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FUEL RESEARCH INSTITUTE OF SOUTH AFRICA

TECHNICAL MEMORANDUM NO. 39 OF 1963

THE MICROSCOPICAL EVALUATION OF THE COAL BLENDS USED AND THE COKES PRODUCED THEREFROM IN THE I/S SERIES OF COKING TESTS CARRIED OUT AT ISCOR

by

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FUEL RESEARCH INSTITUTE OF SOUTH AFRICA

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PROGRESS REPORT ON THE ISCOR-F.R.I. STEERING COMMITTEE

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A. INTRODUCTION

Contemporaneously with the physical testing of the experimental cokes produced in the I/S series, microscopical work was initiated which included the petrographic analyses of the coal blends used in the tests and the evaluation of the cokes obtained after carbonisation.

The first observations carried out on the coke samples were of a qualitative nature, but the desirability of evaluating the coke quantitatively soon became evident.

Petrographic analyses on the coals and blends thereof have been carried out on the first 200 tests. At this stage the project was terminated in order to devote more attention to the evaluation of the coke.

As quantitative coke microscopy is a very tedious undertaking, observations have thus far been carried out on 88 specimens, representing 44 samples taken during the manufacture of the cokes from the various coal blends. The method of selection of these samples will be discussed at a later stage.

B. PRESENTATION OF RESULTS

The results on which this report is based are recorded in Annexures 1 to 3.

Annexure 1 contains the composition of the blends used in the coking tests, as well as the percentages of unfused (i.e. inert material) particles present in the coke, the Shatter and Abrasion Size Stability*, the B.S. Abrasion Index, the Shatter Index (1½"), and the $Micum_{10}$ and $Micum_{20}$

values/....

* The Shatter and Abrasion Size Stability[1)] is the product of the shatter and abrasion mean size stabilities divided by 100, or

$$SASS = \frac{SMSS \times AMSS}{100}$$

values obtained during physical testing of the coke samples.

Annexure 2 contains the petrographic analyses of the 44 coal blends from which the cokes were manufactured, and Annexure 3 contains the average values obtained during the quantitative microscopical examination of the coke samples.

C. SOME GENERAL PETROGRAPHIC CONSIDERATIONS

From a petrographic point of view there are three important properties in a coal which would have a profound influence on the quality and properties of the coke manufactured therefrom. These are: (a) the rank of the coal, (b) the amount of fusible constituents, and (c) the amount of inert constituents present in the coal.

(a) The Rank of the Coal

A definite relationship has been found to exist between the rank of the coal and the pore volume of the coke, and it has also been found that there is a relationship between the coke structure and the reactivity[2)].

The importance of the rank of the coal from which a coke is manufactured must, therefore, not be underestimated.

From Annexure 1 it can be seen that no less than 12 different coals have either been used individually or in admixtures during the experiments.

The ranks of the different coals used in the experiments are as follows:

Coal	% Carbon (d.a.f.)
Hlobane	88.3
Northfield	88.1
Indumeni	± 87
D.N.C.	85.5
Waterberg (Bright)	± 81
Waterberg (No. 2 and 3 seams)	± 83
S.A.C.E. No. 5 seam	84.0
Springbok No. 5 seam	83.5
Welstand	± 84
Soutpansberg	± 83
Transvaal Navigation	83.5
Blesbok No. 5 seam	83.0

It can be noted that only three of the coking coals can be classified as of sufficiently high rank to be

compared/...

compared with, e.g., European coking coals, and that the rank of the rest of the coals, although variable, can generally be regarded as being fairly low by comparison.

In view of Schapiro's[2] findings, it can be expected that the majority of the cokes produced during these tests would tend to be porous.

Furthermore, Juranek[3] and others have shown that coals of different ranks have different softening temperatures and that this may also have an influence on the coke.

It would, therefore, appear that in order to produce a really good coke, the coals comprising a blend should be carefully selected on the basis of their rank.

(b) <u>The Fusible Constituents in the Coal</u>

The fusible constituents in a coal comprise the petrographic entities vitrinite and exinite (i.e. the spores). The vitrinite forms the 'body' of the coke, while the exinite supplies extra bitumen to act as a binder, especially in the case of the lower rank of coking coals[4].

These entities or macerals, as they are normally called, do not occur separately, but in mixtures with each other (to form clarite) or with the inert macerals to form the claro-durites, duro-clarites and vitrinertite. The concentration of the macerals may also vary widely. Thus a coal having a low percentage of vitrite and high percentages of claro-durite, duro-clarite and vitrinertite may, under certain circumstances, yield a coke of the same quality (and even better) as a coal having a high percentage of vitrite and relatively low percentages of vitrinertite and intermediate material. Furthermore, the macerals constituting the intermediate material may vary very widely in concentration.

It can thus be realised that it is not an easy task to forecast from a petrographical analysis what the coking propensity of the coal would be. However, it has been found that as far as South African coals are concerned, the amount of vitrite (i.e. the free vitrinite) serves as a fair measure to judge the coking properties of the coal. If a coal contains a low percentage of

vitrite/...

vitrite, there is in the first place not enough material to form the 'body' of the coke, and in the second place, to bind the inert particles also present in the coke.

It would appear that these fusible constituents (also known as active constituents) are essential in the coking process, but it is doubtful whether they play any important part in the determination of the quality of the coke.

(c) <u>The Inert Constituents</u>

The inert constituents comprise the macerals fusinite, semi-fusinite, micrinite, sclerotinite and carbonaceous shale.

These constituents (excluding the carbonaceous shale) have relatively higher carbon contents than the fusible constituents and, as the name implies, are very inert. Many examples can be found in a coke where they have retained their characteristic forms and did not take part in the reaction.

<u>Photomicrograph No. 1</u> shows a fragment of carbonaceous shale containing small remnants of semi-fusinite partly imbedded in a cell wall of a piece of coke. In the upper right hand corner of the photomicrograph the outline of a sclerotium can just be seen. In this particular case the particles are very small and the bonding has been excellent. In other cases the inert particles are very large and there has not been sufficient fusible material to effect a good bond.

<u>Photomicrograph No. 4</u> shows such an example. In this particular case the inerts consisted of semi-fusinite.

The inert constituents have for a long time been regarded as deleterious to the quality of the coke. However, those with a long experience in the coking industry have realised that a certain percentage of inert constituents actually improved the quality of the coke - hence the expression: "adding bone to the body".

It has now been proved that while the fusible constituents are essential in the coking process, the inert constituents have the greatest influence on the strength of the coke.

Fenton and Bradburn[4)] found a linear relationship between the inertinite content of the coal and its 1½"

Shatter/...

Shatter Index. This relationship could not be found in this particular investigation, probably on account of the fact that the above authors had used specially selected coals for the coking tests, which had a much wider range of inertinite contents than the coals used in this study.

By plotting the inertinite content of the coals used for the present coking tests against the Micum 40 values, a graph was obtained which showed that the majority of the points formed a broad band, rather than a line (see Fig. 1 at the end of this report). The trend of this band is, however, in general keeping with Fenton and Bradburn's conclusions. These authors also found that coke of optimum strength could be produced if the amount of inertinite in the coal could be raised to a level of between 30 and 40%. It would appear that the problem in South Africa is not to raise the level of the inertinite, but rather that of the vitrinite and exinite in order to supply sufficient bonding material. Since South African coals are poor in exinites and relatively poor in vitrinites, it would perhaps be more convenient to reduce the inertinite content of the coal to the optimum level than to attempt to enrich it with active constituents.

(The extent of the problem can perhaps be better visualized by studying the following figures:

In their experiments, Fenton and Bradburn selected three types of coking coals, having levels of rank corresponding to 84, 85 and 87 per cent of carbon. The range of maceral composition varied between 91 - 33% vitrinite, 2 - 26% exinite and 5 - 57% inertinite. By contrast, the range of maceral composition of the coals used in the present investigation varied between 87 - 48% vitrinite (mean 67%), 13.7 - 1.1% exinite (mean 5.4%), and 10 - 45% inertinite (mean 27.5%). The high mean value obtained for the vitrinite and the low mean value for the inertinite can be explained by the inclusion of the numerous samples containing very high percentages of Waterberg bright coals).

THE MICROSCOPIC ASSESSMENT OF THE COKE

The choice of the samples was based on the average S.A.S.S. value obtained on the first series of 100

samples/...

samples, viz. 35.

The samples chosen for further investigation were mostly those which gave substantially higher and lower values than the mean. This was done in an attempt to establish the cause for the discrepancies. This work is still proceeding and more samples are being analysed.

For the purpose of the microscopical investigation the distribution of the pore sizes and cell wall thicknesses were determined by measuring them over straight lines on a polished specimen which had previously been impregnated with a special wax.

From the above data the denseness[5)], i.e. the compactness of the coke, which is a ratio of the total length of cell walls to the total length of pores as measured during the traverse over the sample, was calculated. The condition of the pores and cell walls was also converted to index figures based on the mean values of the accumulative percentages of the pores and cell walls respectively.

Thus, the following table could be used for an accurate description and evaluation of the denseness, the state of the pores and the state of the cell walls:

TABLE 1

Indices for the Evaluation of Coke

Denseness Index	
> 0.825	Extremely dense
0.825 - 0.750	Very dense
0.750 - 0.700	Dense
0.700 - 0.650	Average dense
0.650 - 0.600	Average porous
0.600 - 0.550	Porous
0.550 - 0.475	Very porous
< 0.475	Extremely porous
Pore Index	
< 50	Extremely coarse pores
50 - 55	Very coarse pores
55 - 60	Coarse pores
60 - 70	Average pores
70 - 80	Fine pores
80 - 90	Very fine pores
> 90	Extremely fine pores

TABLE 1 (continued)

Cellularity Index	
< 45	Extremely thick cell walls
45 - 50	Very thick cell walls
50 - 60	Thick cell walls
60 - 70	Average thick cell walls
70 - 75	Thin cell walls
75 - 80	Very thin cell walls
> 80	Extremely thin cell walls

If the indices given in this table are applied to the results recorded in Annexure 3, it will be noted that no less than 58 per cent of the samples investigated were extremely porous. Only 6 per cent were extremely dense. In general, 85 per cent of the cokes were on the porous side, while only 15 per cent were on the dense side.

If the condition of the pores is considered, it can be noted that 54 per cent of the coke samples consisted of material which had average pore sizes and that the general tendency for the pores was to be somewhat coarse. In general, some 75 per cent of the samples consisted of material with very coarse to average pores, while only 25 per cent of the samples consisted of material having fine pores.

If the condition of the cell walls is considered, it can be noted that 50 per cent of the samples had cell walls of average thickness. None of the samples had cell walls that could be described as extremely or very thick. The general experience was that the samples had cell walls ranging from average thickness to extremely thin.

To complete the overall picture of the coke samples investigated, it can be stated that the results indicate that most of the coke samples were extremely porous, the pores were coarse and the cell walls varied from average thickness to thin. In other words, the cokes produced from the various blends were of an indifferent to poor quality. This is not surprising, since most of the cokes were produced from blends containing predominantly low rank coals.

However/...

However, there are some tests which merit closer attention.

(a) Two tests were carried out on 100% Waterberg coals, viz. I/S 1 and I/S 150. The former contained coal from the upper bright seams and the latter contained coal from the No. 2 seam of the same field.

The results of the study of these coals and cokes produced from them are summarised in Table 2:

TABLE 2

A Comparison of the Two Waterberg Coals

No. of charge Seam	I/S 1 Upper Bright	I/S 150 No. 2
Denseness	0.250 Ext.por.	0.491 Very por.
State of pores	57.7 Coarse	73.79 Fine
State of cell walls	73.0 Thin	74.2 Thin
% Unfused particles	1.7	8.5
S.A.S.S.	27.5	22
B.S. Abrasion Index	78.5	52
Shatter index 1½"	66	80
Micum 10	9.3	37.1
Micum 40	-	41
Vitrite (%)	44.0	34.4
Clarite (%)	16.6	0.4
Vitrinertite (%)	8.7	36.9
Intermediate Mat. (%)	22.5	24.0
Fusite (%)	0.6	3.9
Carb. shale (%)	7.6	0.4
Vitrinite (%)	85.5	61.1
Exinite (%)	4.0	6.1
Inertinite (%)	6.1	31.0
Vis. Minerals	4.4	1.8
Ratio A/I	8.5:1	2.0:1

The tests carried out on these two cokes are the only tests where the microscopical observations disagreed with the other physical tests.

Photomicrograph No. 2 shows the intermittent cell walls of the coke obtained from 100% Waterberg bright seam coal, as well as the coarse pores.

Photomicrograph/...

Photomicrograph No. 3 shows the cell walls of the coke manufactured from the Waterberg No. 2 seam. The cell walls are still thin, but more continuous, and the pores are finer. The inerts, however, were not bonded (Photomicrograph No. 4).

The petrographic analyses differ, but that of the No. 2 seam still compares favourably with those of other coking coals. Differences in petrographic analysis can be expected since the No. 2 seam coal consists of a mixed coal and that of the bright seams of bright coal only. (Hence the very low amount of inertinite).

However, it must be borne in mind that large, reasonably representative samples were used for the physical testing, while single pieces of coke had to be selected for the microscopical investigation and one could not expect them to be as representative of the coke produced.

(b) I/S 182 contained 70% Waterberg No. 2 seam + 22% D.N.C. + 8% Northfield. The coke obtained from this blend also gave very poor results, but in this particular case the unfused particles amounted to no less than 17.5%. A peculiar feature is that in the cases of I/S 150 (100% Waterberg No. 2 seam) and I/S 182, patches inside the coke were found to contain well-developed coke structures. In general, neither of these two Waterberg seams yielded coke of good quality.

The cokes obtained from the Northfield coals are, perhaps, the most interesting of the whole test series. The data obtained on three of them are recorded in Table 3.

Table 3/...

TABLE 3

Data Relating to Northfield Cokes

	No. of charge State of charge	I/S 164 Dry	I/S 165 Wet	I/S 195 Dry
	Denseness	0.61 (Average)	0.71 (Dense)	0.62 (Av.)
	State of pores	62.1 (Average)	58.4 (Coarse)	61.6 (Av.)
	State of cell walls	69.9 (Av.thick)	73.6 (Thin)	71.5 (Thin)
	% Unfused particles	4.4	5.7	7.8
	S.A.S.S.	43	47	43
	B.S. Abrasion Index	78	83	80
	Shatter Index 1½"	91	91	90
	Micum 10	10.0	7.4	9.8
	Micum 40	75	78	75
Petrographic Analysis of the coal	Vitrite (%)	49.5	48.5	42.4
	Clarite (%)	0.0	0.0	0.0
	Vitrinertite (%)	45.6	43.6	42.0
	Interm. Mat. (%)	2.9	5.4	13.0
	Fusite (%)	1.5	0.5	1.1
	Carb. shale (%)	0.5	2.0	1.5
	Vitrinite (%)	73.5	70.7	76.3
	Exinite (%)	0.5	0.4	1.1
	Inertinite (%)	21.6	24.0	19.3
	Vis. Min. (%)	4.4	4.9	3.3
	Ratio A/I	2.8 : 1	2.5 : 1	3.4 : 1

The petrographic analyses of the coals from which the cokes were manufactured are practically the same. Good results were obtained on all three cokes. The coke from I/S 165 was dry-charged and gave slightly better results.

Photomicrograph No. 5 gives a general view, at low magnification, of this coke. All the unfused particles are well bonded.

Photomicrograph No. 6 gives a detailed view of the pore and cell wall structure. Although the pores are slightly on the coarse side, they vary very little in size, and the cell walls are continuous but somewhat on the thin side.

Northfield coal can at present be regarded as the best coking coal in the country. This is also confirmed by the physical tests.

(c)/...

(c) Another very interesting series of tests was that on the cokes manufactured from what can be described as the normal Iscor coal blend.

The data obtained on these cokes are recorded in Table 4.

TABLE 4

Data Relating to Cokes Manufactured from Iscor Normal Blends

Test No.		I/S 33	I/S 85	I/S 144	I/S 196
Composition		47% SACE 25% Spr. 19% DNC 9% North.	45% SACE 25% Spr. 22% DNC 8% North.	45% SACE 25% Spr. 22% DNC 8% North.	45% SACE 25% Spr. 22% DNC 8% North.
Denseness		0.30 (Ext.por.)	0.34 (Ext.por.)	0.47 (Ext.por.)	0.57 (Porous)
State of pores		62.4 (Av.)	65.7 (Av.)	66.2 (Av.)	61.8 (Av.)
State of cell walls		65.8 (Av.)	79.1 (Very thin)	71.0 (Thin)	59.1 (Thick)
% Unfused particles		4.2	5.0	3.8	10.6
S.A.S.S.		37.1	37.2	45	37
B.S. Abrasion Index		70.2	72.2	75	74
Shatter Index 1½"		89	90	89	88
Micum 10		15.5	15.1	10.4	14.1
Micum 40		67.1	67.6	74	68
Petrographic Analysis of Blends	Vitrite (%)	23.0	19.1	29.0	29.5
	Clarite (%)	4.3	2.2	3.5	3.4
	Vitrinertite (%)	21.4	32.2	41.7	36.0
	Interm. Mat. (%)	46.6	39.9	21.2	26.1
	Fusite (%)	1.7	2.2	2.7	2.3
	Carb. shale (%)	3.0	4.4	1.9	2.7
	Vitrinite (%)	57.0	57.6	65.6	67.9
	Exinite (%)	11.0	5.9	3.5	5.3
	Inertinite (%)	28.3	32.4	25.6	21.9
	Vis. Min. (%)	3.7	4.1	5.3	4.9
	Ratio A/I	2.1 : 1	1.7 : 1	2.2 : 1	2.7 : 1

The cokes tend to be on the porous side. The pores are of average size and the cell walls are thin, except in the case of I/S 196 where the cell walls were thick.

The/...

The results of the physical tests are very similar except in the case of I/S 144, which has a S.A.S.S. value well above the average. This coke was derived from coal which was dry-charged. It would appear from the results obtained on these cokes and those from Northfield that dry-charging certainly improves the Shatter and Abrasion Size Stability of the coke, although this is not very clear from the microscopical observations in this particular case. In general the physical tests show an improvement when the coal is dry-charged.

Photomicrograph No. 7 gives a detailed view of the cell walls and pores of this coke and it can be seen that it is still on the porous side and that the cell walls are rather thin.

The cokes derived from the normal Iscor blend compare very favourably with those of other blends and it would appear at the moment that unless larger proportions of high rank coals are admixed to the blend, the chances are that it would be very difficult to improve on the coke manufactured from this blend.

(d) In two tests, I/S 126 and I/S 141, Indumeni and Soutpansberg coals were admixed to the blends and the results obtained were very promising.

The data relating to these tests are recorded in Table 5.

Table 5/...

TABLE 5

Data Relating to Cokes Obtained From Coal Blends Containing Indumeni and Soutpansberg Coals

Test No.		I/S 126	I/S 141
Composition		18% Indumeni 38% Blesbok 21% DNC 16% Spr. 7% Northfield	15% Soutpansberg 51% SACE 29% Spr. 5% Northfield
Denseness		0.41 (Extr. por.)	0.59 (Porous)
State of pores		70.9 (Fine)	65.3 (Average)
State of cell walls		68.9 (Average)	60.7 (Av.to thick)
% Unfused particles		5.7	9.8
S.A.S.S.		35	40
B.S. Abrasion Index		70	77
Shatter Index 1½"		88	89
Micum 10		14.8	11.8
Micum 40		67	67
Petrographic Analysis of Coal Blends	Vitrite	-	25.8
	Clarite	-	3.4
	Vitrinertite	-	33.8
	Intermed. Mat.	-	30.9
	Fusite	-	2.2
	Carb. shale	-	3.9
	Vitrinite	-	63.9
	Exinite	-	5.2
	Inertinite	-	26.7
	Visible Min.	-	4.2
	Ratio A/I	-	2.2 : 1

Both these blends gave cokes with acceptable values, especially in the case of the Soutpansberg coal blend.

In an attempt to make a more realistic evaluation of the quality of the cokes produced from the various coal blends in the course of these tests, the more important blends have been classified into four groups.

Group 1 consisted of normal Iscor blends and the cokes derived therefrom. Group 2 consisted of coal blends containing 70% and more of coal from the Waterberg bright seams. Group 3 consisted of blends containing Waterberg No. 2 and

No. 3 seam coals as major constituents, and Group 4 consisted of high rank coals from Natal or blends thereof.

The average results obtained on the cokes manufactured from these groups as well as the average petrographical analyses of the blends are recorded in Table 6.

TABLE 6

Average Data Obtained on Cokes Manufactured from 4 Groups of Coal Blends as well as the Average Petrographical Analysis of the Blends

Group	1	2	3	4
Description	Normal Iscor Blend	Waterberg Bright Coals	Waterberg No's. 2 & 3 Seams	High rank Natal Coals
No. of blends cons.	4	4	5	9
Denseness	0.42 Extr. por.	0.20 Extr. por.	0.39 Extr. por.	0.66 Dense
State of pores	64.0 Average	57.5 Av. coarse	63.3 Average	69.5 Av. to fine
State of cell walls	68.8 Av. thick	76.7 Very thin	68.4 Av. thick	62.6 Av. thick to thick
% Unfused Material	5.9	2.8	8.7	6.5
S.A.S.S.	39	33	28	41
B.S. Abrasion Index	73	69	67	78
Shatter Index	89	84	82	89
Micum 10	13.8	16.9	18.8	9.9
Micum 20	69	61	56	74
Petrographic Analysis of Blends				
Vitrite	25.2	46.5	36.4	33.2
Clarite	3.3	7.2	3.5	0.7
Vitrinertite	32.8	12.6	32.9	47.1
Interm. Mat.	33.5	28.9	23.9	15.0
Fusite	2.2	1.4	2.1	2.0
Carb. shale	3.0	3.4	1.2	2.0
Vitrinite	62.0	82.7	73.7	65.5
Exinite	6.4	5.9	4.5	2.7
Inertinite	27.1	8.0	19.4	27.6
Vis. Min.	4.5	3.4	2.4	4.2
Ratio A/I	2.2 : 1	8.3 : 1	4.0 : 1	2.4 : 1

If the above average values are studied and the groups of coal blends from which the best cokes were manufactured

are/...

are to be placed in order of merit, it will be found that the best cokes were produced from the high rank Natal coals while the normal Iscor blends would be placed second.

The poorest results were obtained from the Waterberg coals.

The groups classified in the order of merit are given in Table 7.

TABLE 7

Groups of Coke Samples Manufactured from 4 Groups of Coal Blends Placed in the Order of Merit

Denseness	Group 4	Group 1 Group 3 Group 2		
State of pores	Group 4	Group 1 Group 3	Group 2	
State of cell walls	Group 4	Group 1 Group 3	Group 2	
S.A.S.S.	Group 4	Group 1	Group 2	Group 3
B.S. Abrasion Index	Group 4	Group 1	Group 2	Group 3
Shatter Index 1½"	Group 4 Group 1	Group 2	Group 3	
Micum 10	Group 4	Group 1	Group 2	Group 3
Micum 40	Group 4	Group 1	Group 2	Group 3

The cokes manufactured from the Group 4 coals, i.e. the high rank Natal coals, gave better results than any of those manufactured from the other groups of coals except in the case of the 1½" Shatter Index, where it was equalled by the cokes obtained from the Group 1 coals, i.e. the normal Iscor blends.

The cokes manufactured from the Group 1 blends are placed second in the order of merit.

An interesting feature is that the microscopic evaluation and that from the physical tests differ as far as the placing of Groups 2 and 3 are concerned. According to the microscopic evaluation, the Group 3 blends gave better cokes than the blends from Group 2, while the

physical/...

physical tests show the opposite. The inconsistency of the coke structure found in the cokes produced from the Group 3 coals may be responsible for this.

CONCLUSION

From the available evidence thus far collected in the study of the coke specimens under the microscope, it can be concluded:

1. That the high rank coking coals from Natal are superior to any of the other coals tested and that the best cokes were obtained from these coals.

2. Excluding the high rank coking coals of Natal, no other blend tested gave better results than the normal Iscor blend.

3. In view of the importance of high rank coals in the manufacture of coke, it is doubtful whether Iscor would succeed in manufacturing a better coke than that presently being manufactured by them unless high rank coals are admixed in higher proportions to the blend.

4. That dry-charging of the coal improves the quality of the coke.

5. That Waterberg coals are not suitable for the manufacture of coke if they are utilized as a major constituent to the blend. (As a minor constituent they may give acceptable cokes). They may, however, constitute quite a valuable minor constituent of blends.

6. That Soutpansberg and Indumeni coals can successfully be used as blend constituents.

7. That the cokes manufactured from South African coals in general are very porous in comparison with those manufactured from European coals.

8. That the coal blends with low ratios of active

to inert constituents do not necessarily give cokes of inferior quality and that generous amounts of inertinite are probably beneficial to the coke.

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PRETORIA

12th November, 1963.

OvR.

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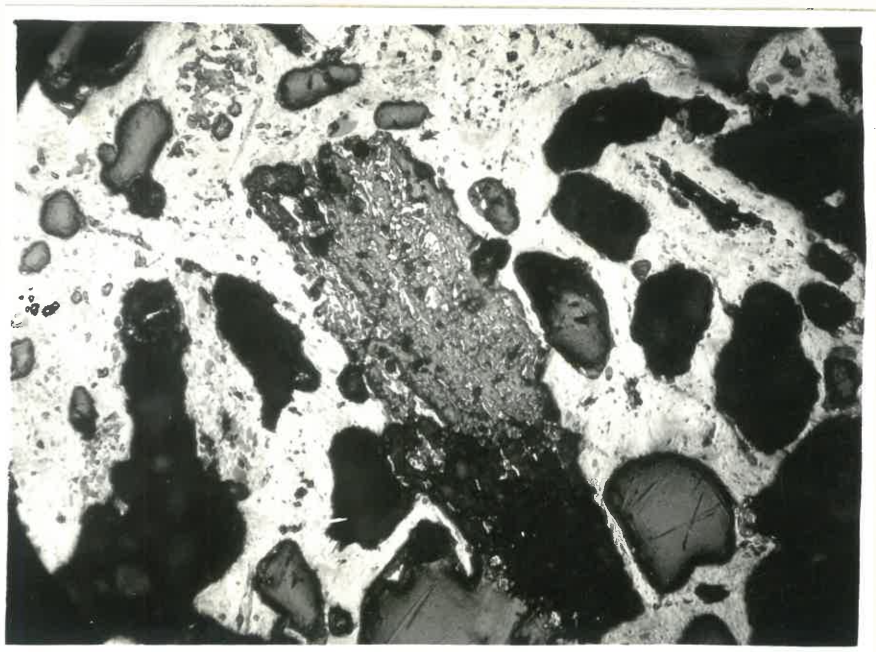
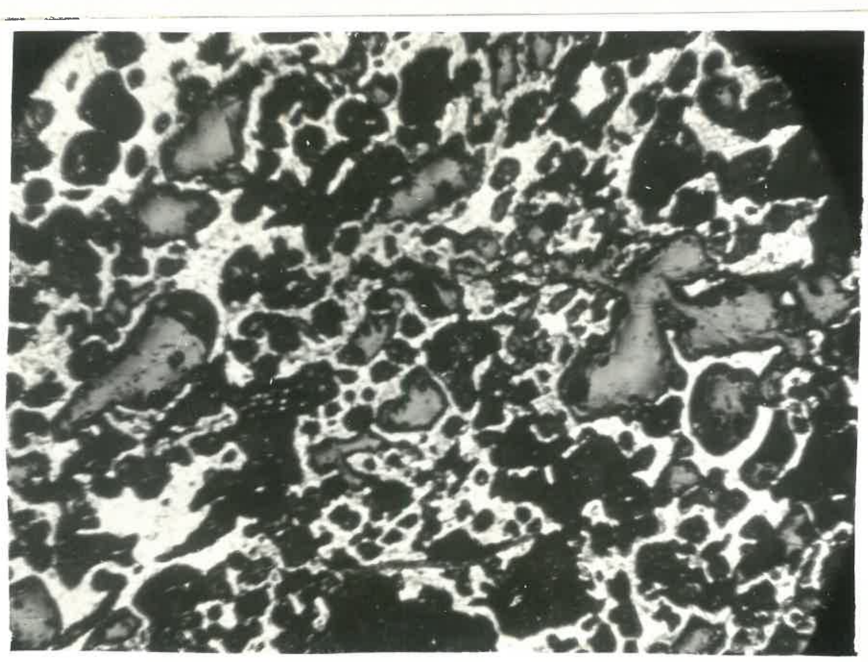


Photomicrograph No. 1

Coke from 100% Northfield Coal

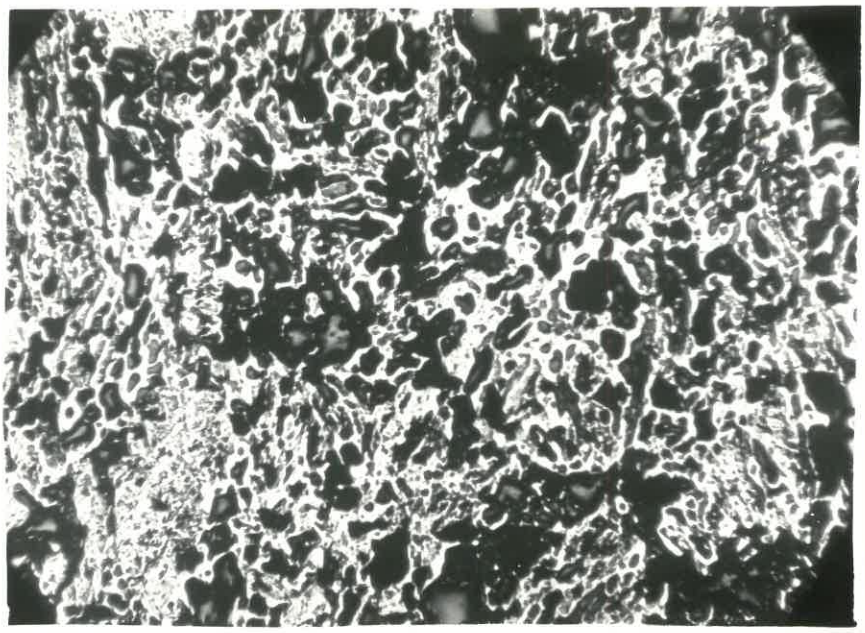
Magn. 80 x



Photomicrograph No. 2

Coke from 100% Waterberg (bright seam) Coal

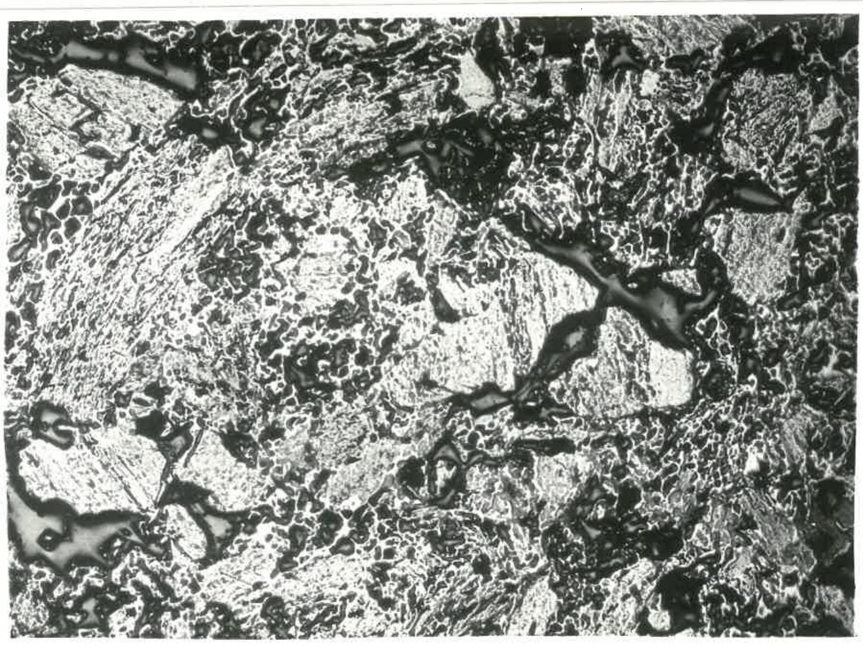
Magn. 25 x



Photomicrograph No. 3

Coke from 100% Waterberg No. 2 Seam Coal

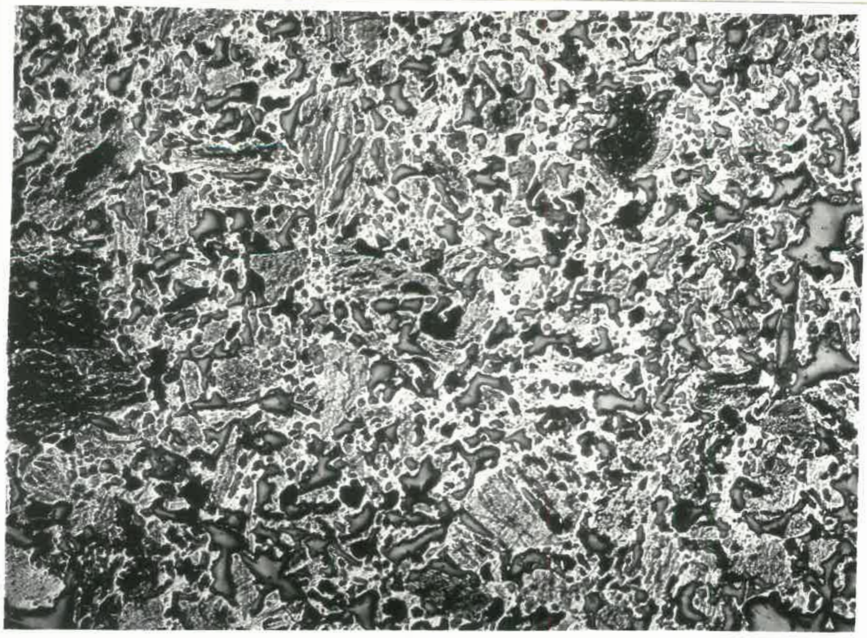
Magn. 25 x



Photomicrograph No. 4

Coke from 100% Waterberg No. 2 Seam Coal

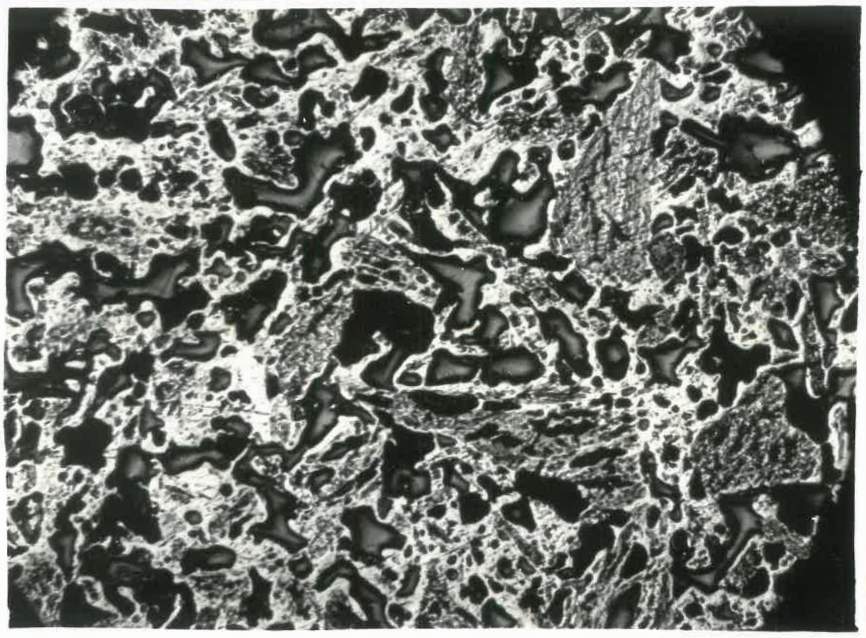
Magn. 10 x



Photomicrograph No. 5

Coke from 100% Northfield Coal

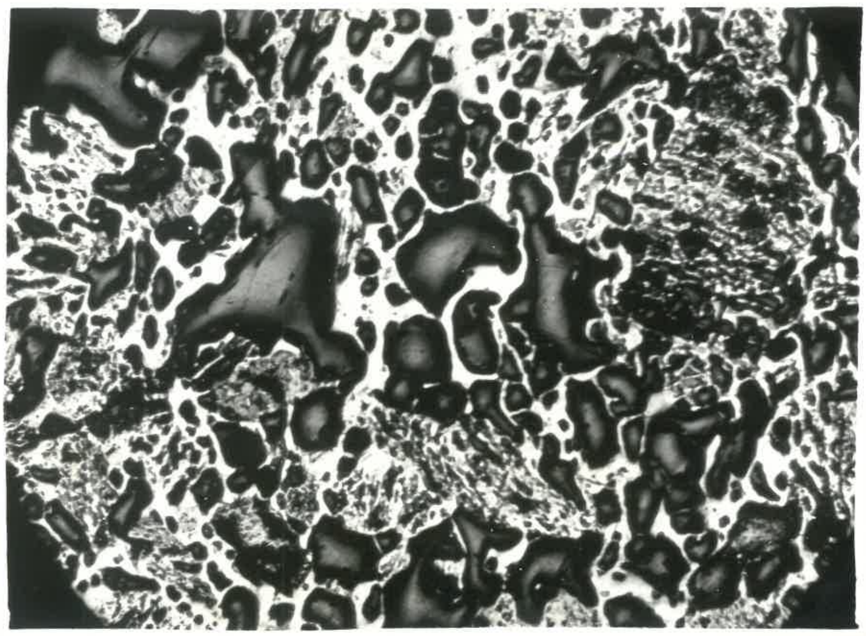
Magn. 5 x



Photomicrograph No. 6

Coke from 100% Northfield Coal (Detailed View)

Magn. 25 x



Photomicrograph No. 7

Coke from Iscor Normal Blend

Magn. 25 x

ANNEXURE 1.

SUMMARY OF THE PHYSICAL PROPERTIES OF THE COKE.

Test No.	Composition of Blend	% Un-fused particles	S.A.S.S.	B.S. Abrasion Index	Shatter Index $1\frac{1}{2}$"	M_{10m}	M_{40}
Is-1	100% Waterberg	1.7	28	79	66	9.3	-
Is-5	80% Waterberg, 20% Slurry	1.9	25	73	75	12.6	38
Is-13	$33\frac{1}{3}$% Waterberg, $33\frac{1}{3}$% T.N.C., $33\frac{1}{3}$%Springbok	7.6	24	62	81	24.1	49
Is-19	70% Springbok, 30% D.N.C.	7.0	34	73	86	13.2	63
Is-20	70% Springbok, 30% Northfield	8.7	37	74	88	11.7	70
Is-25	80% Waterberg, 20% Alpha Anthracite	1.8	24	59	81	28.6	50
Is-30	80% Waterberg, 10% Alpha Anthracite, 10% Northfield	4.7	31	70	83	15.8	60
Is-33	47% Nav.(S.A.C.E.), 25% Springbok, 19% D.N.C., 9% Northfield	4.2	37	70	89	15.5	67
Is-34	70% Waterberg, 20% Northfield, 10% Alpha Anthracite	2.5	34	70	86	13.9	65
Is-36	70% Waterberg, 30% Northfield	2.0	41	77	87	9.1	70
Is-42	70% Waterberg, 30% Hlobane	2.7	38	75	83	10.6	68
Is-43	70% Waterberg, 15% Hlobane, 15% Northfield	2.9	39	73	88	11.6	69
Is-66	70% Welstand, 22% D.N.C., 8% Northfield.	20.1	25	59	85	25.2	55
Is-78	70% Springbok, 22% D.N.C., 8% Northfield.	10.4	37	75	89	12.5	67
Is-85	45% Nav., 25% Springbok, 22% D.N.C., 8% Northfield	5.0	37	72	90	15.1	68
Is-95	100% Indumeni	-	43	77	89	8.5	78
Is-97	70% Hlobane, 30% Indumeni	7.0	39	77	90	10.5	74
Is-102	100% Northfield	4.7	42	80	89	8.2	74
Is-111	61% Hlobane, 33% Northfield, 6% Coke Breeze	4.0	43	76	93	11.8	77
Is-112	63% Hlobane, 34% Northfield, 3% Coke Breeze	3.8	40	77	90	10.6	71
Is-121	45% Waterberg, 25% Nav.(S.A.C.E.), 22% D.N.C., 8% Northfield	8.2	25	57	84	26.8	53
Is-122	45% Nav.(S.A.C.E.), 25% Waterberg, 22% D.N.C., 8% Northfield	6.4	28	62	86	24.0	59
Is-123	45% Waterberg, 25% Nav.(S.A.C.E.), 22% D.N.C., 8% Northfield	5.5	25	57	85	26.6	55

ANNEXURE 1 (Continued).

Test No.	Composition of Blend	% Unfused particles	S.A.S.S.	B.S. Abrasion Index	Shatter Index $1\frac{1}{2}$"	M_{10m}	M_{40}
Is-124	70% Waterberg, 22% D.N.C., 8% Northfield	5.0	22	54	83	31.2	47
Is-126	38% Blesbok, 21% D.N.C., 18% Indumeni, 16% Springbok, 7% Northfield	5.7	35	70	88	14.8	67
Is-141	51% Nav., 29% Springbok, 15% Soutpansberg, 5% Northfield	9.8	40	77	89	11.8	67
Is-144	45% Nav., 25% Springbok, 22% D.N.C., 8% Northfield	3.8	45	75	89	10.4	74
Is-148	70% Waterberg(3), 22% D.N.C., 8% Northfield.	2.1	28	65	83	17.2	61
Is-150	100% Waterberg(2)	8.5	22	52	80	37.1	41
Is-152	60% Waterberg(2), 40% Soutpansberg(2)	3.6	35	81	78	8.0	60
Is-161	70% Waterberg(2), 30% Soutpansberg	5.6	27	61	83	23.7	57
Is-162	60% Waterberg(2), 40% Soutpansberg(3)D	6.1	29	69	82	16.5	60
Is-164	100% Northfield	4.4	43	78	91	10.0	75
Is-165	100% Northfield	5.7	47	83	91	7.4	78
Is-166	100% D.N.C.	5.5	43	77	88	10.6	72
Is-168	70% Waterberg(2/3), 30% Northfield	7.8	25	59	83	26.0	52
Is-169	60% Waterberg(2/3), 40% Northfield	8.3	29	67	84	18.0	61
Is-173	80% Amcor Hlobane, 20% Amcor Northfield	7.3	41	79	88	10.1	74
Is-174	65% Amcor Hlobane, 35% Amcor Northfield	6.4	39	79	87	8.6	72
Is-175	100% Amcor Hlobane	7.7	40	80	86	10.1	72
Is-177	60% Amcor Hlobane, 25% Amcor Northfield, 15% Alpha Anthracite	5.6	35	73	86	13.9	67
Is-182	70% Waterberg(2), 22% D.N.C., 8% Northfield	17.5	24	58	83	23.8	53
Is-187	70% Waterberg(2), 15% Waterberg Grootgeluk, 15% Soutpansberg(3) (washed at D.N.C.)	9.3	29	66	85	21.1	60
Is-189	50% Waterberg(3), 25% Waterberg Grootgeluk, 25% Soutpansberg(3) (washed at D.N.C.)	6.0	30	75	80	12.8	58
Is-190	70% Waterberg(3), 15% Waterberg Grootgeluk, 15% Soutpansberg(3) (washed at D.N.C.)	8.6	29	70	80	19.0	50
Is-195	100% Northfield	7.8	43	80	90	9.8	75
Is-196	45% Nav., 25% Springbok, 22% D.N.C., 8% Northfield	10.6	37	74	88	14.1	68
Is-199	50% Welstand, 25% Waterberg Grootgeluk, 25% Soutpansberg(3) (washed at D.N.C.)	5.1	27	67	82	18.2	52

Annexure 2.

PETROGRAPHICAL ANALYSES OF THE BLENDS.

Test No.	Microlithotype Analysis						Maceral Analysis				Ratio Act : Inert Const.
	Vt. %	Cl. %	V.I. %	I.M. %	Fu. %	C.S. %	Vn. %	Ex. %	In. %	Vis. Min.%	
Is-1	44.0	16.6	8.7	22.5	0.6	7.6	85.5	4.0	6.1	4.4	8.5:1
Is-5	55.4	7.7	5.2	20.6	1.2	9.9	79.1	5.0	6.5	9.4	5.3:1
Is-13	26.7	4.7	19.9	45.0	2.1	1.6	55.9	11.8	29.2	3.1	2.1:1
Is-19	17.3	4.6	11.6	59.6	2.9	4.0	54.5	9.6	31.1	4.8	1.8:1
Is-20	26.5	1.8	11.4	53.1	1.2	6.0	56.3	13.7	24.8	5.2	2.3:1
Is-25	53.6	8.4	7.2	26.5	2.2	2.1	87.6	4.6	4.7	3.1	11.8:1
Is-30	45.0	9.8	13.6	26.9	0.8	3.9	79.8	5.1	10.3	4.8	5.6:1
Is-33	23.0	4.3	21.4	46.6	1.7	3.0	57.0	11.0	28.3	3.7	2.1:1
Is-34	45.0	6.1	13.3	30.8	1.8	3.0	81.2	6.7	8.4	3.7	7.3:1
Is-36	42.7	4.3	16.4	31.6	0.9	4.1	82.2	7.2	8.4	2.2	8.4:1
Is-42	39.0	5.1	15.4	36.1	1.2	3.2	73.5	6.0	16.3	4.2	3.9:1
Is-43	46.4	4.0	19.0	28.0	1.0	1.6	81.7	5.6	10.9	1.8	6.9:1
Is-66	17.9	1.5	33.6	43.3	1.5	2.2	48.9	5.6	41.3	4.2	1.2:1
Is-78	15.7	0.7	20.9	56.7	3.0	3.0	54.8	13.0	24.7	7.5	2.1:1
Is-85	19.1	2.2	32.2	39.9	2.2	4.4	57.6	5.9	32.4	4.1	1.7:1
Is-95	28.4	1.7	37.4	28.7	2.1	1.7	73.8	4.4	18.7	3.1	3.6:1
Is-97	31.4	2.5	24.0	37.5	1.7	2.9	65.2	11.2	18.6	5.0	3.2:1
Is-102	-	-	-	-	-	-	-	-	-	-	-
Is-111	26.8	1.4	52.6	12.8	2.3	4.1	56.0	3.5	33.3	7.2	1.5:1
Is-112	17.8	0.5	63.1	14.0	2.4	2.2	54.3	3.8	36.6	5.3	1.4:1
Is-121	24.7	2.2	25.2	42.3	3.1	2.5	62.1	7.0	27.5	3.4	2.2:1
Is-122	22.8	3.4	36.8	30.8	2.3	3.9	65.0	5.0	26.8	3.2	2.3:1
Is-123	27.2	1.5	28.6	39.8	1.9	1.0	64.5	9.1	24.4	2.0	2.8:1
Is-124	23.9	1.4	39.8	29.1	4.5	1.3	60.2	8.0	30.5	1.3	2.1:1

Annexure 2(Continued).

Test No.	Microlithotype Analysis						Maceral Analysis				Ratio Act : Inert Const.
	Vt. %	Cl. %	V.I. %	I.M. %	Fu. %	C.S. %	Vn. %	Ex. %	In. %	Vis. Min. %	
Is-126	-	-	-	-	-	-	-	-	-	-	-
Is-141	25.8	3.4	33.8	30.9	2.2	3.9	63.9	5.2	26.7	4.2	2.2:1
Is-144	29.0	3.5	41.7	21.2	2.7	1.9	65.6	3.5	25.6	5.3	2.2:1
Is-148	-	-	-	-	-	-	-	-	-	-	-
Is-150	34.4	0.4	36.9	24.0	3.9	0.4	61.1	6.1	31.0	1.8	2.0:1
Is-152	49.0	6.0	22.5	17.3	4.0	1.2	77.4	4.7	14.8	3.1	4.6:1
Is-161	35.6	5.0	33.9	21.8	3.3	0.4	69.1	4.1	22.7	4.1	2.7:1
Is-162	32.5	6.2	29.8	24.0	5.4	2.1	67.9	5.4	24.9	1.8	2.7:1
Is-164	49.5	0.0	45.6	2.9	1.5	0.5	73.5	0.5	21.6	4.4	2.8:1
Is-165	48.5	0.0	43.6	5.4	0.5	2.0	70.7	0.4	24.0	4.9	2.5:1
Is-166	25.0	3.0	37.1	28.9	3.0	3.0	58.8	6.2	30.4	4.6	1.9:1
Is-168	31.7	3.4	46.7	13.9	1.9	2.4	68.9	2.6	26.9	1.6	2.5:1
Is-169	30.5	0.9	43.1	20.9	3.2	1.4	67.2	2.9	25.6	4.3	3.2:1
Is-173	30.7	0.4	58.2	2.5	5.7	2.5	54.2	0.8	41.0	4.0	1.2:1
Is-174	25.9	0.5	56.5	13.4	0.9	2.8	51.9	1.5	42.2	4.4	1.1:1
Is-175	20.4	0.5	61.0	15.3	0.9	1.9	59.3	2.0	34.8	3.9	1.6:1
Is-177	22.0	0.5	56.9	16.3	3.3	1.0	64.2	2.6	28.1	5.1	2.0:1
Is-182	28.5	0.4	45.4	23.1	2.2	0.4	63.6	4.0	30.8	1.6	2.1:1
Is-187	43.8	3.2	34.3	15.9	1.4	1.4	75.9	3.7	17.8	2.6	3.9:1
Is-189	39.6	3.9	28.4	24.9	1.1	2.1	75.3	5.2	15.3	4.2	4.1:1
Is-190	33.6	6.6	23.6	31.5	3.9	0.8	80.0	5.0	13.6	1.4	5.7:1
Is-195	42.4	0.0	42.0	13.0	1.1	1.5	76.3	1.1	19.3	3.3	3.4:1
Is-196	29.5	3.4	36.0	26.1	2.3	2.7	67.9	5.3	21.9	4.9	2.7:1
Is-199	-	-	-	-	-	-	-	-	-	-	-

ANNEXURE 3.

QUANTITATIVE COKE ANALYSIS.

Test No.	Pores %					Cell walls %					Denseness	State of pores	State of cell walls	Mean Pore dia. (m.m.)	Mean cell wall thickness (m.m.)
	-0.1	0.1-0.2	0.2-0.5	0.5-1.0	+1.0	-0.05	0.05-0.1	0.1-0.2	0.2-0.5	+0.5					
Is-1	12.8	17.6	30.6	23.6	15.4	37.1	27.8	25.2	9.9	0.0	0.25	57.74	73.02	0.20	0.050
Is-5	13.6	18.6	36.2	18.7	12.9	42.7	25.7	23.1	8.5	0.0	0.28	60.22	75.66	0.19	0.045
Is-13	12.4	14.6	26.5	27.8	18.7	34.1	26.8	25.2	12.3	1.6	0.29	54.83	73.10	0.22	0.053
Is-19	8.0	12.8	27.5	26.0	25.7	40.8	27.5	21.4	10.3	0.0	0.1484	50.27	74.69	0.2665	0.0461
Is-20	12.1	10.4	32.4	27.2	17.9	33.4	28.4	26.3	11.9	0.0	0.2453	54.32	70.83	0.2214	0.0520
Is-25	15.7	13.7	33.5	24.2	12.9	57.9	23.9	15.8	2.4	0.0	0.1785	58.99	82.46	0.1858	0.0368
Is-30	13.3	15.0	26.0	23.7	22.0	46.6	22.7	21.6	9.1	0.0	0.1785	54.77	76.68	0.2094	0.0428
Is-33	16.9	16.6	38.1	18.6	9.8	37.2	23.7	24.5	14.6	0.0	0.2972	62.44	65.84	0.1699	0.0504
Is-34	16.1	17.5	32.1	18.7	15.6	39.2	24.6	22.4	13.8	0.0	0.2395	59.94	72.28	0.1771	0.0481
Is-36	14.9	16.1	35.8	19.4	13.8	38.2	24.8	24.6	10.8	1.6	0.1907	56.47	75.17	0.1849	0.0495
Is-42	15.1	23.4	32.1	13.9	15.5	31.7	33.6	23.1	11.6	0.0	0.2620	61.73	71.33	0.1744	0.0527
Is-43	21.9	19.4	31.5	13.5	13.7	40.7	22.4	26.1	10.8	0.0	0.3653	64.44	73.23	0.1486	0.0480
Is-66	28.4	16.9	27.2	13.0	14.5	41.8	26.3	21.1	10.8	0.0	0.4153	66.32	74.78	0.1278	0.0459
Is-78	16.2	15.7	30.7	24.4	13.0	31.0	24.9	27.4	16.7	0.0	0.3299	59.53	67.50	0.1496	0.0470
Is-85	20.3	19.1	34.4	21.2	5.0	47.2	28.6	18.0	6.2	0.0	0.3417	65.68	79.17	0.1529	0.0417
Is-95	25.1	28.6	34.3	12.0	0.0	26.8	16.4	37.8	19.0	0.0	0.4867	66.70	62.72	0.1251	0.0627
Is-97	30.2	29.8	30.7	9.3	0.0	29.9	24.9	32.7	12.5	0.0	0.4961	70.22	68.02	0.1110	0.0562
Is-102	30.0	28.4	28.6	13.0	0.0	26.3	26.0	32.5	12.3	2.9	0.5235	68.86	68.86	0.1137	0.0606
Is-111	40.7	27.1	28.6	3.6	0.0	26.7	26.6	31.9	14.8	0.0	0.7315	76.21	66.29	0.0927	0.0595
Is-112	32.7	20.7	32.4	13.0	1.2	20.4	28.5	38.5	12.6	0.0	0.7430	71.34	64.17	0.1120	0.0673
Is-121	21.1	24.4	27.8	17.3	9.4	29.5	28.8	25.6	16.1	0.0	0.4000	66.09	67.90	0.1443	0.0565
Is-122	23.5	32.3	28.5	15.7	0.0	26.1	26.1	35.0	12.8	0.0	0.5047	65.88	64.11	0.1282	0.0603
Is-123	30.8	27.2	31.7	8.7	1.6	33.6	27.0	28.2	11.2	0.0	0.4673	72.37	70.74	0.1111	0.0525
Is-124	26.3	29.8	27.8	14.6	1.5	29.8	32.8	24.0	13.4	0.0	0.3067	69.50	69.73	0.1215	0.0551

ANNEXURE 3.(Continued).

Test No.	Pores %					Cell walls %					Dense-ness	State of pores	State of cell walls	Mean Pore dia. (m.m.)	Mean cell wall thickness (m.m.)
	-0.1	0.1-0.2	0.2-0.5	0.5-1.0	+1.0	-0.05	0.05-0.1	0.1-0.2	0.2-0.5	+0.5					
Is-126	28.5	31.9	26.2	13.4	0.0	30.0	22.8	35.1	12.1	0.0	0.4094	68.87	67.68	0.1149	0.0566
Is-141	23.7	29.3	31.6	15.4	0.0	20.8	22.6	35.4	21.2	0.0	0.5927	65.32	60.74	0.1283	0.0700
Is-144	24.4	18.6	33.5	17.7	5.8	34.8	28.6	28.7	7.9	0.0	0.4727	66.23	71.01	0.1402	0.0517
Is-148	20.5	24.8	32.7	20.9	1.1	28.7	27.5	29.6	14.2	0.0	0.4241	64.46	67.68	0.1438	0.0573
Is-150	35.4	31.8	25.4	7.4	0.0	34.8	36.3	19.9	9.0	0.0	0.4907	73.79	74.20	0.1047	0.0493
Is-152	16.0	25.2	33.3	20.2	5.3	28.5	25.5	29.6	16.4	0.0	0.3600	65.26	66.49	0.1641	0.0588
Is-161	25.8	22.8	31.7	14.5	5.2	24.9	27.9	29.9	17.3	0.0	0.4822	69.87	65.09	0.1280	0.0621
Is-162	22.8	24.3	31.5	20.3	1.1	21.5	23.5	40.8	14.2	0.0	0.5267	65.95	63.08	0.1364	0.0674
Is-164	26.4	26.8	35.7	9.9	1.2	17.5	24.8	39.6	18.1	0.0	0.6138	69.85	60.43	0.1226	0.0743
Is-165	32.3	32.4	21.6	12.2	1.5	21.8	29.0	31.3	17.9	0.0	0.7124	73.59	63.65	0.1062	0.0671
Is-166	26.8	26.6	34.9	10.4	1.3	16.9	27.3	32.8	23.0	0.0	0.6444	70.73	59.52	0.1240	0.0760
Is-168	29.7	29.4	30.2	10.7	0.0	34.1	29.4	31.7	4.8	0.0	0.4601	69.52	73.19	0.1124	0.0505
Is-169	33.5	29.9	25.3	11.3	0.0	30.1	24.1	28.1	17.7	0.0	0.5446	71.45	66.64	0.1044	0.0568
Is-173	31.6	27.6	31.1	9.7	0.0	13.1	25.3	42.3	19.3	0.0	0.9762	70.24	57.99	0.1091	0.0801
Is-174	26.3	25.3	34.6	13.8	0.0	13.7	21.6	41.6	23.1	0.0	0.8298	66.05	56.46	0.1234	0.0848
Is-175	32.1	32.7	23.7	11.5	0.0	16.7	22.9	38.3	22.1	0.0	0.8501	71.34	58.52	0.1082	0.0776
Is-177	32.9	32.2	25.2	9.7	0.0	19.1	22.7	38.2	20.0	0.0	0.7264	72.08	60.22	0.1073	0.0731
Is-182	18.3	24.5	38.5	18.7	0.0	34.0	29.5	28.2	8.3	0.0	0.3269	60.59	72.28	0.1510	0.0510
Is-187	18.4	24.2	37.9	19.5	0.0	27.1	20.7	38.4	13.8	0.0	0.3960	60.37	65.25	0.1517	0.0606
Is-189	21.4	25.5	30.9	22.2	0.0	25.8	20.2	32.7	21.3	0.0	0.4575	61.53	62.62	0.1413	0.0634
Is-190	19.7	30.2	30.1	17.8	2.2	42.0	22.2	25.9	9.9	0.0	0.3507	69.46	74.06	0.1419	0.0463
Is-195	26.7	29.2	34.8	7.8	1.5	20.8	28.4	35.7	15.1	0.0	0.6232	71.48	63.70	0.1198	0.0673
Is-196	22.2	21.9	36.7	19.2	0.0	19.8	18.1	40.8	21.3	0.0	0.5774	61.76	59.07	0.1402	0.0734
Is-199	20.2	23.5	31.0	25.3	0.0	26.2	29.2	33.8	10.8	0.0	0.4122	59.64	67.69	0.1467	0.0594

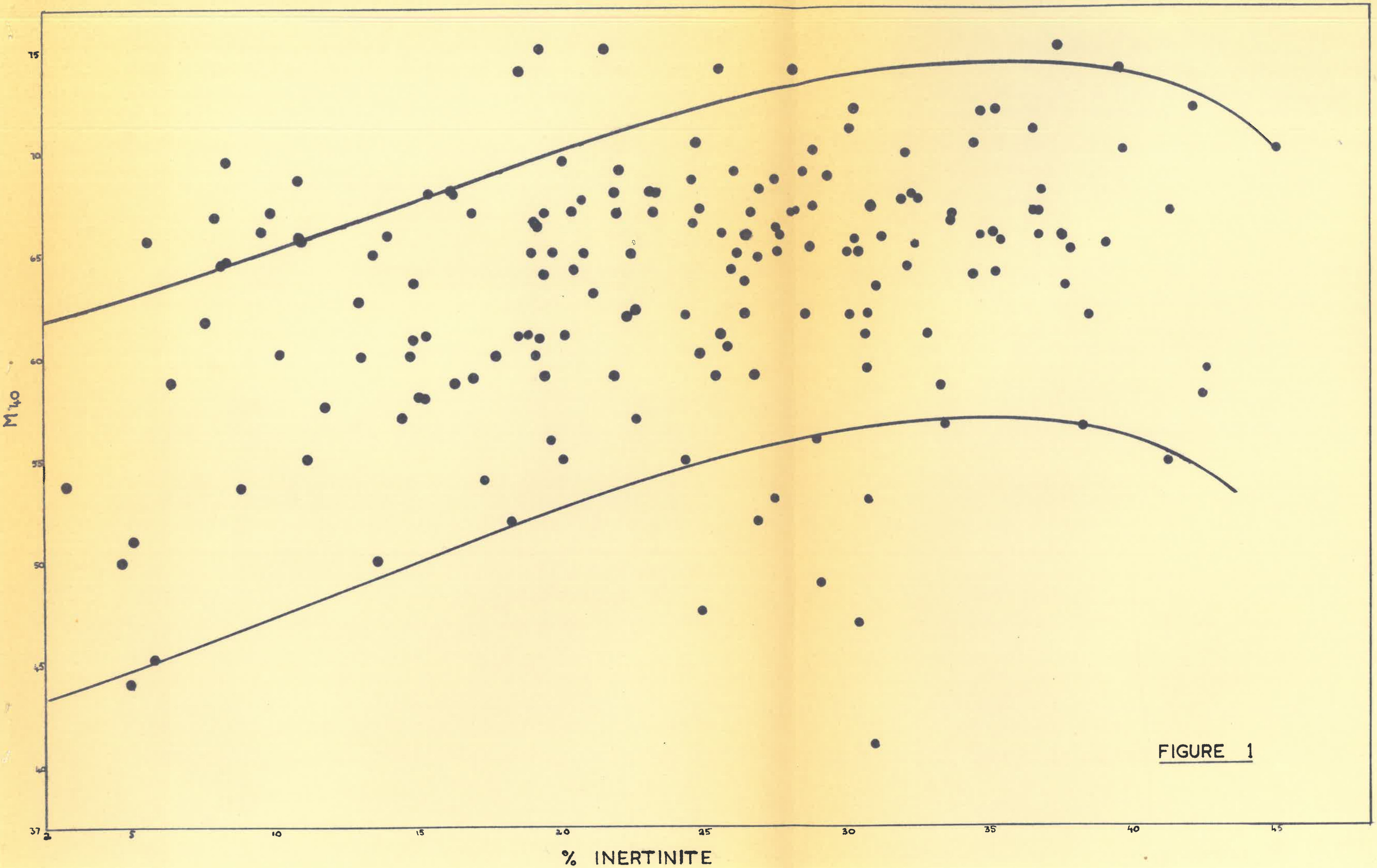


FIGURE 1