Production experience at Port Kembla with Coke made from "fine grind" Oiled Coal charges

W. R. Gadsden

NO SATISFACTORY formula for the evaluation of the physical quality of coke in terms of blast furnace performance has been developed, but it is generally conceded that, since one of the primary functions of coke is to support heavy burdens and allow easy flow of gases upward through the charge, maximum strength is desirable. This is particularly so for furnaces with large working volumes.

It has long been realised that the inclusion of large grains of shale in coke is detrimental to coke strength because of the actual or incipient sources of weakness due to the poor bond between them and the surrounding coke mass. With the advent of coal washing free shale is no longer found before grinding, but some "penny bands" do remain in large pieces of coal when washing interbanded coals such as the Wongawilli Seam of the Illawara coalfield. This coal, which constitutes 40 per cent of the coal used for coking at Australian Iron and Steel Ltd., Port Kembla, is crushed to 2½" size before slide washing and Fig. 1 shows the penny bands of shale (painted white) remaining in large pieces after washing. These bands are liberated and crushed by further grinding, but remain in the coal charge.

In addition to this, and of much greater quantitative significance, is the fact that there tends to be a high concentration of the inert matter of the coal in the larger particles of the hammer mill product at Port Kembla. This is borne out by the results of the British Standard Swelling Test, and the modified Gieseler Fluidities obtained on the size fractions of the hammer mill product. (Table I).

TABLE I

Some coking properties of the size fractions of the hammer mill product—80%-1/8" grind.

Sample		B.S.S. No.	*Maximum fluidity Div/Min.	Ash %	V.M. %
Run of mill	...	7	—	13·2	24·6
Fraction +1/4"	...	1·1/2	5	18·4	19·7
1/4" × 1/8"	...	4·1/2	100	15·7	21·8
1/8" × 30 mesh	...	7·1/2	2,500	11·7	24·6
—30 mesh	...	8	1,500	10·5	26·4

* (Measured by a modified Gieseler Plastometer).

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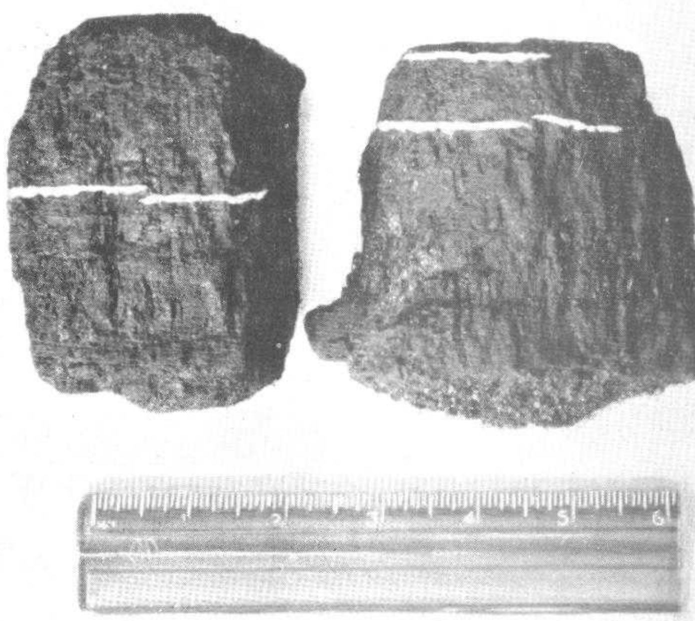
It is now realised that this relatively inert material can have a beneficial effect on coke strength if it is properly incorporated into the charge, and dissemination of both this and any shale material in a finely divided state throughout the fused coke mass is necessary to obtain maximum coke strength. The development overseas of closed circuit and selective grinding techniques is receving attention, but present plant practice is limited to altered levels of grinding with the existing hammer mills.

Coal characteristics

Good quality coking coals are readily available to the Port Kembla steelworks from the Illawarra coalfield. The seams generally mined for coking are Bulli and Wongawilli and characteristics of these



Scale—Inches.

Fig. 1.

coals, after washing, are shown in Table II.

TABLE II

Some characteristics of washed Illawarra coals.

Seam	Moisture	Ash	V.M.	Fixed Carbon	B.S.S. No.	S.
Bulli ...	7·5	11·9	24·1	64·0	4	0·4
Wongawilli	8·5	15·8	23·8	60·4	8	0·6

The Wongawilli seam in particular is very strongly coking and in times of coal famine has been of particular value to the industry because of the quantity of poor quality coking coals that could be blended with it. It has exhibited a tendency to swell dangerously as measured by the Koppers small scale laboratory test and charges of this coal alone in the 900 lb pilot oven at the Works Research Department of The Broken Hill Proprietary Co. Ltd. at Newcastle, N.S.W. have damaged the wall structure. On this basis a limit of 60 per cent Wongawilli seam coal in the blend has been fixed, and this is probably conservative. No tests have been made in a movable wall oven,

TABLE III

Effect on furnace operation of cokes produced from various coal blends and grinds

Period	Medium Grind Southern	Fine Grind including Northern	Fine Grind including Western	Fine Grind Southern (*i*)	Fine Grind Southern (*ii*)	Coarse Grind Southern
Coal Grind +1/4 per cent cum. ...	9	4	4	4	3	17
+1/8 per cent cum. ...	29	22	21	21	20	38
+20 per cent cum. ...	54	52	50	48	48	62
−20 per cent cum. ...	46	48	50	52	52	38
Coal Blend—Bulli Seam per cent	65	55	50	65	65	65
Wonga Seam per cent	35	30	35	35	35	35
High V.M. per cent	—	15	15	—	—	—
*Output tons/day ...	779	801	788	790	861	772
Charges per day ...	153	153	154	151	159	153
Ore cons. lbs/ton ...	3,343	3,391	3,332	3,340	3,289	3,305
Scale cons. lbs/ton ...	103	71	103	113	101	110
Total metallics lbs/ton ...	3,446	3,462	3,435	3,435	3,390	3,415
Nett coke cons. lbs/ton ...	1,915	1,810	1,844	1,874	1,834	1,861
Breeze lbs/ton ...	37	32	44	33	39	43
Gross coke cons. lbs/ton ...	1,952	1,842	1,888	1,907	1,873	1,904
Limestone lbs/ton ...	620	591	585	609	530	577
Dust loss lbs/ton ...	178	156	156	141	146	137
Metallic yield per cent ...	63·0	64·7	63·4	64·9	64·2	63·8
Wind volume cft./min. ...	49,521	49,378	49,717	49,310	50,000	50,000
Blast temperature °F ...	1,018	1,055	1,101	1,031	1,065	1,138
Top temperature °F ...	405	385	382	390	406	396
Air/lb carbon	57·7	56·2	59·0	56·6	55·7	59·6
Iron—Si per cent ...	1·02	1·03	0·96	1·10	1·03	0·99
S per cent ...	0·033	0·037	0·037	0·034	0·037	0·036
P per cent ...	0·14	0·12	0·12	0·13	0·12	0·12
Mn per cent ...	1·35	1·52	1·30	1·39	1·55	1·57
Slag—SiO_2 per cent ...	33·9	33·6	33·9	34·0	33·6	33·5
Al_2O_3 per cent ...	24·4	23·6	26·4	23·5	25·1	25·2
CaO per cent ...	38·9	39·3	38·1	39·4	38·0	38·4
ratio	1·14	1·17	1·12	1·17	1·13	1·14
Slag volume lb/ton ...	888	806	862	849	773	836
Ore—SiO_2 per cent ...	2·71	2·76	3·13	2·64	2·17	2·64
Al_2O_3 per cent ...	2·91	2·57	2·72	2·25	2·19	2·20
Mn per cent ...	1·33	1·48	1·29	1·49	1·88	1·83
Fe per cent ...	62·1	62·9	62·1	63·3	62·7	62·6
Coke ash per cent ...	16·6	17·0	16·7	16·3	16·8	16·5
Ore burden lb/charge ...	18,690	18,480	18,760	18,792	19,333	18,770
Total sand—tons ...	528	562	712	679	609	645
Total sandstone—tons ...	162	207	182	242	192	188

* Stabilising period of one week allowed in calculating average daily production.

and the proportion of Wongawilli coal available from the mines rarely exceeds 45 per cent, but this property is kept well in mind when factors influencing bulk density are altered.

Blast furnace experimental trials

Cokes made from Illawarra coals have a hard, dense appearance and furnace operators believed that a slow driving rate was associated with such cokes. This was attributed to a slow burning rate due to the small pore size, and it was thought that an open cell structure obtained by the addition of a high volatile matter coal to the blend would be beneficial provided that coke strength did not fall below a critical value.

In order to resolve the significance of the different approaches it was decided, after much preliminary work, that the smallest of the three blast furnaces at Port Kembla (hearth diameter 19 feet, nominal output 800 tons of metal per day) would be used for a series of plant scale tests during which all factors would be held constant as far as possible except for planned alterations to the coal grind or the coal blend. Within reasonable limits a constant chemical feed to the furnace was maintained, but it was considered that furnace operating factors should be adapted to furnace conditions to give maximum production.

After a series of trials lasting six months it was evident that the inclusion of high volatile matter content coals was of little value and did not warrant the expensive freight charges incurred, but that variations in grind from the normal 70%–1/8″ to 80%–1/8″ were significant. The increase in pig iron production for the two trial periods, each of approximately four weeks, compared with the normal 70 per cent grind, were 1·4 per cent and 10·5 per cent. These figures probably represented minimum and maximum improvements. Nett coke consumption was lower with fine grind and furnace operation was more regular, giving an improved driving rate and a higher effective burden with fine grind. The data from which these conclusions were made are set out in Table III.

While the blast furnace trials were in progress experimental tests were made in the 900 lb pilot oven at the Research Department of the Broken Hill Proprietary Co. Ltd., and also in full scale sample ovens under controlled conditions at Port Kembla to determine the effect of grind on the physical properties of the coke. The results of this work showed that coke strength increased with increased fineness of grind (Fig. 2). This is in line with overseas experience (Russell and Perch 1942).

The size of the coke at the blast furnace is maintained at 50%–2″ by a toothed, double roll crusher in the coke ovens screening plant circuit. The 1½″ shatter index of the coke is consistently about 85 and has been insensitive to major variations in coal blends. The stability factor, determined by the A.S.T.M. drum test, is now accepted at Port Kembla and the B.H.P. Newcastle plant as a measure of coke strength.

An adequate case had been made when operating with iron ore for producing coke from Illawarra coals ground to 80%–1/8″. Sinter had since been introduced on all three furnaces, and new base periods had to be established for furnace operation with sinter and 70 per cent grind.

While it had been possible to maintain production with the limited quantity of 80 per cent grind charges

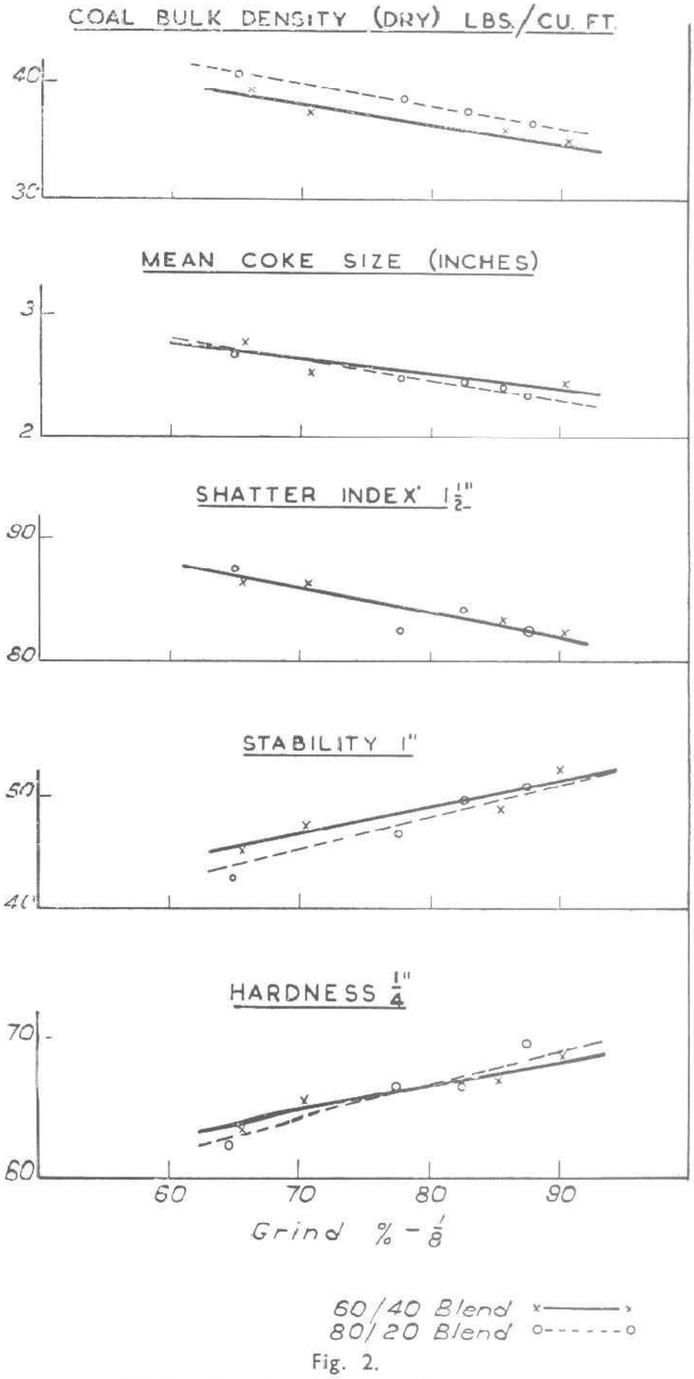


Fig. 2.
Effects of coal grind on coke properties.

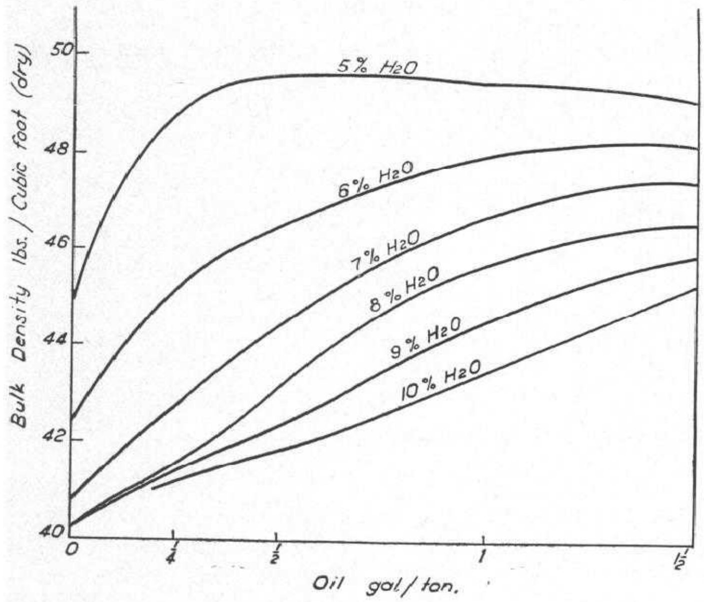


Fig. 3.

The effect of increased additions of diesel oil at various moistures.

Dry basis Grind 70%–1/8″.

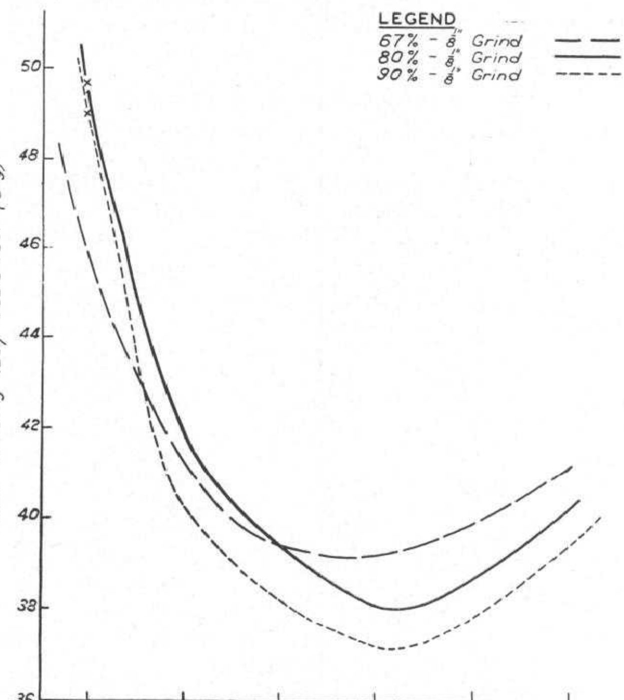
required for the smallest furnace by the normal sequence of rotation of charges through the coke ovens batteries, production on a full scale basis was impracticable. The reduced bulk density associated with finer grinding was known to result in reduced output, below the level required by the furnaces, and gave such shrinkage of the coke mass in the oven chamber that carbon deposition would become critical and naphthalene deposition in the by-products plant a serious problem. Considerable difficulty was experienced in handling this grind with the prevailing moisture content of 8-9 per cent and output was known to drop by 5 per cent.

Oiling experiments

Oiling of the coal charge as a means of increasing battery production has become well known since its developement industrially in the mid-forties. Although furnace type oils are commonly used in quantities of 1/4–1/2 gallon per ton of coal, oiling was unsuccessful at Port Kembla until it was demonstrated that an optimum quantity of low viscosity oil was required for the particular conditions existing. This follows the work of Agroskin in Russia (Agroskin 1955) and was a logical development of the bulk density control methods applied at the Sparrows Point plant of Bethlehem Steel Co. U.S.A. (Stahl and Kurtz 1951). Experimental results obtained with a diesel fuel oil at various moistures and increasing quantities of oil, are shown in Fig. 3. This was followed by batch weighing tests of ten ovens each and confirmed by a run of one week on total battery production, using 70%–1/8″ grind and oiling at the rate of 1 gallon of oil per ton of wet coal. From this work it was known that oiling with 70%–1/8″ grind would increase production of coke by 0·5 tons per oven or that with 80%–1/8″ grind, production could be maintained at the previous level.

Considerable emphasis was placed on the free flowing characteristics of the coal obtained when the oil additions reached a critical level. The coal had a dry, dusty appearance, the number of airborne particles increased because of the finely divided nature of the coal, and the angle of repose was reduced.

It was noted that the drop in production of 5 per cent with 80 per cent grind unoiled coal was greater than that due to bulk density, as shown in Fig. 4. This was attributed to the physical difficulty of fully charging ovens with coal of the combined fineness and moisture content, and visual observation had shown the presence of "noses" and dips in the coke mass when pushed which were largely absent when charging the free flowing oiled coal. This has been of considerable advantage in



VARIATION OF BULK DENSITY WITH MOISTURE AND GRIND (DRY BASIS)

Fig. 4.

enabling the use of high proportions of the wetter Wongawilli seam, which contains more fines than Bulli seam. A blend containing 45 per cent Wongawilli seam coal which normally presents great difficulty in charging was handled comfortably when oiled.

The A.S.T.M. box test for bulk density was used for the earlier work. The results of any one operator were reproducible, but differed between operators. To overcome this the Koppers Cone Method was adopted (Russel 1931). A feature of the cone was that unoiled coal would not flow from it, and in this it simulated conditions in the battery charging machines. Oiled coal charges which did not flow freely from the cone were considered not free flowing. By this test it was found necessary to add one gallon of oil per ton of wet coal to gain optimum free flowing properties.

Although the preliminary work was done with a diesel fuel oil this grade was considered too expensive for general operation, and a cheaper oil was sought from the petroleum industry. Tar oils and by-product solvents were not as efficient as the diesel fuel oil, and the use of chemical additives was not pursued when it became apparent that cheap commercial oils gave satisfactory results. Many grades of oil were tested, commencing with blends of diesel fuel and furnace oils, but ultimately efforts were concentrated on a special type of light furnace oil.

When the limit of laboratory scale testing was reached oiling was applied to the total production of the ovens, using an oil with the following characteristics :

Specific gravity at 15·5°C	...	89
Pour point A.S.T.M. °F	...	38
Viscosity S.S.U. at 100°F	...	87
Flash point °F	...	190
Distillation range °C		
Drop	...	175
5%	...	227
10%	...	251
20%	...	274
30%	...	298
40%	...	320
50%	...	350
60%	...	375

Coke production

The size analysis of the coal charged, and a summary of the coke yields appear in Table IV.

Nuts (3/4″×3/8″) and breeze (−3/8″) figures were not sufficiently accurate for comparisons to be made. They remained substantially unaltered at approximately 0·08 tons per oven and 0·6 tons/oven respectively.

Oiling at 1 gallon of oil per ton of coal had, therefore, made it possible to maintain blast furnace coke production, at the required level while increasing coke quality by the finer grinding of the coal charge.

TABLE IV

The effect on coke yield of oiling and finer grinding

Nominal grind	...	$\frac{1}{8}$″	70%	80%
Size analysis	...		% Cum.	% Cum.
		$\frac{1}{4}$″	9	5
		$\frac{1}{8}$″	27	18
		10 mesh	44	31
		18 mesh	61	50
		36 mesh	72	64
		72 mesh	82	85
Blast furnace coke yield tons/oven				
No oil	...		11·9	11·3
1 gal./ton oil	...		12·4	11·9

Coke ovens operation

Oil additions were made to the coal feed before the hammer mills, and it was evident that mixing in the mill was influenced by coal moisture to a greater extent than in the laboratory work.

It was noticed during testing that higher bulk densities were obtained with oils of waxy nature. Although unfortunately this was associated with pour points above operating temperatures in winter months. Similar observations were reported by Ramsburg and McGurl (1940). It is believed that the oil flow onto the surface of the coal particle is a critical factor and that it occurs at the temperature of the coal mass. Steam heating for handling and pumping would not, therefore, assist this function. Further clarification of this point is required.

A difficult period of bin blockage involving the packing of 2,000 tons of coal in the battery larry bins was associated with a variation in the source of oil. This was also related to a period of high coal moistures and the theory has been advanced that asphaltenes in the oil may have emulsified with the surface moisture when in excess of certain levels, leading to sticking. Pilot hopper and angle of repose tests however pointed to high coal moisture levels being of major significance with most types of oil.

In the light of these experiences it is now required that the viscosity of the oil supplied does not exceed 100 secs. S.S.U. at 100°F, and the pour point (A.S.T.M.) must be less than 40°F. Narrower limits are likely to be set.

It was found necessary to progressively lower the sleeves of the charger canisters to compensate for the increased coal in them due to the altered flow characteristics of the coal.

High coke weights obtained during supervised charging periods were attributed to packing with the leveller beam, and excessive spillage from the chuck door caused loss of machine time. Considerable carbon trouble was experienced and was just held in check by altered operating techniques and close supervision of oven top practice. Although charging was quicker, oven top conditions were made unpleasant by fires, spillage and fumes.

Although it was reported that no increase in heating gas was required with oiled charges (Horsley 1954) it was evident during the preliminary work that more heat was needed for increased charges, and later that with the same nominal yield levels with 80%–1/8″ grind more heat was needed to consistently coke the ovens at the previous rate (1·2 in/hr. nett). Suggestions that better heat transfer would result were not realised on the 70%–1/8″ grind test period and when operating with 80%–1/8″ grind, B.T.U. input per pound of coal increased by 2·5%. (After allowing a period of two months for adjustment).

TABLE V

Battery heat input

		B.T.U. lb/coal
Base period 70% grind unoiled	...	1,155
Test period 80% grind oiled	...	1,184

Although no significant increase in by-product yields due to additional coal was expected, oil additions were sufficiently large (4,000 gal./day) for the pyrolisis products of the oil to be detected. The use of oiling to meet peak gas loads when supplying town gas was known, and as the integrated steelworks was short of fuel and purchasing large volumes of fuel oil, it was believed that the cost of coal oiling would be readily recouped in the additional fuel available. A comparison of by-product yields before and after oiling is shown in Table VI.

TABLE VI

Yield of by-products from unoiled and oiled charges

	Oil Gal/day	B. F. Coke tons/oven	Gas make @ 500 B.T.U.	Tar gal/day	Light oil gal/day
Base period	Nil	11·9	46,019	21,607	8,277
Test period	4,000	11·9	48,139	22,025	8,448

The alterations in battery operating conditions were sufficient to alter the by-product compositions, particularly gas. Gas B.T.U. increased with oiling, but was erratic. For purposes of comparison gas makes before and after oiling were corrected to a basis of 500 B.T.U. per cft. This total heat figure was reasonably constant. The major source of recovery of oil was as gas, with possibly some as tar. (The improved light oil yield can be attributed to more efficient scrubber operation known to have been effected). The value of oiling to the organisation lay largely in the capacity to use this extra gaseous source of heat.

The high yield of by-products, coupled with the increased fuel requirements, pointed to a small increase in the coal charged to the ovens. This was not supported by coke yields, and the question has yet to be resolved.

Having established the recovery of oil to the benefit of the organisation, investigation of the use of increased quantities of oil with increased moisture content of the coal was continued. The aim was to maintain improved flow characteristics rather than increased bulk density of the charges. Oil additions were increased to 1½ gallons per ton at 10 per cent moisture levels for short test periods and the coal flow seemed better. Laboratory scale tests, however, showed that handling difficulties developed with increased coal moisture despite increased oil additions. This discrepancy in results was believed to be due to the achievement of a higher efficiency in the mixing of small experimental batches than occurred in practice. This line of thought was abandoned pending efforts to achieve greater control of coal feed moisture. Until this could be done effective control of bulk density could not be achieved.

No effect on conveyor belting had become apparent after four months of operation but rapid deterioration occurred suddenly after six months.

As oven charges of equal bulk density had been consistently charged for lengthy periods without difficulty, and as the proportion of Wongawilli seam had not exceeded 45 per cent, damage due to swelling pressure has not been feared. However, if grinding practice reverted to 70%—1/8″ the 5 per cent increase in bulk density associated with oiling could cause concern in the event of the coal moisture falling below 7 per cent.

Coke strength

Routine stability tests were made on a daily basis. Average monthly results for the four months of oiled 80 per cent grind from 47–50, and for the base period of three months on 70 per cent grind without oil from 48-49. No improvement can, therefore, be claimed on this basis.

Blast furnace performance

On the basis of the tests previously carried out on No. 1 Furnace it was hoped that increased iron production of the order of 5% would be obtained. Results for the four months under review were inconclusive, although blast furnace operators and management were convinced that operation of the furnaces had improved. It was doubted if long trial periods of general operation were as reliable as shorter test periods, when conditions could be rigidly policed.

A comparison of production figures obtained with the two grades of coke is shown (Table VII). All furnaces were then on sinter burden compared with ore operation on No. 1 furnace for the previous test period.

TABLE VII

Effect on furnace operations of cokes produced from unoiled coal grind of 70%—1/8" and oiled grind of 80%—1/8"

Month		70% Grind March	April	80% Grind May	July	August
				No. 1 Furnace (Hearth Diameter 19'-0")		
% Sinter	...	50	55	57	56	55
*Iron tons/day	...	808	810	838	798	813
Coke lb/ton	...	1,799	1,747	1,745	1,776	1,796
				No. 2 Furnace (Hearth Diameter 24'-6")		
% Sinter	...	57	46	33	51	48
*Iron tons/day	...	1,217	1,215	1,240	1,180	1,240
Coke lb/ton	...	1,803	1,780	1,803	1,835	1,779
				No. 3 Furnace (Hearth Diameter 26'-6")		
% Sinter	...	52	47	48	45	40
*Iron tons/day	...	1,503	1,490	1,518	1,443	1,383
Coke lb/ton	...	1,835	1,810	1,716	1,740	1,805

*Corrected to a 24-hour basis for mechanical delays and planned stops.

A number of factors have a bearing on these results.

During the month of June an overhaul of a turbo blower was carried out. It was known that operations of all furnaces would be adversely affected when using the standby unit and results for the month were disregarded.

After this period the operation of No. 3 Furnace was affected by the rapid deterioration of the lining, which had almost reached the limit of its life. No. 1 Furnace was again subject to interference by a blower repair in September, and the introduction of self-fluxing sinter commenced on all furnaces in the third week of September. At this stage the blast furnace assessment tests of coke ceased.

The test fell into three periods. The first was in May when high production rates were obtained on all three furnaces. This was followed by the months of July and August when production was not significantly different to the previous base period. For the first fortnight of September No. 2 Furnace again gave increased production. For the reasons given above the operation of the other furnaces during this period was not considered. The period was too short for much emphasis to be placed upon it, but it was the behaviour of No. 2 Furnace, which was generally held at an even level of operation that was most encouraging.

The introduction of self-fluxing sinter to the furnaces has constituted a major change in furnace conditions and it will be many months before trial periods can be set up. Reversion to a 70% grind will no doubt be tried to confirm the results of the base period.

Bearing in mind the value of the increased gas yield to the overall steelworks economy and the strong conviction of blast furnace men that improved furnace operation resulted from the use of coke made from coal ground to 80%-1/8", continuation with this grind was justified.

Acknowledgements

The writer wishes to acknowledge the assistance given to him by officers of Australian Iron and Steel Ltd., in the preparation of this paper.

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DISCUSSIONS

Mr. Das Gupta, C.F.R.I., Jealgora: It has been stated by the author that an increase in fineness from 70% to 80%-1/8" improved the reactivity of coke. I am unable to correlate reactivity of coke with fine grinding and would request for some clarification in this matter.

As regards our experience in India, we find some improvements by crushing a coal from 70%-1/8" to 80%-1/8". However, definite advantages are only obtained when we crush it down to 100%

through 3 mm or 1/8". It was also found that in the moisture range of 8 to 10%, addition of about 0·5% oil increases the throughput of the oven by 10%.

Mr. A. A. Parish, B. H. P. Co. Ltd., Australia: As already pointed out by the author: "No satisfactory formula for the evaluation of the physical quality of coke in terms of blast furnace performance, has been developed". You can have a number of theories most of them quite correct and quite a deal of inference of what has been done with the differential grinding of coals, all of which is very good and very necessary for a research basis, but when you have to face the problem in which you have a steelworks with a certain capital of equipment provided for it, then of course, you have to neglect several of the refinements and make the best of what you have got.

I would personally say that it would have been better, had we preferentially ground the fusains from the vitrains and done all the work that possibly should have been done to attain the effect of fine grinding. We had to do what we could and we found that fineness of grinding did increase the porosity and did increase the reactivity of coke as measured in a trial cupola in which we developed maximum temperatures under controlled conditions. The oil has of course a purely mechanical function in that, it does allow the easier flow of coal and the packing with greater flow of bulk density, from gravity effects.

Dr. A. Lahiri, Director, C.F.R.I., Jealgora: Did you have any other measure of reactivity?

Mr. A. A. Parish, B. H. P. Co. Ltd., Australia: The main measure of reactivity control was with a small cupola furnace of the Melbourne University where with standard cokes we developed maximum temperatures under controlled conditions which indicated the rate of burning, and which after all is a direct measure of reactivity and afforded a comparison of the various types of grinds that we developed on the plant. We also did some comparison between cokes made at Port Kembla and cokes made at Newcastle at the same time.