

FUEL OIL FROM INFERIOR JHARIA COALS.

By S. K. ROY, Ph.D. (Zurich), Dhanbad, and S. S. GHOSH, M.Sc., Patna.

The existing coke ovens, owned by the Government and big industrialists, utilise superior grade coals for making hard coke and many of them also recover the various by-products of this high temperature process. So we already possess, thanks to the well-equipped coke ovens at Giridih, Bararee, Jamshedpur, Burnpur, Kulti, etc., a substantial knowledge of the gas and tar contents and in some cases of other products of the superior class coals of the Jharia Coalfield which is now mostly used as fuel. S. S. Ghosh, H. K. Sen, Dr. Sanjana, Dr. Bhattacharjee, Dr. Mukherjee, Dr. Ghosh and others have also interested themselves from time to time with the low temperature carbonisation of Indian coals, but in most cases they interested themselves only with the 'aristocrats' of our coals, and sometimes the samples treated were rather indefinite and unspecified. But whatever may be the case with our high grade coals nothing so far is known about the gas and tar-producing capacities of the immense quantity of second class coals used in the Jharia Coalfield for making soft coke nor do we know anything about the composition of the gas and the derivatives of the tar they produce, although in the manufacture of soft coke about one-third of the coal is lost in the form of gas and tar.

So far as we know, only Dr. C. Forrester, Principal, Indian School of Mines, has carried out in a systematic manner the distillation tests of this type of second class coal utilised for soft coke making, and has determined the tar contents of the coals under various temperatures. But he too has not fractionated his tars and all his results are the property of the Soft Coke Research Committee who have not yet published them.

Taking the most conservative estimate of about 2 million tons of soft coke being annually manufactured in the Jharia Coalfield for which 3 million tons of second class coal is burnt, and putting its tar content at the moderate figure of 10 gallons per ton of coal used, about 30 million gallons of tar, comparatively rich in motor spirit, light oils and other substances, are lost to our country per year. It is, for this reason, that we undertook firstly a series of researches on the gas and tar contents of the poorer grade coals used for soft coke making in the Jharia Coalfield and subsequently endeavoured to find out what are the by-products of this tar. The results of our experiments are given in the following pages. The experimental work was carried out by the junior author in the laboratories of Prof. B. C. Roy, Science College, Calcutta University, under the direction of the senior author and with financial assistance from the senior author and his colleague Prof. S. K. Bose.

Experimental details.

The experiments were carried out in a cylindrical mild steel retort prepared out of a piece of steam pipe of 5" inside diameter and 2'-9" long. The thickness of the wall is $\frac{1}{4}$ ". During the first two experiments the pipe was closed at one end with a screw cap while the other end was provided with a reducing socket 5" to 1" connected with a 1-inch elbow pipe for the extraction of volatile matter. This is more or less similar to the arrangements made on a previous occasion for experiments similar to the present ones by the junior author jointly with Dr. H. K. Sen (S. S. Ghosh and H. K. Sen—*Proc. Inst. Chem. India*, Vol. VI, Part 2, 1934).

But difficulties were experienced in the discharge of coke from such a retort and after the second experiment we were obliged to think out a more suitable retort for further experiments. The reverberatory furnace employed on a previous occasion (*loc. cit.*) for similar experiments was not found suitable on actual tests as it could not maintain the necessary temperature of 500°–530° Centigrade required for our experiments. On account of its firing arrangements from below it used to get very hot in the lower parts—the temperature rising there in the neighbourhood of 750° Centigrade—but in the upper part it was difficult to maintain constantly even 500°C. In order to eliminate this difficulty, we decided, after some discussion, to change the vertical retort into a horizontal one with the following special arrangements for maintaining uniform temperature throughout the retort. Most of the laboratories engaged in low temperature carbonisation work never recommend vertical retort systems, though in large-scale commercial works both types of retorts are in vogue.

The following is the description of our retort and firing system:—

Two flange-heads were welded at two ends of the retort, front and back, and they were provided with removable caps fastened by nuts and bolts. Then, instead of heating the retort from one end, arrangements were made to heat it over its full length by putting it in a horizontal position. And, instead of heating it by direct flame, in which case the portion in direct contact with the flame may be hotter than that in the upper part of the retort, the retort was placed inside a 'tunnel furnace' made of fire-bricks. A space of about 1" was left all round the retort between the tunnel furnace and the retort-wall for proper circulation of hot air from below and equal heating all over. At about 3" from the further end of the retort a $\frac{1}{2}$ " steel pipe was welded at the side of the retort for the extraction of volatile matter generated inside the retort. The heating was done by a burner made of 1" galvanised pipe bored at every half-inch. When kindled, each hole became a burner and we had altogether about 50 burners. This burner pipe was so placed that our retort may be at a distance of 2" from the tips of the flames. Hot air from the flame circulated all round the retort and escaped through the chimney above,

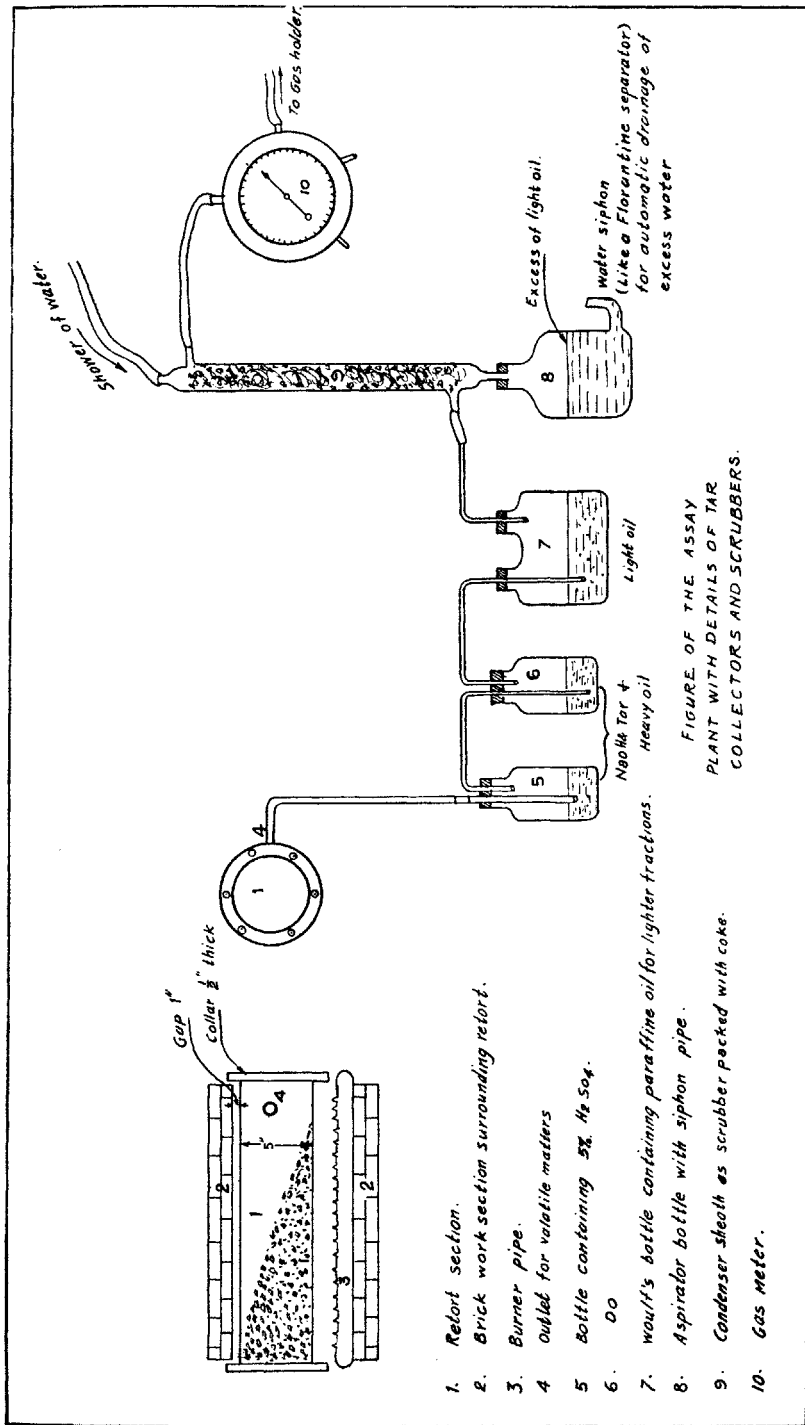


FIGURE OF THE ASSAY PLANT WITH DETAILS OF TAR COLLECTORS AND SCRUBBERS.

FIG. 1.

1. Retort section.
2. Brick work section surrounding retort.
3. Burner pipe.
4. Outlet for volatile matters.
5. Bottle containing 5% Na_2SO_4 .
6. Do
7. Wolff's bottle containing paraffine oil for lighter fractions.
8. Aspirator bottle with siphon pipe.
9. Condenser sheath as scrubber packed with coke.
10. Gas Meter.

which was 4' high. The advantages of this horizontal retort were found to be the following:—

1. Better and more uniform distribution of heat throughout the coal mass. This advantage was never obtained in vertical retorts.
2. Prevention of cracking, to a great extent, of the primary products of distillation.
3. Elimination of the difficulty regarding the extraction of coke experienced in the previous furnace where, in order to extract the coke, the heavy retort had to be taken out every time. But in the present case coke could be extracted by pushing it out, without removing the retort from the furnace.

5 to 10 lbs. of coal was crushed in a jaw crusher and placed in the furnace by un-screwing the cap of the flange at the back. The size of particles was $\frac{1}{4}$ " and below. The flange caps at both ends were tightly fixed with bolts and nuts and asbestos packing. The furnace was then connected with receivers (see figure) to collect gas, ammonia and other substances and after this was done the burners were lighted. The temperature was maintained between 520° and 550° Centigrade, and this was noted by two platinum-iridium-pyrometers inserted through holes in the brick-work, at right angles to the retort. The pyrometer tip just touched the retort.

When we had treated a few charges we found that the conduction of heat to the centre of the coal mass inside the retort from the periphery was not quite what could be expected. In some of the samples of coke we saw that although the distillation was continued for what we considered was the necessary length of time, the coking was not complete. In some cases the experiment has been discontinued by us just when coking of the central portion had started, but not completed.

Coal is a bad conductor of heat. As soon as it is sufficiently heated, it becomes plastic along the periphery of the retort and being spongy and in continuation with a layer of semi-coke inside the retort, it becomes a still worse conductor. Hence it becomes still more difficult for the heat to travel from the periphery to the core of the retort. Speaking theoretically, the time 'C' necessary for complete carbonisation of a layer of coal and the thickness 'T' of the coal layer are related to each other according to the following formula:—

$$C = K(T + K)^2$$

where 'K' is a constant depending on the nature of the particular coal. From Allison's curves it can be easily understood by extrapolation that a bed of coal 2 to 3 inches in thickness can be penetrated by heat within 4 to 5 hours. In the retort used by us for our low temperature assay, the same thickness has been selected, and for complete coking, instead of 4 to 5 hours as suggested by Allison, we had to continue the heating for 5 to 6 hours, in each case, from the time of the first evolution of gas. The hot vapours of tar and gases, as they came out of the retort, passed through a series of collecting bottles containing

absorbers, as shown in the figure. A 5 per cent solution of sulphuric acid was used in the first two bottles to ensure complete absorption of ammonia and separation of tar and heavy oil, whilst the third one which was a Wolf's bottle contained paraffin oil or creosote to absorb the lighter fractions which may escape condensation in the first two bottles. All these bottles were cooled by dipping them in water. Next came a scrubber fitted upright on a small aspirator bottle. The scrubber was provided with an outer sheath of Liebig's condenser packed with coke, over which was a sprayer spraying water all the time. The water scrubbed out all the escaping gases and collected them in the aspirator bottle underneath. The light oil floats on the water. The excess of water runs out constantly through the syphon bend at the side of the aspirator bottle. The washed gases pass through the gasometer and collect in the gas-holder. After the distillation is over the contents of the first two bottles containing ammonium sulphate and tar were separated by means of a separating funnel. The total liquid is made up to a standard volume and the total ammonia is determined by absorption. The total tar oil separated from the liquor was treated with 5 per cent caustic soda to separate the phenolic constituents. From a determination of the volume of the total tar after treatment with alkali, the percentage of phenols present in the original crude tar (sp. gr. 1.06) is known. The neutral tar was then washed three times in water and distilled to obtain the various fractions.

As it is impossible to separate the tar completely from water, and as the moist tar begins to froth as soon as it is heated, a good deal of inconvenience was experienced in the beginning to distil the tar. We, however, got over this difficulty by adopting the principle of 'drop distillation', *i.e.* pouring the tar from a separating funnel drop by drop on the bottom of the distillation flask which already contained a little hot tar and a few pieces of pumice stone, also hot. As each drop of moist tar came in contact with the hot tarry surface of the pumice, it distilled almost immediately without any considerable increase in volume. Frothing was practically eliminated in this way. If this experiment is carefully manipulated, this distillation process more or less becomes a type of steam distillation. In this steam distillation at a low temperature, the lighter fractions of the neutral oils come out with water, leaving resinoids and heavy hydrocarbons behind. The temperature was then increased up to 350° Centigrade to obtain further fractions. At this temperature only liquid pitch remains behind at the bottom of the flask. This is now poured out, cooled and weighed. The oils absorbed in their oil seals and those collected in the scrubber were distilled separately and the lightest fractions, boiling at as low a temperature as 60° Centigrade, were recorded and measured. Analysis of the gas coming out of each specimen of coal was carried out by means of Prof. Junker's gas calorimeter. This forms one of the most essential parts of our experiment and its usefulness will be well understood by fuel technologists.

It will be seen from our experimental results that the data about tar, oil and gas collected out of each sample of our coal had been also a check as to

whether it was carried out under low temperature conditions or not. It is well known that the gas obtained from one ton of coal by the low temperature method is about 5,000 c. ft. while from the same coal by high temperature process we may get even 11,000 c. ft. The calorific value of the high temperature carbonisation gas is only about 500 B.T.U. whereas for the low temperature distillation gas a calorific value of even 800 B.T.U. is quite common. Hydrogen and hydrocarbons are predominant constituents of the high temperature gas but the low temperature gas is rich in saturated hydrocarbons. All these have been very well borne out by the results of our experiments noted below.

I. *List of coals distilled.*

- (1) New Bansdeopur Colliery No. 12 seam, incline No. 15.
- (2) " " " " 11 " " " 14.
- (3) " " " " 10 " bottom of No. 3 pit.
- (4) Godhur Colliery No. 10 seam, No. 1 pit.
- (5) " " " 9 " from near the Jore 10A incline.
- (6) Sendra Bansjora Colliery No. 10 Coal seam.
- (7) " " " " " " " "
- (8) " " " " " " " (slack coal).
- (9) " " " " " " " (" ").
- (10) Matigora Colliery—combined V, VI, VII seams (100 ft. seam).
- (11) " " No. X seam.
- (12) " " Mixture 70% of 100 ft. seam and 30% of No. 10 seam.

II. *Results of Distillation test.*

(1)

Amount of coal distilled 7 lbs.

Temperature of the furnace 525°C.

Products:—

Coke (highly swelling hard coke), 6 lbs. 1 oz. @ 17.32 cwts. per ton.

*Tar oil (moist), 141.5 c.c. @ 10.06 gals. " "

Amm. Sulphate @ 6.62 lbs. " "

Gas, 12 c. ft. @ 3,840 c. ft. " "

Analysis of Gas.

CO ₂	..	..	..	2.41%
O ₂	..	..	..	1.12%
Unsaturated	..	..	..	3.5%
CO	..	..	..	11.23%
CH ₄	..	..	..	47.65%
H ₂	..	..	..	27.90%
N ₂	..	..	..	6.19%

Average calorific value of the gas is equal to 750 B.T.U.

* Measured under moist condition.

(2)

Amount of coal distilled	..	..	8 lbs.
Temperature of the furnace	..	..	520°C.

Products:—

Coke (moderately swelling coke), 7 lbs. 0.5 oz.	@	18.28 cwt.	per ton.
Tar oil (moist), 140 c.e.	..	..	@ 8.7 gals. ,, ,,
Amm. Sulphate	..	..	@ 7.02 lbs. ,, ,,
Gas, 15 c. ft.	..	..	@ 4,230 c. ft. ,, ,,

Analysis of Gas.

CO ₂	..	..	..	2.93%
O ₂	..	..	..	0.85%
Unsaturated	..	..	..	3.17%
CO	..	..	..	12.56%
CH ₄	..	..	..	46.95%
H ₂	..	..	..	28.32%
N ₂	..	..	..	5.22%

Average calorific value of the gas is equal to 750 B.T.U.

(3)

Amount of coal distilled	..	..	8 lbs.
Temperature of the furnace	..	..	535° to 540°C.

Products:—

Coke, 7 lbs. 2 ozs.	..	..	..	@ 17.8 cwt.	per ton.
Tar oil (moist), 144 c.e.	..	..	..	@ 7.9 gals.	,, ,,
Amm. Sulphate	..	..	..	@ 11 lbs.	,, ,,
Gas, 11.9 c. ft.	..	..	..	@ 3,332 c. ft.	,, ,,

Analysis of Gas.

CO ₂	..	..	..	3.23%
O ₂	..	..	..	0.41%
Unsaturated	..	..	..	0.54%
CO	..	..	..	17.88%
CH ₄	..	..	..	46.77%
H ₂	..	..	..	22.77%
N ₂	..	..	..	8.4%

Average calorific value of the gas is equal to 750 B.T.U.

(4)

Amount of coal distilled	..	..	8 lbs.
Temperature of the furnace	..	..	515° to 520°C.

Products:—

Coke, 7 lbs. 0.5 oz.	..	..	..	@ 17.58 cwt.	per ton.
Tar oil (moist), 140 c.e.	..	..	..	@ 8.71 gals.	,, ,,
Amm. Sulphate	..	..	..	@ 8.41 lbs.	,, ,,
Gas, 13.55 c. ft.	..	..	..	@ 3,794 c. ft.	,, ,,

Analysis of Gas.

CO ₂	..	..	..	3.12%
O ₂	..	..	..	0.96%
Unsaturated	..	..	..	2.57%
CO	..	..	..	11.55%
CH ₄	..	..	..	47.68%
H ₂	..	..	..	25.25%
N ₂	..	..	..	8.87%

Average calorific value of the gas is equal to 750 B.T.U.

(5)

Amount of coal distilled	..	..	10 lbs.
Temperature of the furnace	..	..	515°C.

Products:—

Coke, 8 lbs. 11.5 ozs.	..	..	@ 17.44 cwts. per ton.
Tar oil (moist), 160 c.c.	..	..	@ 7.969 gals. ,, ,,
Amm. Sulphate	..	..	@ 23.95 lbs. ,, ,,
Gas, 22 c. ft.	..	..	@ 4,928 c. ft. ,, ,,

Analysis of Gas.

CO ₂	..	..	..	2.58%
O ₂	..	..	..	1.23%
Unsaturated	..	..	..	3.22%
CO	..	..	..	10.98%
CH ₄	..	..	..	47.37%
H ₂	..	..	..	26.32%
N ₂	..	..	..	8.3%

Average calorific value of the gas is equal to 750 B.T.U.

(6)

Amount of coal distilled	..	..	10 lbs.
Temperature of the furnace	..	..	550° to 575°C.

Products:—

Coke, 8 lbs. 8.5 ozs.	..	..	@ 17 cwts. per ton.
Tar oil, 150 c.c.	..	..	@ 7.5 gals. ,, ,,
Gas	..	..	4,600 c. ft. ,, ,,
Calorific value	..	..	770 B.T.U. (I).
			744.7 ,, (II).
			722.8 ,, (III).

Analysis of Gas.

CO ₂	..	..	..	2.83%
O ₂	..	..	..	0.809%
Unsaturated	..	..	..	2.97%
CO	..	..	..	7.15%
CH ₄	..	..	..	42.0%
H ₂	..	..	..	36.98%
N ₂	..	..	..	7.26%
Ammonium Sulphate			..	14 lbs. per ton.

(7)

Amount of coal distilled	..	..	10 lbs.
Temperature of the furnace	..	..	550° to 575°C.

Products:—

Coke, 8 lbs. 8 ozs.	..	..	@ 17 cwts. per ton.
Tar oil, 150 c.c.	..	..	@ 7.5 gals. ,, ,,
Gas	..	..	4,600 c. ft. ,, ,,
Calorific value	..	..	747.3 B.T.U. (I).
			725.1 ,, (II).
			730.3 ,, (III).

Analysis of Gas.

CO ₂	..	..	..	4.724%
O ₂	..	..	..	0.63%
Unsaturated	..	..	..	3.62%
CO	..	..	..	7.08%
CH ₄	..	..	..	46.81%
H ₂	..	..	..	32.22%
N ₂	..	..	..	4.92%
Ammonium Sulphate			..	12.5 lbs. per ton.

(8)

Amount of coal distilled	..	..	10 lbs.
Temperature of the furnace	..	..	515°C.

Products:—

Coke, 8 lbs. 14 ozs.	..	..	@ 17 cwts. 78.5 lbs. per ton
Tar oil (moist), 170 c.c.	..	..	@ 8.46 gals. per ton.
Amm. Sulphate	..	..	@ 5.8 lbs. ,, ,,
Gas, 15.3 c. ft.	..	..	@ 3,427 c. ft. ,, ,,

Analysis of Gas.

CO ₂	..	..	..	1.27%
O ₂	..	..	..	1.2%
Unsaturated	..	..	..	2.52%
CO	..	..	..	9.3%
CH ₄	..	..	..	48.2%
H ₂	..	..	..	26.22%
N ₂	..	..	..	11.3%

Average calorific value of the gas is equal to 750 B.T.U.

(9)

Amount of coal distilled	..	..	10 lbs.
Temperature of the furnace	..	..	550°C.

Products:—

Coke, 8 lbs. 12 ozs.	..	..	@ 17.5 cwts. per ton.
Tar oil (moist), 188 c.c.	..	..	@ 9.4 gals. ,, ,,
Amm. Sulphate	..	..	@ 10.5 lbs. ,, ,,
Gas, 17.3 c. ft.	..	..	@ 3875.2 c. ft. ,, ,,

Analysis of Gas.

CO ₂	..	..	..	2.3%
O ₂	..	..	..	0.406%
Unsaturated	..	..	..	2.17%
CO	..	..	..	14.49%
CH ₄	..	..	..	48.57%
H ₂	..	..	..	20.46%
N ₂	..	..	..	11.6%

Approximate calorific value of the gas is equal to 750 B.T.U.

(10)

Amount of coal distilled	..	..	10 lbs.
Temperature of the furnace	..	..	525°C.

Products:—

Coke, 8 lbs. 8 ozs.	..	..	@ 17.5 cwts. per ton.
Tar oil (moist), 143 c.c.	..	..	@ 7.12 gals. ,, ,,
Amm. Sulphate	..	..	@ 5.9 lbs. ,, ,,
Gas, 16.5 c. ft.	..	..	@ 3,696 c. ft. ,, ,,

Analysis of Gas.

CO ₂	..	..	..	3.8%
O ₂	..	..	..	0.9%
Unsaturated	..	..	..	3.5%
CO	..	..	..	7.2%
CH ₄	..	..	..	45.4%
H ₂	..	..	..	27.9%
N ₂	..	..	..	11.3%

Approximate calorific value of the gas is equal to 750 B.T.U.

(11)

Amount of coal distilled	..	..	10 lbs.
Temperature of the furnace	..	..	525°C.

Products:—

Coke, 8.0 lbs. 9 ozs.	..	..	@ 17.25 cwts. per ton.
Tar oil (moist), 175 c.c.	..	..	@ 8.71 gals. ,, ,,
Amm. Sulphate	..	..	@ 8.2 lbs. ,, ,,
Gas, 26.7 c. ft.	..	..	@ 5,980 c. ft. ,, ,,

Analysis of Gas.

CO ₂	..	..	..	4.24%
O ₂	..	..	..	0.15%
Unsaturated	..	..	..	2.9%
CO	..	..	..	9.4%
CH ₄	..	..	..	44.4%
H ₂	..	..	..	26.83%
N ₂	..	..	..	12.08

Approximate calorific value of the gas is equal to 750 B.T.U.

(12)

Amount of coal distilled	..	..	8 lbs.
Temperature of the furnace	..	..	515°C.

Products:—

Coke, 7 lbs. 1 oz.	..	..	@ 17.6 cwts. per ton.
Tar oil (moist), 120 c.c.	..	..	@ 7.47 gals. ,, ,,
Amm. Sulphate	..	..	6.7 lbs. ,, ,,
Gas, 12.9 c. ft.	..	..	@ 3,612 c. ft. ,, ,,

Analysis of Gas.

CO ₂	..	..	..	5.59%
O ₂	..	..	..	0.00%
Unsaturated	..	..	..	3.4%
CO	..	..	..	7.35%
CH ₄	..	..	..	46.7%
H ₂	..	..	..	27.4%
N ₂	..	..	..	9.56%

Approximate calorific value of the gas is equal to 750 B.T.U.

III. *Tar oil fractions (i.e. Fuel oil, etc.)* :—

Sample No. (1).

Up to 100°C.*	..	..	11·3 c.c.	@ 0·8 gal. per ton.
100° to 135°C.	..	..	12 c.c.	@ 0·85 " " "
135° to 150°C.	..	..	8·4 c.c.	@ 0·59 " " "
150° to 210°C.	..	..	10·1 c.c.	@ 0·72 " " "
210° to 350°C.	..	..	56 c.c.	@ 3·98 " " "
Phenols	..	..	19 c.c.	@ 10·35 " " "
Pitch	..	..	18 gms.	@ 12·8 lbs. " "
Oil absorbed in paraffin oil-seal	..	..	6·2 c.c.	@ 0·44 gal. " "

Sample No. (2).

Up to 100°C.	..	..	10·4 c.c.	@ 0·65 gal. per ton.
100° to 135°C.	..	..	13·4 c.c.	@ 0·83 " " "
135° to 150°C.	..	..	10·2 c.c.	@ 0·63 " " "
150° to 210°C.	..	..	15·8 c.c.	@ 0·98 " " "
210° to 350°C.	..	..	58·0 c.c.	@ 3·6 " " "
Phenols	..	..	15 c.c.	@ 0·93 " " "
Pitch	..	..	18 gms.	@ 11·2 lbs. " "
Oil absorbed in paraffin oil-seal	..	..	6·5 c.c.	@ 0·4 gal. " "

Sample No. (3).

Up to 100°C.	..	..	8·6 c.c.	@ 0·535 gal. per ton.
100° to 135°C.	..	..	4·8 c.c.	@ 0·3 " " "
135° to 150°C.	..	..	4·4 c.c.	@ 0·274 " " "
150° to 210°C.	..	..	12·4 c.c.	@ 0·772 " " "
210° to 350°C.	..	..	48·5 c.c.	@ 3·018 " " "
Phenols	..	..	5·0 c.c.	@ 0·311 " " "
Pitch	..	..	13·6 gms.	@ 8·46 lbs. " "
Oil absorbed in paraffin oil-seal	..	..	4·0 c.c.	@ 0·25 gal. " "

Sample No. (4).

Up to 100°C.	..	..	13 c.c.	@ 0·809 gal. per ton.
100° to 135°C.	..	..	4·4 c.c.	@ 0·2738 " " "
135° to 150°C.	..	..	4·6 c.c.	@ 0·286 " " "
150° to 210°C.	..	..	20·9 c.c.	@ 1·301 " " "
210° to 350°C.	..	..	64·8 c.c.	@ 4·032 " " "
Phenols	..	..	12·0 c.c.	@ 0·7469 " " "
Pitch	..	..	18·0 gms.	@ 11·2 lbs. " "
Oil absorbed in paraffin oil-seal	..	..	6·3 c.c.	@ 0·392 gals. " "

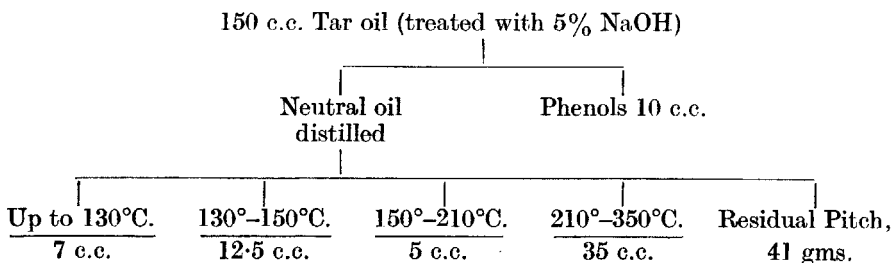
* For properties, see end of this paper.

Sample No. (5).

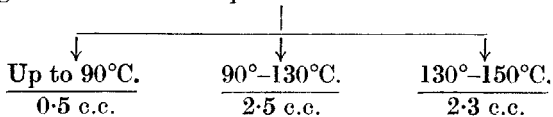
Up to 100°C.	..	..	14.5 c.c.	@ 0.7218 gal. per ton.
100° to 135°C.	..	..	8.8 c.c.	@ 0.438 " " "
135° to 150°C.	..	..	15.0 c.c.	@ 0.747 " " "
150° to 210°C.	..	..	21.5 c.c.	@ 1.0702 " " "
210° to 350°C.	..	..	62.0 c.c.	@ 3.0862 " " "
Phenols	..	..	7.0 c.c.	@ 0.3488 " " "
Pitch	..	..	23.5 gms.	@ 11.7 lbs. " " "
Oil absorbed in paraffin oil-seal	..	..	10 c.c.	@ 0.5 gal. " " "

Distillation of the tar :—

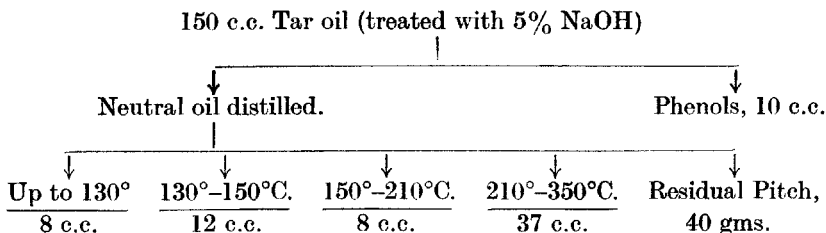
Sample No. (6).



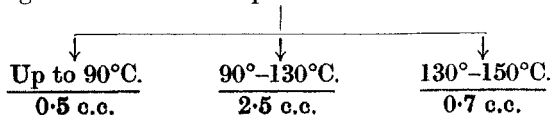
Light oils dissolved in paraffin oil bottle distilled.



Sample No. (7).



Light oils dissolved in paraffin oil bottle distilled.



Tar oil fractions :—

Sample No. (8).

Up to 100°C.	..	..	13.5 c.c.	@ 3.024 litres per ton.
100° to 130°C.	..	..	16.5 c.c.	@ 3.696 " " "
*130° to 150°C.	..	..	11.2 c.c.	@ 2.509 " " "
150° to 210°C.	..	..	13.7 c.c.	@ 3.0692 " " "
210° to 350°C.	..	..	73.0 c.c.	@ 16.352 " " "
Phenols	..	..	15.0 c.c.	@ 3.36 " " "
Pitch	..	..	36 gms.	@ 17.9 lbs. " "

Sample No. (9).

Up to 100°C.	..	..	21.6 c.c.	@ 1.075 gals. per ton.
100° to 135°C.	..	..	3.8 c.c.	@ 0.19 " " "
135° to 155°C.	..	..	3.3 c.c.	@ 0.164 " " "
155° to 210°C.	..	..	12.8 c.c.	@ 0.637 " " "
210° to 350°C.	..	..	62 c.c.	@ 3.086 " " "
Phenols	..	..	14 c.c.	@ 0.7 " " "
Pitch	..	..	39 gms.	@ 19.4 lbs. " "
Oil absorbed in paraffin oil-seal	..	..	8 c.c.	@ 0.398 gal. " "

Sample No. (10).

Moist tar oil	..	..	..	@ 7.12 gals. per ton.
Up to 90°C.	..	..	5.7 c.c.	@ 1.8 litres " "
90° to 130°C.	..	..	8 c.c.	@ 1.792 " " "
130° to 150°C.	..	..	21 c.c.	@ 4.704 " " "
150° to 210°C.	..	..	4.2 c.c.	@ 0.9408 " " "
210° to 350°C.	..	..	42.7 c.c.	@ 9.565 " " "
Phenols	..	..	9.9 c.c.	@ 2.218 " " "
Pitch	..	..	42.2 gms.	@ 12.224 lbs. " "

Sample No. (11).

Moist tar oil	..	..	175 c.c.	@ 8.71 gals. per ton.
Up to 90°C.	..	..	5.2 c.c.	@ 1.165 litres " "
90° to 135°C.	..	..	11.2 c.c.	@ 2.51 " " "
135° to 150°C.	..	..	20 c.c.	@ 4.48 " " "
150° to 210°C.	..	..	10.2 c.c.	@ 2.285 " " "
210° to 350°C.	..	..	95 c.c.	@ 21.28 " " "
Phenols	..	..	11 c.c.	@ 2.464 " " "
Pitch	..	..	19 gms.	@ 9.46 lbs. " "

* This includes 8 c.c. of a fraction which has been dissolved in the paraffin oil-seal.

Sample No. (12).

Up to 90°C. . .	..	..	9.0 c.c.	@ 2.52 litres per ton.
90° to 135°C. . .	..	..	10 c.c.	@ 2.8 " " "
135° to 150°C. . .	..	..	14.2 c.c.	@ 3.97 " " "
150° to 210°C. . .	..	..	5.2 c.c.	@ 1.46 " " "
210° to 350°C. . .	..	..	53.0 c.c.	@ 14.84 " " "
Phenols . . .	..	..	8.0 c.c.	@ 2.24 " " "
Pitch . . .	..	..	21 gms.	@ 13.1 lbs. " " "

Average for Nos. 6 and 7. Tar oil fractions :—

Up to 90°C. . .	0.112 litre	} Motor spirit, per ton of coal.
90°–130°C. . .	2.352 litres	
130°–150°C. . .	2.85 litres	} Light oil, kerosene, per ton of coal.
150°–210°C. . .	1.8 litres	
210°–350°C. . .	8.2 litres.	Fuel oil. " "
Phenols . . .	2.25 litres (Carbolic acid and Creosote oil),	per ton of coal.
Residual Pitch	19.7 lbs.	per ton of coal.

Difficulty is usually experienced in the carbonisation treatment of low grade coals either by low or high temperature methods. These difficulties are due either to the high percentage of ash in these coals, or low binding power of its particles, or in some cases due to the presence of a considerable amount of binding material in the coal. In the low temperature method if the coal does not possess sufficient binding property, the defect is rather of a serious nature because in that case the coke becomes very friable. But the presence of a very large quantity of binding material is also sometimes rather inconvenient, especially when it is combined with a high swelling index of the coal. Sometimes in such cases distillation becomes impossible. The reason is, as has been explained before, that after the distillation has started the layer of coal immediately next to the hot walls of the retort melts and becomes frothy, this combining with the still unchanged coal lying next to it forms a solid non-conductive layer surrounded by a layer of coke from which most of the volatile matter has been expelled. Conduction of heat in the interior of the retort from such a spongy mass becomes slow and before the above-mentioned solid layer of coal, formed by the mixture of plastic coal and undecomposed coal, becomes hot enough to melt, and again becomes frothy with the evolution of gas, a considerable amount of time is spent. The plastic mass, together with particles of coal still lying undecomposed above it, is pushed all about the inside of the retort by the pressure of the escaping gases, whose pressure increases gradually due not only to the evolution of gases but also, usually, due to the choking of the outlet pipe by the plastic coal-coke. Although we had started our experiments with a retort only half-filled with coal, in the course of time the whole of the interior of the retort becomes filled up with coke and coal. When we extracted the coke of such coals we

found that the coke was quite hard round the periphery while it was lighter and spongy towards the core. This is due to the greater pressure to which the coal in the periphery was subjected by the evolving gases. In the case of such coals, the distillation period becomes very much protracted and due to occasional choking of the outlet near about the end of the experiment, the volatile matter comes out slowly and spasmodically. Therefore, in case of such coals, we were compelled to carry out our experiments with a smaller quantity than usual. That is the reason why in the tables on pp. 368-373 it will be found that some experiments had been carried out with 10 lbs. of coal and others with a smaller quantity, our 'optimum quantity' in the retort. The figures are inversely proportional to the degree of plasticity and swelling index of the samples. For instance, we first tried to distil 10 lbs. of our sample No. 11. But scarcely had the distillation been continued for an hour, the gases and volatile matter started leaking profusely through the various joints of the retort while there was practically no flow of volatile matter through the absorbent system. When this was the case, the distillation was discontinued and we had to find out a way to get over the difficulty.

When the retort containing the products of our experiment was opened by removing the flanges, the whole of its inside was found to be filled up with a frothing, swelled, mass of partially distilled coal. We were, therefore, obliged to find out the optimum charge of each of our samples by trial. Thus it may be understood that we have carried out our experiments with optimum charges for our retort (see table on p. 380). In order to determine the practicable quantity of each type of coal to be placed in the retort (so that satisfactory results may be obtained) we carried out the following simple experiments by means of which the amount of the optimum charge could be found out.

This is a modification of the method used by the research staff of the Woodalt Duckham Co. (*Gas Journal*—'Coke Number'—November 9th, 1925, page 15). But at Woodalt Duckham Co.'s laboratory the coal was tested by means of a button which was treated in an ordinary silicate crucible at 900°C. In our case, however, we did not find this heating, right up to 900°C., quite satisfactory. It gives sometimes misleading information regarding the swelling property of some of our samples, the reason being that certain coals swell at low temperature and do not look swelled so much at 900°C. This is due to the fact that at a certain stage between its swelling points at about 500°-600°C., the coke collapses and at the higher temperature of 900°C. we find it showing a much lower volume than at a lower temperature.

Sometimes also a coke which may be swelling at 900°C. may be quite non-swelling at 550°C. For this purpose some preliminary experiments had to be carried out to avoid any serious breakdown in the middle of the experiment. This preliminary experiment consists of the following:—

About one gram of the finely powdered coal was made into a loose tablet by means of a small screw compressor and this was placed in a small covered

silica crucible. The crucible was then placed into a muffle furnace whose temperature was maintained at 550° to 600°C. A reducing atmosphere was maintained round the crucible by putting a few pieces of wood charcoal within the muffle. Violent evolution of gas takes place within a minute or two and the gas sets itself afire. A flame is formed round the lid of the crucible. This is watched through a hole in the door of the muffle. The time of the evolution of the gas and disappearance of the flame is noted and even after the flame has died out the crucible is allowed to remain inside the muffle for a few minutes. It is then taken out and the coke button in the crucible is examined for swelling properties. As stated above, this simple experiment has helped us a good deal to determine the approximate amount of the coal to be charged in our retort for each experiment.

The same experiment was also made to determine the most suitable blend of our samples Nos. 10 and 11, for the low temperature carbonisation test. Both of these are coking coals but their coke buttons behave very differently under different conditions. For instance, the coke button of sample No. 10 at 900°C. shows very little swelling while that of sample No. 11 was found to be of a very highly swelling nature. Both of them formed coke. No. 11 again not only becomes a very highly swelling coke during low temperature tests but it becomes very plastic during the experiment. In this plastic state it chokes the outlet and checks the evolution of volatile matter. The plastic coal forms a spongy mass which on the surface has a frothy appearance. As explained above in certain cases the frothy mass forms a non-conducting layer round the still unaffected coal powder in the crucible and develops a rather heterogeneous texture of the coke of the low temperature carbonisation process. No. 11 possesses almost double the plasticity and swelling power of sample No. 10. For all these reasons sample No. 11 alone is not very suitable for low temperature coking. It can be used for high temperature practice, where the swelling of coke is not of much consequence and where a large quantity of gas is welcome. Sample No. 10 does not show the plasticity and swelling of No. 11 and the coke is hard and compact with little or no sponginess. But blending of samples 10 and 11 reduces the excessive swelling tendency of the mixture during distillation. A 50% mixture behaves almost exactly as pure sample No. 11, and ultimately it was found that the best coke can be made out of these two coals by a mixture containing 30% of sample No. 11 and 70% of sample No. 10. Such a blend showed very little sign of plasticity and swelling, and the distillation period was much less protracted than that of sample No. 11. The yield of volatiles was also more than that for pure No. 10. The coke was fairly hard, compact and of uniform structure.

In the following table we have given a tabulated list of our samples showing the nature of their low and high temperature coke buttons, the nature of their cokes and the optimum distillation charge of each one of them for our own retort.

Number of the coal sample.	Nature of the low temperature coke button.	Nature of the high temperature coke button.	Optimum distillation charge.	Nature of the low temperature coke obtained after assay.
1 ..	Normally caked fairly swelling.	Slightly less caking and swelling than the low temperature button.	7 lbs.	Fairly hard compact structure on the surface with spongy internal structure.
2 ..	Caked and slightly swelling.	Very little swelling and compact coke button.	8 lbs.	Fairly hard and compact coke with slight spongy internal structure.
3 ..	Caked and slightly swelling.	Swelling more appreciable than in the case of low temperature coke button.	8 lbs.	Fairly hard and compact coke with slight spongy internal structure.
4 ..	Do.	No appreciable swelling.	10 lbs.	Robust and compact coke.
5 ..	No appreciable swelling.	Very slightly caking and swelling.	10 lbs.	Hard, robust and compact coke.
6 ..	Do.	Slightly caking and swelling.	10 lbs.	Hard and compact coke with graphite surface.
7 ..	Do.	Do.	10 lbs.	Do.
8 ..	Very slight swelling and caking.	Non-caking, mass apparently shrinks in size slightly.	10 lbs.	Do.
9 ..	Do.	Do.	10 lbs.	Do.
10 ..	Very slight swelling and non-caking.	Very slight swelling and caking.	10 lbs.	Hard and robust coke.
11 ..	Very highly swelling and caking.	Normally swelling and caking.	5 lbs.	Swelled coke with frothy surface appearance and spongy internal structure.
12 ..	Slightly swelling and caking.	Do. ..	8 lbs.	Slightly swelled cokes fairly hard with very uniform internal structure.

Properties of the Distillates.

We hope it may not be out of place if for ready reference we add at this place some of the most important uses of the tar oil fractions as obtained from the coals treated by us.

Distillation temperature up to 100°C. (*Neutral light oil*).—This fraction has all the properties of petroleum ether and solvent naphtha and mixed with the next fraction can be used as motor spirit.

Distillation temperature up to 135°C. (*Neutral light oil*).—This is equivalent to petrol or motor spirit as is obtained in the petroleum refineries.

Distillation temperature up to 150°C. (*Neutral oil*).—This is equivalent to the lightest kerosene known as white kerosene obtained in the petroleum refineries.

Distillation temperature up to 210°C. (*Neutral oil*).—This is equivalent to heavy kerosene known as yellow kerosene obtained in the petroleum refineries.

Neutral heavy oil.—This fraction distilling between 210°–350°C. has been considered as a whole. The specific gravity of this fraction is 0.95 and flash point as determined by us is 171°C. The last portion of this fraction, distilling between 300° to 350°C., possesses a greasy consistency. With a suitable blending material this can be converted into vaseline and lubricating greases. Separated from the greasy matter, the heavy neutral oil becomes less viscous and as such can be suitably employed as fuel for the Diesel engines, or after cracking can be changed into motor spirit, lubricating oils, fuel or Diesel oils. Hydrogen, hydrocarbons and carbon black can also be manufactured out of it.

Phenol.—This is the dark red liquid having a specific gravity 1.05 to 1.1 and possessing a strong creosotic smell obtained after the separation of the heavy oils. It can be employed as a disinfectant or for creosoting timber, or it can be directly employed for Bakelite industry where such mixed phenols are necessary.

Pitch.—The last residue of our distillation is pitch. The uses of coal tar pitch are many and are constantly increasing.

The gas obtained from our low temperature carbonisation experiment has a very high calorific value. It can be economically employed for firing boilers for the generation of electric power. As the problem of storing of such large quantities of gas has not yet been solved, it seems quite reasonable that its combustion in the boilers is so far the most profitable way of utilising the gas. The gas can also be utilised in gas engines. Nowadays even motor cars are running by such gas. The start which the Government of Bihar has given in this direction needs special mention. For the success of their newly conceived electrification scheme, they propose to generate power by firing their boilers with this 'waste' gas. They have recently installed an experimental low temperature coking plant at the Science College, Patna, for conducting systematic researches with various samples of low grade Bihar coal. The junior author, Mr. S. S. Ghosh, M.Sc., is the chemist in charge of this plant. The main purpose behind this experimental plant is to make good smokeless domestic coke out of poor grade coals and recover the valuable by-products such as tar, ammonium sulphate and gases. How far the gas can be utilised to generate power will also be investigated.

We are grateful to Dr. C. S. Fox, Director, Geological Survey of India, for his very kindly reading through the manuscript of this paper and making many useful suggestions.

Our thanks are due to Prof. B. C. Roy, M.Sc. (Leeds), of the University College of Science and Technology, Calcutta, for offering facilities for conducting

these researches in his laboratory and also for many useful suggestions. Thanks are also due to Prof. S. K. Bose, Indian School of Mines, Dhanbad, who rendered some financial assistance to prosecute the work and to Mr. S. K. P. Sinha, B.Sc. (Glasgow), Special Officer in charge Electrification, Bihar, for his keen interest throughout the research work.