of the plastic range was therefore determined directly and clearly which was impossible by Foxwell's method when the water was allowed to flow continuously into the nitrogen holder and when no rate of flow gauge was employed.

6. Determination of the Volatile Matter Evolved

(A) Before, and (B) During, the Plastic Range at Given Rates of Heating

(a) Method 1

In the earlier determinations the following method was used to obtain the percentage of volatile matter evolved before and during the plastic range of a coal when it was heated at a given rate:-

Two glass combustion tubes 27 in. long and $\frac{5}{8}$in. diameter were placed side by side, in a central position, in an electric furnace 18 in. long. A silica boat containing about 1 gm. of air-dried coal ground to 60's mesh I.M.M. was placed in each tube. The tubes were provided with thermocouples, the ends/

ends of the sheaths being placed in contact with the ends of each boat during the experiment. A slow stream of nitrogen, carefully freed from oxygen and moisture, was allowed to pass through each tube. The temperature of the furnace was raised rapidly to 250°C and the external resistance adjusted to give the desired rate of heating. When the temperature of the beginning of the plastic range was attained, one of the silica boats was pushed to the cold front end of the tube and allowed to cool in the stream of nitrogen. The heating was continued at the same rate until the temperature of the end of the plastic range was reached, when the second silica boat was pushed to the front end of the tube. The boats when cold were withdrawn and weighed. The moisture and total volatile matter contents of the coals were determined by the standard methods. From these results the volatile matter content of the coal at the end of the plastic range can also be obtained.

(b) Method II

Owing to the special significance of the volatile matter contents of the coals and blends at definite temperatures, it was considered desirable that the volatile matter should be determined continuously as the temperature of each coal was increased progressively.

A method similar to that described by Audibert (Revue de l'Industrie Minérale, 15 Mars, 1926) was standardised and used/

used for the examination of coking coals.

A sketch of the apparatus used is shown in Fig. 5.

The coal was heated in an atmosphere of nitrogen, which had been purified by washing carefully in a 20% solution of pyrogallic acid in caustic soda. Nitrogen, from a cylinder, was passed into the first washer. By means of an injector, shown in the diagram, the soda-pyrogallol solution was carried up with the gas to the top of the absorption tower. The nitrogen passed from the bottom of this tower to the second scrubber where any trace of oxygen still remaining in the gas was removed. By this method of washing, a very large surface of fresh solution is exposed to the gas passing down the tower. It is easy to determine by the appearance of the solution when it requires renewing. The quantity of solution passing to the top of each tower can be regulated by increasing or reducing the pressure in each bottle. The gas after being dried by means of calcium chloride entered the bottom of the silica tube.

The lower end of the silica tube was closed by a well fitting rubber bung. The free space inside the tube was reduced by packing the bottom part with asbestos wool. A layer of small pieces of wood charcoal and some asbestos wool were placed above this asbestos. A monel metal tube having a large flange to which an asbestos plug was fixed, fitted into the top of the silica tube. A cage made of nichrome wire was also fixed to the flange of the monel tube. The cage was filled/

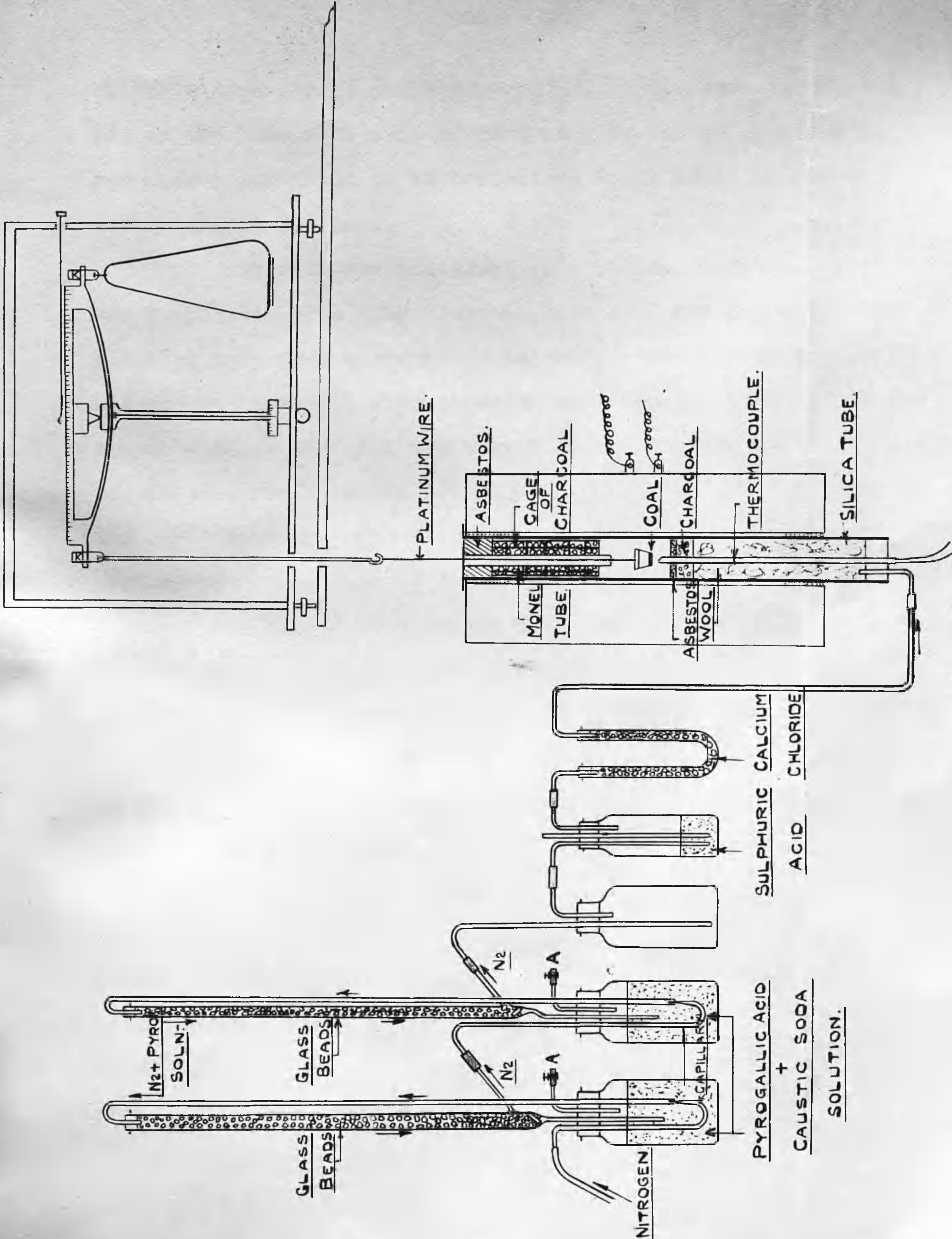

PLATINUM WIRE
ASBESTOS
CAGE OF CHARCOAL
MONEL TUBE
COAL
CHARCOAL
ASBESTOS WOOL
THERMOCOUPLE
SILICA TUBE
SULPHURIC ACID
CALCIUM CHLORIDE
N_2
A
N_2
A
N_2 + PYRO SOLN.
GLASS BEADS
GLASS BEADS
CAPILLARY
NITROGEN
PYROGALLIC ACID + CAUSTIC SODA SOLUTION.

FIG. 5

filled with charcoal which removed any oxygen entering at the top of the tube. A rate of flow of nitrogen of about 50 cc. per minute was found to be sufficient to maintain an inert atmosphere in the tube.

The coal was contained in a silica crucible, which was suspended, by a fine platinum wire of 0.008 in. gauge and a nickel rod, from a sensitive balance. The silica crucible and the thermocouple were situated in a central position in the silica tube. The coal was heated at the desired rate by means of the electric furnace.

When the apparatus had been assembled, the crucible containing about 1 gm. of finely powdered coal was weighed. Nitrogen was passed through the system at a rate of about 50 cc. per minute for 60 minutes, after which the heating of the coal at the given rate was commenced. The loss in weight of the coal was determined every 10°C. The temperature was maintained at 950°C for about 40 minutes after which interval there was no further loss in weight.

METHODS OF EXAMINATION OF COKES

1. Sampling of Coke

(a) Full scale tests

A sample of about 3 cwt. of each coke examined, was taken. An attempt was made to obtain a representative sample containing the correct proportions from each part of the oven charge.

(b) Experimental Oven tests

All of the coke from the experimental oven was used for the screening test and a representative sample of about 3 cwts. was taken for the other tests.

(c) Bag tests

All of the coke, usually about 200 lb. was used.

(d) Preparation of Laboratory sample

The 50 lb. average sample of coke used for one of the shatter tests was crushed by means of a manganese steel jaw crusher mill to pass a ½in. square mesh screen. A sample of about 4 lb. was then taken in 10-15 increments and used for the determination of the moisture. This dried sample was crushed in/

in a manganese steel roller mill to pass a 10's mesh I.M.M. sieve and reduced to about 4 oz. by coning and quartering in the usual way. The 4 oz. sample was ground to 60's mesh I.M.M. using a manganese steel pestle and mortar, care being taken to avoid any rubbing action.

2. Analysis of Coke

(a) Screening Analysis

Each sample of coke on arrival at the laboratory was screened using stamped steel square mesh screens having the following apertures:-

4in., 3in., 2in., 1½in., 1in., and ½in.

(b) Shatter Test

The method used to determine the resistance to shatter of the cokes was that adopted and advocated by the Midland, Northern and Scottish Coke Research Committees ("Fuel in Science and Practice" 1930,9,151), and is as follows:-

"(1) Apparatus

The shatter test apparatus (1) shall consist of a box 18 in. in width, 28 in. in length, and approximately 15 in. in depth, supported above a rigidly mounted cast-iron or steel plate, not less than ½in. in thickness and not less than 38 in. in width and 48 in. in length. The inside of the bottom of the/

the box when in its highest position shall be 6 ft. above the plate. The bottom of the box shall consist of two doors hinged lengthwise and latched so that they will swing open freely and not impede the fall of the coke. Boards about 8 in. in height shall be placed around the plate so that no coke is lost. To minimise the breakage of coke, which might otherwise occur while placing the sample in the box, the box shall be so suspended that it can be lowered to a convenient level for filling. A convenient form of shatter test apparatus is shown in Fig. 6.

(2) Screens

For determining the breakage of the coke sample, square mesh screens having the following openings shall be used:-

2in., $1\frac{1}{2}$in., 1in., and $\frac{1}{2}$in.

These screens shall be machine stamped from mild steel plates with a limit of error of 1/32 in.

(3) Procedure

Fifty pounds of coke, (2) all over 2 in., shall be placed in the box of the shatter test apparatus, the coke levelled, the box raised and the coke dropped on to the plate. The box shall be lowered and all the coke shovelled into it indiscriminately, but taking care to avoid breakage. The box shall then/

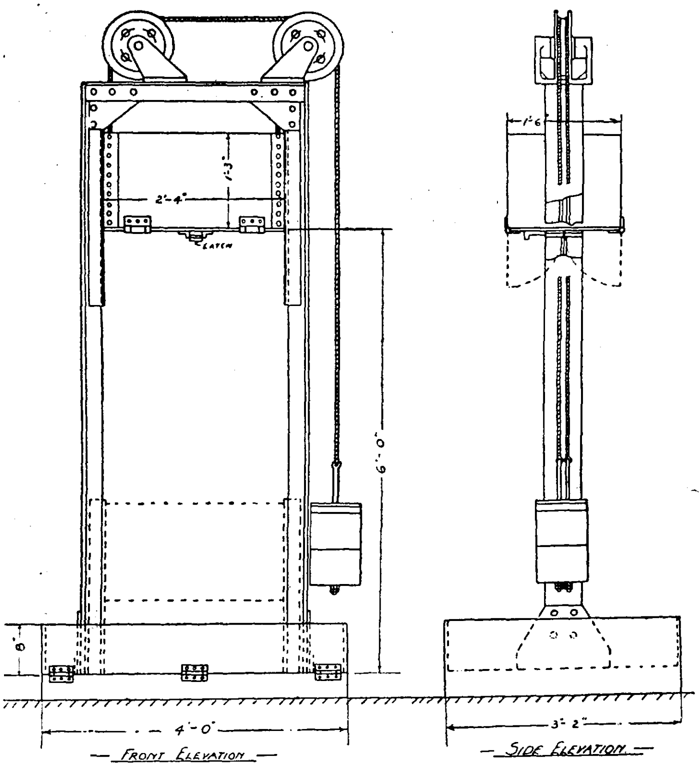


FIGURE 6 - **Standard Shatter Test Apparatus**

then be raised and the coke again dropped. When the coke has thus been dropped four times in all, it shall be screened by hand in such a way that any piece which can pass through the screen in any position shall be counted as undersize, and the weights of coke of each grade shall be determined to the nearest ounce.

At least three tests shall be made and the results stated as percentages remaining on 2 in., 1½ in., 1 in., and ½ in. screens.

References:-

(1) The essential dimensions of the shatter test apparatus are those given by the American Society for Testing Materials in "Standard Method of Shatter Test for Coke", Serial Designation D 141-23 (A.S.T.M. Standards, 1927, Part II, Non-metallic Materials, p.571).

(2) If for any reason the shatter test cannot be made with a true average sample of the original coke over 2 in., the grading of the coke taken for shatter test should preferably be such that the weight-ratio of the 2 in., 3 in., and 4 in. grades is that found in a preliminary size-analysis of the original coke"

Note on The Shatter Test

The method of carrying out the shatter test is described on/

on page 29.

(a) Experimental Error

A series of preliminary tests using a Scottish Coke were carried out by the author to determine the experimental error of the shatter test. Similar tests were carried out later by Briscoe and Marson and their results together with those of the author are given in Fuel, 1931, 11,464. As a result of these tests Briscoe and Marson concluded that,

(1) The magnitude of the error is dependent on the type of coke examined.

(2) When comparing the means of three tests for each of two cokes for the same class:-

  (a) Differences of the 2 in. shatter index having a probability of 1/101 are for two Durham, one Cumberland and one Scottish coke, 2.9, 3.3, 4.0 and 3.3 units respectively.

  (b) Differences in the 1½ in. shatter index, having a probability of 1/101 are, for these same cokes, 1.2, 1.7, 2.8 and 3.0 units respectively.

When comparing the shatter indices of cokes examined in the present investigation it has been considered that no alterations have been made in the 2 in. or 1½ in. indices of the cokes unless these indices differed by at least 4.0 and 3.0 units respectively.

(b)/

(b) Relation between the 2 in. and 1½ in. shatter index.

Mott and Wheeler (Coke for Blast Furnaces, p.116) have observed that there is not a constant relation between the 2 in., 1½ in., 1 in., and ½ in., shatter indices of cokes.

They state that:-

"If for a given 1½ in. index, the 2 in. index is higher than the normal, the coke is usually abnormally blocky; if the 2 in. index is lower than the normal, the coke is abnormally prismatic. If the 1 in. and ½ in. indices are lower than the normal, the coke is usually friable".

The graph given in Fig. 8 shows the normal relationship between the 2 in. and 1½ in. shatter indices obtained by Mott and Wheeler from the examination of a large number of cokes. The 2 in. and the 1½ in. indices of a representative series of Scottish cokes have been plotted in the same figure. It will be observed that the cokes having relatively high 2 in. indices were blocky, while those possessing relatively high 1½ in. indices were prismatic.

Four cokes were made in 20 in. ovens from a compressed coal having a very high volatile matter content. The 2in./1½in. shatter indices of these cokes were 50/64, 53/65, 55/68 and 54/65. These cokes contained longitudinal fissures running from one end of the pieces of coke, but not continuing as far as the cauliflower end (that is the end next to the oven wall). The/

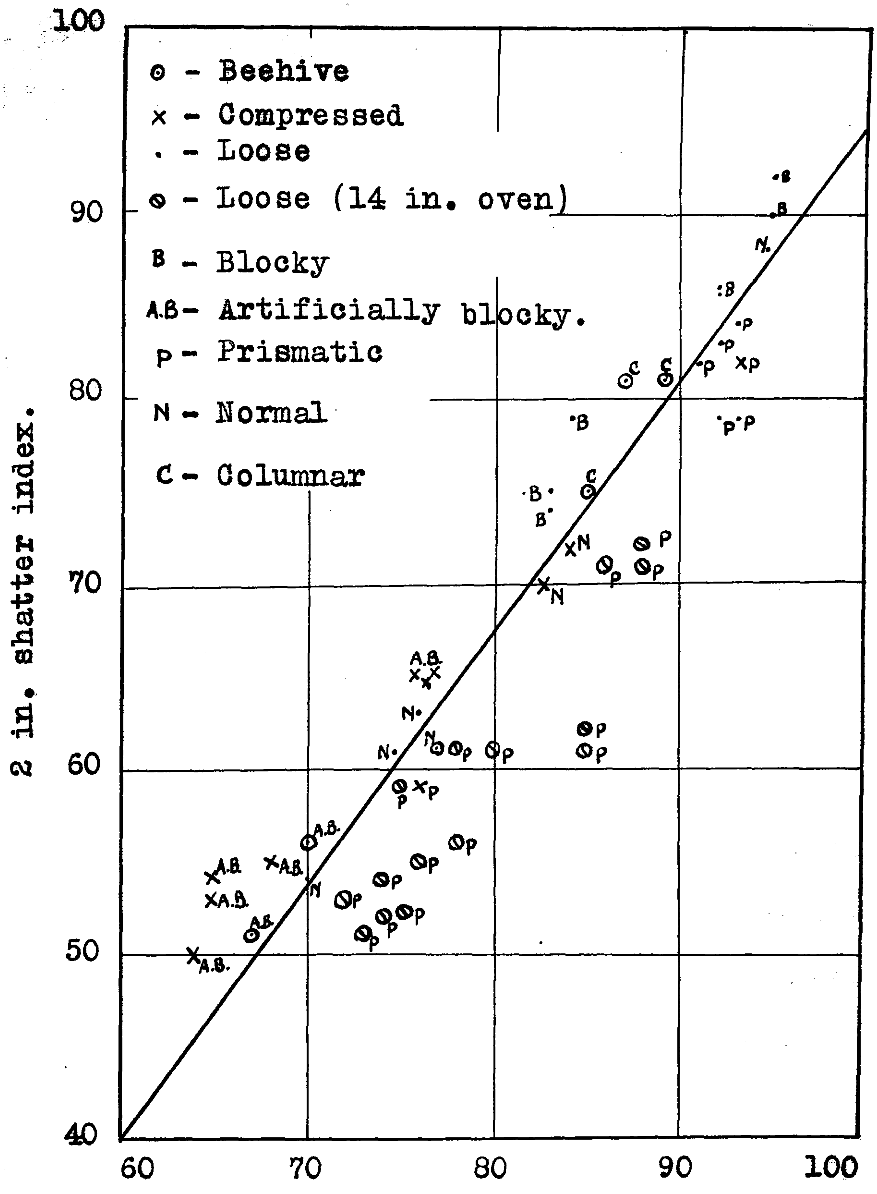


FIGURE 8 - Relation between the 2 in. and 1½in. shatter indices of Scottish cokes.

The one end of the piece of coke was therefore separated into fingers of small cross-section. When these cokes were submitted to the shatter test these fingers broke off and since they were of small cross-sectional area they passed through not only the 2 in. but also the $1\frac{1}{2}$ in. screen. The majority of the blocky cauliflower ends were retained by the 2 in. screen. These cokes were in this way rendered blocky and have been termed "artificially" blocky.

(c) Apparent Specific Gravity.

Five or six representative pieces of coke were selected from the bulk sample, care being taken that each piece was as far as possible of uniform cross-sectional area and represented the full half-width of the oven.

The pieces of coke, weighing in all about 4-6 kgs. were dried to constant weight in an air oven maintained at a temperature of about 200°C. The weight in air (W) was found. The pieces of coke were then completely immersed in distilled water and boiled for ½ hour. The water was allowed to cool, the pieces of coke still remaining submerged. The coke pieces were then weighed under water (Ww), removed, allowed to drain and weighed in air (Wa). The apparent specific gravity is then

$$\frac{W}{Wa - Ww}.$$

(d) True Specific Gravity.

Two/

Two grams of coke ground to 60's mesh I.M.M. were placed in a 50 c.c. specific gravity bottle, covered with about 25 c.c. hot distilled water and boiled at reduced pressure for ½ hr. in a water bath. The bottle was shaken at intervals to wash down the coke adhering to the sides. The bottle was then allowed to stand during 1 hour in a constant temperature bath at 15°C, completely filled with water at the same temperature and weighed, (w_1). The bottle was then cleaned, filled with distilled water and immersed in a constant temperature bath at 15°C for 1 hour. The weight of the bottle filled with water at 15°C (W_2) is then determined. The true specific gravity of the coke is:-

$$\frac{2{,}0000}{W_2-(W_1-2.0000)}$$

(e) Porosity

The porities of the cokes were obtained in the following manner:-

$$\text{True porosity} = \frac{\text{True Spec. Grav.} - \text{Apparent Spec. Grav.}}{\text{True Spec. Grav.}} \times 100$$

$$\text{Apparent porosity} = \frac{\text{Volume of water absorbed by coke}}{\text{Outside volume of coke}} \times 100$$

This is directly determined from the formula $\frac{Wa - W}{Wa - Ww}$.

(f) /

(f) Ash content

1-2 gm. of coke ground to 60's mesh I.M.M. were heated at 750°-$800^\circ C$ in an oxidising atmosphere in a muffle furnace until constant weight.

CHAPTER II

EXPERIMENTAL

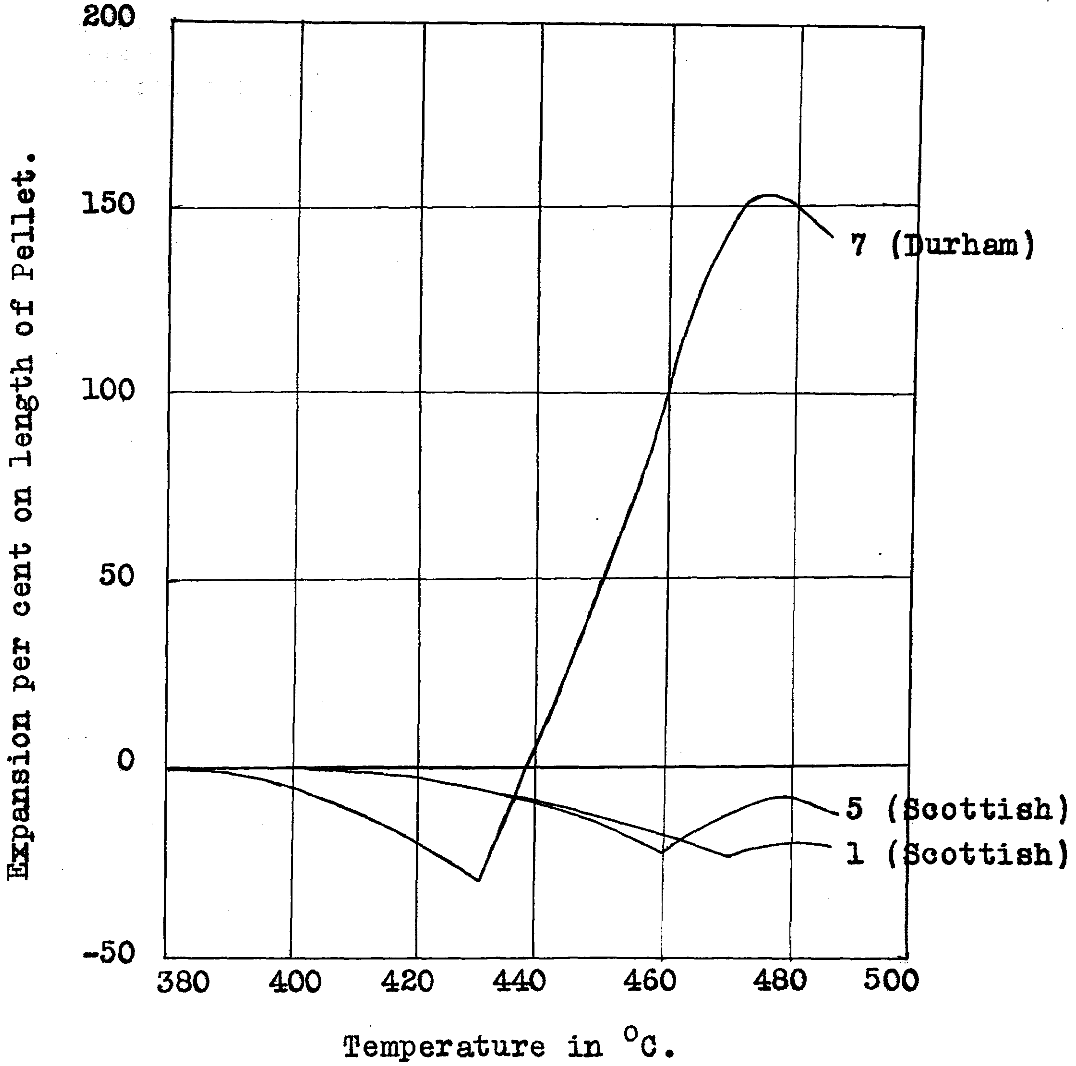
The Degree of Expansion of Scottish Coking Coals.

Many experimenters have attached great importance to the degree of swelling of coking coals and have attempted to correlate this property with the quality of the cokes obtained therefrom.

The degrees of expansion at rates of heating of 1,3 and 5°C per min. have been determined for a representative series of Scottish coking coals and a typical Durham coal, by the method described on page 19

The rate of heating obtained when carbonising coal in a modern coking oven does not exceed 2°C/min., and is generally about 1°C/min. It was found that not one of the Scottish coals examined gave any expansion when they were heated at a rate of 1°C/min. At this rate of heating the Durham coal gave an expansion of 128%. The change in length of the coal pellets of a few typical coals when they were heated at a rate of 3°C/min. may be observed from Fig. 9. The results obtained from the tests carried out at a rate of heating of 5°C/min. are set forth in Table I.

The most striking feature of the results obtained from/



Rate of Heating - 3°C/min.

FIGURE - 9 - Expansion of Coal Pellets with increase of Temperature.

Table I - Results of Swelling Tests on Coking Coals.

Rate of heating - 5°C/min.

Coal No.	Temperature in degs. Cent. of:			Contraction per cent on length of pellet.	Expansion per cent on length of pellet.	Shatter Indices of cokes obtained. 2"/1½".
	Initial plasticity.	Initial Expansion.	Final Expansion.			
1	405	470	480	22	5	78/85
2	410	480	490	23	7	61/78
3	410	-	490 X	18	nil	92/95
4	415	-	500 X	30	nil	56/70
5	405	460	485	22	22	81/87
6	420	-	485 X	33	nil	85/92
7 (Durham)	380	430	490	25	271	85/93

X Temperature of final contraction.

from these experiments, is the great difference in the degree of expansion between the Scottish coals and the Durham coal No. 7. It is noteworthy that the non-swelling Scottish coal gave the coke having the greatest resistance to shatter. Coal No. 5 is the only Scottish coal which, even when heated at the comparatively rapid rate of 5°C per min. does not give a coke pellet shorter than the corresponding coal pellet. It should be pointed out that, while the final length of the coke pellet obtained from coal No. 5 was the same as the coal pellet before heating, the volume had increased. When the coal pellet is heated it becomes plastic and tends to flow and fill up the dilatometer tube. The cross-sectional area of the pellet is therefore increased.

These experiments show that no correlation can be made between the degree of swelling of Scottish coking coals and the quality of the coke produced from them.

Audibert and Delmas (Fuel 1926,5,229) considered that when a coking coal was heated it melted completely, the fluidity which they measured by the degree of intumescence varying with the type of coal and the rate of heating. They were of the opinion that to obtain the best coke from a given coal or blend the fluidity should be such that the coal or blend just begins to intumesce at the rate of heating obtaining in the coke oven. They claim that this degree of fluidity is necessary to ensure the complete filling up of the network of/

of voids between the particles of coal so that a strong coherent coke may be obtained and that higher values of fluidity give too swollen, spongy, and therefore weak cokes.

The dilatometer experiments described by the author show that at the average rate of heating obtaining in a coke oven, namely about 1°C/min. the typical Scottish coking coals examined showed no tendency to swell and even when heated at 5°C/min. only one of them gave an intumescence equal to the contraction of the coal pellet, that is, the optimum intumescence suggested by Audibert and Delmas. These coals should according to their findings give abradable cokes, but this was not found to be the case.

It is therefore apparent that Scottish coking coals are of a very different type to those from many other coalfields and also that there must be factors which have a more important bearing on the physical properties of the coke than the degree of swelling of the coal.

An examination of some other properties which it was thought might have an influence on the nature of the coke was therefore carried out.

CHAPTER III

The Significance of the Volatile Matter Contents at the End of the Plastic Ranges of Coking Coals.

On page 8 it was pointed out that, Rose, (Fuel, 1926, 5,562) found that there is some relation between the total volatile matter content and the nature of the coke obtained from a coking coal. Coals containing high percentages of volatile matter gave highly fissured cokes, while those having low volatile matter contents gave blocky cokes with comparatively few fissures.

Now, since the fissuring of a coke takes place during the period subsequent to the plastic range of a coal, the degree of fissuring should be related to the percentage of volatile matter evolved during this period. Accordingly, by comparing the volatile matter contents of the coals after heating to the temperature of the end of the plastic range and also the nature of the cokes obtained, a more accurate correlation should be obtained.

Method of Determination of the Plastic Ranges of Coking Coals.

The plastic ranges of a series of Scottish coking coals were therefore determined, firstly by the modification of/

of Audibert's method described on page 17 and secondly by the modified Foxwell Method described on page 19.

The results of these experiments are given in Table II.

These results show that, the temperatures obtained for the beginning of the plastic ranges of the coals, by either method, agree closely. The temperatures obtained for the end of the plastic ranges were, however, usually about 50°C lower when these were determined by the modified Audibert method.

In the case of the modified Audibert method, while the temperature of final expansion was easily determined, the temperature of the end of the plastic range of a coking coal was not sharply defined. The highly swelling Durham coal became so fluid as to stick to the side of the dilatometer tube and the contraction subsequent to the expansion range was therefore hindered. The temperatures of final expansion of less highly swelling coals and the temperatures of final contraction of non-swelling coals were ill-defined, small contractions occurring over a wide range of temperature.

The beginning and the end of the plastic range of coking coals, when determined by the modified Foxwell method, were very sharply defined and moreover, duplicate determinations agreed to within 2°C.

The temperature of the end of the Foxwell plastic range of a coal, is that temperature, subsequent to the plastic stage,/

Table II - Plastic Ranges of Coking Coals

Rate of heating - 5°C per min.

Coal No.	Modified Audibert Method.		Modified Foxwell Method	
	Temperature in °C of :-		Temperature in °C of :-	
	Initial Plasticity	Final Expansion or Contraction	Initial Plasticity	Final Plasticity
1	405	480	405	530
2	410	490	410	532
3	410	490	410	542
4	415	500	415	523
5	405	485	410	540
6	420	485	420	533
8	400	480	400	535
7	380	490	370	567

stage, at which gas just begins to flow through a plug of the coal when it is heated progressively. From the foregoing experiments it was ascertained that there is usually an interval of about 50°C between the point when the coal ceases to be plastic and becomes rigid and the point when the rupturing of the cell walls occurs, thus allowing the passage of gas through the semi-coke.

As a result of these considerations, the temperature of the end of the plastic range when determined by the modified Foxwell method, was thought to represent more closely the point at which the fissuring of the coke commences. This method was therefore adopted for future determinations.

Examination of a Series of Coking Coals

A representative series comprising Scottish, Durham, Northumberland, Yorkshire and Derbyshire coking coals were examined. The plastic ranges, the percentages of volatile matter evolved before, and during the plastic ranges when these coals were heated at rates of 1,3 and 5°C/min. were determined by the methods described on pages 19 and 23 respectively.

The results obtained from these experiments are recorded in Table III.

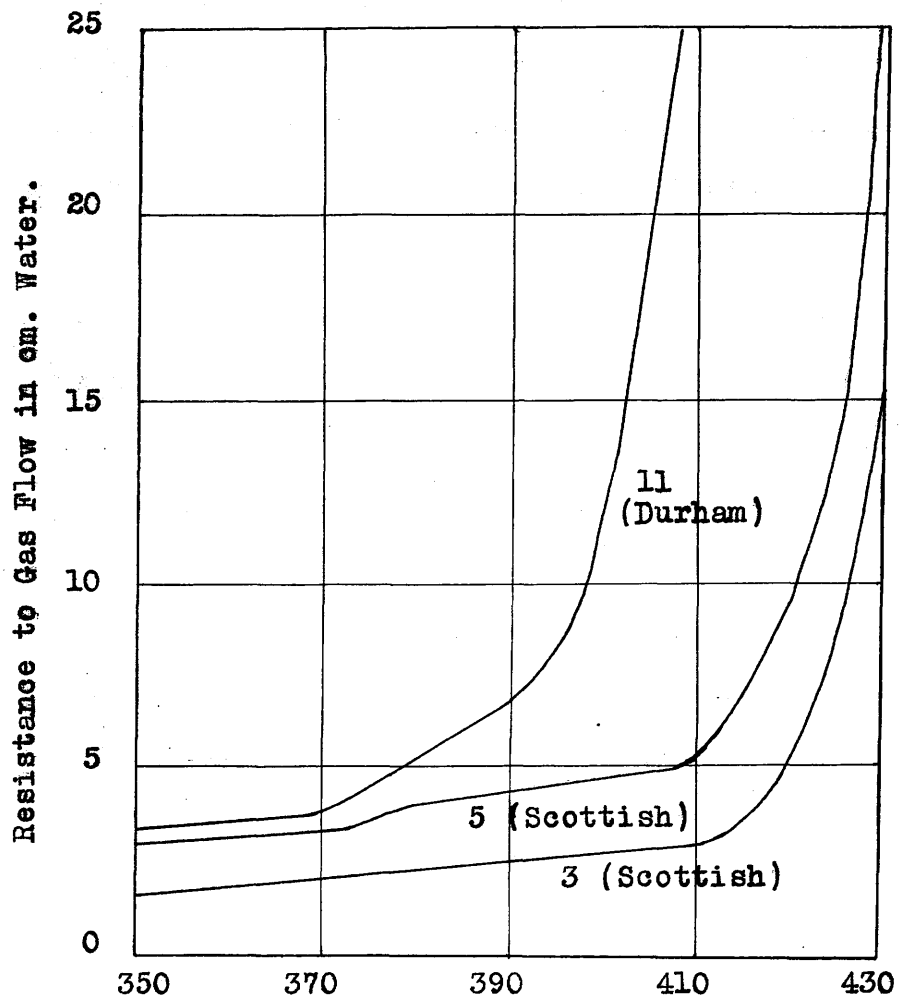
The temperature of the start of the plastic range for each coal examined is independent of the rate of heating for the given rates, but the temperature of the end of the plastic range/

X

Table III - Plastic Ranges and Volatile Matter Determinations for a Series of Coking Coals.

Coal No.	Origin of Coal.	Rate of heating.	Temperature in °C of: Beginning of plastic range.	End of plastic range.	Plastic range.	Total volatile organic matter content.	Vol. organic Matter evolved before beginning of plastic range.	Vol. organic matter evolved during plastic range.	Vol. organic matter content at end of plastic range.	Caking Index Gray-Campredon.
		°C/min.				Per cent.	Per cent.	Per cent.	Per cent.	
8	Scottish.	1	400	480	80	33·9	1·3	14·4	18·2	27
		3	400	516	116		1·3	17·1	15·5	
		5	400	535	135		1·3	18·0	14·6	
3	,,	1	413	469	56	26·8	1·2	7·6	18·0	24
		3	413	514	101		1·2	10·0	15·6	
		5	413	542	129		1·2	10·2	15·4	
4	,,	1	417	451	34	35·1	2·0	7·4	25·7	19
		3	417	500	83		2·0	15·8	17·3	
		5	417	523	106		2·0	15·8	17·3	
9	,,	1	405	489	84	33·6	1·2	12·3	20·1	28
		3	405	522	117		1·2	17·7	14·7	
		5	405	538	133		1·2	18·3	14·1	
10	,,	1	397	482	85	34·0	2·3	13·3	18·4	21
		3	397	514	117		2·3	17·8	13·9	
		5	397	530	133		2·3	18·1	13·6	
11	Durham.	1	361	508	147	27·4	0·2	14·9	12·3	37
		3	361	548	187		0·2	15·9	11·3	
		5	361	564	203		0·2	15·8	11·4	
12	Northumberland.	1	409	480	71	38·1	1·1	16·7	20·3	26
		3	409	521	112		1·1	19·0	18·0	
		5	409	532	123		1·1	21·2	15·8	
13	Yorkshire.	1	410	462	52	35·1	1·6	8·8	24·7	24
		3	410	509	99		1·6	14·2	19·3	
		5	410	523	113		1·6	15·3	18·2	
14	,,	1	401	481	80	34·7	1·4	12·9	20·4	28
		3	401	514	113		1·4	16·8	16·5	
		5	401	531	130		1·4	17·2	16·1	
15	,,	1	376	495	119	33·0	1·4	16·7	14·9	38
		3	376	532	156		1·4	16·7	14·9	
		5	376	549	173		1·4	18·4	13·2	
16	,,	1	384	513	129	37·3	1·7	15·6	20·0	38
		3	384	525	141		1·7	17·9	17·7	
		5	384	543	159		1·7	21·3	14·3	
17	Derbyshire.	1	—	—	—	35·8	—	—	—	11
		3	430	460	30		3·9	6·5	25·4	
		5	430	485	55		3·9	7·2	24·7	

X taken from Davidson, "Fuel in Science and Practice", 1930,9,489.



Temperature in °C.

Rate of Heating - 3°C/min.

FIGURE - 10 - Increase of Resistance of Coal Plug to Gas Flow with Increase of Temperature.

range varies with the rate of heating.

The high temperatures obtained for the start of the plastic ranges in the case of the Scottish coals are noteworthy. It was observed in the examination of the given series of coals, that with certain coals of average caking index a very small increase occurred in the resistance to gas flow through the plug of coal, at a temperature about 30°C below that recorded for the temperature of the start of the plastic range. This increase was very small and not continuous, even in the case of the Scottish coals of highest caking index. In the case of the Durham coal, No. 11 and the two strongly coking Yorkshire coals Nos. 15 and 16, this initial increase was large and almost continuous with the later and more rapid increase of pressure. The temperature corresponding to this large initial increase of pressure was taken as the start of the plastic range for these coals. The above phenomenon may be observed from Fig. 10 showing the increase of the pressure of the system, with increase of temperature, for several coals.

The Derbyshire coal No. 17 has a very low agglutinating value, 11, and a very high temperature for the start of the plastic range. When heated at rates of 1, 3 and 5°C/min., this coal does not at any time during the experiment become sufficiently plastic to completely resist gas flow. At 1°C/min. only a very small resistance to gas flow is obtained. Coal No. 4, of next lowest caking index, 19, gives a high temperature for/

for the beginning of the plastic range. When this coal is heated at a rate of 1°C/min., it also does not become sufficiently plastic to completely resist gas flow. All the other coals of the series completely resist gas flow at each rate of heating employed.

The results of the volatile determinations are also set forth in Table III. For the coals examined, the percentages of volatile matter evolved before the beginning of the plastic ranges are the same at rates of heating of 1, 3 and 5°C/min., and were in all cases a small percentage only of the total volatile matter content of the coal.

A very outstanding feature shown by these tests is, that there is no constant connection between the total volatile matter content of a coal and that part of it which is retained by the coal when heated to the temperature of the end of its plastic range. The total volatile matter contents of coals Nos. 8 and 3 differ by 7.1% and yet retain similar percentages at the ends of their plastic ranges, while coals Nos. 4, 13, 14 and 17 have similar total volatile matter contents but widely different volatile matter contents at the end of their plastic ranges.

Generally the volatile matter contents at the end of the plastic ranges of a coal, determined at rates of heating of 3 and 5°C/min. did not differ greatly but these varied to a greater or less extent according to the coal examined from that determined/

determined at a rate of heating of 1°C/min. The values obtained for the strongly caking coals Nos. 11 and 15 varied little for each rate of heating. There is an indication therefore that a relatively large improvement of the coke quality would be obtained by increasing the speed of carbonisation of poor coking coals since their plastic ranges are very considerably increased and the reductions of their volatile matter contents at the end of their plastic ranges are, compared with the coals of high agglutinating value, very great.

In the majority of cases there is a distinct relationship between the nature of the coke obtained and the percentage of volatile matter evolved subsequent to the plastic range. For example, coal No. 4, yields a fingery, highly fissured coke, and coal No. 9, a columnar coke with comparatively few fissures when each is coked in beehive ovens under the same conditions. Further, the Durham coal No. 11, which gives an excellent coke, has a very low volatile matter content at the end of the plastic range for each rate of heating.

CHAPTER IV

The Significance of the Volatile Matter Contents at the End of the Plastic Ranges of Blends of Coking Coals with Non-Caking Materials having low Volatile matter contents.

INTRODUCTION

The results obtained from the experiments described in Chapter III suggest that if the volatile matter retained by a coal at the end of the plastic range could be diminished, a coke having less fissures would be obtained. This could be attained in two ways, either by adding a material having a low volatile matter content, for example, high temperature coke, which does not reduce the temperature of the end of the plastic range, or by raising this temperature by the addition of a coal having a higher temperature for the end of the plastic range and a lower volatile matter content at this temperature.

The blast furnace trials recorded by Evans (Gas World, 1926. vol. 84, Jan. 2, coking section, 9, 14) and later those carried out by Marshall and Wheeler (Journal of the Iron and Steel Institute, No. 1, 1933) have shown conclusively the detrimental effect which breeze has on the performance of coke in the furnace.

The production of small coke from the time it leaves

the/

the screens at the coke ovens until it arrives at the stock level of the furnace is caused chiefly by the various drops to which the coke is subjected. The shatter test was designed to determine the liability of cokes to produce smalls when handled in a manner similar to that occurring during the loading of the coke into wagons at the ovens, unloading at the blast-furnace plant and charging into the furnace. It is now generally believed that the shatter indices of a coke, especially the 1½ in. index, afford a reliable measure of one of the most important properties which determine the comparative usefulness of cokes for metallurgical purposes. The significance of the shatter indices of a coke are further discussed on pages 32-34.

EXPERIMENTAL

The following series of blending experiments were carried out to determine the effects on the quality of the resultant coke of blending Scottish coking coals with materials having low volatile matter contents:-

A. - Top-Charged Blends

(a) Bag Tests

Series I and II - Blends of a coking coal with low and high temperature coke crushed to various sizes.

(b) Experimental Oven Tests

Series III - Blends of a coking coal, having a high volatile matter content, with high temperature coke crushed to various sizes.

Series IV - Blends of a coking coal having a low volatile matter content, with high temperature coke crushed to various sizes.

Series V - Same as IV except that fusain was the blending material.

Series VI - Same as IV except that finely crushed anthracite/

anthracite was the blending material used.

B. - Compressed Charged Blends

(a) Bag Tests.

Series VII, VIII and IX - Blends of a coking coal having a high volatile matter content with low temperature coke, "burnt" coal and high temperature coke, respectively, crushed to various sizes.

Series X and XI - Blends of two coking coals having very high volatile matter contents with finely crushed high temperature coke.

Series XII, XIII and XIV - Blends of a coking coal having a low and two coking coals having very high volatile matter contents, with finely crushed anthracite.

A. - TOP CHARGED BLENDS

(a) BAG TESTS

Series of Blends I and II - Effect of blending with low and high temperature coke.

Coal No. 18. was used for both series of blends. This coal was the $\frac{3}{8}$-3in. washed, crushed, screenings of a single seam and was coked regularly at the plant.

Examination of Blends:-

Blends were made of coal No. 18. with 5, 10, 15 and 20% of finely crushed low temperature coke No. 1, for series No. I and of finely crushed high temperature coke for series No. II.

The temperatures obtained for the plastic ranges of these blends were the same as those obtained for the plastic range of the straight coal.

The analyses of the straight coal and blends are recorded in Table IV and they show that the addition of high temperature coke reduces the volatile matter content at the end of the plastic range of the resultant blend to a much greater extent than does the addition of the same percentage of low temperature coke.

The difference between the true specific gravities

of/

Table IV - Analyses of Blends.

Air-Dried

Sample No.	Low or High Temp. coke in blend %	Moisture %	Volatile Organic Matter %	Ash %	Fixed Carbon %	Agglutinating Value	Volatile Org.Matt. Content at end of Plastic Range %
18	0	1.4	26.0	4.2	68.4	24	13.2
L.T.C.I	100.L	3.2	11.8	7.6	77.4	nil	(9.3) X
20	5.L	1.5	25.5	4.4	68.6	23	13.1
21	10.L	1.6	24.9	4.5	69.0	21	13.0
22	15.L	1.7	24.3	4.7	69.3	19	12.8
23	20.L	1.7	23.8	4.9	69.6	17	12.7
24	5.H	1.3	24.8	4.3	69.6	23	12.8
25	10.H	1.3	23.3	4.4	71.0	21	12.2
26	15.H	1.3	22.2	4.5	72.0	20	11.6
27	20.H	1.2	21.0	4.6	73.2	18	10.9

X - % volatile organic matter retained when L.T.C. No.1 is heated to the temperature of the end of the plastic range of coal No.18.

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of the low temperature coke No. 1 and the high temperature coke No. 18 is of some importance. The specific gravity of the low temperature coke No. 1 was 1.47 and that of the high temperature coke No. 18 was 1.90. Since the blends were made up as percentage weights, a given percentage of low temperature coke will have a greater surface than the same percentage of high temperature coke. This will explain the reason for the fact that the addition of a given percentage of low temperature coke lowers the agglutinating value to a slightly greater extent than does the addition of the same percentage of high temperature coke.

Description of Constituents of Blends:-

Coal No. 18 was used in the whole series of blends. This coal was the washed, crushed ⅜-3in. screenings from a single seam and was coked regularly at the plant. The screening analyses of the coal and finely crushed low and high temperature cokes, as used for the preparation of the blends, are given in Table V. Each blend had a total moisture content of about 6.5%

Carbonisation of Blends:-

About 260 lb. of each blend were coked in a bag placed in an oven charge of the straight coal. The oven was top-charged, had a mean width of 18 in. and sole-flue heating. The dimensions of the bag filled with the blend were about 36 in. x 22 in. x 18 in. The surface of the bag was soaked with water and/

Table V. - Screening Analyses of Coal and Cokes used in Blending Experiments.

Percentages.

Sample	Series of blends	Thro' $\frac{1}{2}$ in.	Thro' $\frac{1}{4}$ in.	Thro' $\frac{1}{8}$ in.	Thro' 1/10 in.	Thro' 1/20 in.	Thro' 1/40 in.	Thro' 1/120 in.	Thro' 1/200 in.	Thro' 1/400 in.
Coal No. 18.	I and II	99	97	90	83	60	35	12	9	4
Low Temp. Coke No. 1.	IA	-	-	-	-	-	-	-	100	93
	IB	-	-	-	100	93	66	32	19	7
	IC	100	97	57	49	25	18	7	5	2
High Temp. Coke No.18.	IID	-	-	-	-	-	-	-	100	90
	IIE	-	-	-	100	92	70	42	31	14
	IIF	100	93	47	37	29	20	10	6	2

and smeared over with a thin coating of fireclay. This insured that there would be a sharp line of demarkation between the coke inside and that outside the bag, when the coal had been coked. The bag was placed on a short, thick, wooden plank, pushed about 8 ft. into the oven and the charging of the coal immediately performed. The average flue temperature was about 1,000°C and the blends were all drawn after 24½ hours coking.

Examination of Blend Cokes

(a) Comparison of Full scale and Bag Test Cokes.

The cokes made from coal No. 18 when coked in a bag, by the method just described, and in a full scale oven were examined. The results are given in Table VI.

Table VI - Screening and Shatter Indices of Bag and Full scale oven cokes made from the same coal

Coke	Screening Indices				Shatter Indices			
No.	1"	2"	3"	4"	½"	1"	1½"	2"
18 (full oven)	99	95	66	35	98.9	98	93	79
18(b) (bag)	99	95	67	40	98.6	97	89	68

There/

There is a good agreement in the screening indices of the full scale oven and bag cokes made from the same coal. The 2 in. and 1½ in. shatter indices of the full scale oven coke No. 18 are higher than those of the bag test coke No.18(b). The reason for this is apparent when it is remembered that the coke from the bag test is representative of the coke from the bottom three-fifths part of the oven charge, the height of the bag being 3 ft. and that of the oven charge being 5 ft. Mott and Wheeler (Coke for Blastfurnaces, p.108.) have shown that the coke from the lower part of an oven charge is less resistant to shatter than that from the middle and even more so than that from the top part of the charge. These differences are increased when there is sole flue heating.

It is unfortunate that the bag coke is not representative of the coke from the whole oven, but since the bag cokes in the present blending experiments were all prepared in exactly the same manner, the results obtained will be truly comparative. The results from these tests were confirmed by the examination of the cokes made from several of these blends in an experimental coke oven.

(b) Effect of increasing the proportion of coal passing through a 200's mesh I.M.M. Sieve

A series of control tests were next carried out to determine if the increase in the fineness of the mixture which would/

would be obtained in the blending experiments, caused any alteration in the resultant cokes.

Two blends of coal No. 18 as charged to the oven, mixed with 5 and 10% of the same coal, ground to 200's mesh I.M.M. were coked. The results obtained from the screening and shatter tests of the cokes made from these two blends are contained in Table VII.

Table VII - Screening and Shatter Indices of Cokes

Coke No.	% addition of coal No. 18 ground to 200's mesh I.M.M.	Screening Indices				Shatter Indices			
		1"	2"	3"	4"	½"	1"	1½"	2"
18	0	99	95	67	40	98.6	97	89	68
18	5	99	90	60	19	98.9	96	89	71
18	10	99	92	49	23	98.9	97	88	70

The addition of 5 and 10% of coal No. 18, ground to 200's mesh I.M.M. to the same coal, crushed as charged to the ovens, caused a small decrease in the size of the coke but no alteration in its resistance to shatter.

(c) Series of Blends - I - Effect of blending with low temperature Coke.

Coal No. 18 was blended with 5, 10 and 15% of low temperature/

temperature coke No. 1, ground to three different sizes, viz. 0-1/400in., 0-1/20in. and 0-¼in.

The screening and shatter indices of the cokes are recorded in Table VIII, while the 2 in. and 1½in. shatter indices of the cokes and the volatile matter contents at the end of the plastic ranges of the blends are shown graphically in Fig. 11.

The scale chosen for the 2 in. and 1½ in. shatter indices is such that the 2 in. and 1½in. indices of cokes of normal shape will coincide. Therefore, if the 2 in. shatter index is placed higher in the figure than the 1½in. index the coke will be blocky but if the reverse occurs the coke will be prismatic.

If therefore an increase of the 2 in. shatter index of a coke is obtained, the 1½in. index remaining the same, a change in the shape of the coke has occurred. It has been made blockier, but since the 1½in. index has not been improved the percentage of smalls obtained by handling during transport will not be reduced and no alteration of the actual hardness has therefore taken place. The connection between the 2 in. and 1½in. shatter index is discussed on page 34.

Consideration of Fig. 11 shows that the addition of 5,10 and 15% of low temperature coke lowered the volatile matter content at the end of the plastic range of the coal by a small percentage only. Increases in the sizes and the 2in. shatter/

Table VIII - Screening and Shatter Indices of Blend Cokes

Coke No.	Low temp. coke added		Screening Indices				Shatter Indices			
	%	size	1"	2"	3"	4"	½"	1"	1½"	2"
18(b)	0	-	99	95	67	40	98.6	97	89	68
19(b)	2	0-1/400"	97	90	63	34	98.5	97	91	69
20(b)	5	"	99	94	64	34	98.5	96	89	67
21(b)	10	"	99	98	82	64	98.8	97	92	75
22(b)	15	"	98	84	48	28	98.2	97	86	70
28(b)	5	0-1/20"	98	94	77	58	98.6	96	89	72
29(b)	10	"	99	92	72	49	98.5	97	91	70
30(b)	15	"	98	86	64	41	98.6	97	91	62
31(b)	5	0-¼"	98	89	67	31	98.5	97	90	69
32(b)	10	"	98	95	93	91	97.6	93	87	81
33(b)	15	"	98	93	79	65	98.4	97	91	77

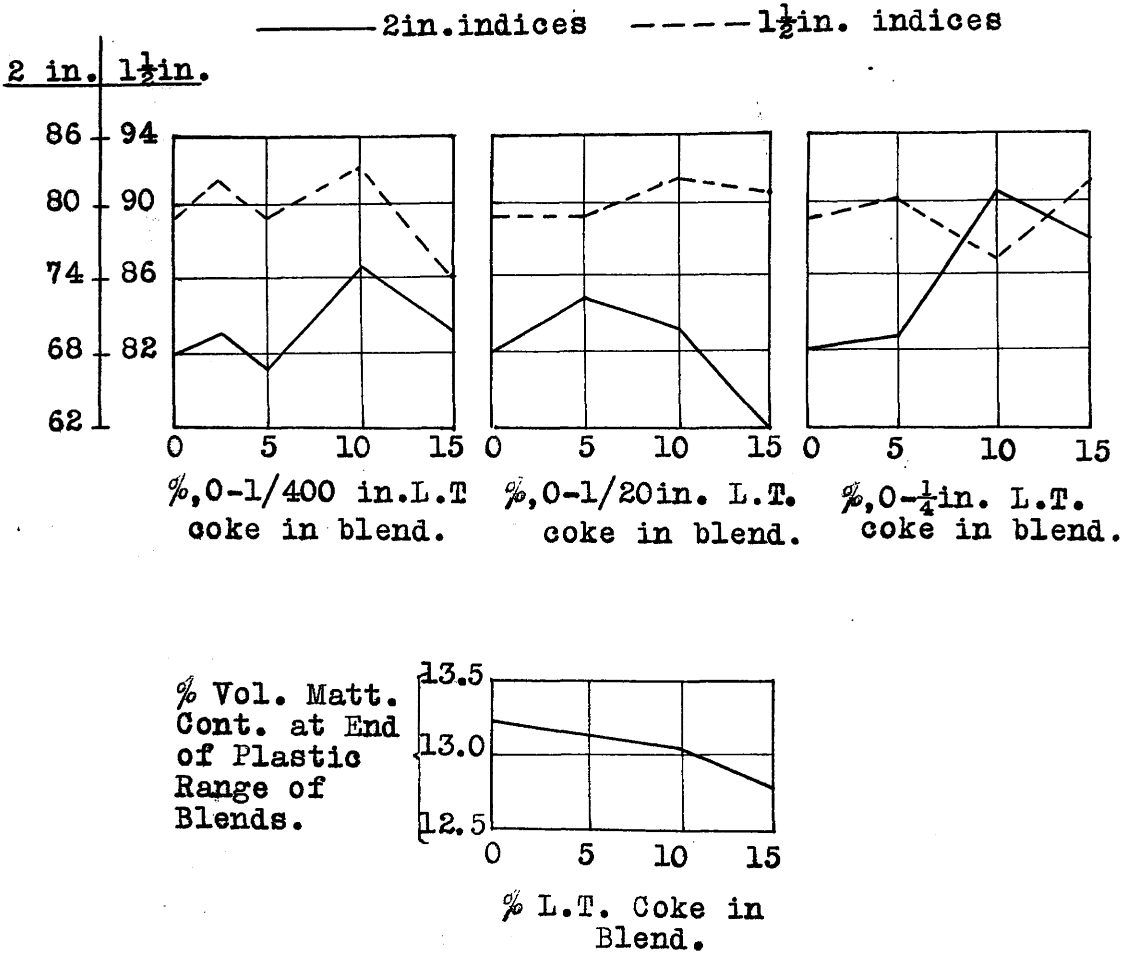


FIGURE - 11 - Effect of blending coal No. 18 with low temperature coke No. 1.

shatter indices only were obtained by the addition of 10% of 0-1/400in. and 10 and 15% of 0-¼in. low temperature coke to coal No. 18. The 1½in. shatter indices of the cokes made from the blends did not differ much from that of the coke made from the straight coal. No real improvement in the hardness of the resultant coke was therefore obtained by blending this coal with low temperature coke No. 1.

It is important to note that although the addition of 15% of low temperature coke No. 1 reduced the agglutinating value of coal No. 18 from 24 to 20 and further that this coal was non-swelling even when heated at a rate of 5°C/min. the ½in. shatter index and therefore the abradability of the resultant coke was not increased.

(d) Series of Blends - II - Effect of blending with high temperature coke.

Three series of blends of coal No. 18 with high temperature coke No. 18 ground to three different sizes, namely, 0-1/400in., 0-1/20in. and 0-¼in. were coked.

The screening and shatter indices of the cokes made from the blends are recorded in Table IX. The 2 in. and 1½in. shatter indices of the cokes and the volatile matter contents of the corresponding blends at the end of their plastic ranges are set forth in Fig. 12.

Fig. 12 clearly indicates that the addition of high temperature coke to coal No. 18 reduces considerably the volatile/

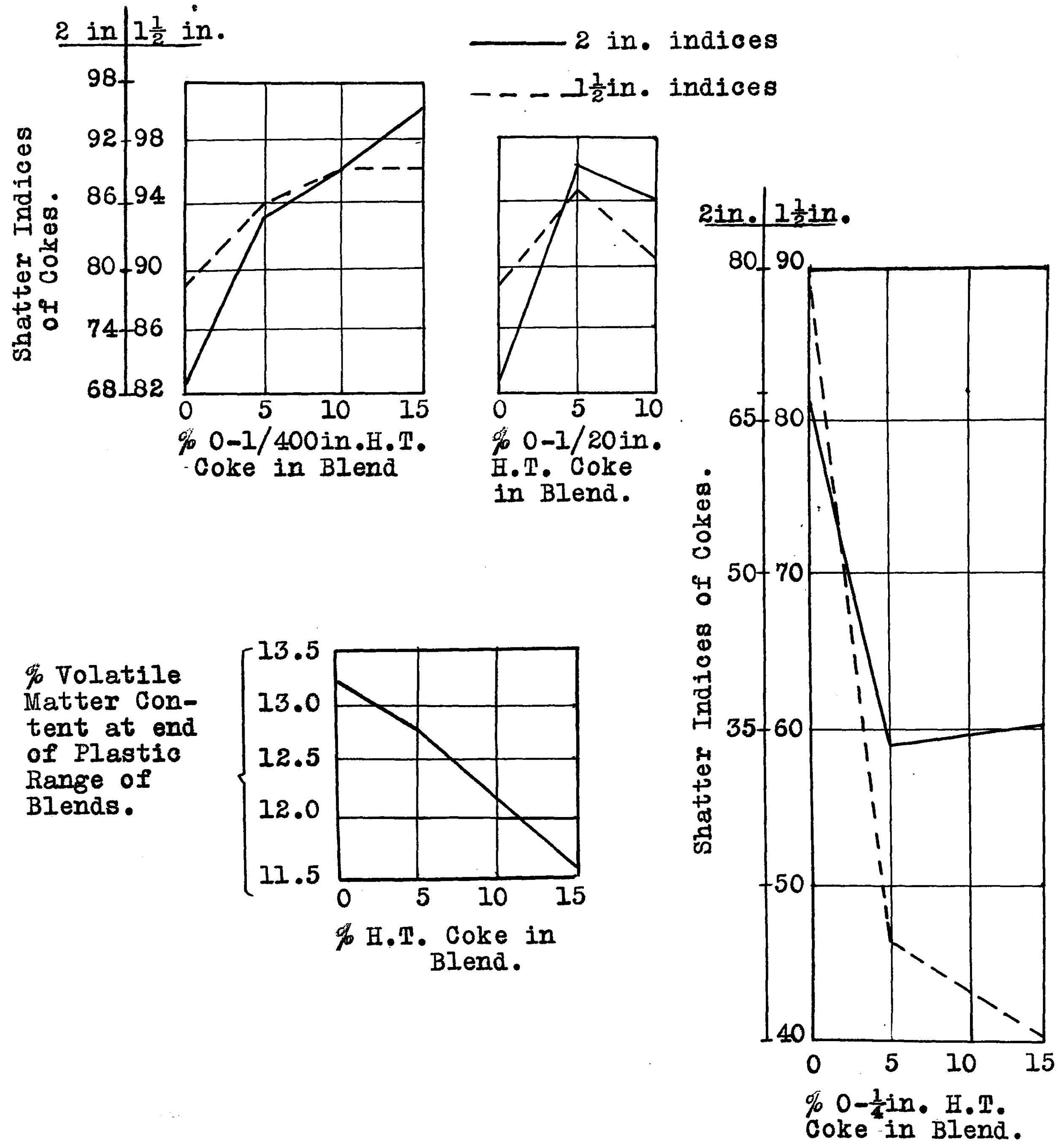


FIGURE 12 - Effect of Blending Coal No. 18 with High Temperature Coke No. 18.

Table IX - Screening and Shatter Indices of Blend Cokes

Coke No.	High temp. coke added.		Screening Indices				Shatter Indices			
	%	Size	1"	2"	3"	4"	½"	1"	1½"	2"
18(b)	0	-	99	95	67	40	98.6	97	89	68
24(b)	5	0-1/400"	99	97	93	76	98.4	97	94	85
25(b)	10	"	99	98	90	74	99.0	98	96	89
26(b)	15	"	99	98	94	94	98.6	98	96	95
34(b)	5	0-1/20"	98	96	88	73	98.2	97	95	90
35(b)	10	"	98	92	85	69	95.8	94	91	87
36(b)	5	0-¼"	83	64	50	36	92.0	66	47	34
37(b)	15	"	63	54	49	33	68.0	49	41	36

volatile matter content at the end of the plastic range of the coal. The reductions of the volatile matter contents of the blends at the end of their plastic ranges are accompanied by considerable increases in the sizes and resistances to shatter of the corresponding cokes, when the limits of size and percentage addition of the blending material are not exceeded. It is also shown in Fig. 12 that coke No. 18 is decidedly prismatic, the 2in./

2in. shatter index being relatively low when compared with the 1½in. index. The additions of high temperature coke causes a relatively greater increase in the 2in. index than in the 1½in. index with the result that the cokes made from these blends are blocky. The length of the coke pieces are limited to the half-width of the oven and the reduction in the longitudinal fissures, (perpendicular to the oven wall), caused by the addition of the blending material, will cause an increase in the blockiness of the coke pieces.

The addition of 5,10 and 15% of high temperature coke, ground to 0-1/400in., caused a large and progressive increase in the size and resistance to shatter of the resultant coke. The 15% blend gave a remarkably large coke which was comparatively free from fissures.

The blends of coal No. 18 with 5 and 10% of coke ground to 0-1/20in., gave cokes of increased resistance to shatter. The ½in. shatter index of the 10% blend was comparatively low, this being due to the existence of a large number of small cross-fractures in the coke which made it abradable. The limit of the percentage addition of high temperature coke ground to 0-1/20in., to give improvement in the hardness of the resultant coke, has therefore been exceeded in the case of this blend.

The addition of 5 and 15% of high temperature coke ground to 0-¼in. to coal No. 18 gave cokes containing a large number of cross-fractures which were more pronounced than those made from the blends with the more finely crushed high temperature/

temperature coke of the size 0-1/20in. There were practically no large fissures, perpendicular to the oven wall in these cokes and the whole bag of coke came out in two halves. These cokes however, gave an extremely large percentage of breeze on handling.

The cause of the occurrence of the cross-fractures in the cokes from the blends of coal No. 18 with the larger sizes of crushed high temperature coke may be traced to the non-homogeneity of these blends. In the case of the blends of the coal with the coke ground to pass a 200's mesh I.M.M. sieve, a very intimate and homogeneous mixture is obtained. The blends of the coal with the coke ground to pass a 10's mesh I.M.M. sieve and to a much greater degree, the blends with the coke ground to pass a ¼in. mesh sieve, will not be so homogeneous. When the coal, after passing through the plastic stage, attains that temperature above which further decomposition will cause fissuring, the semi-coke formed from the coal still contains about 13% of volatile matter, while the particles of high temperature coke added contain only about 1% of volatile matter. There will, therefore, be considerable shrinkage of the semi-coke formed from the coal, while no shrinkage will take place in the case of the high temperature coke particles. The non-homogeneity of the blend will, therefore, cause rupturing at the surfaces of the particles of high temperature coke. In the case of the blends of coal with the very finely ground coke, the particles are so small that the fractures caused by them are as small as the pores of the coke and do not weaken the coke structure. It is apparent, that the larger size of the high temperature coke particles used in the blend, the more pronounced will be the fractures at the surfaces of these particles.

It should be noted that the lines of weakness in the coke structure are formed subsequent to and not during the plastic stage of the coal. This is indicated from the fact that the blends of coal No. 18 with low temperature coke No. 1, even those containing the largest size of coke particles, gave cokes which varied but little, in their resistances to shatter, from the coke made from the straight coal. At the temperature of the end of the plastic ranges of the blends, the low temperature coke particles contain 9.3% of volatile matter, while the semi-coke formed from the coal contains 13.2% of volatile matter. The difference between the degrees of shrinkage of the components of these blends are not so great and will not cause as much weakening of the coke structure, as is the case with the blends of this coal with the larger sizes of high temperature coke particles.

These experiments also show that the improvement of the resistances to shatter of the cokes obtained by blending with finely crushed high temperature coke is not wholly due to a reduction of the volatile matter contents at the ends of the plastic ranges of the blends. The improvement is partly caused by the more even distribution of the shrinkage cracks throughout/

throughout the coke pieces as a result of the formation of the small fractures at the surfaces of the coke particles added to the coal. The longitudinal fissures (perpendicular to the oven wall) will therefore be reduced in size and number and an improvement in the resistance to shatter of the coke pieces will result, provided that the small fractures are not sufficiently large to cause a weakening of the coke structure.

(b) EXPERIMENTAL OVEN TESTS

It was observed in the foregoing bag tests that the coke obtained did not truly represent that made from the same coal when coked in a full scale oven. In order to overcome this disadvantage, an experimental oven was erected at one of the coking plants for the carbonisation of coals and blends which it was desired to topcharge.

Descriptions of the experimental oven and the method of preparation of the charge to be carbonised are given on pages 10 to 14.

Comparison of Full Scale and Experimental Oven Cokes.

The two coking coals which were used in the top-charged blending experiments, described later, were coked in large scale ovens and also in the experimental oven at approximately the same rates of heating, and the cokes obtained were compared. The results of these tests are given in Table X.

There is an excellent agreement in the screening and shatter indices of the full scale and experimental oven cokes made from the same coals. There is however, a difference between the apparent specific gravities of the cokes made in each oven. Since the real specific gravities of the cokes made from the same coal were alike, the apparent and total porosities/

porosities of the cokes made in the experimental oven were higher than those made from the same coals in the full scale oven. These differences of porosity were attributed to the differences in height and therefore differences in compression of the coal charges in the two ovens. The heights of the coal charges in the experimental and full scale ovens were 2 ft. 6 in. and 5 ft. respectively.

Table X - Comparison of Full Scale Oven and Experimental Oven Cokes made from the same coals.

Coke No.	Coal used	Type of oven	Screening Indices				Shatter Indices				Apparent specific gravity.
			1"	2"	3"	4"	½"	1"	1½"	2"	
38	38	F.S. ø	93	74	33	15	98.0	93	79	59	0.85
38(E)	38	E. X	95	75	34	18	97.5	92	79	58	0.78
39	39	F.S. ø	98	95	78	37	98.9	98	93	79	0.90
39(E)	39	E. X	95	-	74	-	98.8	98	94	81	0.85

ø F.S. = Full scale oven test
X E. = Experimental oven tests.

Series of Blends III and IV.

Effect of blending with high temperature coke.

Coals/

Coals Nos. 38 and 39 were blended with finely crushed high temperature coke. These coals were the ⅜-3in., washed crushed screenings from single seams and were coked regularly at the plant. Coal No. 39 was the same as coal No. 18 which was used in the series of bag test blending experiments Nos. I and II.

Examination of Blends

The results obtained from the analyses of the blends are contained in Table XI.

Table XI - Analyses of Blends

Coal No.	% addition of high temp. coke.	Moisture. %	Volatile org. matter. %	Ash %	Fixed Carbon %	Agglutinating Value	Vol. org. matter content at end of plastic range %
38	0	2.1	33.6	3.6	60.7	24	15.2
40	5	2.0	31.8	3.7	62.5	22	14.5
41	10	1.9	30.2	3.8	64.1	21	13.9
39	0	1.4	26.0	4.2	68.4	24	13.2
42	5	1.3	24.8	4.3	69.6	23	12.8
43	10	1.3	23.3	4.4	71.0	21	12.2
H.T. coke No.39.	-	0.5	0.3	6.2	93.0	-	-

The addition of 10% of high temperature coke ground to 10's mesh I.M.M. was found to cause no alteration in the plastic ranges of coals Nos. 38 and 39, but reduced considerably the volatile matter content of each coal at the end of its plastic range. The reduction of the total volatile matter contents and the agglutinating values of these coals may also be observed from Table XI.

Screening Tests on Coals and Cokes used in Blending Experiments

The size analyses of the blend constituents are given in Table XII.

Table XII - Size Analyses of Coals and Blending Materials

Sample	Percentages passing through:-						
	½"	¼"	⅛"	1/10"	1/20"	1/40"	1/120"
Coal No.38.	99	95	81	70	44	24	11
Coal No.39.	99	97	90	83	60	35	12
H.T. Coke No.39.	-	-	-	-	85	60	30

Carbonisation of Blends

The/

The blends of coals Nos. 38 and 39 with finely crushed high temperature coke were prepared in the usual manner and were coked in the experimental oven. The average flue temperature was 1,060°C.

Examination of Blend Cokes

Six of the blending tests were done in duplicate and excellent agreement was obtained in the screening and shatter test results.

The screening indices, determined on the total coke from the oven, and the shatter indices are shown in Table XIII and the relation between the 2 in. and 1½ in. shatter indices and the volatile matter contents at the ends of the plastic ranges of the blends are shown in Fig. 13.

The blends of coal No. 38 with 5 and 10% of high temperature coke, ground to 0-1/16in., gave cokes of increased size and resistance to shatter. By adding 7% of water to the charge of coal No. 38 the rate of carbonisation of the coal was decreased and this caused an increase in the size but no increase in the resistance to shatter of the coke obtained. The addition of 7% water to the 10% blend decreased the rate of coking and also the ½in. shatter index of the coke. Blending with 10% of coke ground to 0-1/400 in. gave the best results.

It was observed on page 51that a reduction of the rate/

Table XIII - Screening and Shatter Indices of Blend Cokes.

Coke	Coal used	% and size of high temp. coke added	Moisture in charge	Coking period hrs.	Screening Indices				Shatter Indices			
					1"	2"	3"	4"	½"	1"	1½"	2"
38(E)	38	0	5	16	95	75	34	18	97.5	92	79	58
38(E)a	"	0	12	17	97	92	70	19	96.5	93	79	63
40(E)	"	5%;0-1/16".	5	18	98	94	83	53	95.9	90	81	62
41(E)	"	10%; " .	5	18	97	91	69	49	96.2	91	83	71
41(E)a	"	10%; " .	12	19	96	89	68	40	94.9	89	80	71
44(E)	"	10%;0-1/400.	5	18	98	94	85	52	97.5	96	90	77
39(E)	39	0	5	17	95	-	74	-	98.8	98	94	81
42(E)	"	5%;0-1/16"	5	17	94	-	80	-	97.9	96	94	86
43(E)	"	10%; " .	5	17	95	-	89	-	96.8	96	95	92
43(E)c	"	10%; " .	5	18	96	-	91	-	98.3	98	95	90
45(E)	"	10%;0-1/400"	5	18	96	-	80	-	97.2	96	95	93

rate of heating had a proportionately greater effect on the plastic ranges of poor caking coals than was the case with strongly caking coals. This will explain why a reduction of the rate of heating causes no alteration of the shatter indices of the coke obtained from the straight coal and an increase in the abradability/

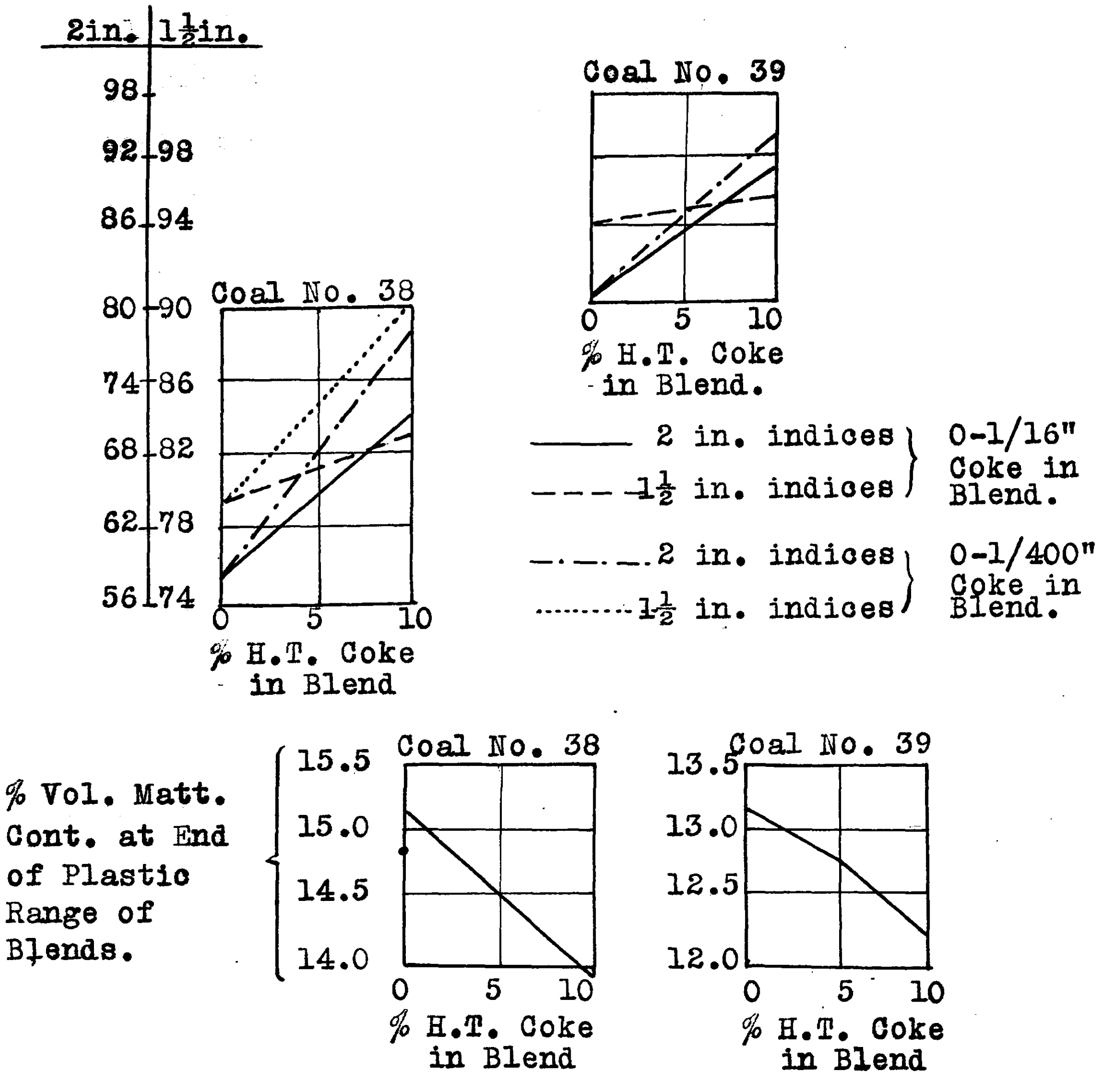


FIGURE - 13 - Blends of Coals Nos. 38 and 39 with finely crushed High Temperature Coke.

abradability of the coke made from the poorer caking blend of the straight coal with 10% of high temperature coke.

The results of the blending tests in which coal No. 39 was used, were very similar to those obtained from the bag tests when the same coal was blended with various sizes of high temperature coke. It was again found that the addition of high temperature coke, especially when finely ground, improved the resistance to shatter of the resultant coke. The relation between the shatter indices of the coke and the volatile matter contents of the corresponding coals observed in previous blending experiments was again shown in Fig. 13.

The high temperature coke blends required a longer coking period than the straight coal.

Series of Blends - V.

Effect of Blending with Fusain

Mott and Wheeler, (Coke for Blast Furnaces, p.186), have shown that the size and resistance to shatter of Yorkshire and Derbyshire cokes can be increased by the addition of small percentages, usually 1 to 3%, of fusain. They found that better cokes were often obtained by coking slurries, that is, the smallest coal from the seam, than by coking the larger sizes of coal screenings from the same seam, both coals being crushed to approximately the same size. These slurries contained almost the whole of the fusain from the seam.

Similar/

Similar results were obtained from the examination of the full scale oven cokes made from the 0-⅜in. and the ⅜ to 3 in. screenings, crushed to approximately the same degree, from the same Scottish coking coal seam.

The screening and shatter tests of the cokes are given in Table XIV.

Table XIV - Screening and shatter indices of Full Scale oven cokes made from different sizes of coal screenings.

Coke No.	Size of coal screenings.	Screening Indices				Shatter Indices			
		1"	2"	3"	4"	½"	1"	1½"	2"
3	0-⅜in.	98	96	88	69	98.3	97	95	92
18	⅜-3in.	98	95	78	37	98.3	97	93	80

The values in Table XIV show that the coke made from the larger screenings is definitely smaller and a little less resistant to shatter than the coke made from the smaller coal screenings. The difference in the resistance to shatter is, however, almost confined to the 2 in. index. It has been shown that coke No. 18 is prismatic in shape and coke No. 3 is therefore blockier and more normal in shape. The blending of coal No. 18 with non-coking materials having low volatile matter/

matter contents resulted in a blockier coke being obtained and the effect of blending with fusain might be expected to be similar.

Accordingly coal No. 47(from the same seam as coal No. 18) was blended with 10 and 20% of Parkgate cyclone dust No. 48(d) which contained 20% of fusain. The blends therefore contained 2 and 4% of fusain. Control tests were carried out, the effect of blending coal No. 47 with Parkgate coal No. 48 ground to the same fineness as the cyclone sust, being determined.

The blends were coked in the experimental oven, the flue temperature being 1180-1200°C. The moisture in each charge was about 6% and the coking period about 16 hours.

The results obtained from the examination of the blends and the cokes are given in Tables XV, XVI and XVII.

The full scale and experimental oven cokes made from coal No. 47 were again found to be very similar in size and resistance to shatter. The results contained in Table XVII show that increases in sizes and resistances to shatter of the resultant cokes were obtained by the addition of 6 and 15% of Parkgate coal, to coal No. 47. No improvements in the quality of the resulting cokes were obtained by blending coal No. 47 with 2 and 4% of fusain since only their 2 in. shatter indices were slightly increased.

The 0-$\frac{3}{8}$in. and the $\frac{3}{8}$-3in. screenings of coal No. 47 were then examined microscopically and it was found that even the/

Table XV - Analyses of Coal and Fusain Blends.

Coal No.	% Blending Material.	Moisture. %	Vol. Org. Matter. %	Ash %	Fixed carbon %	Agglutinating Value.	Vol. Org. Matt. Content at end of plastic range %
Blends of coal No. 47 with Parkgate coal No. 48							
47	0	1.9	26.2	4.6	67.3	25	16.8
48	100	2.3	36.5	2.8	58.4	33	-
49	6	1.9	26.8	4.5	66.8	26	17.1
50	15	2.0	27.7	4.3	66.0	28	17.7
Blends of coal No. 47 with Parkgate cyclone dust No. 48(d)							
48(d)	100	2.3	29.0	11.5	57.2	20	-
51	10	1.9	26.5	5.3	66.3	25	17.0
52	20	2.0	26.8	6.0	65.2	25	17.3

Table XVI - Screening Analyses of Components of Fusain Blends.

Coal No.	Percentages passing through;						
	½"	¼"	⅛"	1/10"	1/20"	1/40"	1/60"
47	99	96	88	80	61	37	13
48	-	-	-	-	-	-	100
48(d)	-	-	-	-	-	-	100

the 0-⅝in. screenings contained only small traces of fusain. The fact that the larger coal screenings gave a smaller coke than the smaller coal screenings, when they were crushed to approximately the same sizes and coked under similar conditions, could not, therefore be attributed to a deficiency of fusain in the crushed nuts. It is probable that the difference in the ash contents (2.5%) of these coals may be of some significance.

Table XVII - Screening and Shatter Indices of Fusain Blend Cokes

Coke No.	Blending Material	% Blending Material	Screening Indices				Shatter Indices			
			1"	2"	3"	4"	½"	1"	1½"	2"
47(E)	Parkgate Coal No. 48.	0	94	-	56	34	98.3	97	92	76
49(E)		6	96	-	73	52	97.3	96	95	85
50(E)		15	96	-	78	61	98.2	97	94	85
51(E)	Parkgate Cyclone Dust No. 48(d)	10	96	-	65	37	98.1	97	90	82
52(E)		20	91	-	68	42	97.4	96	92	85

Series of Blends VI

Effect of Blending with finely crushed anthracite

Coal/

Coal No. 47 was blended with two Scottish anthracites, Nos. 53 and 54, ground to pass a 10's mesh I.M.M. sieve. The blends were coked in the experimental oven using a flue temperature of 1230°C. The moisture content of each oven charge was about 5% and the coking period about 15 hours.

The results obtained from the examination of the blends and the corresponding cokes are given in Tables XVIII, XIX and XX. The volatile matter contents of the blends at the end of their plastic ranges and the 2 in. and 1½in. shatter indices are given in Fig. 14.

The addition of 10% of finely ground anthracite caused small increases in the sizes and resistances to shatter of the resultant cokes but the blends with 20% of anthracite gave abradable cokes, the ½in. shatter indices being considerably reduced.

Fig. 14 shows that there is again a relationship between the volatile matter contents of the blends at the end of their plastic ranges and the shatter indices of the corresponding cokes as long as the limit of percentage addition of the blending material is not exceeded.

Table XVIII - Analyses of Anthracite Blends.

(Air-dried)

Coal No.	Blending Material added	% Blending Material	Moisture %	Vol. Org. Matter. %	Ash %	Fixed Carbon %	Agglutinating Value	Vol.Org. Matter at end of plastic range %
47	-	0	1.9	26.2	4.6	67.3	25	16.8
54	Anthracite No.54	100	3.9	4.6	2.2	89.3	-	-
55		10	2.1	24.0	4.3	69.6	22	15.5
56		20	2.3	21.9	3.9	71.9	19	14.2
53	Anthracite No.53.	100	2.6	7.0	1.7	88.7	-	-
57		10	2.0	24.3	4.3	69.4	23	15.7
58		20	2.0	22.4	4.0	71.6	20	14.7

Table XIX - Screening Analyses of Components of Anthracite Blends.

Sample No.	Percentages passing through:						
	½"	¼"	⅛"	1/10"	1/20"	1/40"	1/120"
47	99	96	88	80	61	37	13
53	-	-	-	100	91	50	17
54	-	-	-	100	95	60	21

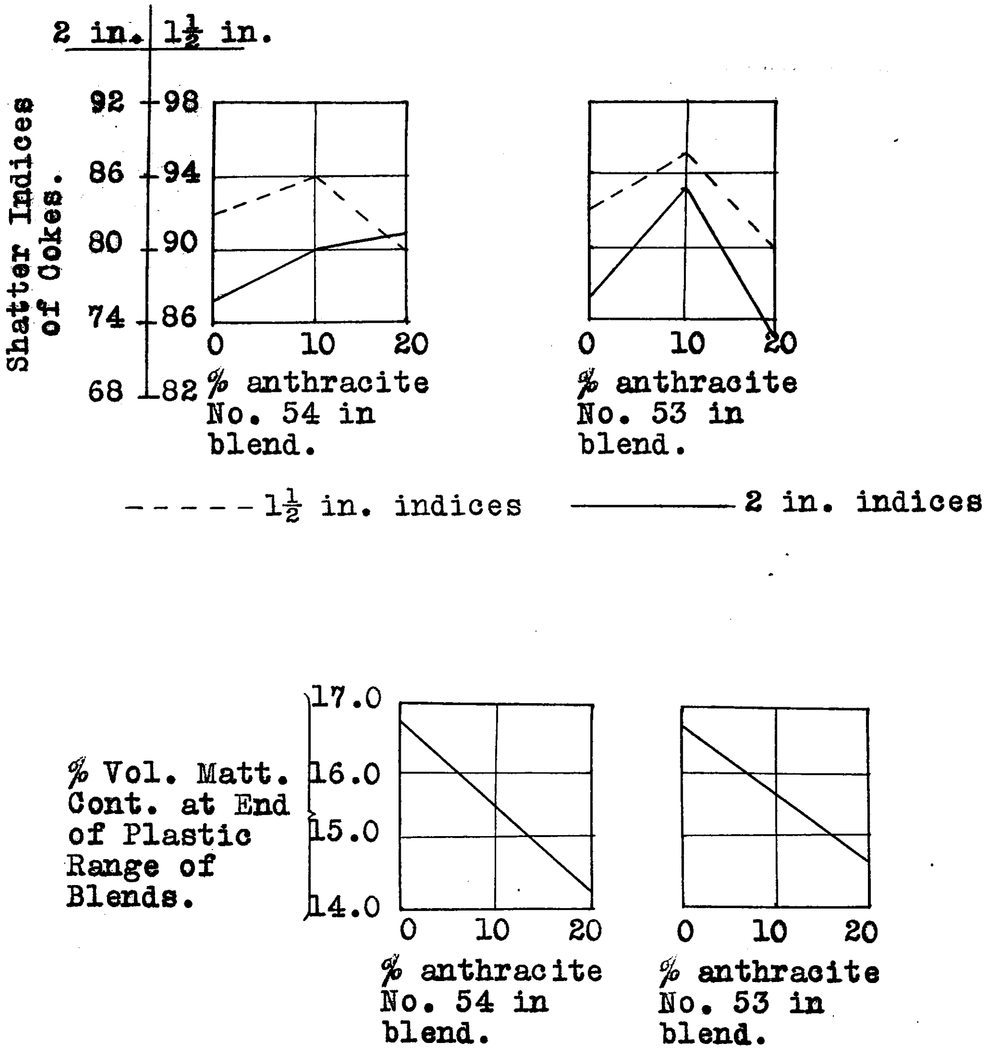


FIGURE 14 - Effect of Blending Coal No. 47 with finely crushed Anthracites Nos. 53 and 54.

Table XX - Screening and Shatter Indices of Anthracite Blends.

Coke No.	Blending Material	% Blending Material	Screening Indices			Shatter Indices			
			1"	3"	4"	½"	1"	1½"	2"
47(E)	-	0	94	56	34	98.3	97	92	76
55(E)	Anthracite No.54.	10	97	72	50	98.5	97	94	80
56(E)		20	86	77	69	95.7	94	90	81
57(E)	Anthracite No.53.	10	95	71	48	98.0	97	95	85
58(E)		20	92	59	47	96.3	95	90	73

Effect of Flue Temperature

The effect on the character of the resultant cokes of varying the flue temperature of the experimental oven for the carbonisation of coal No. 47 and one of the most successful blends, coal No. 47 mixed with 10% of high temperature coke ground to pass a 200's mesh I.M.M. sieve, is indicated by the following table of results.

These results show that the straight coal gives a coke which is smaller and slightly less resistant to shatter when coked in the experimental oven using the higher flue temperature. When, however, the blend of coal No. 39 with 10% /

10% of very finely ground high temperature coke was carbonised using flue temperatures of 1060°C and 1200°C the cokes obtained gave identical screening and shatter indices. It should also be noted that the bag test coke No. 25(b) which was made from exactly the same blend as cokes Nos. 45(E) and 47(E) possessed the same resistance to shatter as these cokes, despite the fact that the bag test blend was subjected to a much greater compression than those coked in the experimental oven.

Table XXI - Effect of Flue Temperature - Screening and Shatter Indices of Cokes

Coke No.	Description of Coal and blend.	Flue Temp. °C.	Coking Period hours.	Screening Indices			Shatter Indices			
				1"	3"	4"	½"	1"	1½"	2"
39(E)	Coal No. 39.	1060	17	95	74	-	98.8	98	94	81
47(E)		1230	15	94	56	34	98.3	97	92	76
45(E)	Coal No.39 plus 10% H.T.C. 0-1/400".	1060	18	96	80	-	97.2	96	95	93
59(E)		1200	15½	97	81	63	97.1	96	94	91

It should be noted that these alterations of the conditions of carbonisation of the straight coal, namely the increase of the flue temperature and the compression of the coal charge, made the resulting coke still more prismatic. The tests which have been described earlier have shown that the addition/

addition of finely crushed high temperature coke to a coking coal caused an increase in the blockiness of the coke obtained and it is therefore not surprising that the effects of increased temperature of carbonisation and compression of the coal on the nature of the coke obtained have been counteracted by blending with this material.

B. - Compressed Charged Blends

(a) Bag Tests

The blends examined in the following series of experiments were carbonised by the method described on page 14.

Comparison of Full Scale oven and bag test cokes

The Scottish coking coals, Nos. 60, 61 and 62 were used for the compressed charged blending experiments. These coals were coked in bags placed in an oven charge of the same coal. The results of the examination of the cokes made in the bags and those made in the full scale oven are given in Table XXII.

The agreement obtained between the screening and shatter indices of the full oven and bag cokes made from the same coals was very good.

Series/

Table XXII - Comparison of Full Oven and Bag Test Cokes.

Coke No.	Screening Indices				Shatter Indices				Total Porosity %
	1"	2"	3"	4"	½"	1"	1½"	2"	
60	94	83	68	42	96.4	88	76	65	48.3
60(b)	95	80	68	57	95.7	88	77	61	48.6
61	99	95	86	63	98.0	94	83	70	47.9
61(b)	99	95	85	61	98.3	95	85	70	47.6
62	97	88	76	55	96.0	85	70	54	47.5
62(b)	97	90	72	51	97.2	87	70	52	47.2

Note - Suffix (b) denotes bag test coke.

Series of Blends - No. VII

Effect of Blending with Low Temperature Coke

Coal No. 60, used in this series of blending experiments, was a mixture of the 0-1in. washed, crushed, screenings from two very similar seams.

This coal was blended with 5 and 10% of low temperature coke No. 2, ground to 0-1/20in., and the blends were coked/

Table XXIII - Analyses of Blends with Low Temperature Coke.

Coal No.	% Low Temp. coke added	Moisture %	Vol. Org. Matter. %	Ash %	Fixed Carbon %	Agglutinating Value	Vol. Org. Matter Content at end of plastic range %
60	0	2.3	33.6	8.7	55.4	23	15.3
L.T.C. No. 2.	-	2.4	6.0	4.3	87.3	-	5.1 X
63	5	2.3	32.2	8.5	57.0	22	14.8
64	10	2.3	30.8	8.2	58.7	21	14.3

X - % of volatile organic matter retained when low temp. coke No. 1 is heated to the temperature of the end of the plastic range of coal No. 60.

Table XXIV - Screening Analyses of Components of Blends.

Sample No.	Percentages passing through:						
	½"	¼"	⅛"	1/10"	1/20"	1/40"	1/120"
Coal No.60.	100	89	70	57	36	23	14
L.T.Coke No.2.	-	-	-	100	93	67	35

coked in bags placed in an oven charge of the straight coal. The moisture content of each blend was about 9%, the flue temperature of the oven about 1100°C and the coking period, 23½ hours. The mean oven width was 17 in.

The results of the examination of the coal and blends and the corresponding cokes are recorded in Tables XXIII, XXIV and XXV and in Fig. 15.

Table XXV - Screening and Shatter Indices of Blends with Low Temperature Coke.

Coke No.	% Low temp. coke added	Screening Indices				Shatter Indices			
		1"	2"	3"	4"	½"	1"	1½"	2"
60(b)	0	95	80	68	57	95.7	88	77	61
63(b)	5	96	91	85	79	93.7	87	78	72
64(b)	10	96	91	85	75	92.4	90	85	77

Both blends gave cokes of increased size. There was also an improvement in the 2 in. and 1½in. shatter indices of these blends, but this was negatived to some extent by the lowering of the ½in. indices, showing that the blend cokes were more abradable. The size of the small cross-fractures in these cokes could be reduced by crushing the blending material more finely and this would probably also reduce the abradability of the/

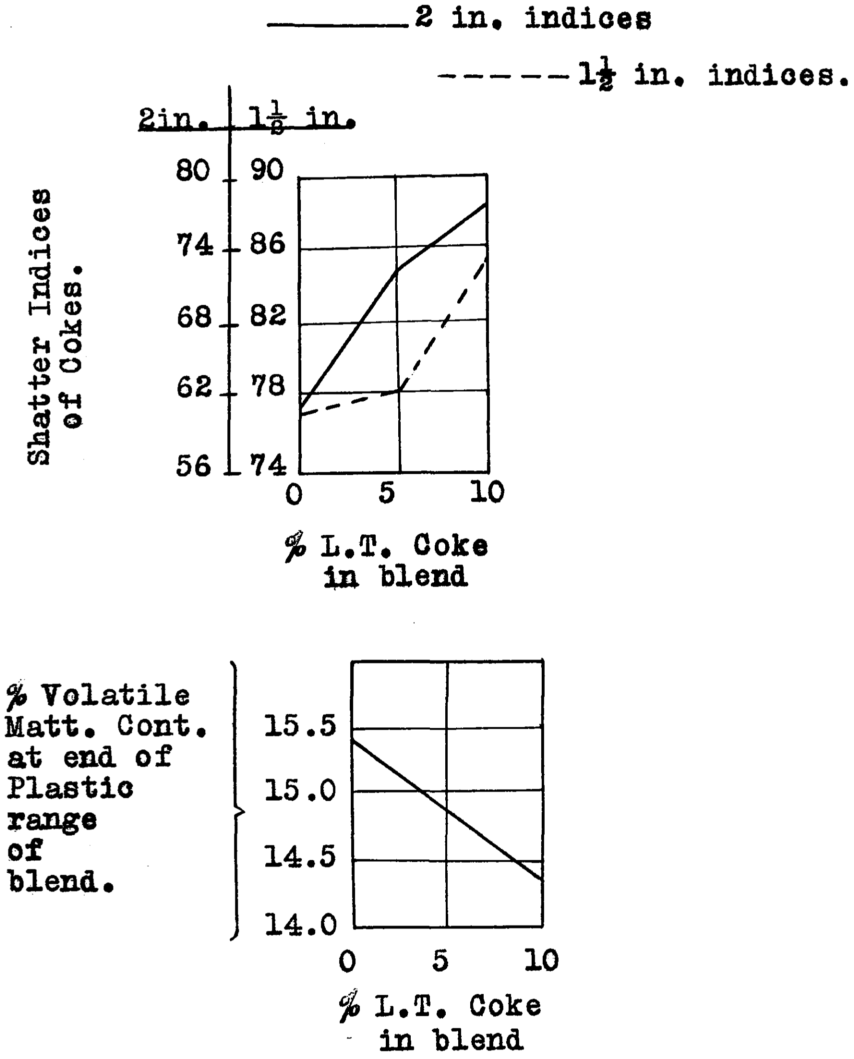


FIGURE 15 - Effect of blending Coal No. 60 with finely crushed Low Temperature Coke, No. 2.

the coke.

Consideration of Fig. 15 shows that the reduction of the volatile matter content at the end of the plastic range in the case of the blends is accompanied by an increase of the 2 in. and 1½in. shatter indices of the corresponding cokes.

Series of Blends VIII.

Effect of blending with "burnt" coal

Coal No. 60 was again used for this series of blends and was blended with 10, 20 and 30% of "burnt" coal, ground to 10's mesh I.M.M. and 10% of the same coal ground to 0-¼in.

The blends were prepared and examined by the same methods as were used for series VII. The results are set forth in Tables XXVI, XXVII and XXVIII and in Fig. 16.

These results show that blending with 10, 20 and 30% "burnt" coal although reducing the total volatile matter contents resulted in practically no changes of the volatile matter contents at the end of the plastic ranges of the blends or of the sizes and resistances to shatter of the resultant cokes. The low 1 in. screening and ½in. shatter index show that the coke made from the 30% blend was abradable.

Table /

Table XXVI - Analyses of Blends with "Burnt" coal

Coal No.	"Burnt" Coal in blend %	Moisture %	Vol. org. matter. %	Ash %	Fixed carbon %	Agglutinating Value	Vol. Org. Matter content at end of plastic range %
60	0	2.3	33.6	8.7	55.4	23	15.3
39	100	1.0	24.4	3.1	71.9	7	15.2 X
66	10	2.0	32.8	8.1	57.1	22	14.9
67	20	1.9	31.7	7.6	58.8	21	14.9
68	30	1.9	30.7	7.0	60.4	20	15.2

X = % Volatile organic matter retained by "burnt" coal No. 39 when it is heated to the temperature of the end of the plastic range of coal No. 60.

Table XXVII - Screening Analyses of Blend Constituents

Coal No.	Percentages passing through:						
	½"	¼"	⅛"	1/10"	1/20"	1/40"	1/120"
60	100	89	70	57	36	23	14
39	-	-	-	100	94	75	50

Table/

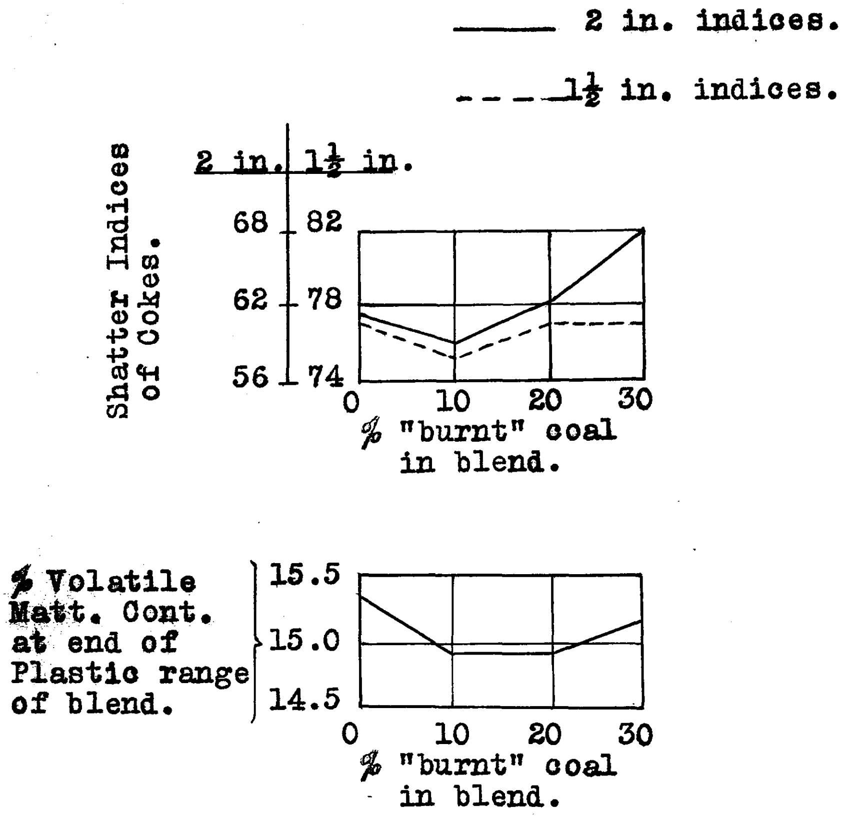


FIGURE 16 - Effect of Blending Coal No. 60 with "burnt" coal No. 39.

Table XXVIII - Screening and Shatter Indices of Blend Cokes.

Coke No.	% and size of "Burnt" Coal added.	Screening Indices				Shatter Indices			
		1"	2"	3"	4"	½"	1"	1½"	2"
60(b)	0	95	80	68	57	95.7	88	77	61
66(b)	10; 0-1/20"	95	81	57	41	94.8	85	72	59
67(b)	20; "	95	82	65	55	96.6	90	77	62
68(b)	30; "	91	84	74	60	91.1	85	77	67
69(b)	10; 0-¼".	97	83	64	53	96.6	90	79	68

Effect of Blending with High Temperature Coke

Series of Blends IX

Coal No. 60 was blended with 5 and 10% of 0-1/20in. and 5,10 and 15% of 0-1/400in. high temperature coke No. 60.

Series of Blends X

Coal No. 62, the 0-1½in. washed, crushed screenings, from a single seam was blended with 10 and 15% of the breeze from/

from coke No. 62, crushed to 0-1/20in.

Series of Blends XI

Coal No. 70, the 1/16-¼in. washed, crushed, screenings from a single seam, was blended with 5 and 10% of the breeze from coke No. 62 crushed to 0-1/20in.

Carbonisation of Blends

The series of blends, IX, were prepared and coked by the method described on page 14. The moisture content of each blend was about 9%, the flue temperature of the oven about 1100°C and the coking period 23½ hours. The mean oven width was 17 in.

The blends of series X and XI were prepared by the usual method and were coked in an oven having a mean width of 20 in. The flue temperature was about 1150°C and the coking period 36 hours. The moisture in the blends when charged to the oven was 8-10%.

The results obtained from the examination of the blends and the corresponding cokes are given in Tables XXIX, XXX and XXXI and in Fig. 17.

Similar results were obtained from these compressed charged blending experiments as were obtained from the top-charged blending experiments described on pages 67-73. Increases of the size and the resistance to shatter of the resultant cokes were again obtained when the volatile matter contents/

Table XXIX - Analyses of Blends with High Temperature Coke.

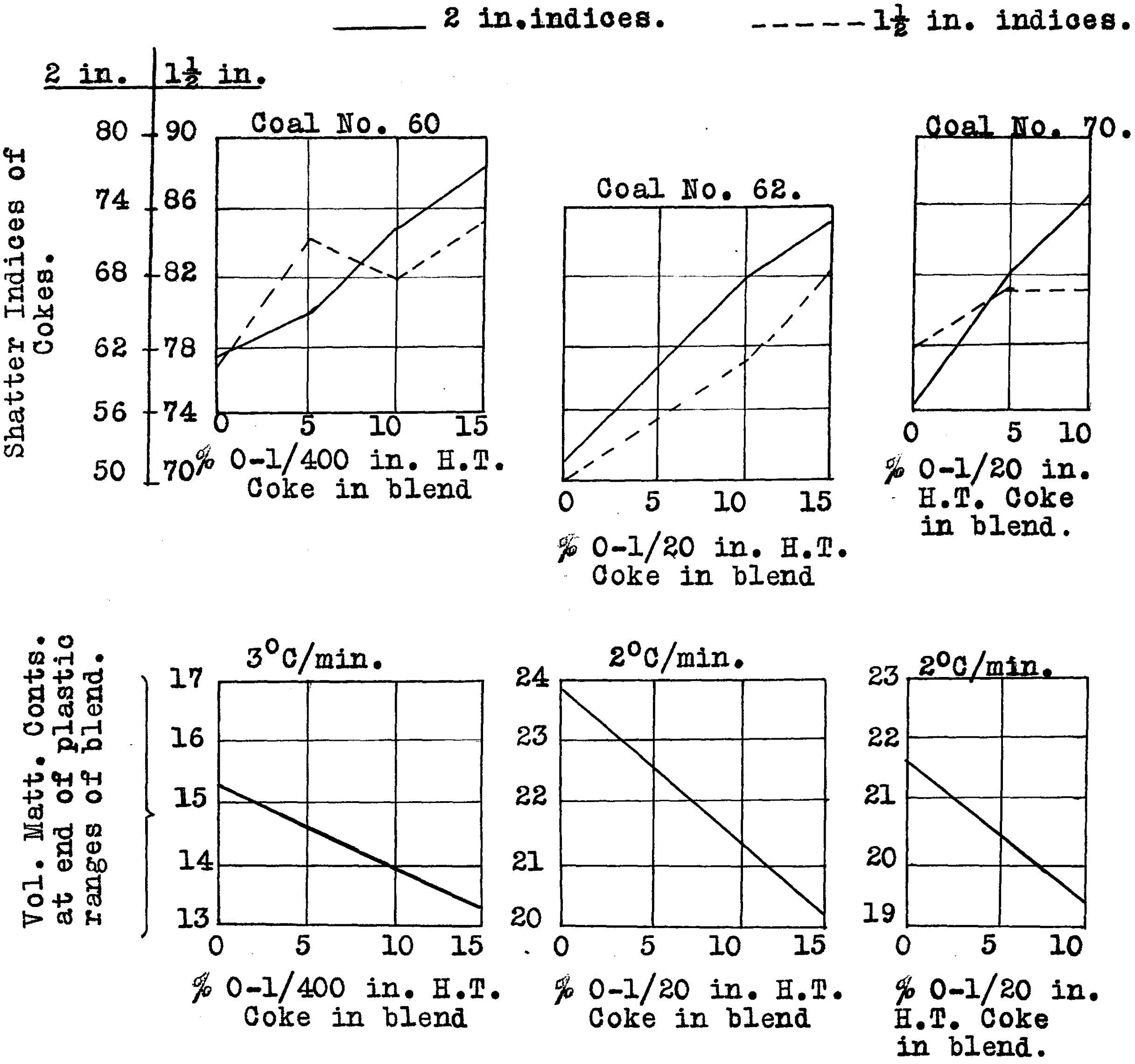
Coal No.	% Blending Material	Moisture %	Vol. Org. Matter. %	Ash %	Fixed Carbon %	Agglutinating Value	Vol. Org. Matter Content at end of plastic range %
60	0	2.3	33.6	8.7	55.4	23	3°C/min. 15.3
H.T.C. No.60.	100	0.9	1.2	9.9	88.0	-	-
71	5	2.2	31.6	8.8	58.7	23	14.6
72	10	2.1	30.4	8.9	60.4	22	13.9
73	15	2.0	28.7	8.9	62.1	19	13.3
62	0	3.9	38.2	5.8	52.1	26	2°C/min. 23.8
Coke Breeze No. 62.	100	-	4.8	21.8	-	-	-
74	10	3.2	35.0	7.8	54.0	24	21.4
75	15	2.8	33.1	8.2	55.9	23	20.2
70	0	2.1	35.7	4.2	58.0	32	2°C/min. 21.5
Coke Breeze No.62.	100	-	4.8	21.8	-	-	-
76	5	2.0	33.9	5.2	58.9	30	20.5
77	10	2.1	32.5	6.3	59.1	29	19.5

Table XXX - Screening Analyses of Components of Blends with High Temperature Coke.

Sample No.	Percentages passing through:						
	½"	¼"	⅛"	1/10"	1/20"	1/40"	1/120"
Coal No. 60.	100	89	70	57	36	23	14
H.T.C.No. 60.0-1/20"	-	-	-	100	92	70	42
Coal No. 62.	99	97	88	81	60	39	17
Coke breeze No. 62.	-	-	-	100	90	79	48
Coal No. 70.	100	97	82	72	52	39	23
Coke breeze No. 62.	-	-	-	100	90	79	48

Table XXXI - Screening and Shatter Indices of Cokes from Blends with High Temperature Coke.

Coke No.	%, nature and size of blending material	Screening Indices				Shatter Indices			
		1"	2"	3"	4"	½"	1"	1½"	2"
60.(b)	0	95	80	68	57	95.7	88	77	61
71.(b)	5%,H.T.C;No.60 0-1/400"	97	87	73	46	96.7	91	84	65
72.(b)	10%, " "	97	91	80	66	95.3	87	82	72
73.(b)	15%, " "	97	95	88	70	94.1	92	85	77
78.(b)	5%,H.T.C;No.60 0-1/20"	99	93	89	81	95.2	88	81	73
79.(b)	10% " "	97	92	82	72	96.1	89	75	58
62.(b)	0	97	90	72	51	97.2	87	70	52
74.(b)	10%,H.T.C.Breeze 0-1/20"	97	93	82	68	96.0	87	77	68
75.(b)	15%, " "	97	92	83	68	95.7	91	82	72
70.(b)	0	99	92	71	44	98.4	93	78	57
76(b)	5%,H.T.C.Breeze 0-1/20"	97	91	75	57	97.3	93	81	68
77.(b)	10%, " "	98	95	91	78	95.9	89	81	75



<u>FIGURE 17</u> - <u>Effect of Blending Compressed Charged Coals with finely crushed High Temperature Coke</u>.

contents of the blends at the end of their plastic ranges by the addition of finely ground high temperature coke.

Coke No. 62(b) was made from a coal having a very high total volatile matter content, and it contained a very large number of longitudinal fissures which separated the coke pieces into fingers. On handling, these fingers broke off leaving a blocky cauliflower end. Blending with finely crushed coke breeze reduced the size of the fissures, increasing the cross-section area of the fingers of coke, and thus gave a more normal shaped coke. An increase in blockiness of the resulting coke was also obtained in the other blending experiments.

Effect of Blending with Anthracite

Series of Blends XII

Coal No. 61, the 0-2in. washed crushed screenings from a single seam, was blended with three Scottish anthracites, ground to pass a 10's mesh I.M.M. sieve.

These blends were prepared in the following manner:-

About 260 lb. of each blend was mixed in an edge runner pan mill. Blends Nos. 61(b), 80(b), 81(b), 82(b), 83(b), 84(b), and 85(b) were mixed in the pan mill for 10 minutes, blend No. 80(b)1 for 30 minutes and blend No. 85(b)1 for 7 minutes. During the mixing the blend was crushed to some extent. The screening analysis of each blend is given in Table XXXIII.

The/

The blends were carbonised in an 18 in. oven having a flue temperature of 1100°C. The moisture contents of the charges were 8-10% and the coking periods about 30 hours.

The cokes, Nos. 85, 86 and 87 were carbonised in full scale ovens and were prepared by the method described on page 10.

Series of Blends XIII and XIV

Coal No. 62 was blended with 10% of the Scottish anthracite No. 53, crushed to 0-1/20in., for series of blends No. XIII. Coal No. 70 was blended with 5,10 and 15% of the same blending material to give series of blends No. XIV.

These blends were prepared and carbonised by the method described on page14.

The oven had a mean width of 20 in. and an average flue temperature of 1150°C. The coking periods were about 36 hours and the moisture in the blends, as charged to the oven, about 7%.

The results obtained from the examination of the blends and the cokes made from them are recorded in Tables XXXII, XXXIII and XXXIV and in Fig. 18.

Only in the cases of the blends of coal No. 70 with 5,10 and 15% of anthracite No. 53 were there definite increases in the sizes of the resultant cokes. Small increases in the 4 in. screening indices are observed in blends of coal No. 85 with/

Table XXXII - Analyses of Blends with Anthracite.

Sample No.	% and No. of 0-1/20 in. anthracite added	Moisture %	Vol. Org. Matter %	Ash %	Fixed Carbon %	Agglutinating Value	Vol. Org. Matter Content at end of plastic range %
61	0	1.3	28.7	5.7	64.3	24	3°C/min. 15.9
54	100% No.54	3.9	4.6	2.2	89.3	-	-
80	10 % "	1.6	26.3	5.4	66.7	22	14.7
81	20 % "	1.8	24.0	5.0	69.2	19	13.4
53	100% No.53	2.6	7.0	1.7	88.7	-	3°C/min. -
82	10 % "	1.4	26.5	5.3	66.8	22	14.9
83	20 % "	1.6	24.4	4.9	69.1	19	13.8
84	30 % "	1.7	22.2	4.5	71.6	17	13.0
88	100% No.88	2.3	7.2	11.6	78.9	-	3°C/min. -
85	9 % "	1.4	26.8	6.2	65.6	22	15.0
86	10 % "	1.4	26.6	6.3	65.7	22	14.9
87	10 % "	1.3	28.7	5.7	64.3	24	14.8
62	0	3.9	38.2	5.8	52.1	26	2°C/min. 23.8
53	100% No.53	2.6	7.0	1.7	88.7	-	-
89	10 % "	3.7	35.2	6.1	55.0	24	21.9
70	0	2.1	35.7	4.2	58.0	32	2°C/min. 21.5
53	100% No.53	2.6	7.0	1.7	88.7	-	-
90	5 % "	2.1	34.2	4.1	59.6	31	20.7
91	10 % "	2.2	32.8	4.0	61.0	29	19.8
92	15 % "	2.2	31.4	3.8	62.6	28	18.8

Table XXXIII - Screening Analyses of Anthracite Blends.

Blend No.	Percentages passing through:						
	½"	¼"	⅛"	1/10"	1/20"	1/40"	1/120"
61.	100	98	95	91	78	53	28
61.(b)	-	-	100	97	90	76	39
80.(b)	-	-	100	98	91	77	49
80.(b)1	-	-	-	100	99	91	66
81.(b)	-	-	100	97	91	79	49
82.(b)	-	-	100	99	92	76	33
83.(b)	-	-	100	99	92	76	36
84.(b)	-	-	100	98	93	80	53
85.	-	100	99	97	87	67	25
85.(b)	-	-	100	98	89	73	37
85.(b)1	-	-	100	94	82	66	39
86.	100	96	92	85	73	54	23
87.	100	99	97	93	82	60	27
89.(b)	100	99	91	86	69	55	33
70.(b)	100	97	82	72	52	39	23
90.(b)	100	96	82	71	52	38	21
91.(b)	100	96	84	75	54	41	23
92.(b)	100	97	85	76	56	43	24
53.	-	-	-	100	91	50	17
54.	-	-	-	100	95	60	21
88.	-	-	-	100	95	78	46

Table XXXIV - Screening and Shatter Indices of Cokes made from Blends with Anthracite.

Coke No.	%, and No. of 0-1/20 in. anthracite added.	Screening Indices				Shatter Indices			
		1"	2"	3"	4"	½"	1"	1½"	2"
61.		99	95	86	63	98.0	94	83	70
61.(b)	0	99	95	85	61	98.3	95	85	70
80.(b)	10%;No.54.	99	94	70	51	98.6	97	93	74
80.(b)1	10%; "	98	97	65	27	98.6	98	94	78
81.(b)	20%; "	98	95	78	63	97.4	95	90	76
82.(b)	10%;No.53.	98	94	69	49	98.5	97	93	80
83.(b)	20%; "	97	91	71	56	95.7	92	86	70
84.(b)	30%; "	99	92	59	41	97.6	96	92	74
85.	9 %;No.88.	99	96	86	74	98.3	97	91	78
85.(b)	10%; "	99	95	82	73	97.8	96	89	72
85.(b)1	10% "	98	94	87	74	97.3	95	87	74
86.	10%; "	99	96	88	76	98.2	96	90	77
87.	10%; "	97	93	86	66	98.6	97	91	78
62.(b)	0	97	91	69	40	97.2	87	71	52
89.(b)	10%;No.53.	95	85	73	46	96.9	90	79	68
70.(b)	0	99	92	71	44	98.4	93	78	57
90.(b)	5 %;No.53.	98	91	73	52	97.8	93	80	60
91.(b)	10%; "	98	96	90	74	97.5	93	84	73
92.(b)	15%; "	99	96	90	81	97.7	95	89	82

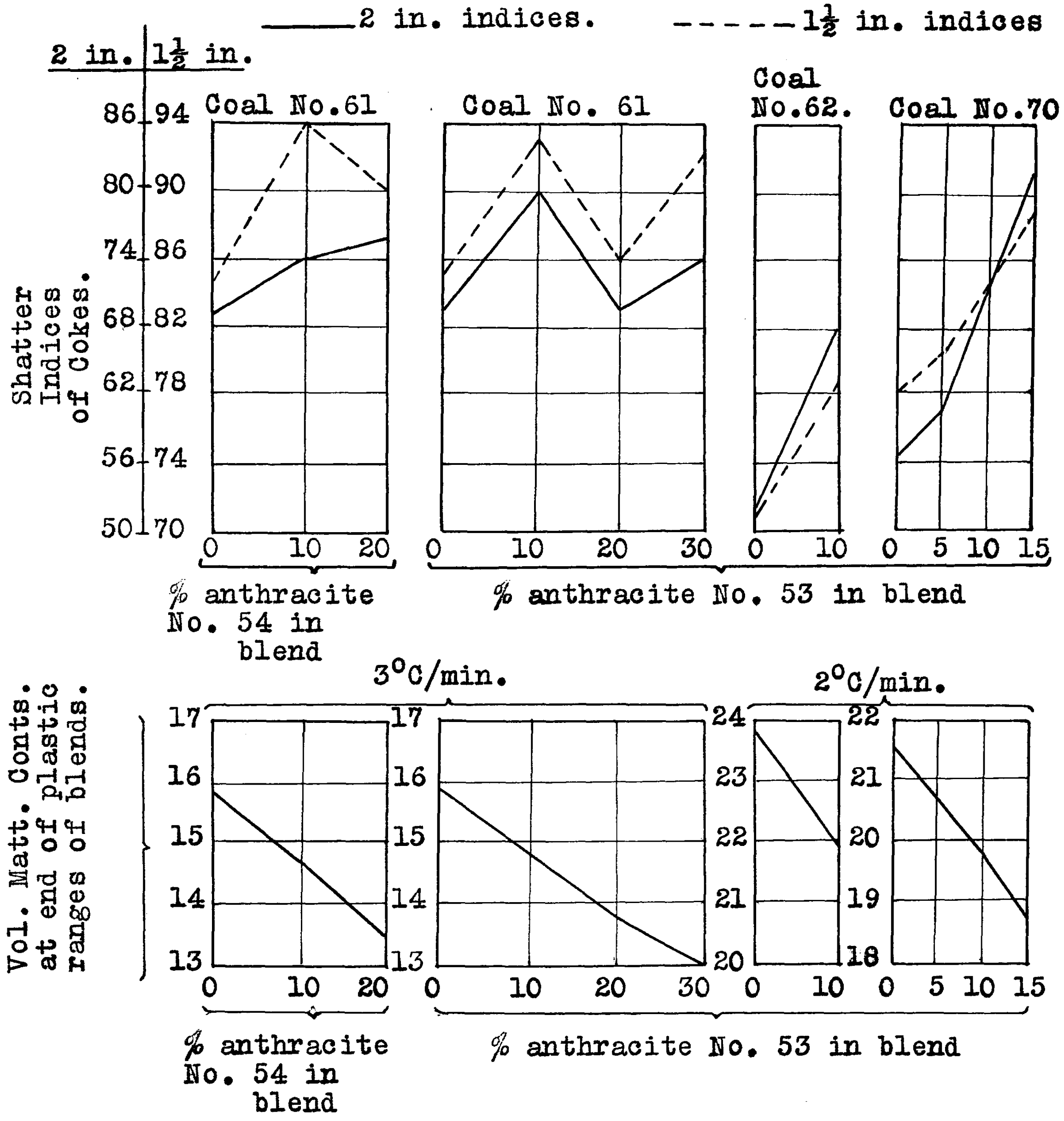


FIGURE 18 - Effect of Blending Compressed Charged Coals with finely crushed Anthracite.

with 10% of anthracite No. 88. The blending of each coal with 10% of finely crushed anthracite however, resulted in definite increases in the resistances to shatter of the resultant cokes. As would be expected these increases were greatest for the coals Nos. 62 and 70 which had very high volatile matter contents, at the end of the plastic ranges. Smaller cokes of unchanged resistance to shatter were produced when coal No. 61 was blended with 20 and 30% of anthracite No. 53.

It may be seen from Table XXXIII that blend No. 80(b)1 was ground very finely. This caused a decrease only in the percentage of 3 and 4 in. coke obtained, but no change in the shatter indices of the coke. This coke was very uniform in size and cubical in shape.

It is shown in Fig. 18 that the blending of these coals with finely crushed anthracite caused little change in the blockiness of the cokes obtained.

Coal No. 61 is now blended regularly at the coking plant, with 10% of finely crushed anthracite No. 88. The resulting coke has been examined over a long period and its size and resistance to shatter has been found to remain remarkably constant. The more normally shaped coke obtained from the blend is not so susceptible to the small changes which take place from time to time in the conditions of carbonisation, as the coke made from the straight coal.

Cupola Testing of Cokes

The above blend coke is now being successfully used for foundry purposes and has been found to give as good results as good Durham or Welsh cokes. The coke made from the straight coal did not possess sufficient strength for a foundry coke. The results of several cupola tests which have been made to compare the melting efficiency of this blend coke with that of probably the best Durham foundry coke are now described. Until recently the majority of Scottish foundries, particularly those making light castings, used only Welsh and Durham cokes. The Welsh coke used was extremely large and strong, but owing to the high cost of transport, its use was usually limited to the making up of the cupola bed. The Durham cokes were, however, also used for fusion.

The chief details of the manufacture and the analyses of the cokes are shown in Tables XXXV and XXXVI. The latter table shows that these cokes, especially the Welsh coke, were of very good quality. The Scottish coke gave very high shatter indices for one made from compressed charged coal. It was much denser than the other cokes, and it may be seen from the results of the cupola tests Nos. 1 to 4, and 10 to 12, recorded in Table XXXVII that more of this coke was required for the bed than was the case when the Durham coke was used. In the other tests, Welsh or Durham coke was used for the bed.

At Foundries A, B and C, ordinary types of cupolas, having/

*TABLE XXXV - Details of Manufacture of Cokes used for Cupola Tests

Coke.	Moisture in coal charge. Per cent.	Compressed or loose coal.	Mean width of oven. In.	Flue temperature. Deg. C.	Coking period. Hrs.
Welsh	9.0	L.	19	—	48
Durham	2.5	L.	21	1,000	42
Scottish	9.0	C.	18	1,100	34

*TABLE XXXVI- Analyses of Cokes used for Cupola Tests.

Coke.	Moisture.	Ash.	Sulphur.	Screening indices.			Shatter indices.			
				4 in.	3 in.	2 in.	2 in.	1½ in.	1 in.	½ in.
	Per cent.	Per cent.	Per cent.							
Welsh	1.3	5.8	0.9	70	85	97	93	96	98	98.6
Durham	2.8	7.0	0.7	55	85	96	90	96	98	98.9
Scottish	3.8	7.4	0.6	50	86	96	80	92	96	98.2

*TABLE XXXVII - Average Results of Cupola Tests

Test No.	Percentage scrap.	Coke. Percentage of			Total cast. Tons.	Metal : Coke ratios.		Melting Rate. Tons/hr.	Metal Temperatures in deg. C.			Per cent. CO_2 in top gases.	Per cent. CO in top gases.	Coke in bed. Cwts.	Blast press. Ozs.
		Welsh.	Durham.	Scottish.		Including bed.	Excluding bed.		Average.	Min.	Max.				
Tests carried out at No. A. Foundry using an ordinary type cupola of 39 in. diameter.															
1	42	—	100	—	17	8.3 : 1	11.9 : 1	5.9	1,325	1,300	1,350	14.1	9.0	12	21
2	44	—	100	—	17	8.6 : 1	11.9 : 1	6.0	1,325	1,310	1,350	15.7	7.0	11	21
3	41	—	—	100	17	8.2 : 1	12.0 : 1	6.7	1,330	1,300	1,350	14.4	8.2	13	21
4	35	—	—	100	16	7.8 : 1	11.3 : 1	5.9	1,365	1.340	1,400	14.8	8.7	13	21
Tests carried out at No. B Foundry using an ordinary type cupola of 45 in. diameter.															
5	30	26	37	37	15	9.2 : 1	16.0 : 1	6.1	1,340	1,310	1,365	18.3	4.1	14	13
Monthly average ..	30	28	—	72	14	8.5 : 1	15.2 : 1	6.0	Temps. approx. same in each case.			—	—	14	13
,, ,, ..	30	28	72	—	14	8.0 : 1	13.2 : 1	5.9				—	—	14	13
Tests carried out at No. C Foundry using an ordinary type cupola of 60 in. diameter.															
6	30	20	—	80	45	9.1 : 1	13.2 : 1	11.8	1,325	1,300	1,420	14.4	9.0	30	14
7	30	25	—	75	46	10.8 : 1	14.8 : 1	12.7	1,340	1,300	1,410	15.0	8.3	23	14
Monthly average ..	30	22	78	—	44	10.2 : 1	13.8 : 1	12.3	Temps. approx. same in each case.			—	—	26	14
,, ,, ..	30	20	—	80	46	10.0 : 1	13.6 : 1	12.0				—	—	27	14
Tests carried out at No. D Foundry using a Balanced-Blast cupola of 54 in. diameter.															
8	50	—	50	50	29	12.0 : 1	19.2 : 1	10.4	1,315	1,300	1,330	18.2	3.0	18	10
9	46	—	100	—	31	12.3 : 1	19.2 : 1	11.2	1,310	1,300	1,330	20.6	1.4	18	10
10	50	—	—	100	37	11.4 : 1	16.4 : 1	11.5	1,320	1,300	1,340	16.6	6.0	19	12
Tests carried out at No. E Foundry using a Poumay cupola of 51 in. diameter.															
11	33	—	—	100	43	10.4 : 1	14.7 : 1	13.0	1,325	1,310	1,340	19.7	0.3	25	22
12	33	—	100	—	41	11.0 : 1	16.0 : 1	12.7	1,315	1,300	1,340	19.6	0.4	23	18

* Taken from Davidson, Foundry Trade Journal, July 26, 1934.

having only one row of tuyeres, were used, while at Foundry No. D, a balanced-blast type having three rows of tuyeres was employed.

The results given in Table XXXVII show that considerable percentages of carbon monoxide were present in the top gases of the cupolas of the ordinary type. When it is remembered that only 33% of the possible heat is obtained when carbon is burned to carbon monoxide, the great loss of efficiency is realised. Moreover, the presence of oxygen in the melting zone has a harmful effect upon the iron.

In the balanced-blast cupola designed by Mr. Fletcher, of the British Cast Iron Research Association, the air entering the cupola through the main row bottom tuyeres is adjusted by means of valves so as to limit the percentage of free air or oxygen present in the gases in the lower part of the coke bed and, at the same time, to maintain the optimum percentage of carbon monoxide in these gases. The carbon monoxide formed just above the lower tuyeres is burned by air admitted by two or more rows of small auxiliary tuyeres.

In the Poumay cupola, used at Foundry E, the same efficient combustion is obtained by a slightly different method. The auxiliary tuyeres are arranged spirally round the circumference of the cupola, but, like the main row of tuyeres, are connected directly to the windbelt, and since valves are not fitted to the main tuyeres, the control of the air is not so simple/

simple as with the balanced-blast cupola.

Comparison of the results given in Table XXXVII of tests Nos. 1 and 2, using Durham coke, with those from No. 3, when Scottish coke was used, shows that the performance of the Scottish coke was equal at least to that of the Durham coke in the ordinary-type cupola. A small increase (6%) in the quantity of coke (Scottish) used for test No. 4 resulted in a large increase of the metal temperatures.

At Foundry No. B, Scottish coke was used for fusion and Welsh coke for the bed. The metal temperatures obtained were comparatively high for the metal:coke ratios used, but this is probably due to the comparatively low percentage of carbon monoxide observed in the top gases. Improved metal:coke ratios were obtained at this foundry by the use of Scottish coke.

It is the practice at Foundry No. C to use a lower metal:coke ratio for the "fill up" of the cupola, a very high metal temperature being desired for the special castings made from the first 12 tons of metal. The average metal temperature for the first quarter of the cast was usually 1,350°C and for the remainder of the cast 1,315°C.

Tests were also carried out in both cupolas at Foundry C when they had been relined, the sides in each case being made parallel. The average results obtained from these tests are recorded as test No. 7. The average results obtained from the five casts immediately before the relining of the cupola are given/

given as test No. 6. An appreciable saving was made in the quantity of coke required for the bed. A higher average metal-temperature, even with a higher metal:coke ratio, shows that the relined cupola was more efficient. At this foundry, Welsh coke was used for the bed and Durham or Scottish coke for fusion. The average monthly values given show that the metal:coke ratios when using Durham or Scottish coke were very similar.

The chief features of the tests carried out at Foundry D using Durham coke in the Balanced-blast cupolas were the high metal:coke ratios, the low percentages of carbon monoxide and the very uniform metal temperatures. The high percentage of light scrap used at this foundry must assist greatly in the obtaining of such high metal:coke ratios. It is important to note that no reduction of the metal temperatures occurred when 50% of this Durham coke was displaced by Scottish coke, without altering the metal:coke ratio, even although a small increase was observed in the carbon monoxide content at the top gases. For test No. 10, using 100% Scottish coke, much lower metal:coke ratios were used and only slightly higher metal temperatures were obtained. This difference of melting efficiency is accounted for by the fact that the top gases contained 6% of carbon monoxide in this test of Scottish coke, while only 1.4% was present when Durham coke was used. Durham coke had previously been used in this foundry and it was found necessary to close the top (third) row of auxiliary tuyeres, and they were therefore built up./

up. It is evident from these tests that when using the Scottish coke the efficiencies of the cupolas could almost certainly be increased to the high values obtained from Durham coke by re-opening the upper tuyeres or by reducing the air supplied by the main row of tuyeres at the bottom of the furnace. The latter method would, however, cause a reduction of the melting rate.

The results of the tests carried out at No. E Foundry with the Poumay cupolas show that uniform metal temperatures and very low percentages of carbon monoxide were obtained for each coke. The metal:coke ratios used for the Durham coke were higher than those for the Scottish coke. Slightly lower metal temperatures were obtained with the Durham coke.

It should be pointed out that since different metal mixtures were used at each foundry no comparison is possible between the melting efficiencies of the various cupolas.

CHAPTER - V

The Significance of the Volatile Matter Contents at the End of the Plastic Ranges of Blends of Two Coking Coals.

It has been shown in the preceding chapter that the blending of Scottish coking coals with non-caking materials having low volatile matter contents caused decreases in their volatile matter contents at the ends of their plastic ranges, which were accompanied by corresponding increases in the resistances to shatter of the resulting cokes.

Having examined these simple binary blends, the next step was to study the blends of two caking coals.

The Northern Coke Research Committee, Armstrong College, Newcastle-upon-Tyne, carried out a very interesting series of experiments in which they blended,

(a) a Scottish coking and a Durham coking coal,
(b) a Durham coking and a Durham gas coal, and
(c) a Northumberland coking and a Cumberland coking coal.

They found that the shatter indices of the cokes made from the blends were not always related to those of the cokes from the straight coals.

Samples of these coals and blends were examined by the/

the author to determine if there was any relationship between the shatter indices of the cokes made from these blends and the volatile matter contents at the end of their plastic ranges. The chief results of these tests are recorded in Tables XXXIX, XL and XLI and in Fig. 19.

The volatile matter contents of the blends at the end of their plastic ranges were not proportional to those of the parent coals. If the suggestion that a reduction of the volatile matter contents at the end of the plastic range of a blend should be accompanied by an increase in the resistance to shatter of the resultant coke is correct, then the graphs in Fig. 19 giving the shatter indices of the cokes made from the blends should be mirror images of the graphs showing the volatile matter contents at the end of the plastic ranges of the corresponding blends. The corresponding graphs show a general relationship.

Since the temperatures obtained for the end of the plastic ranges of the blends were proportional to those obtained for the straight coals, and the volatile matter contents of the blends and the parent coals at the end of their plastic ranges were not related, it was considered desirable that the volatile matter content should be determined continuously as the temperature of each coal and blend was increased.

Table XXXIX - Blends of a Scottish and a Durham Coal. Analyses of Blends and Shatter Indices of Cokes obtained.

(Air-Dried)

Blend	Durham coal in blend %	Moisture. %	Ash %	Vol. Org. Matter. %	Fixed Carbon. %	Agglutinating Value. Gray-Campredon.	Vol. Org. Matter at end of Plastic Range %	Shatter Indices 2/1½in.
93.(E)	0	1.6	1.7	30.8	65.9	26	15.3	49/79
94.(E)	10	1.5	1.9	29.6	67.0	28	13.6	53/83
95.(E)	20	1.5	2.1	28.8	67.6	30	14.2	69/89
96.(E)	30	1.4	2.3	29.5	66.8	30	13.9	64/88
97.(E)	40	1.3	2.6	28.8	67.3	31	15.2	62/85
98.(E)	50	1.2	2.6	28.7	67.5	32	14.9	57/84
99.(E)	60	1.1	4.2	27.7	67.0	32	14.4	58/83.5
100(E)	80	1.0	4.2	27.3	67.5	32	12.8	54/83
101(E)	100	1.0	4.2	26.6	68.2	33	11.6	71/89

Table XL - Blends of Durham Coking Coal No. 102 with Durham Gas Coal No. 107. Analyses of Blends and Shatter Indices of Cokes obtained.

(Air-Dried)

Blend No.	Description.	Moisture. %	Ash %	Vol. Org. Matter. %	Fixed Carbon. %	Agglutinating Value. Gray-Campredon.	Vol. Org. matter at end of Plastic Range %	Shatter Indices. 2in/1½in.
102	100% 102	0.9	4.9	26.7	67.5	30	12.3	77/91
103	(80% 102 (20% 107	1.0	4.2	27.9	66.9	31	12.8	78/88
104	(60% 102 (40% 107	1.1	3.5	29.6	65.8	31	12.5	65/87
105	(40% 102 (60% 107	1.2	2.7	31.5	64.6	32	14.0	63/85
106	(20% 102 (80% 107	1.3	2.0	33.3	63.4	33	15.1	63/84
107	100% 107	1.4	1.3	34.9	62.4	34	15.6	53/80

Table XLI - Blends of Northumberland Coking Coal 113 with Cumberland Coking Coal 108. Analyses of Blends and Shatter Indices of Cokes obtained.

(Air-Dried)

Blend No.	Description.	Moisture. %	Ash %	Vol. Org. Matter. %	Fixed Carbon. %	Agglutinating Value. Gray-Campredon.	Vol. Org. matter at end of Plastic Range %	Shatter Indices. 2in/1½in.
108	100% 108	2.2	3.5	35.4	58.9	31	15.7	63/83
109	(80% 108 (20% 113	1.9	4.0	32.9	61.2	32	13.6	77/89
110	(60% 108 (40% 113	1.7	4.5	30.6	63.2	32	12.2	66/89
111	(40% 108 (60% 113	1.4	4.9	28.5	65.2	31	11.7	65/88
112	(20% 108 (80% 113	1.2	5.4	26.7	66.6	32	11.6	72/91
113	100% 113	0.9	5.9	25.0	68.2	32	11.4	74/91

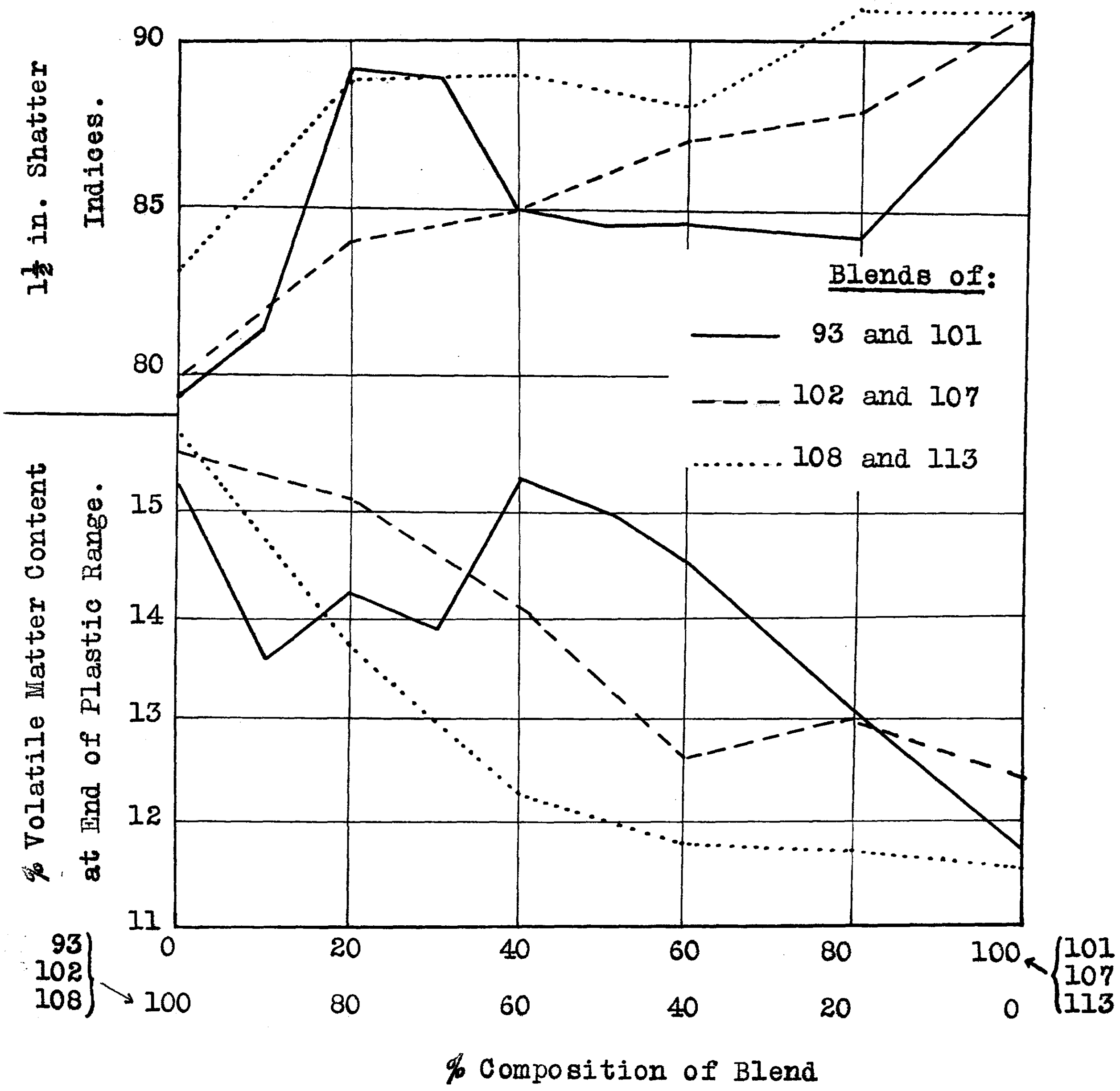


FIGURE 19 - Binary Blends of Coking Coals.

Evolution of the Volatile Matter from a Coal with Increase of Temperature.

The method used for these determinations is described on page 24 (Method II).

The results of the determinations of the percentages of volatile matter evolved at temperatures up to 950°C and rates of heating of 2 and 5°C/min., for several coking coals are given in Fig. 20. The total volatile matter contents of the coals determined at rates of heating of 2 and 5°C/min., and also by the standard platinum crucible method are contained in Table XLII. The values obtained by the latter method were found to agree within 0.5% with those of the muffle method, in which a silica crucible containing 1 gm. of coal was heated for 7 minutes in a muffle furnace at a temperature of 950°C. All values are given as percentages of ash-free dry coal.

Effect of Compression of Coal on the Percentage of Volatile Matter Evolved.

The percentage of volatile matter evolved, at any given temperature, from a coal when heated at the given rates was not appreciably altered by compressing the coal into a pellet of density 1.15gm./c.cm.

Effect of Rate of Heating on the Percentage of Volatile Matter Evolved

Fig./

Table XLII - Analyses of Coals used and Results of Volatile Matter Determinations.

Coal No.	Moisture.	Ash	Agglutinating Value. Gray-Campredon.	Total Volatile Matter Contents at rates of heating of:-			Total Vol. Matter Contentby Platinum Crucible Method.
				Compressed or Loose Coal.	2°C. per min.	5°C per min.	
	% of air-dry coal.				% of ash-free dry coal.		
114	1.5	7.2	25	(C.	28.5	29.6	
				(L.	28.3	29.4	31.4
115	1.5	6.7	27	(C.	25.9	27.2	
				(L.	26.1	27.2	30.1
116	1.5	1.9	16	(C.	19.9	21.5	
				(L.	19.9	21.6	24.9
117	1.5	3.0	14	(C.	20.8	21.6	
				(L.	20.5	21.5	25.2
118	1.5	5.5	25	(C.	25.4	26.8	
				(L.	25.4	27.0	29.3
61	1.5	5.7	24	(C.	24.2	26.0	
				(L.	24.1	26.2	28.9
62	3.7	6.8	26	(C.	34.4	35.1	
				(L.	34.1	35.1	40.8
70	2.7	4.1	32	(C.	31.2	32.7	
				(L.	31.1	32.5	37.8
48	2.7	3.5	33	(C.	30.3	31.5	
				(L.	30.5	31.3	37.7
119	1.2	4.6	25	(C.	24.7	25.7	
				(L.	24.7	25.8	28.6

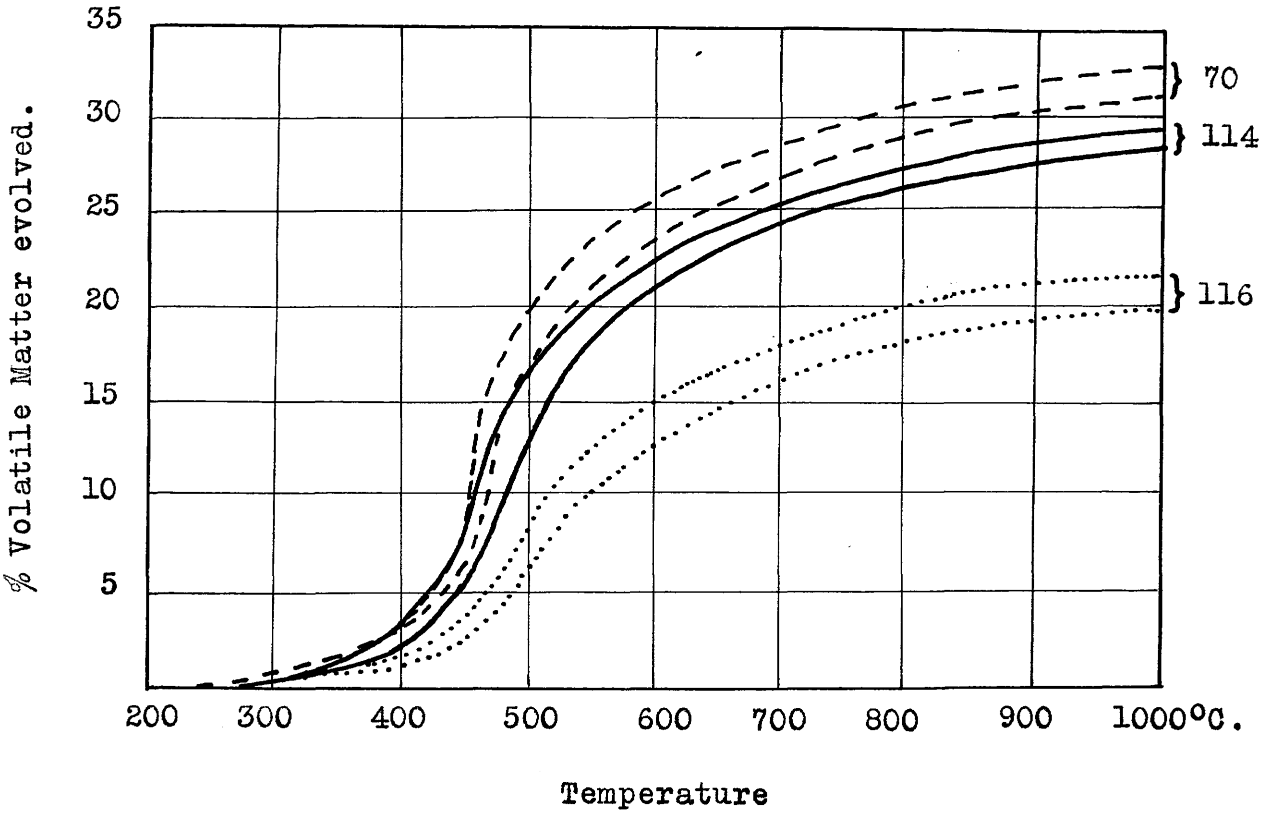


FIGURE 20 - Evolution of Volatile Matter with increase of temperature

Fig. 20 shows that the rate of heating has a considerable effect on the percentage of volatile matter evolved up to any given temperature. The percentage of volatile matter evolved was lower at any given temperature when the coal was heated at the slower rate. There were differences of from 1.0 to 2.0% between the total volatile matter contents of the coals when determined at rates of heating of 2 and 5°C/min. Differences of from 3 to 7% were observed between the total volatile matter contents of the coals when determined at rates of heating of 2 and about 400°C/min. The latter rate of heating was approximately that obtained in the determination by the platinum crucible method.

Since the standard platinum crucible method was used for all previous determinations of the total volatile matter contents of all coals and blends, the values given for the volatile matter contents at the end of the plastic ranges will be too high. In the case of the blends of the coking coals with non-caking materials the values given for each series will be comparative, since the same rates of heating were employed for the determination of the percentages of the volatile matter evolved up to the end of the plastic ranges of the blends of each series. It is possible however that, since variations of from 3 to 7% were observed between the total volatile matter contents of coking coals, when determined by the continuous method at a rate of heating of 2°C/min. and by the standard/

standard platinum crucible method, the values given for the volatile matter contents at the end of the plastic ranges of the binary blends of coking coals may not be strictly comparable. The determinations of the values for these blends could not be repeated since the coals were affected by oxidation. The blends of two Scottish coking coals were examined, using the continuous method for the determinations of the total as well as the volatile matter contents at the end of the plastic ranges of the coals and blends. An excellent correlation was obtained between the volatile matter contents at the end of the plastic ranges of the coals and blends and the shatter indices of the corresponding cokes.

Examination of Blends of Two Scottish Coking Coals.

At one of the Scottish coking plants it is the practice to blend two dissimilar coking coals in equal proportions. One of the coals, No. 120, has low ash and volatile matter contents and a low agglutinating value while the other coal, No. 125, has comparatively high ash and volatile matter contents and a much higher agglutinating value. It is impossible to coke coal No. 120 alone, since insufficient shrinkage takes place to allow the coke to be pushed without risk of damaging the walls of the oven. Blending of this coal with coal No. 125 is therefore resorted to.

Examination of Blends

The results of the examination of the blends of coals Nos. 120 and 125 are recorded in Table XLIII. The volatile matter contents at the end of the plastic ranges of the coals and blends were determined by the method described on page 24.

Table XLIII- Analyses of Blends of two Scottish Coking Coals

Blend	Description	Moisture. %	Ash %	Agglutinating Value.	Volatile matter content. %	Volatile matter content at end of plastic ranges.	
						2°C/ min. %	5°C/ min. %
					on ash	free dry	coal.
120	100% 120	1.3	3.7	15	25.7	12.6	9.6
121	80% 120 20% 125	1.3	4.7	18	26.6	11.7	9.2
122	60% 120 40% 125	1.3	5.7	20	27.7	12.5	9.5
123	40% 120 60% 125	1.2	6.7	22	28.5	12.7	9.7
124	20% 120 80% 125	1.2	7.7	24	29.5	12.0	9.0
125	100% 125	1.2	8.7	26	30.6	12.8	9.7

Relatively low values were obtained for the volatile matter contents at the end of the plastic ranges of two of the blends, namely the one comprising 20% of coal No. 120 and 80% of coal No. 125 and that containing 20% of coal No. 125 and 80% of/

of coal No. 120. It is also noteworthy that coals having total volatile matter contents which differ by almost 5% should possess the same percentages of volatile matter at the temperatures of the end of their plastic ranges.

Owing to the interesting results obtained from the examination of the blends of these two coals, cokes were prepared from each by the method described on page14 and examined.

Each of the blends contained about 8% of moisture and were coked in 36 to 38 hours. The width of the oven was 20 in. and the flue temperature 1100°C.

Examination of Cokes

The cokes obtained from the blends described above were screened and their resistances to shatter tested. The results are given in Table XLIV.

The volatile matter contents of the blends at the end of their plastic ranges, when determined at rates of heating of 2 and 5°C/min., together with the 2 in. and 1½in. shatter indices of the cokes produced from each, are also shown graphically in Fig. 21. These graphs indicate that there is a close relationship between the volatile matter contents of the blends at the end of their plastic ranges, for each rate of heating, and the shatter indices of the corresponding cokes.

It is also significant that optimum values are obtained/

obtained for the resistances to shatter of the cokes from the blends containing 20% of either of the parent coals. This very striking feature is in agreement with the results obtained by the Northern Coke Research Committee in several of their blending experiments.

Table XLIV

Blend No.	Description of Blend	Volatile matter content at end of plastic range of blend.		Screening Indices				Shatter Indices			
		2°C/ min.	5°C/ min.	4"	3"	2"	1"	2"	1½"	1"	½"
120	100% 120	12.6	9.6	65	86	95	98	79	90	96	98.2
121	80% 120 20% 125	11.7	9.2	72	87	95	98	88	93	97	98.0
122	60% 120 40% 125	12.5	9.5	80	92	98	99	81	91	96	98.0
123	40% 120 60% 125	12.7	9.7	78	91	96	99	80	90	95	97.7
124	20% 120 80% 125	12.0	9.0	87	95	97	99	86	93	96	98.1
125	100% 125	12.8	9.7	83	91	96	98	81	90	95	97.7

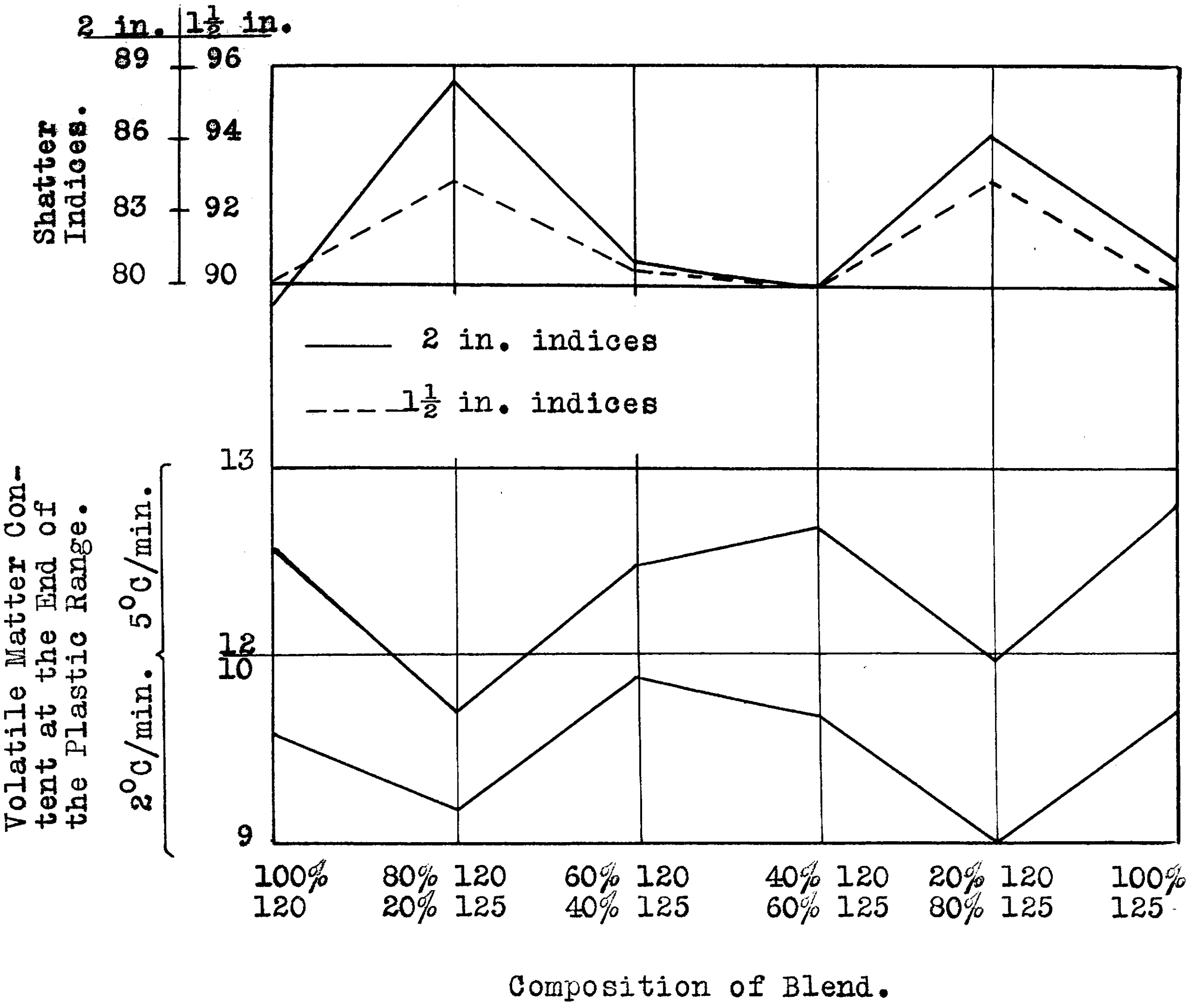


FIGURE 21 - Results of Examination of Blends of two Scottish Coking Coals.

CHAPTER VI

The Significance of the Volatile Matter Contents of Coking Coals at the Temperatures of the End of their Plastic Ranges.

For a large number of blends of coking coals and of coking coals with non-coking material it has been established that there is a close relationship between the volatile matter contents at the end of the plastic ranges of the blends and the resistances to shatter of the corresponding cokes. A series of coals has now been examined to determine if there is a similar relationship in the case of single coals and their resultant cokes.

The proximate analysis and the agglutinating value of each coal were determined. The plastic ranges of each coal when heated at rates of heating of 2 and 5°C/min. were determined by the modification of Foxwell's method described on page 19 The volatile matter contents of each coal at temperatures up to 950°C when heated at the same rates were determined by the method described on page 24 (Method II).

The results obtained from these experiments are recorded in Table XLV and those from the volatile matter determinations for several of the coals in Fig. 22.

The temperature of the initial plasticity of a coal is independent of the rate of heating. The temperatures obtained/

TABLE XLV. - RESULTS OF EXAMINATION OF COKING COALS.

Coal.	Moisture.	Volatile Organic Matter. (Plat. crucible method) % on ash free dry coal.	Ash.	Agglutinating value. Gray Campredon.	Rate of heating.	Temp. in °C of -		Volatile matter evolved up to -			Volatile matter content at end of plastic range.
						Beginning of plastic range.	End of plastic range.	Beginning of plastic range.	End of plastic range.	950°C.	
	%		%		°C/min.			Percentage on Ash free dry coal.			
Two-Foot Nine S.Wales.	0.8	24.0	4.0	33	2	397	540	0.8	10.7	20.6	9.9
					5	397	575	0.8	12.7	21.2	9.5
Brierley Hill S. Staffs.	5.4	37.6	8.5	1	2	-	-	-	-	-	-
					5	405 ?	430 ?	3.5	5.9	32.1	26.2
Fenton S. Yorks.	2.1	39.6	8.7	20	2	385	489	2.0	17.9	34.4	16.5
					5	385	526	2.0	23.6	35.7	12.1
Parkgate S. Yorks.	1.3	34.9	4.7	38	2	356	504	1.4	17.9	29.4	11.5
					5	356	530	1.4	20.0	30.2	10.2
Silkstone S. Yorks.	1.0	36.0	3.3	44	2	348	502	2.0	18.0	30.0	12.0
					5	348	530	2.0	22.0	31.2	9.2
Barnsley A, S. Yorks.	1.9	37.2	4.0	19	2	380	495	1.7	18.0	31.0	13.0
					5	380	538	1.7	21.1	32.0	10.9
Barnsley B, S. Yorks.	3.7	38.5	2.9	15	2	392	481	1.6	12.8	29.3	16.5
					5	392	511	1.6	17.3	31.5	14.2
Barnsley C, S. Yorks.	1.9	36.4	2.1	18	2	385	482	1.9	17.2	30.4	13.2
					5	385	514	1.9	20.2	32.7	12.5
8 Scottish.	3.1	37.8	8.0	25	2	392	488	1.1	18.0	31.5	13.5
					5	392	526	1.1	20.0	32.2	12.2
2 Scottish.	2.1	34.0	5.7	23	2	394	502	1.3	15.8	29.2	13.4
					5	394	527	1.3	19.2	30.7	11.5
3 Scottish.	1.3	29.1	7.5	24	2	390	515	2.0	15.5	26.3	10.8
					5	390	547	2.0	17.5	27.3	9.8
18 Scottish.	1.4	28.9	6.4	25	2	390	513	2.0	15.5	25.9	10.4
					5	390	554	2.0	18.3	27.4	9.1
4 Scottish.	4.3	38.5	4.1	19	2	398	483	1.5	14.8	31.5	16.6
					5	398	514	1.5	18.0	32.5	14.5
6 Scottish.	1.3	29.2	7.6	24	2	391	512	1.4	13.6	24.9	11.3
					5	391	534	1.4	14.8	25.4	10.6
90 Scottish.	2.6	38.7	5.4	32	2	390	504	1.5	20.0	32.6	12.6
					5	390	536	1.5	24.0	33.6	9.6
120 Scottish.	1.3	25.7	3.7	15	2	398	505	1.8	9.7	22.3	12.6
					5	398	552	1.8	13.8	23.4	9.6
121 Scottish.	1.3	26.6	4.7	18	2	393	507	1.7	11.2	22.9	11.7
					5	393	552	1.7	14.8	24.0	9.2
122 Scottish.	1.3	27.7	5.7	20	2	392	505	1.8	11.7	24.2	12.5
					5	392	552	1.8	15.3	25.2	9.9
123 Scottish.	1.2	28.5	6.7	22	2	387	507	2.0	12.5	25.2	12.7
					5	387	555	2.0	16.5	26.2	9.7
124 Scottish.	1.2	29.5	7.7	24	2	385	507	1.8	13.9	25.9	12.0
					5	385	555	1.8	17.6	26.6	9.0
125 Scottish.	1.2	30.6	8.7	26	2	384	507	1.9	14.2	27.0	12.8
					5	384	555	1.9	17.8	27.5	9.7

FIGURE - 22.

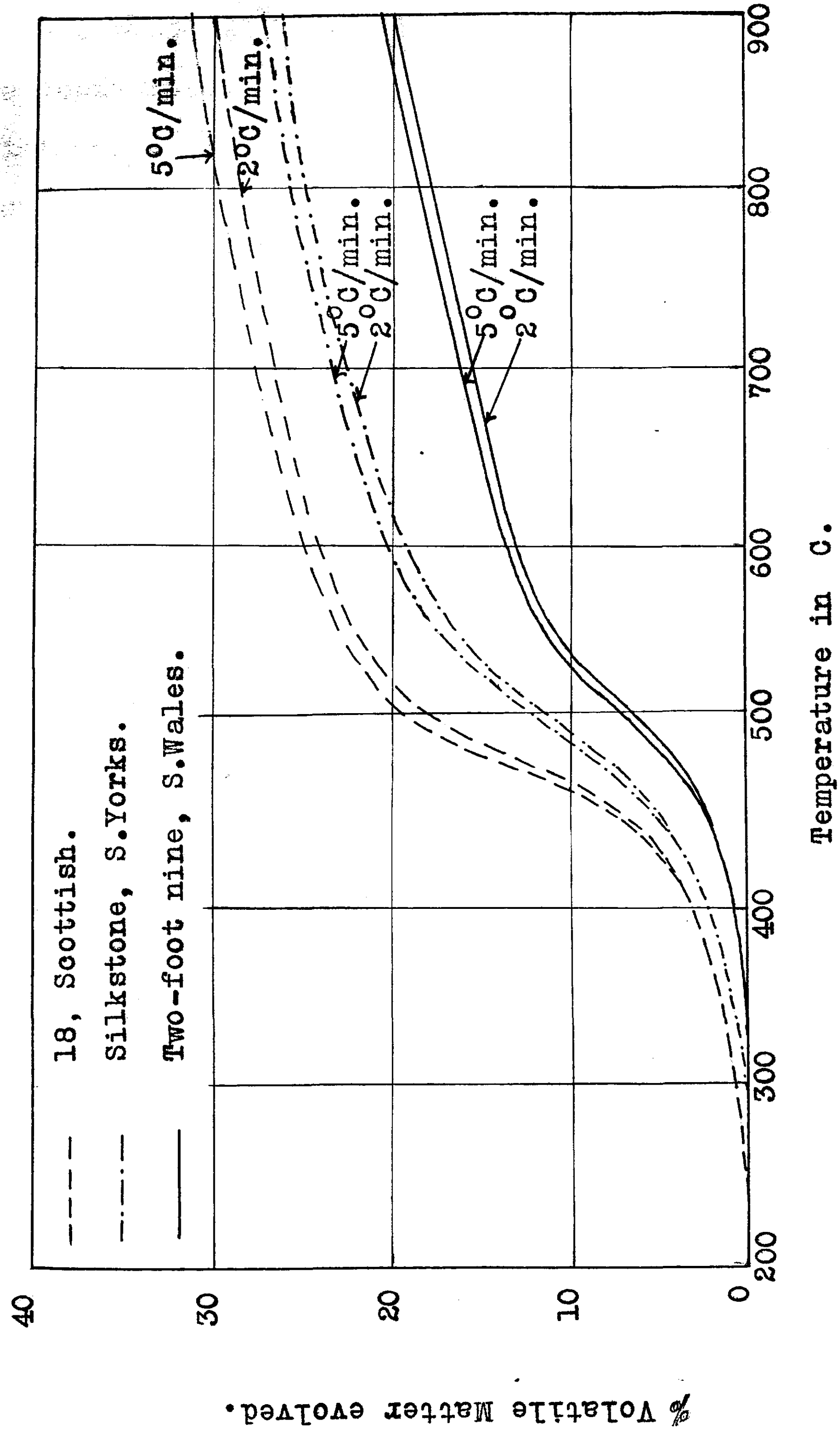


FIG. 22 Evolution of Volatile Matter with increase of temperature.

obtained for the end of the plastic ranges of the coals are, however, 25 to 48°C higher when the coals are heated at the more rapid rate. Coals Nos. 120-125 show the greatest variations. The high temperatures obtained for the end of the plastic ranges of the S. Wales coals, Two-Foot Nine, when it is heated at 2 and 5°C/min. are noteworthy.

In the case of the blends of coal No. 120 with coal No. 125, the agglutinating values increase as the temperatures obtained for the beginning of the plastic ranges decrease. Silkstone coal, possessing the remarkably high agglutinating value of 44 also gives the lowest temperature for the initial plasticity, while coal No. 120 has the lowest agglutinating value and the highest temperature for the initial plasticity. The coals giving intermediate values, however, do not show a similar relationship.

Fig. 22 shows that only a small percentage of volatile matter, usually about 1-2%, is evolved before the coal becomes plastic. When the coal attains the temperature of initial plasticity, the evolution of the volatile matter becomes more rapid and continues at this increased rate until the temperature of the end of the plastic range is reached, at which point the rate of evolution decreases to a relatively slow rate again. Usually more than 50% of the total volatile matter contained in a coal is evolved during the plastic range when the coal is heated progressively at the given rates of heating.

Correlation of Results:

The cokes made from the S.Wales and English coals have been examined by the Midland Coke Research Committee, The University, Sheffield, and the results are included with those obtained from the Scottish cokes in Table XLVI.

In this table the cokes are placed in the order of decreasing resistance to shatter to facilitate the comparison of the shatter indices with the volatile matter contents at the end of the plastic ranges of the coals.

Generally, the volatile matter contents at the end of the plastic ranges of the coals increase as the shatter indices of the corresponding cokes decrease. There are several exceptions but these can be explained by a consideration of other factors which influence the nature of the coke obtained from a given coal. The volatile matter values obtained at a rate of heating of 2°C/min. for coals No. 18, Silkstone, Parkgate, and Nos. 6 and 90 are relatively low. Coal No. 18, Silkstone and Parkgate coals were coked at a relatively fast rate of heating and they would most probably give cokes having higher resistances to shatter if they were coked in an oven having a lower flue temperature. It is also possible that the extremely high swelling properties possessed by the Silkstone and Parkgate coals may produce an adverse effect on the quality of the resultant coke. The cause of the discrepancies in the case of coals Nos. 6 and 90 may be found/

Table XLVI - Examination of Coking Coals and their Cokes.

Coke. (in order of 1½in. shatter indices).	Volatile Matter content at end of plastic range of coal.		Screening Indices			Shatter Indices			
	2°C/min.	5°C/min.	4"	3"	2"	2"	1½"	1"	½"
Two-foot nine, S. Wales.	9.9	9.5	65	86	96	90	97	98	99.0
3, Scottish	10.8	9.8	54	85	96	87	93	96	98.3
121, Scottish	11.7	9.2	72	87	95	88	93	97	98.0
124, "	12.0	9.0	87	95	97	86	93	96	98.1
18, "	10.4	9.1	32	60	95	83	92	97	98.1
122, "	12.5	9.9	80	92	98	81	91	96	98.0
125 "	12.8	9.7	83	91	96	81	90	95	97.7
123, "	12.7	9.7	78	91	96	80	90	95	97.7
120, "	12.6	9.6	65	86	95	79	90	96	98.2
Silkstone, S.Y.	12.0	9.2	52	76	92	73	86	94	97.3
Parkgate, S.Y.	11.5	10.2	74	87	94	75	85	93	96.7
6, Scottish	11.3	10.6	60	84	95	71	83	94	98.0
Barnsley, A:S.Y.	13.0	10.9	58	77	90	67	82	91	96.9
2, Scottish	13.4	11.5	14	48	85	60	78	90	97.0
90, "	12.6	9.6	44	71	92	57	78	93	98.4
8, "	13.5	12.2	42	68	83	65	76	88	96.4
Barnsley C, S.Y.	13.2	12.5	33	61	81	60	75	88	94.4
Barnsley B, S.Y.	16.5	14.2	35	55	72	59	72	83	91.9
4, Scottish	16.6	14.5	20	43	82	56	70	89	97.8
Brierley Hill, S.Staffs.	- x	26.2	2	11	34	42	56	74	89.3

x This coal does not become plastic atthis rate of heating found in the fact that these coals were compressed before charging to the oven. Had these coals been topcharged, cokes having higher resistances to shatter would have been obtained.

When the $1\frac{1}{2}$in. shatter indices of the cokes are compared with the volatile matter values obtained for the corresponding coals at the faster rate of heating, a better correlation is obtained. The volatile matter values obtained for the S. Wales coal, Two-Foot Nine, and coal No. 3, are relatively high in relation to the shatter indices of their cokes but this may be explained by the fact that these coals were topcharged, while the coals succeeding them in Table XLVI, the 120-125 series, were compressed before coking. Silkstone coal and coal No. 90 again give relatively low volatile matter contents at the end of their plastic ranges but the explanations put forward before may again be used to account for the discrepancies shown by these coals.

Effect of the Rate of Heating of a Coal on the Quality of the Resultant Coke:

One of the most interesting features of the results of the experiments described above is the fact that in the case of each coal examined higher values are obtained for the volatile matter contents at the end of their plastic ranges when the coals are heated at 2°C/min. than when they are heated at 5°C/min. The values obtained at each rate of heating for the coals/

coals of the 120-125 series, Silkstone coal and coal No. 90 show the greatest differences. These results appear to indicate that cokes of greater resistance to shatter would be obtained when these coals were carbonised at the more rapid rate of heating.

Scottish coke makers generally believe that Scottish coking coals having comparatively low agglutinating values give better cokes when they are coked at rapid rates of heating than at slow rates of heating, but work is now proceeding to determine the effect, on the physical properties of the coke, of carbonising poor and good coking coals at different rates.

CHAPTER VII

Effect of Blending Good and Poor Coking Coals with Bitumen or Pitch.

Shale oil bitumen supplied by the Scottish Oils, Ltd., containing about 2% of lime, and pitch supplied by the Scottish Tar Distillers, Ltd. were used for this series of tests. The softening points of both materials were about 140°F. and they could be readily powdered.

The coals used were No. 18, having a low volatile matter and a moderate agglutinating value, No. 38, having a high volatile matter content and a lower agglutinating value, and No. 130, having a low volatile matter content and a low agglutinating value.

The coals and blends were carbonised in the experimental oven and the results of the examination of the coals and cokes are given in Table XLVII.

One of the best Scottish coking coals, No. 18, was blended with 2½ and 5% of bitumen and the cokes produced (Nos. 127E and 126E) were found to be almost identical with coke No. 18E, made from the straight coal.

When the poor coking coal No. 38 was blended with 5% of bitumen a large reduction of the percentage of breeze obtained from the oven and a large increase of the shatter indices of the coke were obtained.

The/

TABLE XLVII - RESULT OF BLENDING COALS WITH BITUMEN AND PITCH:

Coke No.	Coal used.	Coking Period	Moisture in Charge	Proximate Analysis of air-dried coal.				Screening Indices of Cokes.				Shatter Indices of Cokes.				
				Moisture.	Ash	Vol. Org. Matter	Fixed Carbon	4"	3"	2"	1"	½"	2"	1½"	1"	½"
		hr.	%	%	%	%	%									
18.E.	100% of 18.	18	4.0	1.0	7.1	26.2	65.7	62	80	93	97	97.7	84	93	97	98.6
126.E.	95% of 18 + 5% Bitumen.	18	3.8	1.0	5.7	27.4	65.9	52	77	93	98	98.6	82	93	97	98.6
127.E.	97½% of 18 + 2½% "	18	4.1	0.8	4.8	26.8	67.6	49	77	93	98	98.5	83	93	98	98.6
38.E.	100% of 38.	17	6.5	2.4	13.1	30.4	54.1	70	82	89	93	93.9	78	86	93	96.2
128.E.	95% of 38 + 5% Bitumen.	18	6.0	1.8	15.3	30.5	52.4	81	89	93	96	96.5	90	91	93	97.2
129.E.	100% of 129.	18	2.7	1.3	6.7	24.4	67.6	55	77	90	96	97.0	82	89	96	98.0
130.E.	100% of 130.	18	2.8	0.9	6.9	24.0	68.2	-	-	-	-	88.0	-	-	-	-
130.E.1.	100% of 130.	23	3.0	0.9	6.9	24.0	68.2	51	70	81	84	84.5	81	89	93	94.6
131.E.	95% of 130 + 5% Bitumen	18	2.8	0.9	6.3	24.8	68.0	71	87	94	97	97.8	86	93	96	98.4
132.E.	95% of 130 + 5% Pitch.	18	2.2	1.0	7.0	24.5	67.5	67	83	93	97	97.6	86	93	97	98.2

The effect of blending No. 130, a coal similar to No. 129 but containing a larger proportion of a weakly caking coal, with 5% of bitumen or pitch was next determined. The cokes produced (Nos. 131E and 132E) were identical and were even a little better than coke No. 129E. The reduction of the percentage of breeze from the oven and the increase obtained in the shatter indices of the cokes by the 5% additions of these materials is remarkable.

From these results it would appear that less abradable cokes may be obtained when coals, having an insufficient supply of the plastic material necessary to bind the coal particles together, are blended with bitumen or pitch. Obviously, any coal having an adequate quantity of this plastic material will not be benefited by further additions. Many Scottish coking coals have comparatively high volatile matter contents and give when coked, weak, highly fissured cokes. It was found that when finely crushed non-caking low volatile materials were added to several of these, that although the resulting cokes were less fissured, they were more abradable. The coal did not have the necessary agglutinating value to bind the non-caking material to give a strong coke. It is probable that if bitumen or pitch were added to these blends, greatly improved cokes would be obtained.

PART II

The Significance of the particle size of coal.

The Significance of the Particle Size of Coal with regard to the Combustible properties of the coke produced.

INTRODUCTION

The author was exceedingly fortunate in having the use of the special thermal laboratory of Messrs Smith and Wellstood, Bonnybridge, for testing the suitability of fuels for burning in domestic stoves, boilers and open grates, and at the outset an investigation was made of the performances in these heating appliances of furnace cokes, which were of course made from crushed coals.

In order that full advantage may be taken of the discovery that the screening out of coke less than 1¼in. size greatly enhances the performance of a furnace coke, a remunerative market must be found for this small coke.

The demand for fuel for domestic stoves and boilers is rapidly increasing with the better realisation of their very economic and trouble free operation. In Scotland, anthracite has supplied the greater part of this demand but should oven coke prove suitable it should find a ready market because of its comparatively low price and uniformity of quality.

An investigation of the suitability of the oven cokes at present being made in Scotland for burning in open grates was/

was also carried out.

The majority of experimenters with open grates have confined their attention to the examination of the burning of bituminous coal, low temperature coke and gas retort coke.

Dr. M. W. Fishenden has shown (The Coal Fire, Fuel Research Board, Special Report No. 3) that burning in ordinary open grates bituminous coal gave radiant efficiencies of 20-25% and low temperature coke, values of 30-33%. She found that the old fashioned type of grate was slightly more efficient than the modern barless type.

The work of Milner, Dyde and Hodsman (J.S.C.I., 1931, 50,113T) confirms these results. These investigators obtained radiant efficiencies of 25%, 30% and 33% for bituminous coal, low temperature coke and vertical retort coke, respectively.

The comments of Dr. Hodsman (Gas Journal, 22/3/33) on the work of Dr. F. J. Dent and Professor J. W. Cobb(Gas Fellowship Report, 1927) are also very important. He writes -

> "Dr. Dent and Professor Cobb have shown that differences in combustibilities of cokes appear to become negligible about 800°C. The considerable differences commonly recognised could be detected only below red heat. This conclusion has not received the attention it merits. It implies that a fuel which is to be adequately "combustible" and easy to ignite needs to have these qualities on the surface only. When the fuel has attained a red heat, the character of the interior is relatively unimportant. Indeed in point of heating efficiency it has been shown elsewhere (Milner, Dyde and Hodsman, J.S.C.I., 1931,113T) that the advantages then lie with high temperature cokes.

"In/

> "In our laboratory, Thomson, Bell and Lloyd (unpublished) found that a film of coal itself is nearly ideal for the purpose. The coke was sprayed simultaneously with coal dust using hot road tar as an adhesive.
>
> "Vertical retort coke treated by this process, so that the volatile matter content was raised to 4%, was clean, almost odourless, could be ignited as easily as low temperature coke and burned up more quickly than coal or low temperature coke."

These investigations have shown that high temperature retort coke is difficult to ignite but once properly kindled will burn satisfactorily giving a high radiant efficiency. To try and overcome this difficulty of kindling and also the slowness of recovery of the fire after refuelling a number of special coke grates have been designed. Gas burners are generally incorporated in these grates for convenient lighting. One feature common to all is the provision of a front bar to increase the capacity of the grate.

The following grates having special features have been designed for burning retort coke:-

Glow-Worm Open Fire (O. Bruster and Richardson, 4, Lloyds Avenue, London, E.C.3.). The fire basket is wedge shaped and is 10½in. high and 10in. wide. The fuel burns from the front to the back. The air for combustion passes through the front bars, part of it going down through the fire to the ash pit and then up through a special flue at the back of the fire and the remainder of the air passing upwards directly/

directly to the flue. It is claimed that this special construction causes the ash to be carried through to the ash pan and prevents it entering the room. The use of anthracite or gas retort coke is recommended.

N.C. Open Coke Grate. (R. & A. Main, Ltd., Gothic Works, London.). This grate is provided with deeply serrated bricks at the back and sides of the fire basket. The front bar is about 6 in. high. When rapid combustion is desired the ash pit is closed and air is drawn through the front bars and through the fuel to the serrations. For slow burning the ash pit is opened and cold air is drawn directly through the serrations. Graded gas coke is recommended.

Peveril Grate. (R. Russel & Sons, Ltd., Peel Foundry, Derby.). This grate is provided with a patent "coke valve". This valve consists of a cast iron plate, hinged at the top, behind the canopy, so that the bottom may be drawn forward over the fire and thus forming a back flue. The canopy is at the same time closed and a strong draught is produced. The "coke valve" is brought into operation when kindling or stoking the fire. When the fire becomes bright the coke valve may be partly or wholly closed by pushing back and raising the plate into position and opening the canopy. This plate is somewhat cumbersome and becomes difficult to move after considerable use.

L. W. C. Fireback. (The London Warming Co. Ltd., 2 Percy Street, Rathbone Place, London, W.1.). This sheet-iron fireback, with front bars attached, is supported by the existing/

existing bottom grate so that a back flue about 2 in. deep and 8 in. wide is formed. The opening in the bottom of the fireback to the back flue is about 2 in. high and 6 in. wide. There is an opening, approximately 8" x 4", near the top of the fireback which is closed by a damper when the back flue is brought into operation. This damper closes the back flue when it is pushed back to open the front flue. A special poker is supplied to clear the ash from the bottom of the back flue when it becomes choked.

Designing of an Open Coke Grate

None of these grates appeared to be entirely satisfactory for burning oven coke but it was decided to determine the effects of some of their features of design on the efficiency and the ease of igniting and burning of high temperature cokes. It might then be possible to devise a more suitable grate for oven coke.

Manufacture of an Open Grate Coke

An examination of the effects of some of the conditions of carbonisation of coals on the combustible properties of the resulting coke was undertaken with a view to the determination of a method for the manufacture of a special open grate coke in ordinary ovens.

CHAPTER I

METHODS OF EXAMINATION

1. EXAMINATION OF FUELS.

The analyses of the fuels were carried out according to the methods described on pages 15 and 16.

2. DOMESTIC STOVE TESTS

Construction of Stoves

The chief points of the design of the oval-shaped closed stove "Jeunesse" used in the majority of these tests is shown in Fig. 23.

The "Esse-Dura" stove used in four of these tests is designed to operate with the doors closed or open. When used as a closed stove it must be refuelled more often than the "Jeunesse" ~~or "[illegible]~~" stove since, having no hopper, its fuel capacity is much smaller. It has, however, a similar appearance to an open grate when used with the doors open and when a suitable fuel is used the fire can be kept burning overnight. Fig. 24 shows the chief features of this stove.

Description of Testing Plant

The test room, a plan of which is shown in Fig. 25, was made as air-tight as possible by lining the walls, ceiling and window casings with lead sheets, the floor with cement and by sealing the double doors. There was a ventilating air inlet/

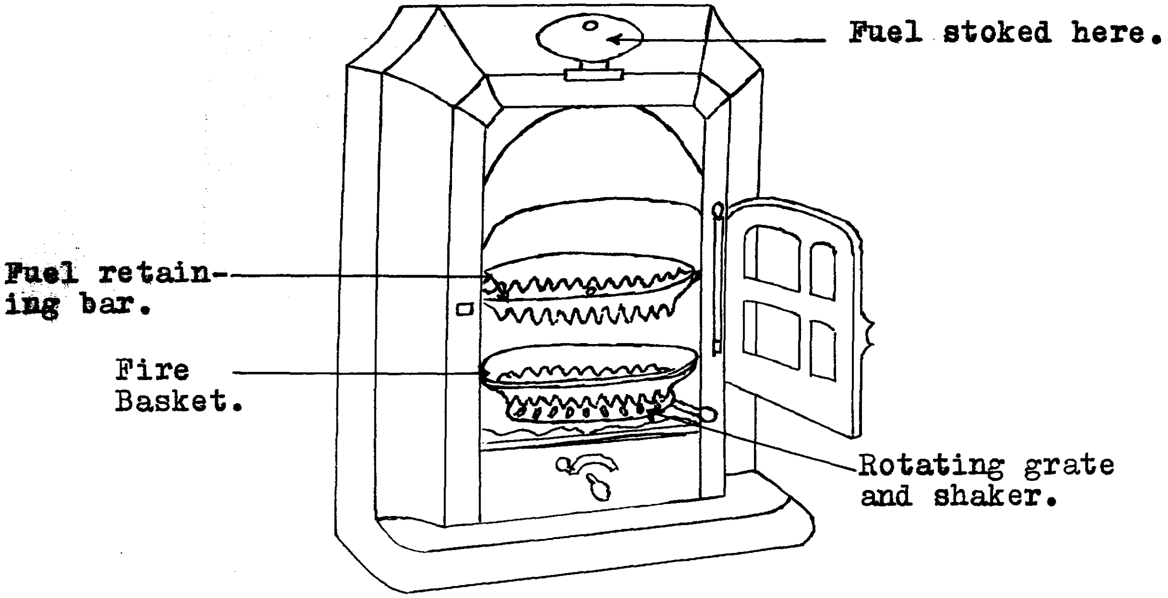


FIGURE 23 - Diagram of Closed Stove.("Jeunesse")

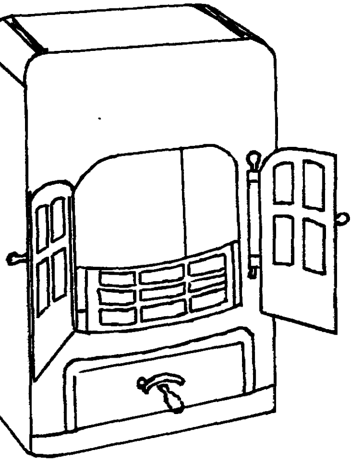
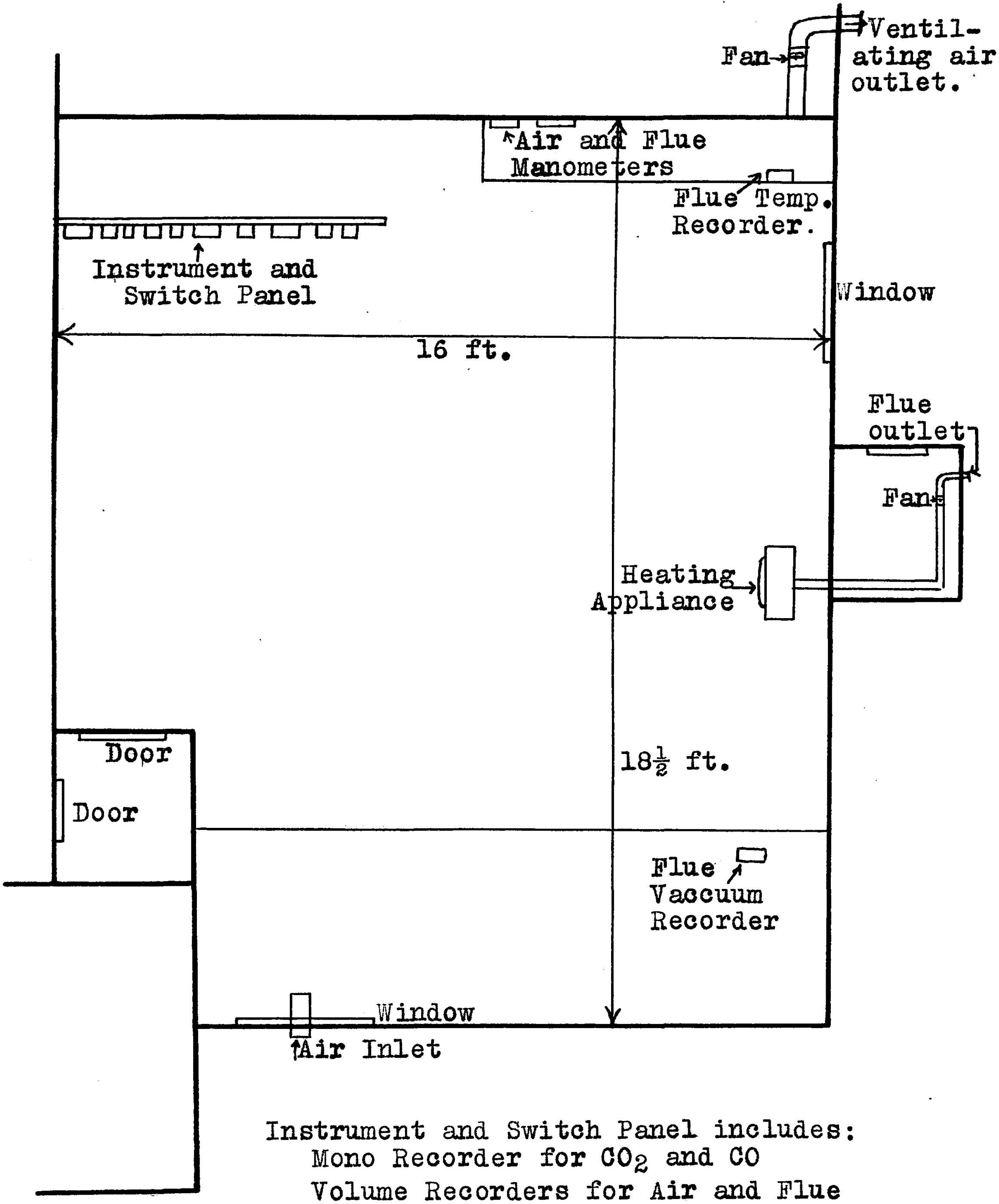


FIGURE 24 - Diagram of Semi-Closed Stove.



Instrument and Switch Panel includes:
Mono Recorder for CO_2 and CO
Volume Recorders for Air and Flue
3-Point Temperature Recorder,
Ammeters, Voltmeters etc.

Capacity of Test Room - 2,950 cb.ft.

FIGURE 25 - Plan of Test Room.

inlet pipe situated at the bottom and an outlet pipe placed at the top of opposite walls of the room. Usually about 20,000 cb.ft., six changes of air per hour, were drawn through the room by means of a fan placed in the outlet pipe.

The heating appliance to be examined was placed on a table about 18 in. from the wall and at a height suitable for observing the radiated heat. A constant volume of air per hour was drawn through the fire by a fan placed in the flue pipe of the stove.

The volumes of ventilating air and of the flue gases were recorded continuously during the test by Bailey Fluid meters, calibrated by the Industrial Combustion Engineers. These meters were frequently checked by means of differential pressure gauges and adjustments were made when necessary.

The flue vacuum, in inches of water, at a point immediately behind the stove was recorded by a Cambridge draught recorder.

The temperatures of the inlet ventilating air, the room, the outlet air and the flue gases were recorded continuously by Cambridge instruments. All the thermocouples were placed in the pipes at the point where each passed through the wall of the room. The percentages of carbon dioxide and carbon monoxide in the flue gases were found by means of a Mono recorder. These recorders were also checked during each test.

Radiant Efficiency

A water cooled Cambridge thermopile and galvanometer, calibrated to give the radiation in B.Th.U's., falling on one square foot area, 51 in. from the centre front of the heating appliance, was used to determine the radiant efficiency of each heating appliance by the "Leeds" method. The thermopile was mounted on a semicircular hoop of radius 51 in. which could be rotated about the vertical axis of the centre of the fire. The surface of the hemisphere swept out by this semicircle was divided into 81 areas, thermopile readings being taken at the centre of each. By multiplying each of the 81 readings by the area in square feet of the area, at the centre of which each reading was taken, and obtaining the sum, the total radiation passing through the surface of the hemisphere was found. The "distribution factor" was obtained by dividing the total radiation by the central reading. This factor was found to vary but little for each heating appliance and fuel and was determined only two or three times during an experiment. The central reading was, however, observed at intervals of 10-15 minutes. The average central reading was multiplied by the distribution factor and the product, expressed as a percentage of the total heat in the fuel stoked, was taken as the "radiant efficiency" of the heating appliance.

Calibration of Room "Losses":

Since a heat balance for each test was desired it was necessary/

necessary to determine the heat passing through the walls of the room for a series of inside and outside temperature differences.

For this calibration, electric heaters were substituted for the heating appliance. The same procedure adopted in a test was followed, except that the flue fan remained off. A constant volume of ventilating air was drawn through the room. The temperatures of the inlet and outlet air, and of the room, the volume of ventilating air and the number of units supplied by the electric heaters were recorded. The test was continued until the difference between the room and inlet air temperatures remained almost constant for a period of 48 hours.

From the observations made, the heat supplied by the electric heaters, the heat carried away by the ventilating air and the average inlet and room temperatures were determined. The difference between the heat supplied and the heat given to the ventilating air gave the heat passing through the walls of the room for the observed inside and outside temperature difference. A large number of these tests were carried out using various numbers of half-unit electric heaters. Fig. 26 shows the quantity of heat passing through the room walls for various temperature differences.

It was found that the air temperatures were usually more constant between 7 p.m. and 11 p.m. than during any other period of the day and all tests were therefore, started and/

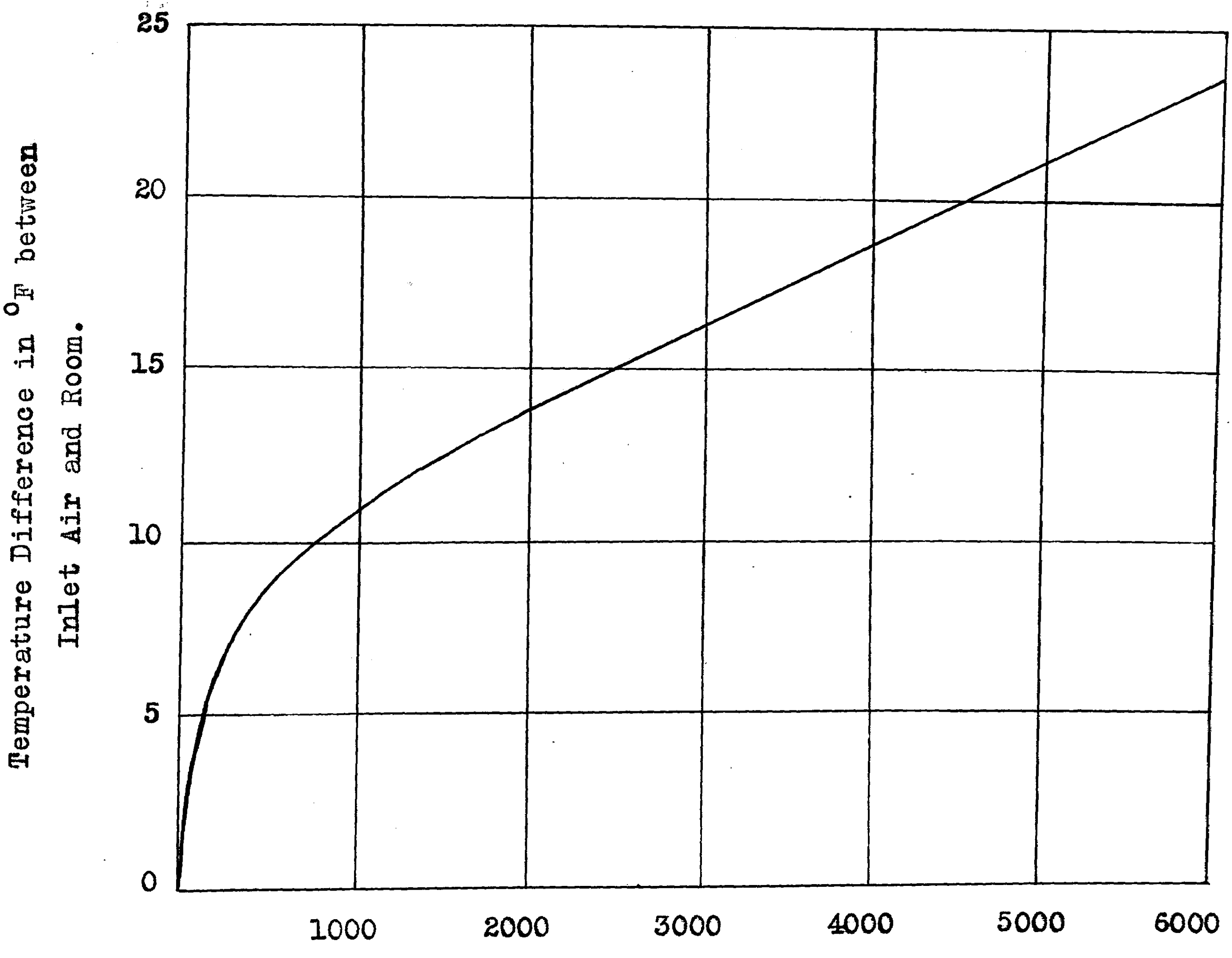


FIGURE 26 - Calibration of Heat Losses through Room Walls.

and stopped about 11 p.m. If the temperature of the room at the beginning and the end of the test differed, a correction had to be made for the heating or cooling of the test room. This correction was found from a separate calibration.

The temperature of the room was maintained at a high value, while a steady volume of ventilating air was drawn through the room. The electric heaters were then switched off and the room allowed to cool for about 12 hours. The heat given to the ventilating air for each drop of 1°F was found after allowing for the heat loss through the room walls. If the room cooled too quickly only one of the electric heaters was switched off.

Method of Conducting Domestic Stove Tests;

When the fire had been burning for a few hours the ventilating air fan was switched on. About 24 hours later the test was started; the fire was shaken, the ash removed, and the stove completely filled with fuel. These operations were repeated at intervals, varying from 2 to 10 hours over a period of 48 to 72 hours, and each time the weight of fuel stoked and the ash removed were noted. A sample of the fuel was also taken and kept in a closed tin. The "distribution factor" for the heat radiated from the stove and the central thermopile readings were found by the "Leeds" method already described. The volumes and temperatures of the ventilating air/

air and of the flue gases and the percentages of carbon dioxide and carbon monoxide in the flue gases were observed from the recorders. The draught vacuum in the flue at a point immediately behind the stove was recorded and the barometric pressure was also noted. One or two test periods of 24 hours each during which the temperature conditions were fairly constant were then selected and the following items determined for each:-

(1) Heat in fuel stoked. (calorific value determined by bomb calorimeter).

(2) Heat carried away by ventilating air.

(3) Heat carried away by flue gases.

(4) Heat passing through room walls (obtained from Fig.26).

(5) Heat loss due to unburnt combustible in ash (calorific value determined by bomb calorimeter).

(6) Overall efficiency of stove. $\frac{(2) + (4)}{(1)} \times 100$

(7) Heat radiated.

(8) Heat convected ((2) + (4) - (7))

(9) Weight of dry flue gases per pound of fuel as fired. $\frac{\text{Volume of flue gases x density}}{\text{Weight of fuel.}}$

(10) Excess air $\frac{\text{(9) - Theoretical weight required}}{\text{Theoretical weight required.}} \times 100$

(11) Fuel fired per therm delivered to room.

$$\frac{100,000}{\text{Net cal. val. of fuel as charged x Overall Effy.}}$$

(12) Cost per therm delivered to room.
(lb.fuel fired per therm (11) x cost per lb.)

3. Open/

3. Open Grate Tests.

In each test the fire was made up in the usual way. The paper and wood were placed in the grate and on top of this the unburnt fuel remaining from a previous fire of the same sample. Sufficient fresh fuel was then added to give a total of 12 lb. The fire was then kindled and the time required to attain a certain brightness (determined by a definite reading of the thermopile) was observed. The fret was then closed, no air being admitted to the ash-pit, so that the fire could be kept radiating for as long a period as possible above this given value for a bright fire. When the radiation decreased to this value the fret was opened, the ash removed from the fire and usually 7 lb. of fuel added. The time required for the fire to become bright again was noted when the fret was again closed and the above procedure repeated.

Radiant Efficiency:

The radiant efficiency of each fire was determined in the same manner as that described on page 154 for the domestic stove tests.

4. Domestic Boiler Tests

The performances of various fuels when burned in two domestic boilers were examined.

The boiler to be tested was connected to a 45 gallon tank/

tank which was well lagged to prevent loss of heat. By means of a constant flow tank water was continuously passed at a constant rate into the 45 gallon receptacle, the same quantity of water being continuously drawn off after passing through the system. The total quantity of water heated during each test was determined by weighing.

The temperatures of the cold water entering and the hot water leaving the system were recorded by platinum resistance thermocouples, which were connected to a Cambridge recorder. The flow of water through the circuit was continued from the kindling of the fire until the temperatures of the water leaving and entering the system were the same.

The efficiency of the boiler was the percentage, of the total available heat of the fuel burned, given to the water.

5. Manufacture of an Open Grate Coke

The special cokes used for the investigation of the effect of the size of the coal carbonised on the combustible properties of the coke were made in the experimental and full scale ovens using the methods described on page 10.

CHAPTER II

EXPERIMENTAL

Suitability of furnace coke smalls for burning in domestic stoves.

The performances of various oven cokes at present being made in Scotland were compared with those of anthracite when burned in open or closed domestic stoves.

Results of Stove Tests:

A description of the fuels used for these tests is given in Table XLVIII. These results show that the weight per cubic foot of oven coke is very much less than that of anthracite. The closed stoves tested hold from 20 to 35 lb. of coke and even with the higher minimum rate of combustion of the least combustible oven coke examined the reserve of fuel was adequate for the maintenance of the fire overnight. Two sizes of oven coke ½"-1" and 1"-1½" (using square mesh screens) were tested. The smaller size was considered to be more suitable since it burned unattended for longer periods, namely 12-15 hours, but chiefly because the smaller fuel passed freely down the stove without any tendency to hold up. Neither size of coke could, however, be considered suitable for burning in the "semi-closed" stove "Esse-Dura" since it held/

TABLE XLVIII - DESCRIPTION OF FUEL USED IN DOMESTIC STOVE TESTS.

Fuel No.	Type of Fuel.	Conditions of Manufacture of Cokes.				Size of Fuel.	Weight per cubic foot.	Gas required to ignite.
		Oven Width in.	Flue Temp. °C.	Coking Period. hr.	Compressed or loose charged coal.	in.	lbs.	cu. ft.
C.1.	Bituminous coal, 28.8% vol. matter.	-	-	-	-	1 - 3	43.7	1
L.1.	Low Temp. Coke, 17.7% " "	-	-	-	-	⅜ - ¾	18.6	1.5
A.1.	Welsh Anthracite, 4.7% " "	-	-	-	-	1 - 2	47.0	3.75
A.2.	Scottish " 4.8% " "	-	-	-	-	1 - 2	47.8	3.75
H.1.	High Temp. Coke, 1.0% " "	14	1,300	15	L.	½ - 1 1 - 1½	25.3 24.2	2.5 5
H.2.	" " " 1.2% " "	18	1,100	32	C.	½ - 1 1 - 1½	27.2 27.0	3 5.5
H.3.	" " " 1.0% " "	17	1,100	30	C.	½ - 1 1 - 1½	26.9 26.4	2.5 5
H.4.	" " " 1.6% " "	18	1,100	30	L.	½ - 1 1 - 1½	25.0 24.9	2 5.5

held only 12 lb. of coke. These small sizes were necessary for overnight burning, but would not burn brightly when the doors of the stove were opened. A larger size of fuel, giving less resistance to the flow of air must be used to give a faster rate of burning. The minimum size for satisfactory burning with the doors of the stove open was found to be 1-2 in. but the oven cokes examined were not sufficiently combustible for this size to keep the fire burning overnight.

The values given in Table XLVIII show that oven coke of ½-1 in. size is more easily ignited than anthracite of the size recommended (1-2 in.) for use in these stoves. Coke No. H.4 was almost as easily ignited as the low temperature coke.

The chief observations made during the tests and the values calculated from them are recorded in Table XLIX. The heat balances obtained are shown in Fig. 27.

The most important items in Table XLIX are the cost and the weight of fuel fired per therm of useful heat delivered to the room and these should be used for comparing one fuel with another in preference to the overall efficiency, since they take into account the calorific values and the cost of the fuels as well as the overall efficiency of the stove. The weights of dry flue gases per pound of fuel as fired or the percentages of excess air in the flue gases provide a useful comparison of the ease of combustion of the fuels.

TABLE XLIX - DATE AND RESULTS OF DOMESTIC STOVE TESTS.

STOVE ...	Closed Stove - No. 2 Jeunesse.												No. 3 Jeunesse	No. 4 Jeunesse.			Esse Dura No. 3.			
																	Closed.		Open.	
FUEL ...	Low Temp. Coke.		High Temperature Coke.							Anthracite.			Anthracite	H.T. Coke	Anthracite.		Coal	H.T. Coke	Coal	H.T. Coke.
Flue Vacuum ... in. water.	0.02	0.01	0.04			0.035		0.03	0.02	0.04		0.02	0.04	0.06	0.06	0.04	0.05	0.025	0.4	0.025
Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Duration of Test.. hrs.	24	24	24	24	24	24	24	48	24	48	48	48	48	48	48	48	48	48	24	24
Fuel No. ...	L.1	L.1	H.2	H.3	H.4	H.1a	H.2	H.1	H.2	A.1	A.2	A.1	A.2	H.1a	A.2	A.2	C.1	H.3	C.1	H.3
Size of Fuel. ... in.	$\frac{3}{8}$-$\frac{3}{4}$	$\frac{3}{8}$-$\frac{3}{4}$	$\frac{1}{2}$-1	$\frac{1}{2}$-1	$\frac{1}{2}$-1	$\frac{1}{2}$-1	1-1$\frac{1}{2}$	$\frac{1}{2}$-1	$\frac{1}{2}$-1	1-2	1-2	1-2	1-2	1-1$\frac{1}{2}$	1-2	1-2	1-3	1-1$\frac{1}{2}$	1-3	$\frac{1}{2}$-1
ANALYSES OF FUEL AS FIRED:																				
Moisture ... %	5.9	5.9	3.0	5.0	2.8	2.5	2.5	3.0	2.2	1.9	2.1	1.9	2.1	2.5	2.1	2.1	5.7	15.7	5.7	15.7
Ash ... %	2.3	2.3	9.3	6.5	11.0	9.2	8.5	9.3	10.6	6.5	8.8	6.5	8.8	8.2	8.8	8.8	4.3	6.2	4.3	6.2
Net Calorific Value - B.Th.U./lb.	13,090	13,090	12,180	12,300	11,960	12,240	12,330	12,180	12,100	13,890	12,930	13,890	12,930	12,340	12,930	12,930	12,570	11,100	12,570	11,100
FUEL.																				
Fuel fired per hour. lb.	1.32	0.80	1.35	1.03	1.45	1.77	0.94	0.83	0.74	1.44	2.16	0.86	2.10	2.03	2.00	1.80	1.40	0.82	1.30	0.64
Fuel fired per therm delivered to room. lb.	9.4	9.3	11.0	10.2	11.8	10.9	10.3	10.3	10.1	8.8	9.7	9.5	9.8	11.3	11.0	9.9	13.5	12.1	13.0	11.7
Cost per therm delivered. d.	2.00	1.98	1.60	1.55	1.70	1.47	1.48	1.37	1.44	1.87	2.07	2.05	2.08	1.63	2.37	2.12	1.95	1.64	1.88	1.58
TEMPERATURES:																				
Inlet Air temp.... °F.	44	52	52	39	33	34	54	59	59	56	28	61	41	37	48	40	49	42	43	41
Room temp. ... °F.	62	66	70	55	55	60	68	70	70	76	63	76	76	63	78	69	68	55	68	53
Outlet temp. ... °F.	65	68	73	58	58	64	71	72	72	80	68	78	81	67	83	73	71	57	71	55
Flue Gas temp. ... °F.	358	188	367	258	410	540	260	280	207	437	634	255	531	475	592	457	293	173	275	141
VOLUMES:																				
Volume of flue gases. cb./ft./hr.	467	288	716	745	700	650	650	547	412	710	715	454	697	1,125	1,040	683	915	488	705	521
Volume of ventilating air. cb./ft./hr.	22,100	22,600	22,400	20,600	17,900	16,900	22,900	21,400	20,900	22,400	16,800	20,700	16,700	19,200	17,500	18,600	20,800	19,800	11,400	15,700
ANALYSES OF FLUE GASES:																				
Carbon Dioxide.... %	9.4	7.8	6.6	4.3	6.3	10.3	4.3	4.6	4.9	8.1	12.0	5.3	12.0	7.2	8.8	9.2	4.3	5.3	5.0	2.6
Carbon Monoxide... %	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.2	0.4	0.3	0.2	0.4	0.4	0.3	0.3	0.4	0.3	0.4	0.5	0.3
Weight of dry flue gases, per lb. of fuel as fired. lb.	19.5	22.7	27.1	36.5	27.1	18.0	38.2	36.0	34.1	21.9	14.8	31.5	14.9	25.0	19.6	18.9	34.0	28.9	30.3	43.1
Excess Air ... %	105	139	174	278	185	86	287	270	254	130	64	232	65	153	118	110	290	234	248	500
HEAT ACCOUNT:																				
Heat carried away by ventilating air.. %	60.6	65.7	50.0	61.2	36.8	43.6	58.7	54.1	65.2	53.2	43.5	50.9	41.1	42.9	40.6	45.9	39.3	54.4	25.8	56.3
Heat passing through room walls ... %	21.0	16.7	24.6	18.1	34.2	31.3	20.2	26.0	16.3	29.1	36.4	24.9	38.7	28.8	29.4	32.3	19.8	20.3	35.2	20.9
Heat loss in flue gases. %	11.1	8.6	16.0	17.0	19.7	17.0	13.8	12.9	10.9	14.9	15.1	10.9	13.4	19.7	17.4	14.2	32.3	16.5	30.6	11.9
Heat loss in ash.. %	2.4	3.6	5.6	2.3	5.6	4.1	7.1	5.8	7.1	2.4	1.2	8.7	3.5	3.7	5.2	2.7	3.0	2.8	2.7	6.5
Heat unaccounted for. %	4.9	5.4	3.8	1.4	3.7	4.0	0.2	1.2	0.5	0.4	3.8	4.6	3.3	4.9	7.4	4.9	5.6	6.0	5.7	4.4
Heat by radiation. %	9.7	14.7	13.7	13.4	11.1	10.0	12.6	11.4	13.1	15.6	12.6	10.6	13.8	15.7	15.6	10.4	1.8	5.5	11.1	15.6
Heat by convection. %	71.9	67.7	60.9	65.9	59.9	64.9	66.3	68.7	68.4	67.3	66.3	65.2	66.0	56.0	54.4	67.8	57.3	69.2	49.9	61.6
Overall thermal efficiency. %	81.6	82.4	74.6	79.3	71.0	74.9	78.9	80.1	81.5	82.3	79.9	75.8	79.8	71.7	70.0	78.2	59.1	74.7	61.0	77.2
Total heat in fuel minus ash plus flue losses. %	86.5	87.8	78.4	80.7	74.7	78.9	79.1	81.3	82.0	82.7	83.7	80.4	83.1	76.6	77.4	83.1	64.7	80.7	66.7	81.6

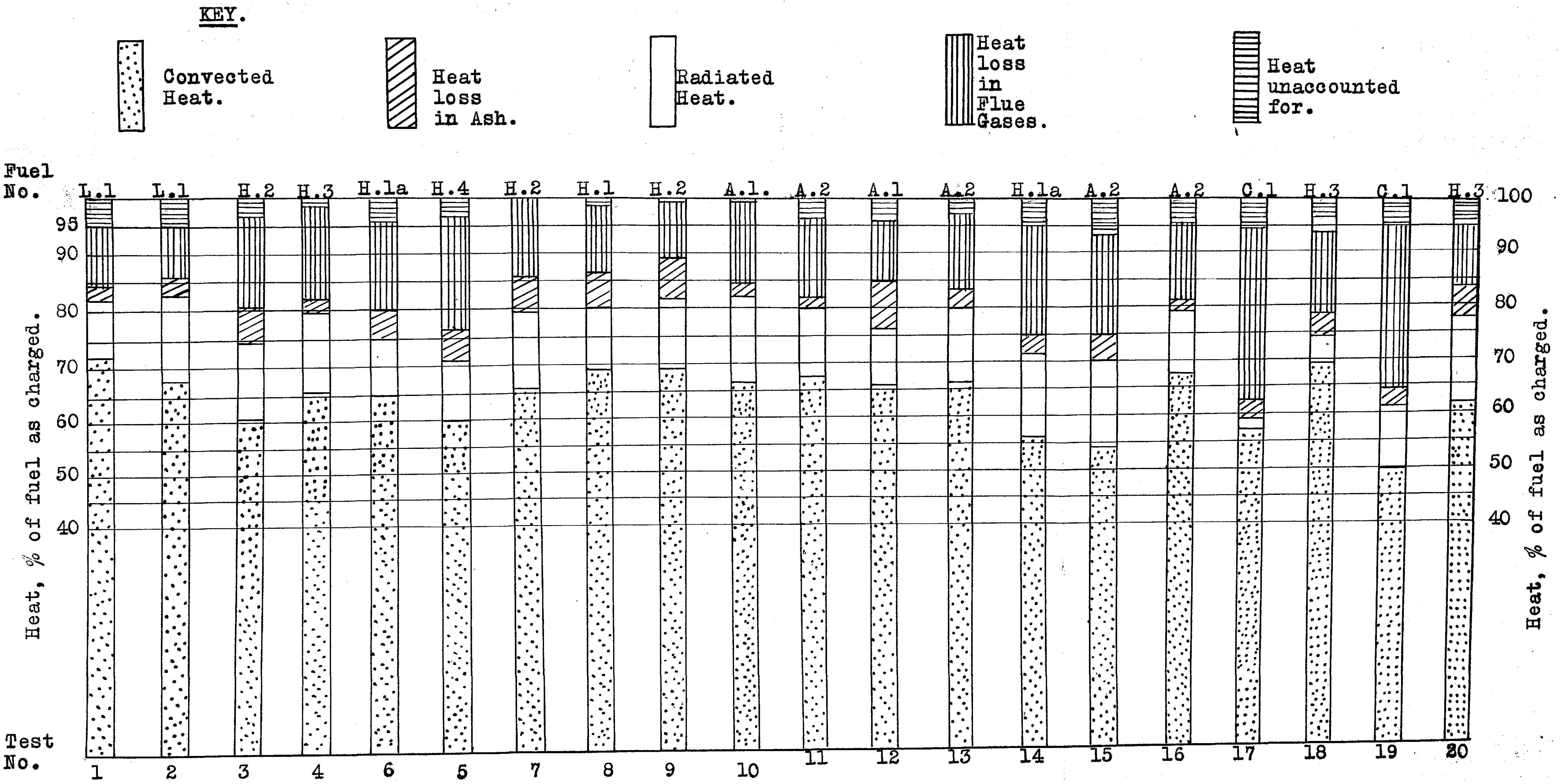


FIGURE 27- Chart showing heat balances obtained for Stove Tests.

It is interesting to observe that a low percentage of excess air is not usually associated with a low flue loss. In tests Nos. 6 and 11, using high rates of combustion in the smallest stove tested, the fuels burned so freely that the height of the incandescent fuel bed was increased above the normal and the oxygen was more completely used up. The flue gas temperatures obtained in these tests were, however, much higher than those obtained in the other tests on the same size of stoves. Again, in the case of each closed stove test the flue loss is always lower and the weight of dry flue gases per pound of fuel fired and the percentage of excess air are always higher for the lower flue draught. The flue loss is very low in the case of test No. 2 when the highly combustible low temperature coke was burned at a slow rate.

The performance of the various fuels may be conveniently compared by a study of the average results given in Table L.

The flue losses are observed to increase considerably with increase of flue draught in the case of anthracite or high temperature coke. The most important observation however, is that the flue losses, percentages of heat radiated and convected and consequently the overall efficiencies obtained when burning anthracite or oven coke smalls in these closed stoves were very similar. Since the oven coke has a lower calorific value than the anthracite an additional 10% by weight of this fuel must/

TABLE L. - AVERAGE RESULTS OF DOMESTIC STOVE TESTS:

Fuel.	Stove.	Flue Draught. in. water.	Heat loss in flue gases. %	Heat radiated. %	Heat convected. %	Over-all efficiency. %	Fuel fired per therm delivered to room. lbs.	Cost per therm delivered to room. pence.	Weight of flue gases per lb. of fuel as fired. lbs.
High temperature coke.	No. 2 Jeunesse.	0.04	16.7	12.2	63.6	75.8	10.9	1.56	29.6
Anthracite.			15.0	14.1	67.0	81.1	9.2	1.97	18.3
Low temperature coke.	No. 2 Jeunesse.	0.02	11.1	12.2	69.8	82.0	9.4	1.99	19.5
High temperature coke.			11.9	12.2	68.6	80.8	10.2	1.41	35.0
Anthracite.			10.9	10.6	65.2	75.8	9.5	2.05	31.5
High temperature coke.	No. 4 Jeunesse.	0.06	19.7	15.7	56.0	71.7	11.3	1.63	25.0
Anthracite.			17.4	15.6	54.4	70.0	11.0	2.07	19.2
High temperature coke.	No. 3 Esse Dura (doors closed.)	0.025	16.5	5.5	69.2	74.7	12.1	1.64	28.9
Bituminous coal.		0.05	32.3	1.8	57.3	59.1	13.5	1.95	34.0
High temperature coke.	No. 3 Esse Dura (doors open).	0.025	11.9	15.6	61.6	77.2	11.7	1.58	43.1
Bituminous coal.		0.05	30.6	11.1	49.9	61.0	13.0	1.88	30.3
Low temperature coke.	Averages of tests in all closed heating appliances.	0.015	9.8	12.2	69.8	82.0	9.4	1.99	21.1
High temperature coke.		0.035	15.5	12.6	63.8	76.4	11.0	1.55	27.1
Anthracite.		0.039	14.1	13.0	64.3	77.3	9.8	2.10	20.3
Bituminous coal.		0.045	31.5	6.5	53.6	60.1	13.3	1.92	34.0

must be added to give the same output of heat to the room, but the price of coke is so much lower than that of anthracite that the cost per therm delivered to the room is nearly 30% in favour of coke. The only advantage which anthracite has over coke as a fuel for closed stoves is its ability to burn unattended for 30 hours compared with 12-15 hours in the case of coke. Although coal is as cheap as oven coke the high flue loss obtained makes it almost as expensive to burn as low temperature coke or anthracite.

Designing of an Open Coke Grate.

An examination of the effect of certain variations of design of open grates on the efficiency and the ease of igniting and burning of high temperature cokes was carried out.

The same type of canopy and fret were used for each grate so that another variable would not be introduced which might mask the effect of other alterations. The distance between the canopy and the top of the front bar and, therefore, the surface of the fuel, was kept constant (12 in.) for all grates. The fret was kept in position during a test and air was admitted to the ash pit through openings in it. Increased radiant efficiencies could have been obtained by using smaller canopies and no fret. The series of fuels used for these tests comprised a bituminous coal of very good quality, four oven/

oven cokes, a low temperature coke and two gas retort cokes. The description and analyses of these fuels are given in Tables LI and LII.

OPEN GRATE NO. 1.

A portable open grate of ordinary design was chosen for the first series of experiments and its construction is shown in Fig. 28.

The depth of this grate (from front bars to back of grate) is comparatively small, being only 7 in. The width was 16 in., height of the front bar 6 in.; the grate area 105 sq.in.; the capacity about 0.52 cb.ft. A close fitting fret is not supplied with this grate and the draught through the fuel-bed was, therefore, unchecked during the test.

A bituminous coal and three oven cokes were burned at their maximum rates, while the usual observations were made.

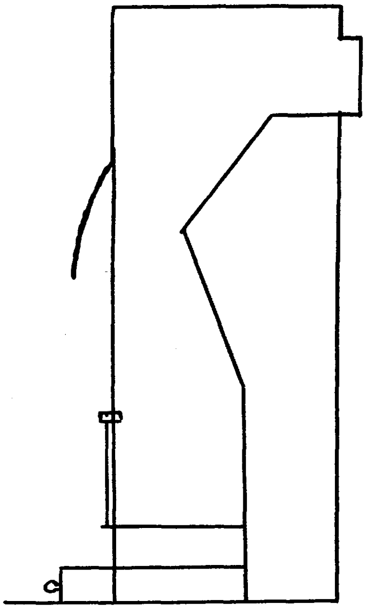


FIGURE 28

Open Grate No. 1.

The fires were kindled with paper plus 1¼ lb.. of wood and 20 lb. of coal or 12 lb. of coke. More rapid kindling was obtained when a piece of sheet iron was placed over the front of the fire for 15-20 minutes to increase the draught through the fuel bed./

Table LI - Description of Fuels used in Open Grate Tests

Fuel No.	Description of Fuel	Conditions of Manufacture of Oven Cokes				Bulk Density lb./cb.ft.
		Oven Width in.	Flue Temp. °C.	Coking Period hr.	Compressed or Loose charged coals	
H.1	High temperature oven cokes.	14	1300	15	L	24.5
H.3		17	1100	30	C	27.0
H.4		18	1100	30	L	25.5
G.1	Vertical retort cokes					20.0
G.2						20.5
L.2	Low temperature coke					19.0
A.2	Anthracite					47.8
C.1	Bituminous Coal					43.7

Table LII - Analyses of Fuels used in Open Grate Tests.

Fuel No.	Size in.	Moisture %	Ash %	Volatile Organic Matter %	Fixed Carbon %	Net Calorific Value B.Th.U/lb.
H.1	1-1½	0.4	7.4	3.4	88.8	13,050
	1-2½	0.5	8.5	2.2	88.8	12,920
H.3	1-1½	0.3	7.6	1.3	90.8	13,000
	1-2½	0.2	7.2	1.0	91.6	13,100
H.4	1-2½	0.4	7.6	0.7	91.3	13,070
G.1	1-2½	2.5	5.2	7.1	85.2	13,200
G.2	1-2½	2.2	8.9	6.0	82.9	12,640
L.2	1-1½	3.5	3.9	4.3	88.3	13,150
	1½-2	0.5	4.1	4.5	90.9	13,550
A.2	1-2½	2.1	8.8	4.8	84.3	12,930
C.1	1-4	4.0	3.0	28.3	64.7	13,000

bed.

The chief results are contained in Table LIII. When the thermopile was placed 51 in. from and at the same height from the floor as the centre front of the fire, a reading of 100 B.Th.U/sq.ft./hr. represents a fairly good fire and the time required to attain this value is given for each fuel.

Table LIII - Results of Tests on Open Grate No. 1

Test No.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
1	Coal No. C.1.	1-4	20.5	45	3.5	2.5
2	Oven Coke No. H.1.	1-2½	21.8	55	1.7	3.7
3	" " " H.1.	1-1½	15.9	60	1.3	6.0
4	" " " H.3.	1-2½	18.6	200	1.1	7.0
5	" " " H.3.	1-1½	19.7	47	1.4	6.0
6	" " " H.4.	1-2½	19.0	68	1.5	6.7

The feature of these results is the very great difference in the rates of combustion of the coal and the oven cokes. An extremely hot fire was obtained with the coal. The/

The 1-2½in. nuts from coke No. H.1., the most combustible and reactive of these oven cokes, performed better than any of the other cokes but even it burned too sluggishly to be satisfactory. This coke also gave the smallest quantity of unburnt fuel when the fire died out. In the test of the 1-2½" nuts of coke No. H.3., 12 lb. of coke was not a sufficient bulk to give a bright fire. The fire burned very slowly until a further 5 lb. of coke were added at the first refuelling.

From these tests there seems little doubt that the efficiencies of the oven coke fires were affected by the rates of combustion. With this grate the coke burned brightly in the heart of it, but the pieces of coke in front did not burn freely and only screened off the radiation. The capacity of the grate must, therefore, be increased so that the quantity of coke burning brightly in the heart of the fire is sufficient to supply the heat necessary to keep the pieces of coke at the front of the grate incandescent. For a normal sized room an open grate which can burn about 2 lb. of fuel per hour is required.

OPEN GRATE NO. 2.

The experiments just described indicate that to burn oven coke more satisfactorily in an open grate,

(1) a method of increasing the draught through the fuel bed/

bed when kindling and immediately after refuelling should be found.

(2) a grate having a larger capacity is necessary.

In an attempt to meet these requirements open Grate No. 2 was built. The depth of the fire was 13½in. and a back flue was constructed by placing a firebrick in the position shown in Fig. 29. The back flue or the front flue could be brought into operation by means of a damper. The total grate area was 152 sq. in., the width of the grate 16 in., the height of the front bar 7 in., the depth of the back flue at the bottom 3½in., and the height of the bottom of the flue dividing brick from the bottom grate 5½in.

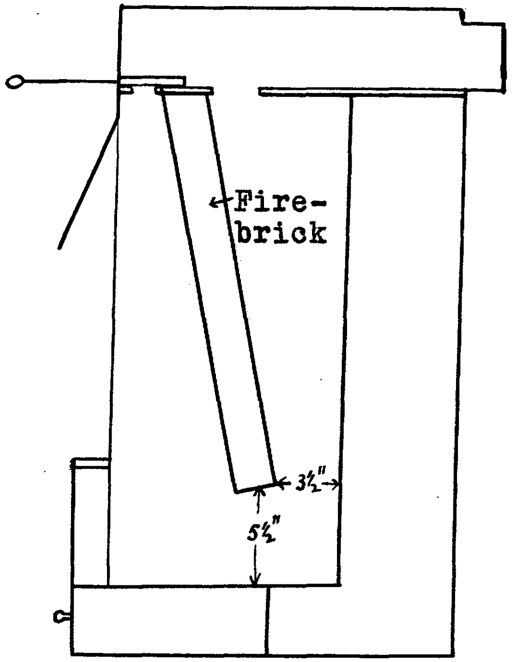


FIGURE 29

Open Grate No. 2.

In this and subsequent tests the following general procedure was adopted:-

The paper and wood (1½ lb.) were placed in the front of the empty grate. The unburnt coke from a previous test was placed on top and behind the wood. As much fresh coke as possible was then filled into the grate and the paper ignited. When/

When the paper had burned away, more coke was added. It was found advantageous to keep the back flue open (and the front flue closed) for the initial 20-30 minutes. At the end of that period the coke at the bottom and back of the grate burned freely and the front flue was then used. After a certain period, or alternatively, when the centre thermopile reading had dropped to a given value the back flue was opened, the ash removed from the fire and fresh fuel added. The front flue was again used after an interval of about 15 minutes.

Table LIV - Results of Test on Open Grate No. 2.

Test No.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
7	Oven Coke No. H.1.	1-2½"	20.1	75	2.0	4.0

Coke No. H.1. was burned in this grate with poor results. The efficiency obtained was lower than that of grate No. 1. Although the rate of combustion was higher, the time required to obtain a bright fire, as denoted by a centre thermopile reading of 100 B.Th.U./sq.ft./hr., was increased by 20 minutes. This was caused by the fuel at the front/

front of the grate remaining dull and the increase in the depth of the grate had perhaps been excessive.

OPEN GRATE NO. 2(a)

This grate had the same construction as No. 2 but the 3 in. extension on the bottom grate of No. 2 was removed. The same front bar was used but the depth of the fire was now 10½in. and the width 14 in.

The results of the test are set forth in Table LV.

Table LV - Results of Test on Open Grate No. 2(a)

Test No.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
8	Oven Coke No.H.1.	1-2½"	22.1	115	1.5	2.5

The radiant efficiency was the same as that of grate No. 1., but the reduction of the grate area caused a large increase in the time of kindling and recovery of the fire after refuelling. The weight of unburnt fuel was, however, very much lower.

OPEN/

OPEN GRATE NO. 3.

In grates Nos. 2 and 2(a) the air spaces in the bottom grate were not continued underneath the back flue. The draught through these fires when the back flue was opened seemed to be too much from front to back. The coke at the back of the fire kindled quickly enough but when the front flue was opened the coke in front of the flue dividing brick ignited very slowly. It was thought that if the air spaces in the bottom grate were continued to the back of the back flue, air would pass up through the hot coke at the back of the fire and then forward and upwards through the front flue and thus assist the kindling of the coke on the top and front of the fire. This alteration would also allow the ash to be removed easily from the back of the fire.

Open Grate No. 3 was made accordingly and the construction is shown in Fig. 30.

The depth of the back flue was increased to 5½in. and the height of the bottom of the flue dividing firebrick was increased to 9 in. to assist further in creating an upward draught through the fire. The total depth of the bottom grate was only 8 in., but it was continued below the back flue. The height of the front bar was 8¼in., the width 16 in., and the grate area 104 sq.in. The capacity of the fire was increased and now 16 lb. of coke could be charged.

The/

The grate was charged with paper plus 1½ lb. wood and 16 lb. of coke No. H.1. Six lb. of coke were added at 2 hr. intervals.

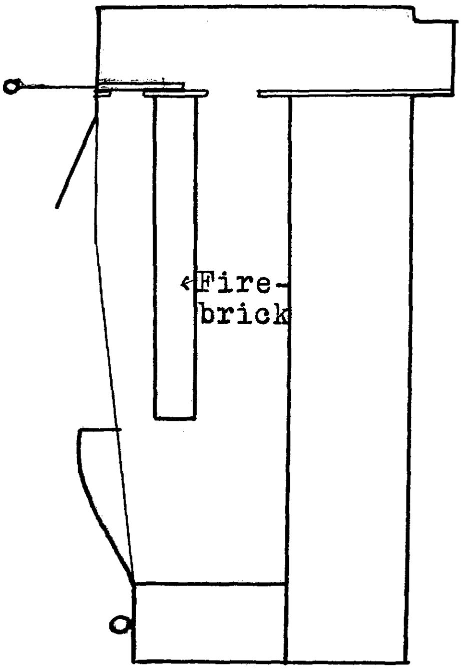


FIGURE 30

Open Grate No. 3.

The most important observations made during this test are given in Table LVI.

The rate of kindling was increased to that obtained with grate No. 1. but, owing to the larger capacity of grate No. 3, the rate of combustion and radiation was considerably increased. The radiant efficiency was stillapproximately the same as that obtained for grate No. 1; that there was no increase may be due to the screening of part of the back of the fire by the 2 in. thick flue dividing brick.

Table LVI - Results of Test on Grate No. 3

Test No.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
9	Oven Coke No.H.1.	1-2½"	21.2	53	2.4	3.5

OPEN GRATE NO. 3 (a).

The appearance of grate No. 3 was slightly improved by reducing the height of the front bar to 7 in. No other alterations were made for grate No. 3(a).

The chief results obtained by burning coal No. C.1. and oven coke No. H.1. are contained in Table LVII.

Table LVII - Results of Tests on Open Grate No. 3(a)

Test NO.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
10	Coal No.C.1.	1-3	19.7	45	3.4	2.5
11	Coke No.H.1.	1-2½	21.7	60	2.4	4.0

The performance of coke No. H.1. in grates Nos. 3 and 3(a) was almost identical. Coal No. C.1. gave a lower radiant efficiency but kindled and burned more rapidly than the oven coke.

OPEN GRATE NO. 4.

Further improvement in the performance and the appearance of the grate was now sought. The firebrick flue dividing brick used in the experiments described was 2 in. thick and presented/

presented a somewhat clumsy appearance and in grate No. 4, shown in Fig. 31 this flue dividing brick was replaced by a cast-iron plate. The reduction of the thickness of the flue partition by almost 2 in. will lessen the screening of the radiation from the back of the fire without making any reduction of the depth of the back flue. Small bolts were attached to the bottom corners of the plate and fitted into holes made in the side bricks of the grate. The plate could be moved by a rod attached to the top so that a back flue or front flue or part of each was brought into operation.

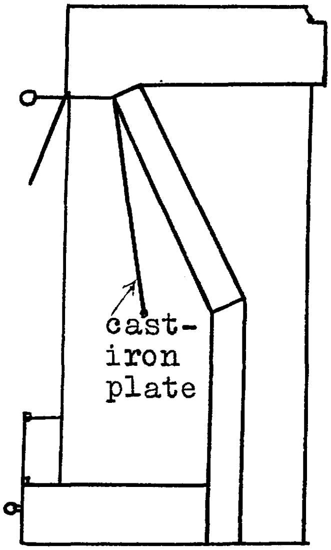


FIGURE 31

Open Grate No. 4.

The appearance of the grate was further improved by using a lower front-bar (4½in. high). The bottom of the flue dividing plate was still 3½in. in front of the back brick and 9 in. above the bottom grate. The grate area was 127 sq. in.

The whole arrangement was extremely simple and possessed the great advantage that any grate could be easily converted to this construction.

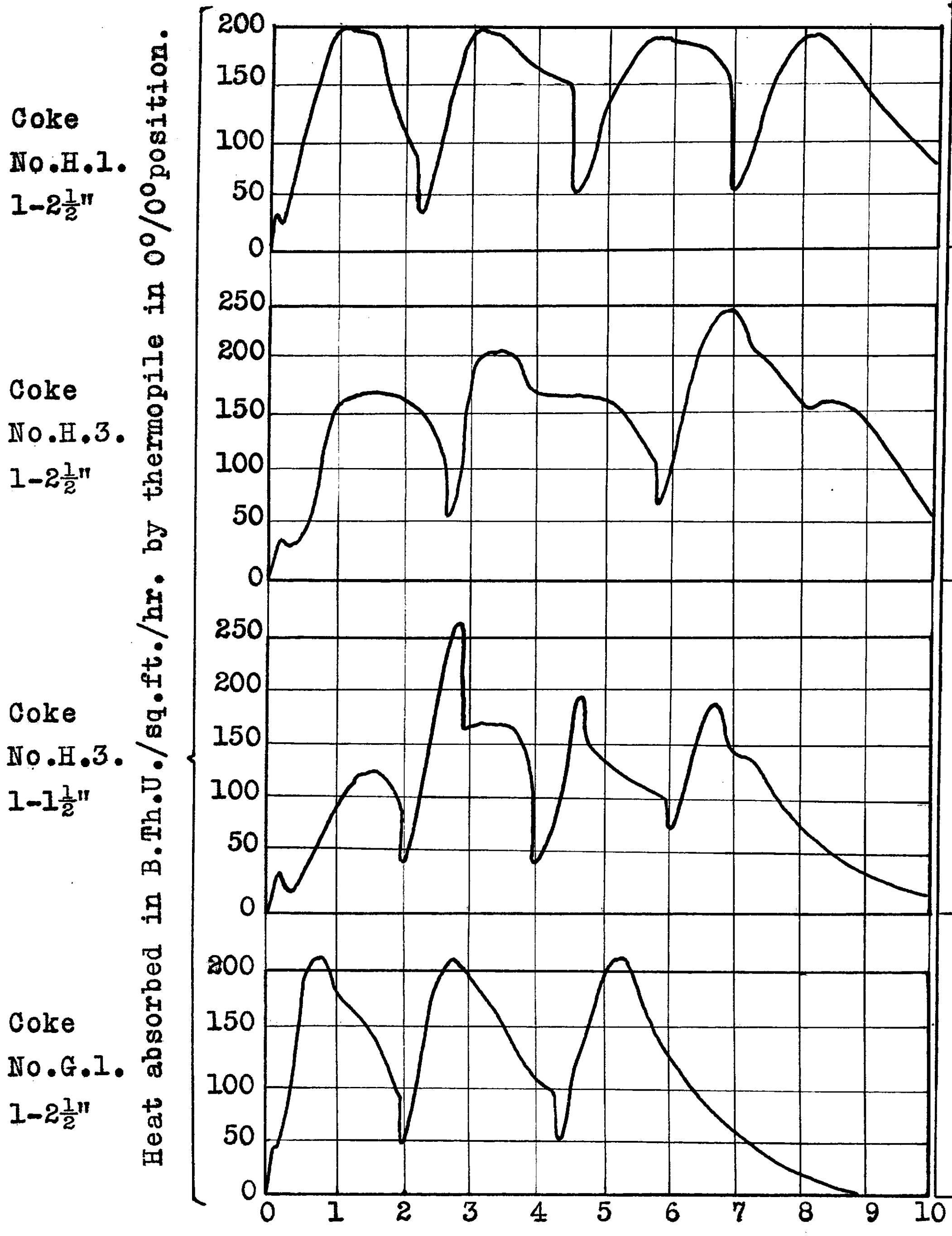
The results of the examination of a series of fuels when burned in this grate are given in Table LVIII and Fig. 32 shows the variation of the heat absorbed by the thermopile, expressed in B.Th.U./sq.ft./hr. when it was placed 51 in. from and at the same height above the floor as the centre front of the fire./

fire. A reading of 100 B.Th.U./sq.ft./hr. with the thermopile in this $0^{\circ}/0^{\circ}$ position represents a good fire. The very considerable increases obtained in the radiant efficiencies and speed of kindling show the superiority of this grate over any of the former ones.

<u>Table LVIII - Results of Tests on Open Grate No. 4 (a)</u>

Test No.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
12	Oven Coke No.H.1.	1-2½	24.4	32	1.9	4.7
13	" " " H.1.	1-1½	24.6	36	2.1	3.0
14	" " " H.1. (back flue used almost throughout test).	1-1½	20.4	35	2.4	2.5
15	Oven Coke No.H.3.	1-2½	27.0	45	2.0	7.1
16	" " " H.3. (back flue used almost throughout test).	1-1½	23.4	60	2.1	5.0
17	Oven Coke No.H.4.	1-2½	21.5	65	1.8	5.7
18	Vertical Retort Coke No.G.1.	1-2½	30.0	23	2.3	1.5
19	Vertical Retort Coke No.G.2.	1-2½	28.4	35	2.3	2.0

Oven/



Fuel Additions	
Time. hour	Wt. lb.
0 2⅛ 4½ 6⅞	12 9 6 6
0 2⅝ 5⅝	15 9 8
0 2 4 6	14¾ 3½ 5 5
0 2 4⅜	12 8 5

FIGURE 32 - Radiation Charts for tests on Open Grate No. 4.

Oven coke No. H.4. was the least combustible and reactive of these fuels and did not burn very brightly. There was no carbon monoxide flames burning above the fuel. The other cokes gave attractive fires.

The two vertical retort cokes Nos. G.1. and G.2. and especially the former kindled quickly and gave high radiant efficiencies and very small quantities of unburnt fuel when the fire died out. The rate of radiation increased rapidly to a high value even though the ash pit was completely closed but this value was not maintained and the rate of radiation decreased rapidly. It is observed from Fig. 32 that the oven coke especially No. H.3. gave more uniform rates of radiation throughout the test. Oven coke No. H.1. gave a bright fire in a very short time.

The effectiveness of the back flue in assisting the kindling and recovery after refuelling of coke fires is clearly demonstrated by the test on the smaller size of coke No. H.3. When the back flue is in operation the air passing through the fuel bed is not only increased because no air is allowed to pass directly to the chimney underneath the canopy, but by the fact that the flue gases are heated to a higher temperature and an actual increase in the flue vacuum is obtained. The flue vacuum is doubled and often trebled when the fire is put on to the back flue.

OPEN GRATE NO. 5.

An ordinary 16 in. barless open grate was converted for burning coke in a similar manner to that of grate No. 4. The construction of this grate may be seen from Fig. 33. The flue dividing plate was made in two parts, the bottom part being fixed in the usual position, while the other part being hinged to this could be operated by means of a poker to close or open the front or back flue. This arrangement was suitable for some types of grates. One horizontal bar 2 in. high was fitted and the well bottom grate added another 1 in. to the height of the fuel. The grate area was 112 sq.in., 15 sq.in. less than grate No. 4.

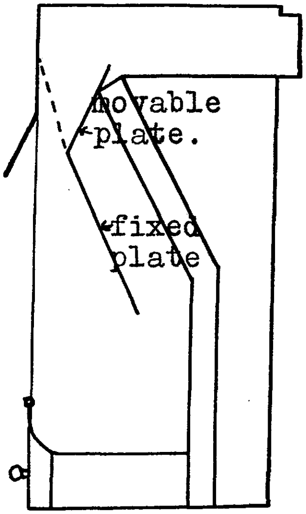


FIGURE 33

Open Grate No.5

Cokes Nos. H.1. and H.4. were tested in this grate and the observations are set out in Table LXIX.

The less combustible and reactive coke No. H.4. gave the least satisfactory results. Both sizes of coke No. H.1. burned efficiently and kindled in a reasonable time. All the kindling times were however, poorer than those obtained with grate No. 4 which had a larger grate area and a higher front bar and therefore a larger fuel bed.

Table/

Table LXIX. - Results of Tests on Open Grate No.5.

Test No.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
20	Coke No. H.1.	1-2½	26.5	45	1.8	4.0
21	" " H.1.	1-1½	26.0	40	1.7	4.0
22	" " H.4.	1-2½	23.8	55	1.7	5.0

OPEN GRATE NO. 5 (a)

To demonstrate the effect of the flue dividing plate a series of tests were carried out in the same grate but with this plate removed.

The same fuels and in addition coal No. C.1. were burned in the new grate. The results are given in Table LX.

The coke could be piled up a little higher in this grate now that the back plate had been removed and usually a faster rate of burning was obtained. A longer period was, however, necessary to obtain a bright fire when kindling or refuelling. The weights of unburnt fuel remaining at the end of the tests were increased but the most noteworthy result of the removal of the back plate is the reduction of the radiant efficiency of each coke fire. The reason for this result is found/

found in the fact that the removal of the back plate caused a decrease in the rate of increase of the radiation when kindling and after refuelling, a longer period being required for the coke in the front of the grate to become incandescent although the coke in the centre and back of the grate burned freely.

Table LX - Results of Tests on Open Grate No. 5 (a)

Test No.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
23	Coal No. C.1.	1-4	20.9	37	2.3	1.6
24	Coke No. H.1.	1-2½	22.6	52	2.2	4.8
25	Coke No. H.1.	1-1½	22.6	55	1.8	4.3
26	Coke No. H.4.	1-2½	22.9	60	1.7	5.8

At this point it is convenient to examine more closely the reason for the increased rate of kindling and recovery of the fire after refuelling when the special back flue is brought into operation. When the fire is replenished and the back flue opened the coke at the back of the grate becomes incandescent very quickly and that in the front of the fire is ignited chiefly by the heat radiated from this rapidly burning coke. Now the quantity/

quantity of heat radiated is proportional to the fourth power of the temperature of the radiating surface so that even a 20% increase of the temperature would more than double the quantity of heat radiated. Therefore, since the use of the back flue increases to a great extent the temperature of the coke at the back of the grate, the rate of ignition of the coke at the front of the fire and the rate of increase of the rate of radiation of the fire are very much increased.

OPEN GRATE NO. 6.

Open grate No. 1 used in the first series of tests was next converted for burning coke.

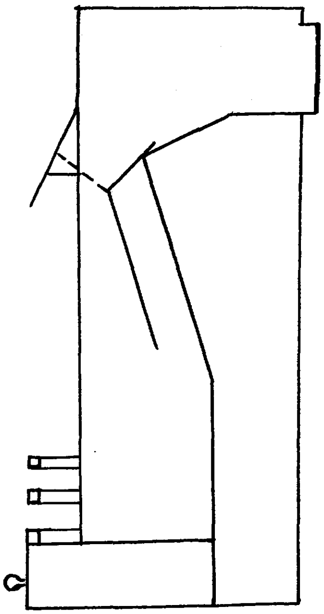


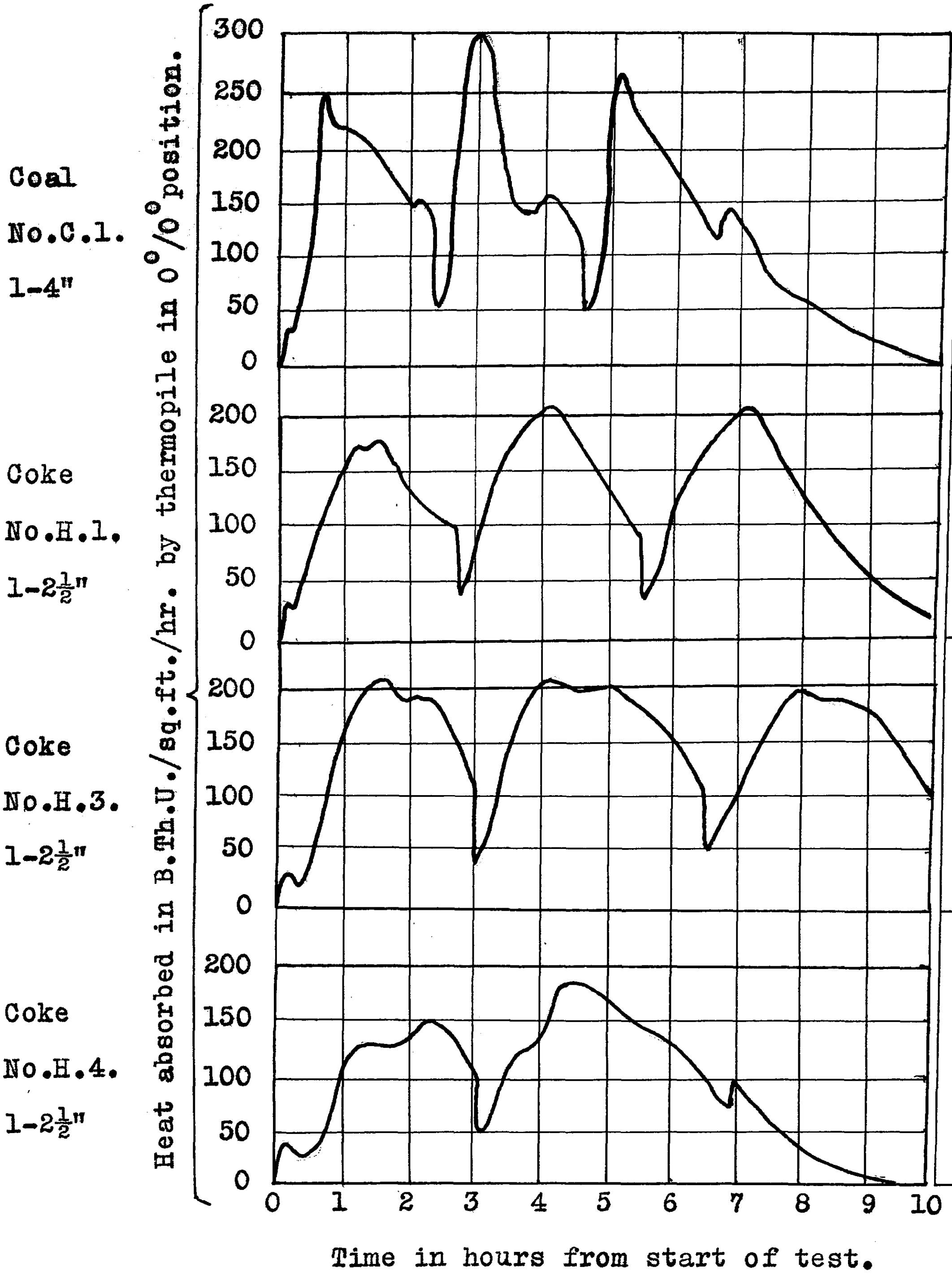
FIGURE 34

Open Grate No. 6.

Fig. 34 shows the construction of the converted grate. The fire was 16 in. wide and 7-10 in. deep; the curved front bar was 4 in. high and the grate area 127 sq. in.

The results of the tests with this grate are contained in Table LXI and Fig. 35.

Cokes Nos. H.1. and H.3. gave higher efficiencies and kindled almost as quickly as coal No. C.1. The radiation curve shown in Fig. 35 for coal No. C.1. was similar to those obtained for the vertical retort/



Fuel Additions	
Time. hour	Wt. lb.
0	14
2¼	8
4¾	9
0	15
2¾	9
5½	9
0	15
3	9
6½	8
0	15
3⅛	8½

FIGURE 35 - Radiation Charts for tests on Open Grate No. 6.

retort cokes and the oven cokes again burned more uniformly throughout the tests. As in previous tests, the least combustible coke No. H.4. gave the lowest efficiency.

Table LXI - Results of Tests on Open Grate No. 6.

Test No.	Fuel	Size of fuel in.	Radiant Efficiency %	Time to give bright fire min.	Rate of combustion lb/hr.	Wt. of unburnt fuel lb.
27	Coal No. C.1.	1-4	21.2	35	2.7	1.8
28	Coke No. H.1.	1-2½	27.2	40	2.1	4.3
29	Coke No. H.3.	1-2½	28.3	40	2.2	5.5
30	Coke No. H.4.	1-2½	23.7	55	1.9	5.0

MANUFACTURE OF AN OPEN GRATE COKE

Even the most combustible of the oven cokes examined in the specially constructed open grate required 1 lb. of wood for kindling and gave about 4 lb. of unburnt coke when the fire died out. Therefore, unless the fire could be kindled by gas, thus obviating the use of wood and also the removal of the unburnt coke, the burning of oven coke would receive very little support. Another point which would hinder the use of ordinary oven coke as an open grate fuel is the very fine state of division of the ash. This fine ash has a low density and not only spoils the appearance of the fire by forming a covering over the pieces of burning coke but would find its way into the room when the fire was raked.

EXPERIMENTAL OVEN TESTS

Significance of the Particle Size of Coal.

The following series of tests were carried out to determine the possibility of producing an oven coke which would be more suitable for burning in an open grate. The treble, double and single nuts of two coals, one (No. 18), having a low volatile matter content and the other, No. 38 having a high volatile matter content were carbonised in the experimental oven described on page 11. The uncrushed 0-3 in. screenings of coal No. 18 and for comparative purposes, the crushed/

crushed drosses of both coals and the crushed 0-3 in. screenings of coal No. 18 were also coked.

Each oven of coke was screened and shatter tests then made on a representative sample. The results are given in Table LXII.

Considering first the cokes made from the various sizes of coal No. 18 it will be observed that the sizes of the cokes increase as the sizes of the coal nuts decrease and that while the shatter indices of the cokes made from the trebles and the doubles are very similar (coke No. 18(d)E seems to be abnormal) those of the cokes made from the singles are higher. The percentages of breeze from the screening and the shatter tests of all these cokes are similar. The shatter indices of the coke made from the uncrushed 0-3 in. screenings are lower than might have been expected but the 2 in. and under shatter indices of the coke made from coal No. 18 when crushed are very much higher than those of the cokes made from the uncrushed coal.

In all tests, except that with the uncrushed 0-3 in. screenings of coal No. 18, the same volume of coal was charged to the experimental oven and it should be noted that the weight of the charge appreciably increased as the size of the coal nuts increased.

The results of the examination of the cokes made from coal No. 38 show that, as in the case of those made from coal No. 18, the size of the resultant coke increases with/

TABLE LXII - RESULTS OF EXPERIMENTAL OVEN TESTS ON THE COKING OF UNCRUSHED COALS.

Coke No.	Coal used.	Coking Period hr.	Moist. in Charge %	Wt. of air-dry Charge lb.	Proximate Analysis of Coal.			Coke Yield % on air-dry coal.						Screening Analysis of Cokes.						Shatter Indices of Cokes.						
					Moist. %	Ash %	Vol. Org. Matter %	On 4"	On 3"	On 2"	On 1"	On ½"	Thro' ½"	On 4"	On 3"	On 2"	On 1"	On ½"	Thro' ½"	4"	3"	2"	1½"	1"	½"	Thro' ½"
18(t)E.	Trebles of 18 uncrushed.	20	3.2	896	1.0	3.6	25.8	-	-	-	-	-	-	59	71	86	96	97.8	2.2	19	41	67	81	91	96.2	3.8
18(t)E.1.	" " "	16	3.0	898	1.0	3.2	25.8	48	60	72	78	78.8	1.4	59	75	87	97	98.2	1.8	26	38	66	82	92	96.4	3.6
18(d)E.	Doubles of 18 "	20	4.7	-	0.9	6.1	25.3	-	-	-	-	-	-	75	81	89	95	96.4	3.6	14	30	55	69	82	93.4	6.6
18(d)E.1.	" " "	18	3.5	879	0.9	6.1	25.3	53	64	71	76	77.1	1.5	68	81	90	97	98.1	1.9	28	41	68	79	90	96.2	3.8
18(s)E.	Singles of 18 "	20	5.4	-	1.1	6.6	26.5	-	-	-	-	-	-	86	89	94	97	98.3	1.7	38	51	72	82	90	95.8	4.2
18(s)E.1.	" " "	16	5.6	840	1.1	6.6	26.5	57	68	72	76	76.8	1.2	74	87	93	97	98.5	1.5	30	56	78	87	93	96.6	3.4
18(u)E.	0-3" of 18 "	20	8.2	808	1.0	7.0	26.0	49	61	70	75	76.2	1.8	62	79	90	97	97.7	2.3	29	50	73	85	92	96.4	3.6
18.E.	0-3" of 18, crushed.	20	3.5	811	1.0	7.1	26.2	51	62	72	75	75.8	1.9	66	80	93	97	97.5	2.5	18	42	83	93	97	98.6	1.4
18.E.1.	" " "	16	4.5	-	"	"	"	-	-	-	-	-	-	58	80	94	97	97.8	2.2	14	44	85	94	97	98.5	1.5
18.E.2.	" " (off in 16hrs.)	50	4.8	-	"	"	"	-	-	-	-	-	-	68	86	95	97	98.0	2.0	26	50	89	95	97	98.5	1.5
18.E.2.	" " " "	50	5.5	-	"	"	"	-	-	-	-	-	-	57	81	93	97	97.7	2.3	20	43	88	95	97	98.5	1.5
3.E.	0-⅜" of 18, crushed.	26	9.0	-	1.1	8.2	25.8	-	-	-	-	-	-	78	88	94	97	98.0	2.0	43	71	86	93	97	98.2	1.8
3.E.1.	" " "	18	8.4	-	1.1	8.2	25.8	-	-	-	-	-	-	65	83	93	98	97.9	2.1	30	60	85	93	96	98.0	2.0
38(t)E.	Trebles of 38 uncrushed.	18	2.0	-	1.8	3.2	34.8	-	-	-	-	-	-	37	51	73	94	95.4	4.6	7	17	43	65	82	93.9	6.1
38(d).E.	Doubles of 38 "	18	2.8	-	2.0	5.8	34.0	-	-	-	-	-	-	44	56	74	93	94.7	5.3	4	12	38	52	76	92.4	7.6
38(s)E.	Singles of 38 "	18	3.0	-	1.9	8.8	34.1	-	-	-	-	-	-	77	82	88	94	95.6	4.4	23	36	50	60	77	90.8	9.2
38(p)E.	Pearls of 38 "	16	5.6	-	2.0	9.0	32.3	-	-	-	-	-	-	77	85	92	96	97.9	2.1	41	54	67	74	84	94.0	6.0
38(p)E.c.	Pearls of 38, crushed.	17	5.0	-	2.1	9.3	32.7	-	-	-	-	-	-	61	77	89	95	95.8	4.2	15	34	66	78	89	96.4	3.6

with decrease of the size of the coal. All the cokes made from the various sizes of coal No. 38, having the higher volatile matter content are less resistant to shatter than the corresponding cokes made from coal No. 18. The percentage of breeze from each of the No. 38 cokes is also comparatively high and is found to increase when the coal nut size is decreased. The strongest coke is again made from the crushed coal.

OPEN GRATE TESTS

Each of the cokes described above were examined when burned in open grate No. 6(a). For comparative purposes the performances of a bituminous coal, gas cokes, and ordinary full scale oven cokes were also tested.

The general construction of the open grate is shown in Fig. 36. It differs from grate No. 6 only in that it is provided with a shaking bottom grate, for convenience in removing the ash. The movable part of the bottom grate is suitably pivoted and supported. The fire basket is supported $\frac{1}{8}$in. above the shaker and is sloped at an angle of about 45° and,/

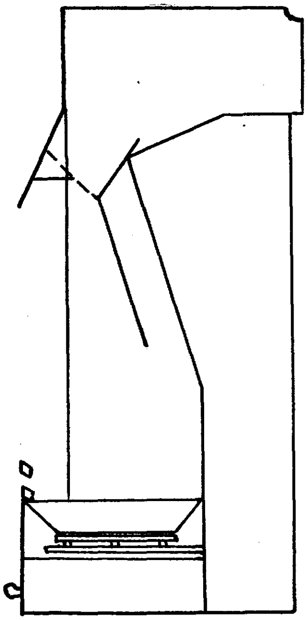


FIGURE 36

OPEN GRATE NO. 6(a)

and, having a large number of air spaces in it, assists the removal of the ash and ensures a sufficient supply of air to the sides of the fire. Two horizontal curved front bars 3 in. high are fitted and with the 2 in. well of the grate this enables a fuel bed 5 in. high at the front and about 9 in. high at the back to be used. The fire was contracted to a width of 12 in. and was 7-10 in. deep.

Exactly the same procedure was adopted in this series as in the open grate tests already described. The fuels are described in Table LXIII, their analyses are given in Table LXIV and the chief results of the tests are recorded in Table LXV.

Kindling.

The most important items in Table LXV giving the results of the open grate tests are probably those relating to the kindling of the fire and its recovery after refuelling. A general examination of these results shows that in those respects the coal and gas cokes were good, the full scale and experimental oven cokes, made from crushed coal, poor; and the experimental oven cokes made from the various sizes of uncrushed coal nuts, good. This classification holds also when the weights of unburnt fuel remaining at the end of each test are considered.

Coal./

Table LXIII - Carbonising Conditions

Fuel No.	Type of fuel	Conditions of Manufacture of Oven Cokes				
		Size of coal charged to oven	Compressed or loose charged coal.	Oven Width. in.	Flue Temp. ^{o}C.	Coking Period. hrs.
H.1	Full scale oven cokes.	0-$\frac{1}{8}$"	L	14	1,300	15
H.3		0-1/16"	C	17	1,100	30
H.18		0-$\frac{1}{8}$"	L	18	1,100	28
H.38		0-$\frac{1}{8}$"	L	18	1,100	28
H. 6		0-$\frac{1}{8}$"	L	14	1,300	15
H. 7		0-$\frac{1}{8}$"	L	18	1,100	30
H. 8		0-$\frac{1}{8}$"	C	18	1,200	25
H.18E.1.	Expt. oven cokes.	0-$\frac{1}{8}$"	L	14	1,100	16
H.18(u)E.		0-3"	"	"	950	20
H.18(t)E		Trebles	"	"	950	20
H.18(d) E.l.		Doubles	"	"	1,000	18
H.18(s) E.l.		Singles	"	"	1,100	16
H.38E.		0-$\frac{1}{8}$"	"	"	1,000	17
H.38(t)E		Trebles	"	"	1,000	18
H.38(d)E		Doubles	"	"	1,000	18
H.38(s)E		Singles	"	"	1,000	18
C.1	Bituminous coal.					
G.2	Gas retort coke.					
G.3	" " "					

Table LXIV - Analyses of Fuels used in Open Grate Tests.

Fuel Nol	Moisture %	Ash %	Volatile Organic Matter %	Fixed Carbon %	Net Calorific Value. B.Th.U./lb.
C.1	5.2	2.6	28.9	63.3	13,000
G.2	0.2	10.2	5.8	83.8	12,740
G.3	5.3	7.8	4.9	82.0	12,400
H.1	0.2	7.8	1.5	90.5	13,090
H.3	0.1	4.0	1.0	94.9	13,600
H.18	0.2	7.7	0.8	91.3	13,110
H.38	0.3	9.8	1.3	88.6	12,800
H.38(wet)	11.3	8.3	1.5	78.9	11,200
H.6	0.1	8.0	1.7	90.2	13,000
H.7(1-2")	3.3	7.8	0.8	88.1	12,620
H.7(¾-1¼")	5.7	7.8	1.0	85.5	12,270
H.8	0.3	7.3	0.9	91.5	13,120
H.18E.1	0.2	7.6	2.8	89.4	13,100
H.18(u)E	0.4	7.5	4.2	87.9	13,080
H.18(t)E	0.3	3.8	4.1	91.8	13,640
H.18(d)E.1	0.1	5.6	2.6	91.7	13,480
H.18(s)E.1	0.2	6.4	3.3	90.1	13,250
H.38E	1.3	15.5	6.6	86.6	11,800
H.38(t)E	0.2	3.9	3.2	92.7	13,650
H.38(d)E	0.3	8.2	4.2	87.3	13,040
H.38(s)E	0.2	8.5	3.9	87.4	12,980

Key

C - Coal
G - Gas coke
H - High Temp coke
E - Expt Oven coke
U - made from uncrushed 0-3" coal
(t)-made from treble nuts.
(d)-made from double nuts.
(s)-made from single nuts.

TABLE LXV - RESULTS OF OPEN-GRATE TESTS.

Test No.	Fuel No.	Width of grate. in.	Size of fuel. in.	Weight of wood used to kindle. lb.	Time to give bright fire. min.	Time to recover after charging 7 lb.fuel. min.	Weight of ash per 100,000 B.Th.U's. radiated. lb.	Weight of unburnt fuel. lb.	Rate of combustion. lb./hr.	Radiant efficiency. %
31	C.1.	16	1-3	¾	37	-	3.9	1.0	3.4	19.9
32	"	11½	"	1	32	17	3.4	1.0	3.0	19.6
33	G.2.	"	1-2½	1	23	19	4.4	1.4	2.6	24.6
34	"	"	"	¾	23	-	6.4	0.9	2.4	20.4
35	G.3.	14	"	1	32	21	3.8	2.6	3.0	23.3
36	H.1.	11½	"	1¼	46	25	4.2	3.9	2.2	20.7
37	"	"	"	1½	37	22	2.9	3.9	2.5	26.5
38	"	14	"	1½	30	21	3.5	4.1	2.8	24.3
39	"	16	"	1½	40	-	3.7	4.9	2.7	23.2
40	H.6.	"	"	1¾	72	40	3.5	6.3	2.1	22.7
41	H.3.	"	"	1½	38	24	2.0	6.0	2.2	26.2
42	H.18.	"	"	2	65	37	3.0	6.3	2.4	21.2
43	H.38.	"	1-2	1½	40	27	4.0	4.2	2.8	21.5
44	H.38.(wet).	"	"	1½	56	36	4.5	5.0	2.6	20.2
45	H.7.	"	"	1½	43	-	2.4	5.6	2.3	27.2
46	"	11½	"	1½	45	24	2.3	4.5	2.0	29.1
47	"	"	¾-1¼	1¼	52	60	6.1	4.7	1.8	23.1
48	H.8.	"	1-2	1½	58	34	2.7	5.4	1.9	28.8
49	H.18.E.	"	1-3	1	45	23	3.5	3.8	2.2	25.0
50	H.18.E.	"	1-2	1	46	20	3.1	3.0	1.9	25.6
51	H.18(u)E.	"	1-3	1	70	26	4.3	3.8	2.5	21.4
52	H.18(t)E.	"	"	½	42	17	1.8	2.8	1.8	32.3
53	"	"	2-3	¾	105	23	2.6	3.0	1.6	19.9
54	H.18(d)E.1.	"	1-3	¾	40	17	2.8	3.0	2.1	28.4
55	H.18(s)E.1.	"	1-3	¾	47	18	2.5	2.3	2.3	27.7
56	"	"	1-2	1	43	21	2.3	3.0	2.1	28.1
57	H.38.E.	"	1-3	1	59	25	6.1	2.5	2.5	26.0
58	H.38(t)E.	"	1-3	¾	35	18	2.5	2.5	1.9	29.4
59	"	"	"	½	59	24	3.3	2.8	1.6	26.5
60	"	"	1-2	¾	27	20	1.6	1.7	1.9	30.3
61	H.38(d)E.	"	1-3	¾	36	20	3.4	2.3	2.3	25.8
62	"	"	1-2	¾	46	21	3.2	2.1	1.9	27.3
63	H.38(s)E.	"	1-3	¾	45	19	3.7	3.0	2.3	27.5

Coal.

In agreement with previous findings the radiant efficiencies of the coal fires were lower than those made with any of the cokes.

Gas Retort Cokes.

Although the gas cokes were easily kindled they gave low efficiencies, partly because coke No. G.2 had a high ash content, 10.2%, and No. G.3 contained 5.7% moisture but chiefly because they were very reactive. In test No. 34 small quantities of fuel were added at short intervals, the fire being often disturbed. This caused a reduction of the radiant efficiency.

Oven Cokes made from crushed coals.

In test No. 36 the special back flue was only used while the fire was kindling and not, as was customary, at each refuelling of the fire. Throughout this test the fire remained dull at the front although burning well at the back. The radiant efficiency was, therefore, much lower than for test No. 37 of the same coke when the back flue was used. When the width of the fire was increased for tests Nos. 38 and 39 of the same coke reductions in the radiant efficiencies resulted.

Coke No. H.6. was made from the coal used to make

coke/

coke No. H.1., blended with 5% of finely crushed anthracite. A comparison of the results obtained from test No. 40 with those from tests Nos. 36-39 shows that the addition of the anthracite gave a coke which was much more difficult to burn. The weight of wood required for kindling, the time taken to obtain a bright fire when kindling and replenishing, and the weight of unburnt fuel remaining in the grate were each greatly increased.

It is important to note that in test No. 41 the low ash coke No. H.3. although being comparatively difficult to burn showed a comparatively high efficiency.

In agreement with previous tests of coke No. H.18, (H.4) test No. 42 shows that this coke was extremely difficult to kindle and burn and gave a very low efficiency.

The increase of the moisture content of coke No. H.38 by 11% for test No. 44 reduced the rate of kindling and recovery of the fire after refuelling. The 1-2 in. size of the South Yorkshire coke No. H.7, used in tests Nos. 45 and 46, was difficult to kindle, and gave a large quantity of unburnt fuel but gave comparatively high efficiencies. The efficiency obtained for the narrower fire was again a little higher. For test No. 47 a smaller size of fuel was used but this was quite unsuitable as an open grate fuel and gave a very dull fire especially towards the end of the test, when the fuel bed became choked with the very small fuel which had accumulated.

Coke/

Coke No. H.8. like H.7 a very dense one, gave similar results.

Experimental Oven Cokes

Coals Nos. 18 and 38, having low and high volatile matter contents, respectively, were used for these tests. Mention has already been made of the unsuitability of coke No. 18 for burning in an open grate (test No. 42). Coke No. 18E made from the same coal but in the experimental oven was a little more easily kindled and gave a higher efficiency even allowing for the possible difference of efficiency due to the difference in the width of the grates used. These results were confirmed when the experimental and full scale oven cokes made from coal No. 38 were examined.

The flue temperatures used for the manufacture of these full scale and experimental oven cokes were approximately the same but since the respective oven widths were 18 in. and 14 in. the carbonising periods were 12 hours less for the cokes made in the narrower experimental oven.

About half of the coke, that from the centre part of the full scale oven will be heated for the same period at the same high temperature as the experimental oven coke and will resemble it closely. The remainder of the coke, that nearer the oven walls, will be heated at this high temperature for an additional period increasing from 0 to 12 hours as its distance from the oven wall decreases. This additional/

additional heating of the coke nearer the wall of the wider oven reduces the combustibility of the coke. Comparative tests are recorded which show that all other carbonising conditions being the same, the experimental oven cokes are similar in their combustible properties to the corresponding full scale 14in. oven cokes. The present examination of the effects of the conditions of coking on the combustible properties of the resultant cokes, in addition to being directly applicable to full scale 14 in. oven practice, will also indicate the results to be expected when wider ovens are used.

Effect of Size of Coal on the Combustibility of the Coke produced

Open grate tests were carried out on the cokes made from the treble, double and single nuts and the uncrushed and crushed 0-3in. screenings of coal No. 18, and the effect of the size of the coal charged to the oven on the open grate performance of the resultant coke thereby determined.(Table LXV).

The coke made from the treble nuts of this coal proved to be the best domestic fuel so far examined. It was very easily kindled, the fire recovered very quickly after it was replenished, only a small quantity of unburnt fuel and ash remained, and the radiant efficiencies were the highest yet obtained. The 1-3 in. size of this coke gave a more attractive fire and moreover it kindled quicker than the smaller size.

The 2-3 in. size of this coke used in test No. 53 was much more difficult to kindle and did not burn brightly. This resulted in a greatly reduced efficiency being obtained.

The coke made from the double nuts was a little more difficult to kindle but nevertheless gave very good results. That made from the single nuts was still a little more difficult to kindle.

Coke No. 18(u)E made from the uncrushed 0-3 in. screenings of the same coal was the poorest open grate fuel of this series being the most difficult to kindle and the fire requiring the longest period for recovery after refuelling.

Coke No. 18E made from the crushed 0-3 in. screenings of this coal gave results intermediate between those obtained from the coke made from the uncrushed 0-3 in. screenings and that made from single nuts.

One of the most important points brought out by these tests was the effect which the state of division of the ash had on the appearance of the fire. As the size of the coal was reduced the fineness of the ash and its detrimental effect were increased.

Similar results were obtained from the examination of the cokes made from the treble, double and single nuts of coal No. 38. Again, these cokes were more easily kindled and gave higher efficiencies than that made from the crushed coal. The coke made from the treble nuts was again a little more/

more easily kindled than that from the double and single nuts.

The structure of the cokes made from the uncrushed coal nuts was quite different from that made from crushed coal. Pockets of much larger pored coke could be observed throughout each piece of coke, and these were more pronounced in the case of the cokes made from the larger treble nuts. During the coking process the plastic material is extruded on to the surface of each piece of coal and fills up the voids of the coal charge and when coked this plastic material gives a large pored coke of low density.

The kindling tests carried out showed that as the size of the coal nuts was increased the easier was the kindling of the fuel. It is also apparent that the greater the size of the nuts the greater will be the size of the voids and, therefore, the pockets of very porous coke, although these will be fewer in number, and the less will be the uniformity of the coke obtained. It is, therefore, probable that these pockets of very porous coke determine the ease of kindling of the coke.

The coke made from crushed coal was uniform in structure and had no pockets of very porous coke to assist the kindling. The structure of the coke made from the uncrushed 0-3 in. coal screenings was similar to that made from the crushed coal with parts of much denser coke, formed from the uncrushed pieces of coal. These parts of dense coke account for the fact that coke made from uncrushed 0-3 in. coal is more/

more difficult to kindle than that made from the same coal when crushed.

The results given in Table LXII (Page 181) show that as the size of the nut coal was increased the bulk density of the charge was increased, allowing a greater weight of coal to be charged to the oven. Therefore, the coke made from these nuts, and especially the larger sizes, will consist of very dense coke with pockets of porous coke distributed throughout. This very dense coke was very non-reactive to carbon dioxide, only a trace of flame being apparent on the surface of the fire when it was burned and this fact must contribute to the high radiant efficiency obtained from this type of coke since highly reactive cokes (e.g., the gas cokes Nos. G.2 and G.3, Table LXV, give comparatively low radiant efficiencies of 24.6 and 23.3% respectively). Another factor which greatly influences the radiant efficiency of the coke made from treble coal nuts is the nature of its ash. Besides being very low in quantity it is dense and is not evenly dispersed throughout the coke pieces. When the pieces of coke burn rapidly and become incandescent the denser ash falls from the surfaces of the coke and therefore a less proportion of the radiation is screened off than is the case with coke made from crushed coal, the ash of which is finely divided and adheres closely to the surfaces of the coke. Again, the ash of the cokes made from nut coal does/

does not hinder the supply of air to the burning coke to as great an extent as the fine ash of cokes made from crushed coal. This fact explains why the former cokes give a more uniform rate of burning and therefore rate of radiation. Having established the fact that the combustibility and radiant efficiency of the resultant coke can be greatly increased by carbonising uncrushed coal nuts, the next step was to determine the effect on the properties of the coke of varying the carbonising temperature and period and so find the best conditions for the manufacture of domestic coke in ovens.

Effect of Carbonising Temperature and Period on the Physical and Combustible Properties of the Coke.

Accordingly, a series of experimental oven tests were made and the treble nuts and a mixture of 50% of double with 50% of single nuts of coal No. 18 were carbonised in the experimental oven using flue temperatures varying from 800 to 1000°C.

The screening and shatter indices of these cokes are given in Table LXVI. Some of these cokes (e.g., No. 133 and No. 140) were not completely carbonised and some very soft semi-coke was present in the centre of the charge. Since this material would break down to give breeze in a full scale oven test when the coke was broken to the desired sizes, it was broken off from the lump coke and crushed to pass the ½ in. screen./

TABLE LXVI - SCREENING AND SHATTER INDICES OF EXPERIMENTAL OVEN COKES:

Description of Coke.	Screening.			Shatter Indices.				Remarks.
	Over 3"	Over 1"	Thro' ½"	2"	1½"	1"	½"	
EXPERIMENTAL OVEN COKES:								
(a). Made from Treble Nuts of coal 18 -								
133 (18 hrs. at 800°C.)	80	93	5.2	-	-	-	-	Carbonisation not complete.
136 (23 hrs. at 850°C.)	75	95	3.1	72	83	93	96.4	Carbonisation overdone.
137 (17 hrs. at 930°C.) water quenched.	73	80	3.9	72	85	93	97.2	" complete.
139 (" " ") dry cooled.	73	80	3.9	73	85	94	96.8	" "
(b). Made from 50% Double plus 50% Single Nuts of coal 18 -								
140 (18 hrs. at 800°C.)	76	86	7.8	77	84	91	95.2	Carbonisation not complete.
146 (20 hrs. at 800°C.)	-	92	4.8	-	-	-	-	" almost "
147 (23 hrs. at 800°C.)	86	96	2.2	-	-	-	-	" overdone.
141 (20 hrs. at 900°C.)	85	94	3.8	81	86	92	95.6	" complete.
142 (17½ hrs. at 1000°C.)	85	93	4.5	82	87	93	96.2	" not quite complete.

screen. The percentage of breeze obtained from the oven charges gives an excellent indication of the completeness of carbonisation. The coking time was considered to be correct when the centre coke had been heated to a temperature of about 600°C or just enough to make it fairly hard and non-abradable. Under these conditions the percentages of breeze through ½in. for these cokes were a little under 4%. The mixture of double and single nuts required a slightly longer coking period than the treble nuts. The shatter indices of the cokes made from treble nuts vary little but small increases are obtained with increase of flue temperature in the case of the cokes made from the mixture of double and single nuts.

OPEN GRATE TESTS

It was desired to determine the performance of these special experimental oven cokes in an ordinary type of grate and that shown in Fig. 37 was used for this series of tests.

This grate had two horizontal curved front bars, 2 in. high and the bottom grate had a 2 in. well. The fire was 11½in. wide and 7-10 in. deep. The chimney draught was kept constant for each test by means of a fan placed in the flue and the method of procedure was the same as that used for previous open grate tests.

Previous/

Previous tests have shown that the special back-plate provided in open grate No. 6 described on page 176 gave increases in the rates of kindling, recovery of the fires after refuelling and the radiant efficiencies of the cokes examined. The removal of this back-plate for the present series of tests resulted only in small increases in the kindling times and small decreases in the radiant efficiencies of the cokes since these were more combustible than those previously examined.

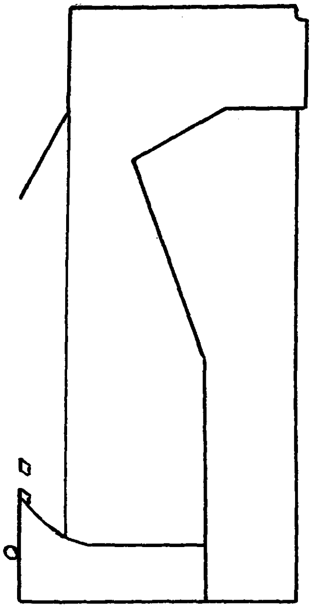


FIGURE 37
Open Grate
No. 7

The analyses and the chief results of the open grate tests of these experimental oven cokes are contained in Table LXVII.

(a) Cokes made from Treble Nuts of Coal No. 18.

Coke No. 133 made at the lowest temperature was slightly under-coked. Of all the cokes examined it was the easiest to kindle, recovered most quickly after refuelling and gave the lowest weight of unburnt coke at the end of the test. Coke No. 136 was made at a slightly higher temperature but was very much overcooked and this increase of the coking time produced/

TABLE LXVII - ANALYSES OF EXPERIMENTAL AND FULL-SCALE OVEN COKES MADE AT DIFFERENT FLUE TEMPERATURES AND RESULTS OF OPEN GRATE TESTS:

Open Grate Test No.	Description of Coke.	Moisture. %	Ash. %	Volatile Organic Matter. %	Fixed Carbon %	Net Calorific Value. B.Th.U/lb.	Size of Fuel used. in.	Wt. of wood used to kindle. lb.	Time to give bright fire. min.	Time to recover after charging 7 lb. fuel. min.	Wt. of unburnt fuel. lb.	Wt. of ash per therm radiated. lb.	Average rate of combustion. lb./hr.	Radiant Efficiency. %
	EXPERIMENTAL OVEN COKES:													
	(a). Made from Treble Nuts of coal 18 -													
64	133 (18 hrs. at 800°C).	3.9	3.5	5.0	87.6	13,200	1-3	⅜	35	16	2.3	3.0	2.2	27.8
65	136 (23 hrs. at 850°C).	3.6	4.7	3.8	87.9	13,000	1-3	¾	40	20	3.5	2.6	2.1	27.1
66	137 (17 hrs. at 930°C, water quenched).	3.5	3.9	4.3	88.3	13,160	1-3	½	37	18	3.0	2.3	2.2	29.1
67	139 (17 hrs. at 930°C, dry cooled).	2.8	3.0	3.0	91.2	13,400	1-3	¾	50	26	3.7	2.1	2.1	23.6
	(b). Made from 50% Double + 50% Single Nuts of coal 18 -													
68	140 (18 hrs. at 800°C).	2.7	5.8	5.1	86.4	13,200	1-3	½	39	15	3.1	3.4	2.1	26.8
69	141 (20 hrs. at 900°C).	3.6	6.1	4.8	85.5	12,820	1-3	½	45	17	3.2	3.2	2.2	27.1
70	142 (17½ hrs. at 1000°C).	3.2	5.3	5.8	85.7	13,250	1-3	½	35	16	3.3	3.0	2.3	26.6
	FULL SCALE OVEN COKES:													
	(a). Made from Treble Nuts of coal 1 -													
71	135 (17 hrs at 1030°C).	1.5	4.7	2.2	91.6	13,250	1-3	½	38	17	3.0	2.3	2.1	30.7
72	143 (16½ hrs. at 1100°C).	0.8	5.0	1.6	92.6	13,380	1-3	½	50	21	3.3	2.6	2.0	29.1
73	144 (12½ hrs. at 1300°C).	1.4	4.1	1.2	93.3	13,300	1-3	1	48	22	4.3	2.0	2.0	26.3

produced a much less combustible coke. Coke No. 137, carbonised in 17 hr. at 930°C was an excellent open grate fuel. It had received the correct coking time and was strong, kindled and recovered quickly after refuelling and burned with a high radiant efficiency. When coke No. 137 was pushed from the oven a portion of the charge was cooled by placing in bins which were immediately sealed. The coke took several hours to cool and during this time the highly combustible inner ends of the lumps were heated by contact with the hotter outer ends and some of the volatile matter was distilled off, breaking the seal on several occasions. This caused the coke, (No. 139), to be less combustible and a much longer period for kindling and recovery after refuelling was required, which adversely affected the radiant efficiency of the fuel.

(b) Cokes made from 50% Double, plus 50% Single Nuts of Coal No. 18.

Cokes No. 140 and No. 142 were both undercoked and were much more combustible than the correctly carbonised coke No. 141. Comparing coke No. 141 with No. 137 made at approximately the same temperatures, it is observed that the latter, made from treble nuts, is the more combustible and efficient. The lower efficiencies obtained for the cokes made from the smaller sizes of nuts may be accounted for by the greater percentage and finer state of their ashes.

FULL SCALE OVEN TESTS.

To determine the effect on the resultant coke, of carbonising coal nuts at temperatures above 1000°C, a full scale 14 in. silica oven was used. Using flue temperatures of 1030, 1100 and 1300°C, cokes Nos. 135, 143 and 144, respectively, were made from the treble nuts of coal No. 1. The analyses of these cokes and the results obtained from open grate tests of them are recorded in Table LXVII,(p.198).

These results show that as the flue temperature was increased the combustibility and the radiant efficiency of the resultant coke was considerably decreased.

Reviewing the results which have been obtained from the open grate tests of cokes made from nut coal, it is apparent that these cokes are much more combustible and efficient and are in every way superior open grate fuels to those made under the same carbonising conditions from the same coals when crushed. It is doubtful whether any smokeless fuel made from crushed coal and, therefore, giving a fine ash of low density would be popular. The cokes made from uncrushed coal nuts moreover, give fires exactly similar in appearance to one of coal after the flames of the latter have died down. The clean glow of the coke fire would, after a little experience, be preferred to the smoky periods of the coal fire subsequent to kindling and refuelling.

Optimum/

Optimum Conditions for the Manufacture of an Open-Grate Coke in Ovens.

The highest radiant efficiencies have been obtained from cokes made from treble nuts (in 14 in. ovens) with a flue temperature of about 1000°C. Those made at higher temperatures are less efficient because they are not combustible enough to give rapid kindling and recovery of the fire after refuelling. Cokes made at the highest temperatures are so incombustible that only the coke in the heart of the fire becomes incandescent and this is surrounded by dull pieces which screen off the radiation. Cokes made at flue temperatures below 1000°C are more reactive and, therefore, burn less efficiently. Cokes made from treble nuts in 14 in. ovens using a flue temperature of 1000°C and a minimum carbonising period of 16-17 hr. are easily kindled with ½ lb. wood and there would appear to be no necessity to use lower temperatures for the manufacture of a satisfactory open grate fuel.

Increasing quantities of domestic coke are now being made at a Scottish Coking Plant using these carbonising conditions. For the manufacture of furnace coke at this plant the crushed coal is coked in 14 in. ovens in 16 hr. using a flue temperature of 1300°C. No difficulty is experienced in maintaining a flue temperature of 1000°C and a carbonising time of 16 hr. When making domestic coke the output of the ovens is increased by 12-15% because of the greater density of the coal/

coal charge. A greater output of richer gas is also obtained.

EXAMINATION OF SMOKELESS FUELS.

It was desired to compare the performance of the special domestic oven coke with those of the low temperature cokes at present being made in Britain, when burned in an open grate or domestic boiler.

A series of fuels, comprising coal, six low temperature cokes and the special oven coke were examined using the ordinary type of open grate (No. 7) described on pages 196 and 197.

The screening analysis and the bulk density of each fuel are given in Table LXVIII.

Table LXVIII - Screening Analyses and Bulk Densities of Domestic Cokes.

Fuel	On 3" %	On 2" %	On 1" %	On $\frac{1}{2}$" %	Thro' $\frac{1}{2}$" %	Wt. of fuel per cb.ft. lb.
Coal	0	90	100	-	-	43.7
A.(Low temp.coke)	ovoids - $2\frac{3}{4}$" x 2" x $1\frac{3}{8}$"				0.7	25.3
B.(")	13	90	95	95	4.8	19.7
C.( )	22	53	82	93	7.3	21.4
C. -	ovoids-$3\frac{1}{2}$" x $2\frac{1}{2}$" x $1\frac{3}{4}$"				1.0	approx. 38
D.(Low temp.coke)	50	88	98	99	0.9	25.6
E. "	38	82	97	98	1.5	20.5
145.(oven coke)	7	57	99	100	0.3	26.2

The fuels differed widely in character and appearance. The special oven coke was the strongest of all although fuels Nos. A. and C. (briquettes), and D. and E. were sufficiently strong to withstand much breakage during their transport to the laboratory. Fuel No. B, and more especially both sizes of fuel No. C. were weak and abradable and gave a large percentage of fines. The bulk densities of fuels Nos. B, C. and E. were very low, while that of No. C. (briquettes) was high and approached nearly to the value for coal.

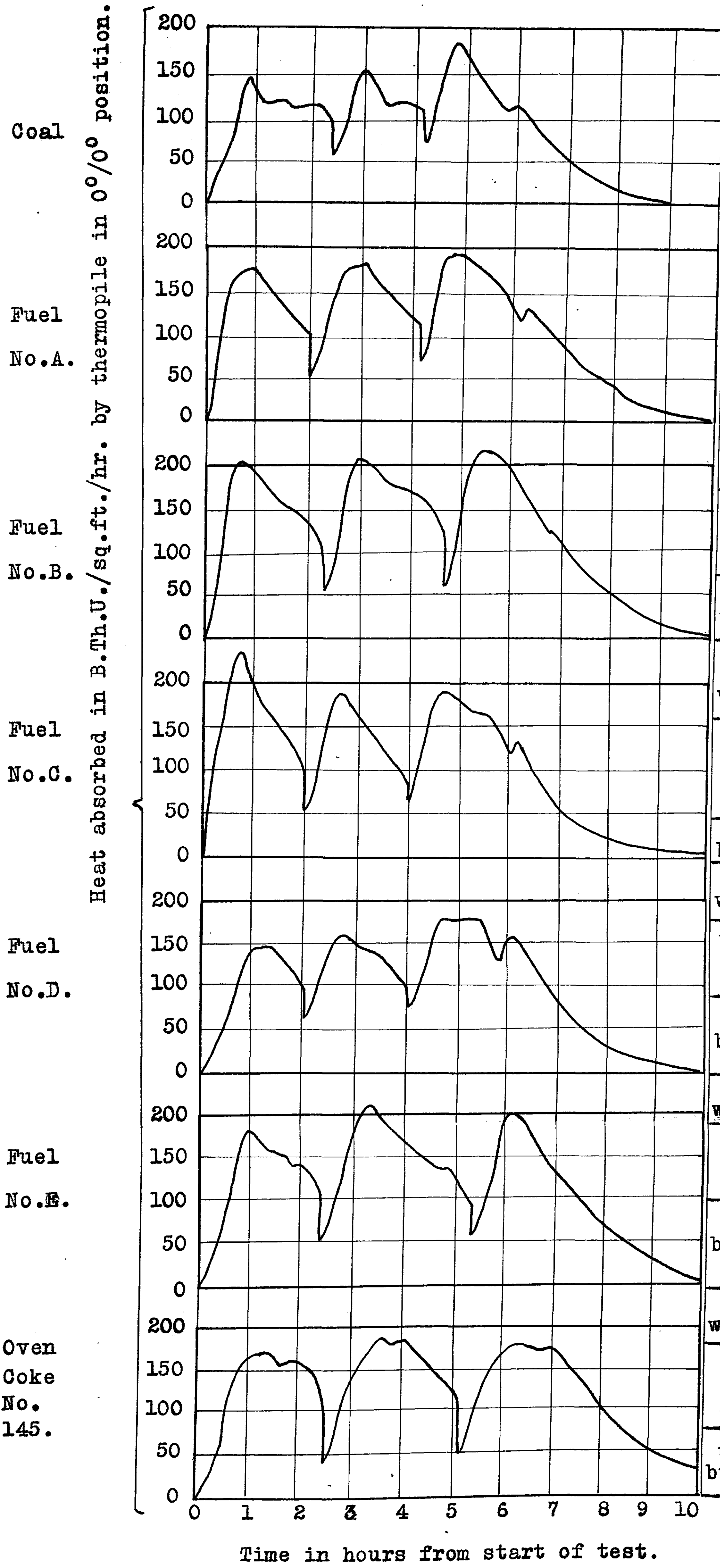
The analyses of the fuels and the chief results of the open grate tests are recorded in Table LXIX and the radiation charts for each test are shown in Fig. 38.

Results of Open Grate Tests

These results show that the performances of the low temperature cokes were, generally, better than that of coal. They each gave a bright fire more quickly when kindled or replenished, a higher radiant efficiency and usually less unburnt fuel. The ash, however, from most of them was fine and of low density and detracted very much from their radiant efficiencies. This was especially so in the case of each of the No. C. fuels. Fuel No. C. sparked violently when kindling and after refuelling and this alone would practically prohibit its use as an open grate fuel. Moreover, the briquettes of this fuel were no less/

TABLE LXIX - ANALYSES OF DOMESTIC FUELS AND RESULTS OF OPEN GRATE TESTS:

Open Grate Test No.	Description of Fuel.	Moisture. %	Ash. %	Volatile Organic Matter. %	Fixed Carbon. %	Net Calorific Value. B.th.U/ lb.	Size of Fuel used. in.	Wt. of wood used to kindle. lb.	Time to give bright fire. min.	Time to recover after charging 7 lb. fuel. min.	Wt. of unburnt fuel. lb.	Wt. of ash per therm radiated. lb.	Average rate of combustion for period of "bright" fire. lb./hr.	Period of "bright" fire. hr.	Radiant efficiency. %
74	<u>COAL</u>.	4.8	2.6	29.5	63.1	13,100	1-3	½	38	17	1.0	3.5	3.8	5.0	19.6
	<u>LOW TEMP. COKES</u>:														
75	A.	3.3	3.7	12.0	81.0	13,240	1⅜x2¾	¼	22	15	0.2	1.5	3.4	5.9	23.6
76	B.	2.4	4.3	9.0	84.3	13,600	1 - 4	¼	28	14	1.1	2.7	3.2	6.3	28.8
77	C.	2.6	5.8	11.9	79.7	13,380	1 - 4	¼	15	14	0.4	2.9	3.7	5.5	23.2
78	C (briquettes).	3.3	6.3	17.8	72.6	13,050	1¾x3½	¼	42	22 (11 lb. added)	0.6	2.7	4.4	-	21.4
79	D.	1.6	3.9	14.0	80.5	13,670	1 - 4	¼	32	14	0.6	2.9	3.6	5.6	22.9
80	E.	3.9	4.0	6.8	85.3	13,300	1 - 4	½	27	18	1.6	2.7	3.1	6.4	25.8
	<u>OVEN COKE</u>:														
81	145.	1.7	4.1	4.1	90.1	13,370	1 - 3	½	32	17	2.7	2.0	2.8	6.9	31.2



Fuel Additions	
Hr.	Wt.lb.
wood	$\frac{1}{2}$ lb.
0 2.4 4.3	12 7 7
unburnt	1.0
wood	$\frac{1}{4}$ lb.
0 2 4.2	12 7 7
unburnt	0.3
wood	$\frac{1}{4}$ lb.
0 2.3 4.7	12 7 7
unburnt	1.1
wood	$\frac{1}{4}$ lb.
0 1.9 4.0	12 7 7
unburnt	0.4
wood	$\frac{1}{4}$ lb.
0 1.9 4.0	12 7 7
unburnt	0.5
wood	$\frac{1}{2}$ lb.
0 2.3 5.3	12 7 7
unburnt	1.1
wood	$\frac{1}{2}$ lb.
0 2.5 5.2	12 7 7
unburnt	2.7

FIGURE 38 - Radiation Charts for tests on Open Grate No. 7.

less smoky than coal. The nature of the ash from fuels Nos. A. and D. was little better and also had a detrimental effect on the appearance and efficient burning of the fire after the point of maximum radiation was obtained. The ash from fuel No. E. was better, being coarser, but a large proportion of this ash was white and of low density. Fuel No. B. gave an ash of a more desirable type. Although not so coarse as that from No. E. it was much denser, a fact which accounts for the much higher radiant efficiency obtained from fuel No. B. than from any of the others.

All the low temperature cokes, except No. E. were very reactive and gave long carbon monoxide flames when burning. The radiant efficiency of this fuel was, therefore, higher than that obtained from any of the others giving ash of the same character.

The most unreactive fuel of this series was, however, the oven coke, No. 145. and since in addition it contained only a small percentage of coarse ash it gave the highest radiant efficiency. Coke No. 145. although a little more difficult to kindle than the low temperature cokes, was as easy to kindle as coal. It gave the largest quantity of unburnt fuel but the weight 2.7 lb. was not large and would not reduce its value as an open grate fuel.

The radiation charts shown in Fig. 38 demonstrate a very important feature of fuels Nos. E. and 145 which are least reactive and which give the coarsest ashes, namely that they/

they burn most uniformly and give bright fires for the longest periods without refuelling.

From these results it is apparent that the special domestic oven coke compares very favourably with any of the open grate fuels at present being marketed.

Factors influencing the suitability of a fuel for burning in an open grate.

It is convenient to discuss here the properties which determine the value of an open grate fuel.

Radiant Efficiency.

Perhaps the efficiency of a fuel when burned in an open grate is in itself not very significant in determining its suitability for this purpose but the factors upon which the efficiency depends are of vital importance.

The quantity and especially the nature of the ash is one of the most important factors influencing the radiant efficiency of a fuel. When the point of maximum radiation is attained the surface of the pieces of fuel burn rapidly and leave a covering of ash. If the ash is in a finely divided state it will cling to the fuel and will cut off to a large extent the radiation from and the supply of air to the fuel. The rate of burning and radiation therefore decrease rapidly. Should the ash be concentrated in larger pieces of greater density/

density it will not exercise so large a screening effect and may, because of its density, fall from the fuel surfaces.

Another factor which influences the radiant efficiency of a fuel, but to a less extent, is its reactivity. In the case of highly reactive cokes a large percentage of the fuel combines with the carbon dioxide formed in the lower part of the fuel bed to give carbon monoxide which combines with oxygen at the surface of the fuel and burns with a blue flame. These flames have a low radiant efficiency, and therefore, the greater the percentage of fuel used up in this way, the lower will be its radiant efficiency.

The open grate tests have also shown that the combustibility (reactivity to oxygen) of a fuel plays an important part in determining its efficiency. Cokes were examined which were so difficult to burn that, only that in the centre and back of the fire burned brightly while the coke in the front remained dull and cut off a large percentage of the radiation from the freely burning coke, thereby reducing its radiant efficiency.

Appearance and Performance of Fuel when burned.

The real significance of the radiant efficiency of a fuel is apparent when the effect of the determining factors, namely the quantity and nature of the ash, its reactivity and combustibility, on the appearance and general performance of the fuel when burned are examined.

The/

The very detrimental effect which a fine ash of low density has on the appearance of the fire cannot be too greatly stressed and it seems imperative that coke intended for burning in open grates should be made from uncrushed nut coal.

The more reactive the fuel the longer will be the carbon monoxide flames which burn on the surface of the fire and this would be a very desirable feature were it not for the attendant drawbacks. A fuel which is very reactive to carbon dioxide is invariably very reactive to oxygen, and when kindled the rate of radiation and burning increase very rapidly to a value depending on the weight of fuel in the grate, even although air is hindered from passing through the bottom grate by closing the fret. The rate of burning can therefore, be kept within reasonable limits only by having a comparatively small quantity of fuel in the grate, and this necessitates frequent refuelling.

The rate of burning and radiation of the unreactive but nevertheless easily combustible coke made from uncrushed coal nuts can be much more effectively controlled by adjusting the volume of air passing through the bottom grate of the fire. A much greater weight of this unreactive fuel than of the very reactive low temperature cokes, may be charged to the fire, still keeping the rate of burning and radiation similar in both cases and therefore the fire requires much less frequent refuelling in the case of the unreactive fuel.

Even although there is only a small flicker of flame from the burning unreactive fuel made by carbonising nut coal, its appearance is very attractive and exactly similar to that of a glowing coal fire after the flame has disappeared and it is considered that the obtaining of additional flame is not worth the sacrifice of more frequent attention and loss of efficiency which it is necessary to pay for it.

DOMESTIC BOILER TESTS

The manufacturers claim that domestic boilers are suitable for burning coal, coke or anthracite but usually show some preference for the last mentioned fuel.

The tests described here were carried out to compare the performances of a series of fuels when burned in a domestic boiler. This series comprised coal nuts, low temperature cokes, anthracites, graded furnace coke and the special domestic cokes made by carbonising coal nuts in ovens.

Description of Boiler

A diagram of the boiler used for this series of tests is given in Fig. 39. This type is in common use for the supply of hot water in medium sized houses. The boiler was not lagged and lower efficiencies were, therefore, obtained but it is usually desired that some of the heat be used to warm the/

the apartment in which it is installed.

About 40 to 50 lb. of each fuel was burned at a rate of approximately 3 lb. per hour and the efficiency of the boiler for each test together with the analysis of each fuel are shown in Table LXX.

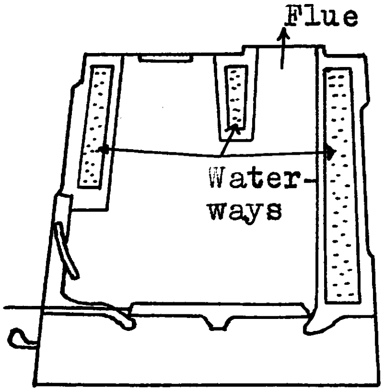


FIGURE 39 - Boiler No. 1.

The poorest result is obtained from the coal nuts; then come the anthracites giving efficiencies 40% higher; then the low temperature cokes still a little higher; and finally, highest of all, the oven cokes. The oven cokes made from treble nuts (Nos. 133E,135 and 134) give efficiencies 60% higher than that obtained from coal and 15% higher than those from the best quality of Welsh or Scottish anthracite. The smalls from the blast furnace cokes, Nos. 1 and 18, made from crushed drosses, and having high ash contents, give good results and it might be thought that it was unnecessary to manufacture a special coke for the domestic boiler. These boilers have, however, a small fuel capacity and a fuel which will burn unattended at a slow rate for a considerable period is necessary. The ½-1 in. size of cokes Nos. 133E,140 and 135 will burn unattended for 27 hr. in a heating appliance having a capacity of only 10 lb. of coke, while/

TABLE LXX - ANALYSES OF FUELS AND RESULTS OF DOMESTIC BOILER TESTS. (a). BOILER NO. 1.

Test No.	Fuel.	Moisture. %	Ash. %	Volatile Organic Matter. %	Fixed Carbon. %	Calorific Value. B.Th.U/lb.	Size of Fuel. in.	Rate of Combustion. lb./hr.	Efficiency of Boiler. %
1.	COAL - Doubles.	4.8	2.6	29.5	63.1	13,100	1 - 2	4.2	31.5
	ANTHRACITES:								
2.	Scottish Singles.	2.5	3.2	7.7	86.6	14,400	$\frac{3}{8} - 1\frac{1}{4}$	3.3	42.6
3.	Scottish Doubles.	2.4	2.5	8.1	87.0	14,560	1 - 2	3.4	43.0
4.	Welsh Singles.	2.1	1.4	4.4	92.1	14,670	$\frac{3}{8} - 1\frac{1}{4}$	2.9	42.0
	LOW TEMPERATURE COKES:								
5.	A.	3.3	3.7	12.0	81.0	13,240	$1\frac{3}{8} \times 2\frac{3}{4}$	3.3	44.7
6.	B.	2.4	4.3	9.0	84.3	13,600	$\frac{3}{4} - 2$	3.2	44.1
7.	C.	2.6	5.8	11.9	79.7	13,380	$\frac{3}{4} - 2$	3.0	43.7
8.	D.	1.6	3.9	14.0	80.5	13,670	$\frac{3}{4} - 2$	3.5	43.4
9.	E.	3.9	4.0	6.8	85.3	13,300	$\frac{3}{4} - 2$	3.1	43.2
10.	F.	5.9	2.3	17.7	74.1	13,100	$\frac{3}{8} - \frac{3}{4}$	3.9	33.9
	EXPERIMENTAL OVEN COKES:								
	(a). Made from Treble Nuts of coal 18 -								
11.	133.E. (18 hrs. at 800°C.)	2.0	3.8	5.2	89.0	13,350	$\frac{1}{2} - 1$	3.3	49.2
	(b). Made from 50% Double plus 50% Single Nuts of Coal 18 -								
12.	140.E. (18 hrs. at 800°C.)	3.0	5.7	4.8	86.5	12,990	$\frac{1}{2} - 1$	3.4	46.6
	FULL SCALE OVEN COKES:								
	(a). Made from Crushed Coal -								
13.	1 ($15\frac{1}{2}$ hrs. at 1320°C, 14 in. oven)	1.3	10.0	1.4	87.3	12,550	$\frac{1}{2} - 1\frac{1}{4}$	3.5	45.1
14.	18 (28 hrs. at 1150°C, 18 in. oven)	0.4	9.2	0.8	89.6	12,840	$\frac{1}{2} - 1\frac{1}{4}$	3.1	46.8
	(b). Made from Treble Nuts of Coal- No. 1								
15.	135 (17 hrs. at 1030°C, 14 in. oven)	0.6	4.1	3.3	92.0	13,560	$\frac{1}{2} - 1\frac{1}{4}$	3.1	48.8
	(c). Made from Treble Nuts of Coal 18 -								
16.	134 ($25\frac{1}{2}$ hrs. at 1200°C, 18 in. oven)	1.0	4.0	1.7	93.3	13,550	$\frac{1}{2} - 1\frac{1}{4}$	3.0	49.1

while the 1-3½ in. size of the same fuels continue to burn for 12 hr. in the same appliance. These values compare favourably with those obtained for anthracite and are almost double those obtained for the same sizes of the most combustible Scottish furnace coke (No. 1). The flexibility of the special domestic oven cokes is so great that no difficulty in maintaining the fire overnight would be experienced.

Test No. 10 was made with a small size of an extremely reactive low temperature coke. This fuel was quite unsuitable, giving very long carbon monoxide flames which passed up the chimney and greatly increased the flue loss. The other low temperature cokes and anthracites gave some flame in the flue but the oven cokes being much less reactive did not, and having therefore a more localised heating effect they gave higher efficiencies. There is, therefore, as in the open grate tests, a relationship between the efficiency of the fuel and its reactivity.

Comparison of the performance of Anthracite and Domestic, Oven Coke Nuts in Domestic Boiler No.2.

A further series of tests were made when the performance of the special domestic oven coke, No. 145, made from treble nuts in 14 in. ovens (16 hours at 1000°C) was compared with that of good quality anthracite when burned at various rates/

rates in a domestic boiler (No. 2), of similar construction to boiler No. 1.

The analyses of the fuels and the boiler efficiencies obtained for these tests are shown in Tables LXXI and LXXII and the efficiencies are also shown graphically in Fig. 40.

Table LXXI - Analyses of Fuels:

Fuel	Moisture %	Ash %	Volatile Organic Matter %	Fixed Carbon %	Net Calorific Value. B.Th.U./lb.
Anthracite	3.6	4.7	8.3	83.4	14,200
Coke	1.7	5.6	4.4	88.3	13,170

Table LXXII - Boiler Efficiencies for Anthracite and Coke.

Rate of Combustion. lb./hr.	½	1	1.2	2	3	4	5	6
% Efficiency of boiler when burning ANTHRACITE.	45.0	45.5	46.0	47.0	48.2	49.0	49.5	49.5
% Efficiency of boiler when burning COKE.	60.5	66.5	70.0	66	61.2	58.0	55.8	-

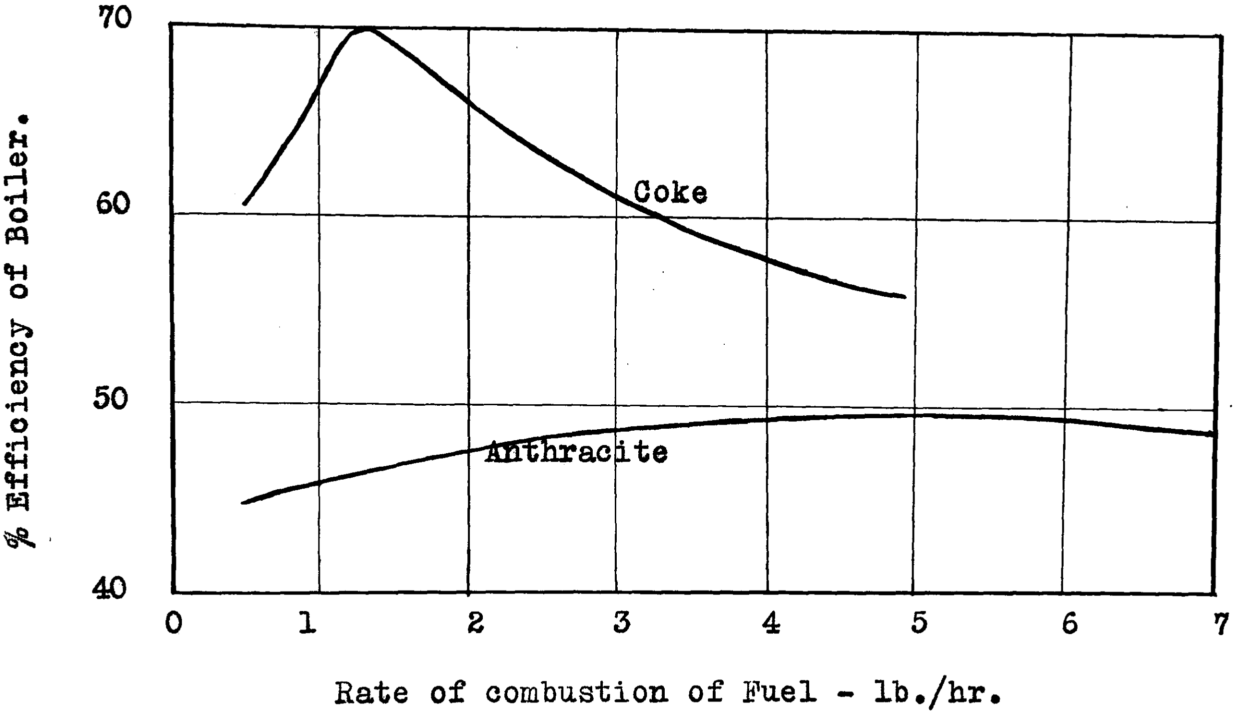


FIGURE 40 - Comparative boiler efficiencies for anthracite and domestic oven coke at different rates of burning.

These results show conclusively that the domestic coke is a much more efficient fuel, especially at slow and moderate rates of combustion, than anthracite. At a rate of burning of 1.2 lb./hr. a rate which is very often used with this size of boiler, the coke gives an efficiency 50% higher than the anthracite. Although the boiler contains only about 12 lb. of coke the fuel can be burned at very slow rates and no difficulty was experienced in maintaining the fire overnight (14 hr.) and for much longer periods when required.

The/

The efficiencies obtained for anthracite vary but little for the different rates of combustion, while those for the coke increase considerably to a maximum for a rate of 1.2 lb./hr. and then decrease again for high combustion rates. The heating in a small domestic boiler is chiefly by radiation from the fuel and this fact not only explains why coke is so much more efficient than anthracite but also why the efficiency varies with the rate of combustion in the case of the coke.

At very slow rates of combustion the air entering at the bottom of the fuel bed is soon used up giving carbon dioxide and the coke, being comparatively unreactive, does not combine with this to give carbon monoxide which would burn on the surface of the fuel bed. The surface of the fire remains dull, therefore, until air is supplied at such a rate that some passes up through the fuel bed and burns the coke on the top which then radiates freely and efficiently to the boiler surfaces. When air is admitted to the fire at a still greater rate there will be an excess of air and this, because of its passage through the hot fuel bed, will carry away an excessive percentage of sensible heat to the flue since little provision is made in small domestic boilers for the efficient extraction of the heat from the flue gases.

The anthracite, however, is comparatively reactive and the carbon dioxide formed in the lower part of the fuel bed reacts with the fuel in the upper part of the bed, giving carbon monoxide,/

monoxide, which burns at the surface of the fuel and radiates heat to the boiler. There is, therefore, a more uniform rate of radiation per lb. of fuel burned at the various rates in the case of the anthracite but this formation and burning of carbon monoxide is a very inefficient method of burning the fuel, the flames, having a very low radiant efficiency, increase the flue gas temperature very considerably.

This coke was also tested in an "Esse" cooker which has a maximum rate of combustion of about $\frac{3}{4}$ lb./hr. Since the coke can be burned at exceptionally slow rates it has proved to be very economical and in every way suitable for this appliance. It gives excellent results in all stoves but it is particularly suitable for the semi-closed type described on page 151, which is now becoming very popular. This stove is provided with two doors which are closed for overnight burning at slow rates and are opened in the day-time to give the appearance of an open grate. A large size of fuel is necessary for burning with the doors open and it is usually necessary to keep also a small size for overnight burning. The 1-3 in. size of this coke, however, will burn unattended for 12 hr. even in the small sizes of this stove, which have a fuel capacity of only 10 lb.

SUMMARY

It was shown that, at the average rate of heating obtaining in a coke oven and even at much faster rates, the majority of Scottish coking coals showed no tendency to intumesce. According to the findings of Audibert and Delmas these coals should therefore give abradable cokes but this was not found to be the case. These Scottish coking coals are therefore very different in type to those of many other coal-fields.

Rose (Fuel, 1926,5,562) has observed that there is some relation between the total volatile matter content and the nature of the coke obtained from a coking coal. Coals having high volatile matter contents gave highly fissured cokes while coals having low volatile matter contents gave blocky cokes with comparatively few fissures.

Since it is during the period subsequent to the plastic range that the fissuring of the coke takes place, the degree of fissuring should be related to the percentage of volatile matter evolved during this period, and it was thought that by comparing the volatile matter contents of the coals after heating to the temperature at the end of the plastic range and the nature of the cokes obtained, a more accurate correlation would be obtained.

The plastic ranges of a series of coals taken from

the/

the chief coalfields of Britain were determined by a modification of Foxwell's method. The volatile matter contents of these coals at the temperatures corresponding to the end of their plastic ranges were also determined. Since the shatter index of a coke has been found to give a valuable indication of its quality, the shatter indices of the coke made from these coals were accordingly obtained.

These determinations have shown that there is a decided relationship between the volatile matter contents of the coals at the end of their plastic ranges and the shatter indices of the corresponding cokes.

From indications of the various results obtained it was thought probable that if the percentage of volatile matter retained by a coal at the end of the plastic range could be diminished, a less fissured coke would be produced.

Accordingly several Scottish coking coals were blended with non-coking materials having low volatile matter contents and in every blending test in which an appreciable reduction of the volatile matter content of the mixture at the temperature of the end of the plastic range was obtained, there was also a definite increase in the size and the resistance to shatter of the coke obtained from the blend, provided that the limits of size and percentage addition were not exceeded.

The tests carried out demonstrated that the reduction of the large fissures present in a coke by blending the coal with/

with non-coking materials having low volatile matter contents was not wholly due to the actual reduction of the volatile matter content at the end of the plastic range, but was partly due to a more even distribution of the shrinkage cracks occuring in the coke.

Binary blends of coking coals were also examined. The Northern Coke Research Committee obtained some remarkable results from a series of experiments in which pairs of coking coals were blended. They found that "small additions of an inferior coking coal to a good coking coal and small additions of a good coking coal to an inferior coking coal produce more than proportionate effects on the shatter index of the coke; a 20% addition seemed to be a critical quantity in both types of result. In many experiments an optimum blend composition has been discovered, such a blend sometimes giving a coke of higher shatter index than that obtained from either of the parent coals" Several of these blends were examined during the present investigation and it was found that there was a close relationship between the volatile matter contents of the blends at the end of their plastic ranges and the shatter indices of the corresponding cokes.

Results similar to those obtained by the Northern Coke Research Committee were obtained from the examination of blends of two Scottish coals.

One of the cokes made from a blend of coking coal with

non-coking/

non-coking material having a low volatile matter content was tested in several cupolas and the improvement in quality indicated by the shatter test were confirmed. This coke gave results which compared very favourably with those obtained from one of the best Durham foundry cokes.

The blending of two poor coking coals with 2½ and 5% of shale oil bitumen or coal tar pitch was found to have extremely beneficial results on the qualities of the resultant cokes. These materials had no effect on the cokes obtained when they were blended with good coking coals since these were not deficient in the material which becomes plastic when heated and is necessary to bind the coal particles strongly together. Many Scottish coals having high volatile matter contents have not the necessary agglutinating power to bind any non-coking material of low volatile matter content to give non-abradable cokes of high resistance to shatter. It is suggested that small additions of bitumen or pitch would be beneficial in these cases.

It was shown that the percentage of volatile matter evolved from a coal when heated to a given temperature varied with the rate of heating employed.

A series of tests in which anthracite, bituminous coal, low and high temperature cokes were burned in two types of domestic stoves revealed that the smalls from several furnace cokes were excellent fuels for these heating appliances.

The/

The effect of several factors of design of open grates on the ease of kindling and burning and on the radiant efficiencies obtained from high temperature cokes made from crushed coals, was ascertained. An open coke grate suitable for burning a few of the furnace cokes was devised.

Cokes made from crushed coals, however, have very fine ashes and this detracted very much from the appearance and efficiency of the fires obtained from them. These cokes were more difficult to ignite than coal and also gave larger quantities of unburnt fuel when the fire died out.

A large number of tests were carried out to determine the effect of certain conditions of carbonisation of coals on the physical and combustible properties of the resultant cokes. It was established that the ease of kindling and burning of a coke could be greatly increased by an increase of the particle size of the coal carbonised. This result was attributed to the alteration of the structure of the coke obtained. The effect of the carbonising temperature on the suitability of the resulting coke for burning in an open grate was also determined. As a result of the open grate tests described a relationship was found between the radiant efficiency given by a fuel when burned in an open grate and its reactivity, combustibility and the nature of its ash.

The best open grate fuel was obtained by carbonising the treble nuts of a coking coal in 14 in. ovens using a flue temperature/

temperature of 1000°C and a coking period of 16 hr. This coke compared favourably with any of the special low temperature cokes manufactured in Britain for burning in an open grate. A series of domestic boiler tests showed that this coke was much superior to low temperature coke or anthracite for burning in these appliances.

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