The size requirement of Blast Furnace Coke (I)

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THE exact specification for the physical characteristics of blast furnace coke remains controversial even today. But the advantage of using coke of consistent quality and in closely graded size has been generally recognised. Greater emphasis is being given on the size distribution of the coke rather than on the strength of the coke as assessed by conventional tests. It is believed that after the coke has been charged in the furnace, its strength is probably of less consequence, the size consistency being the dominant factor.

The maintenance of proper voids in the stock column of a blast furnace to permit effective gas flow for promoting good gas to solid contact is one of the most important factors influencing blast furnace operation.

Besides providing heat and reducing gases, the coke in a blast furnace burden must be able to afford the necessary voidage enabling this essential reaction between gas and solid without any chanelling in the stock column.

Coke charged to a blast furnace is a mass of broken solids of irregular size and shape. The greater the range of sizes the greater is the likelihood of the voidage between the larger pieces being filled by the smaller particles. The resulting decrease in the effective voidage resists the passage of the air blast and reduces the time of contact with the coke. Thus less coke is burnt and less iron is produced. The minimum useful size of a blast furnace coke has often been stipulated at 1 in. and 1½ in. But added in separate charges ¾ in. or even lower sizes coke has also been used in recent years[1, 2, 11]. There are references in the literature[3, 4] about the successful performance of blast furnace by the use of coke graded between the size of 3 in. to 1½ in. It is thus difficult to uphold the general bias in favour of the use of larger size coke in blast furnaces. It might have arisen from the popular belief that the presence of larger size in a consignment of coke ensures the absence of an undue proportion of breeze which is, no doubt, undesirable.

Although besides coke, the quality and size of the ore and fluxes are important contributory factors in blast furnace operation, the blast furnace operator is prone to blame coke alone for all the maladies of a blast furnace.

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The economic value of the processes of preparation of the blast furnace burden with sintering of the ore fines and charging the furnace with a material in a uniform size (even of 1 in.–2 in.) is however of late being more and more realised[5]. But it has to be admitted that such procedures have not so far been given the serious consideration they deserve for universal adoption.

Various factors e.g. quality of coals, their grain size, moisture, bulk density, rate of heating, etc. are some of the predominent factors that influence the size of coke as produced in a coke oven.

Apart from this, the treatment the coke receives in its travel from the coke ovens wharf to the blast furnace stock column profoundly affects the ultimate size of the coke as used in the furnace. In this paper the influence of these different factors on coke size is discussed based on data available from study made in the Central Fuel Research Institute. A suggestion has been made to alter the present carbonisation technique to produce coke of more graded size which might ultimately lead to economy in coke consumption besides serving the purpose of conservation of the coking coal reserves.

Influence of various factors on size of coke

Effect of nature of coal: Fig. 1 shows that with a decrease in the rank of the coals (as represented by the percentage of carbon) the percentage of material on 4 in. size steeply falls whereas the percentages of materials lying between 4 in.–3 in., 3 in.–2 in. and 2 in.–1½ show a trend of increase.

Mott and Wheeler[6] observed that coals with higher caking index give coke of larger pieces. But this statement is erroneous. The size of the coke is determined by the coking characteristics of the coals and not by their caking index values which are only remotely related to their coking behaviour.

Effect of fineness of crushing: The effect of fineness of crushing of the coals will be evident from Fig. 2. The normal coke oven practice is to crush coals about 80 per cent through 1/8 in., such crushing producing maximum percentage of material on 4 in. size. With finer crushing the oversize on 4 in. diminishes gradually but the percentage of material in the intermediate sizes e.g. 4 in.–3 in., 3 in.–2 in. and 2 in.–1½ in. steadily increases. The cumulative percentage of total material on 1½ in., however, remains the same. The effect of non-coking coals there is a trend of decrease in the plus 4 in. size and increase in the 4 in. to 3 in. and 3 in. to 2 in. sizes, percentage of material between 2 in. and 1½ in. remaining about the same.

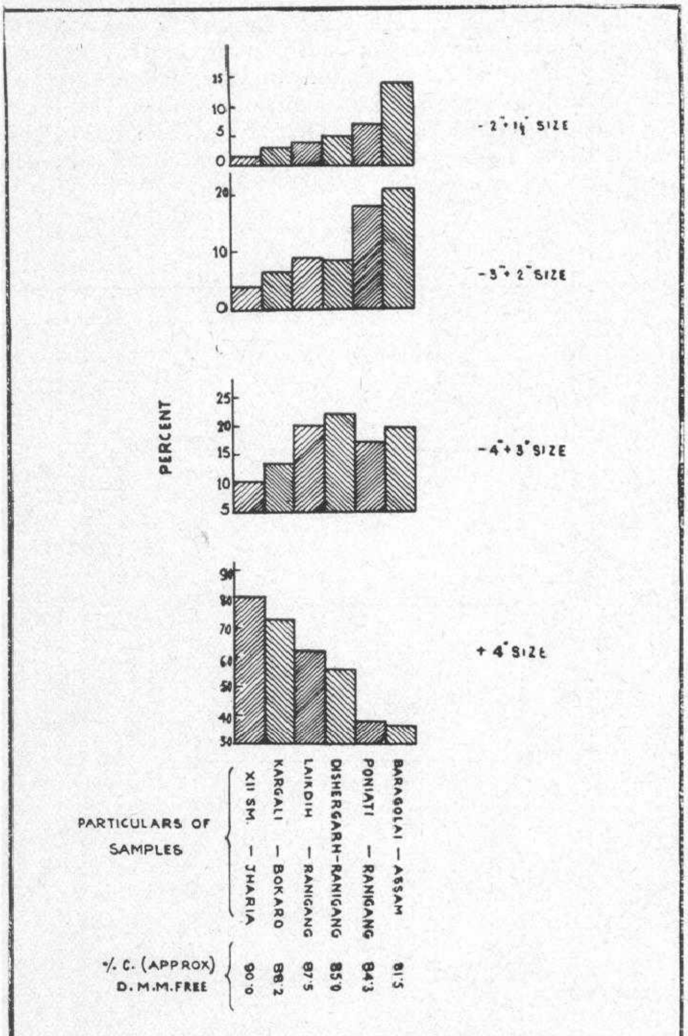

FIG. 1. EFFECT OF NATURE OF COALS.

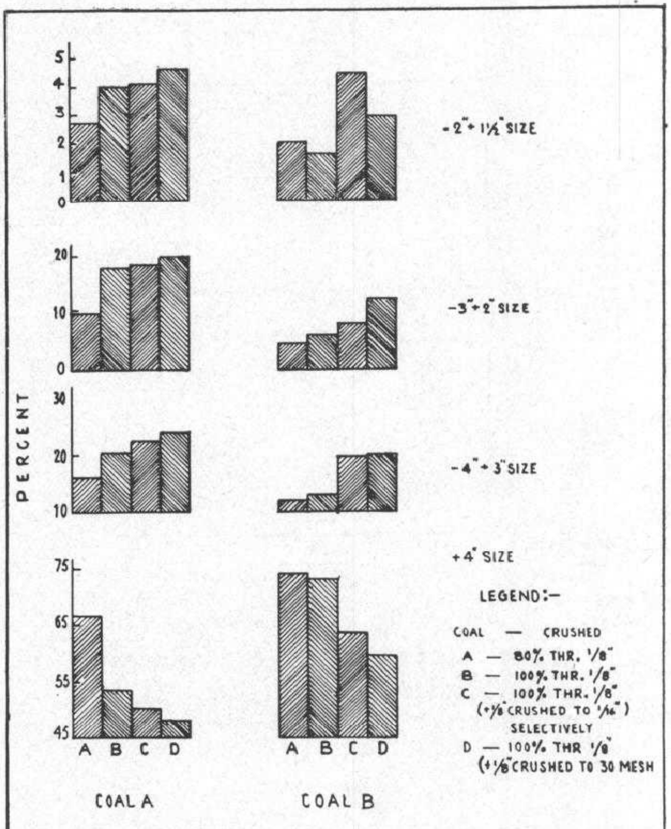

FIG. 2. EFFECT OF GRAIN SIZE

selective crushing i.e. crushing the material initially to about 80 per cent through 1/8 in. screening the over size on 1/8 in. and recrushing this fraction to pass through 1/16 in. produces a more pronounced effect.

Effect of rate of heating: The trend of decrease in the plus 4 in. size coke and increase in the intermediate sizes may again be noticed from Fig. 3. The heating rate, however, affects little the total percentage of the blast furnace coke on 1½ in. In modern silica by-product ovens of a more or less standardized width of about 16 in. permitting a quicker heating rate due to higher flue temperature and better heat conductivity through the silica walls, less blocky cokes are produced compared to the massive blocks made in earlier days in beehive ovens in fire-brick ovens of larger width.

Effect of addition of non-coking coals: Fig. 4 shows that with an increase in the percentage of

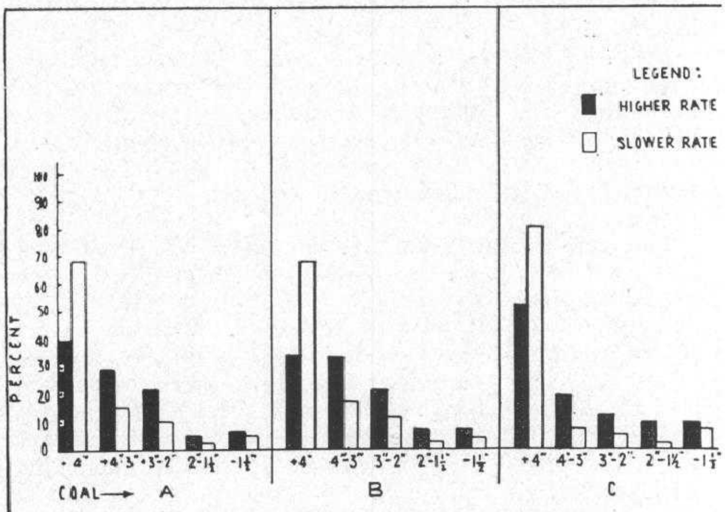

FIG. 3. EFFECT OF RATE OF HEATING

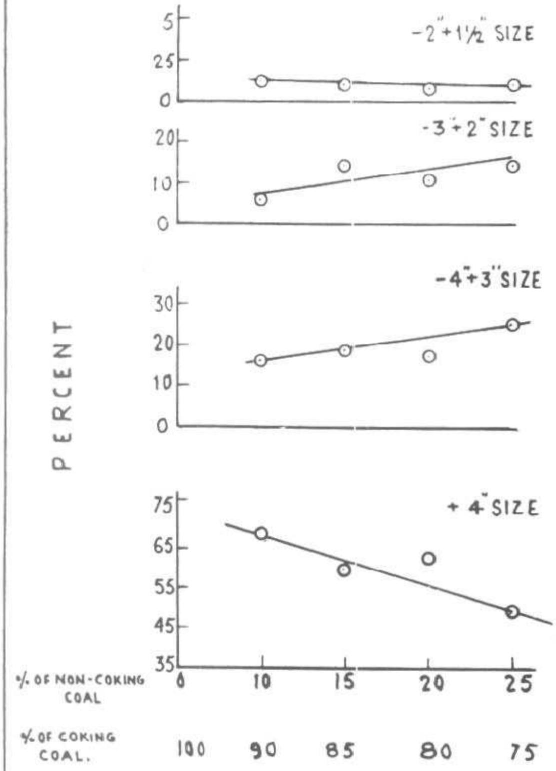

FIG. 4. EFFECT OF ADDITION OF NONCOKING COAL IN BLEND

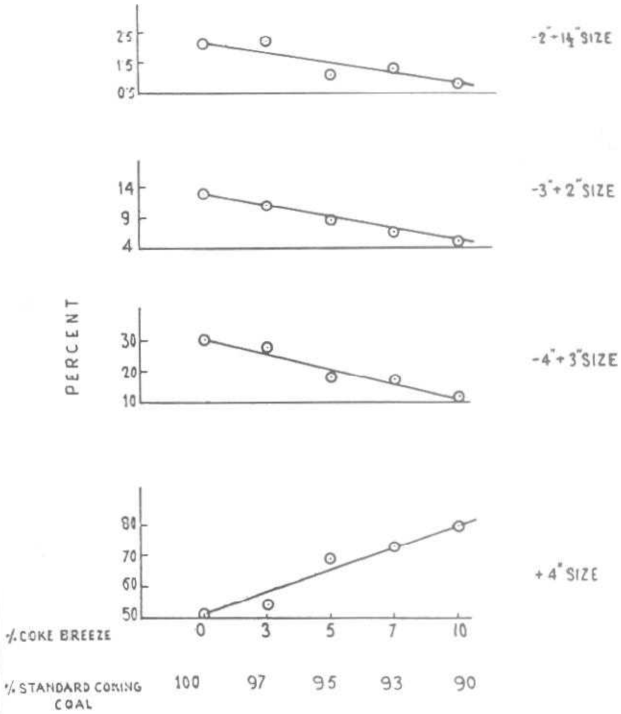

FIG. 5. EFFECT OF ADDITION OF COKE BREEZE

Effect of addition of coke breeze: Fig. 5 shows that as the proportion of coke breeze added to a blend increases, the percentage of material remaining on 4 in. shows a steep rise followed by an equally steep fall for the percentage of material in the other intermediate sizes.

Effect of washing: From Fig. 6 it may be seen that though on cleaning of coal the percentage of coke on 4 in. diminishes considerably, the fractions in the intermediate sizes show considerable increase.

Degradation of coke size in transit

The run-of-oven coke i.e. the coke as discharged from a coke oven is blocky in nature and often contains pieces as large as 9″ to 10″ in length depending on the width of the oven. But the larger pieces, exhibiting the well-developed cauliflower appearance, contains a number of visible longitudinal and horizontal fractures, besides innumerable fine fissures not detectable by the naked eye. Fracturing of the coke pieces is also caused by shock quenching with water.

Considerable degradation takes place in the size of the coke in its handling i.e. screening and conveying, whether it is done manually or wagons over rail-roads or mechanically over belts. The size grading of a coke as tested on the coke wharf at the producers' end is thus never the same as tested for a consignment of coke received at the consumers' end. Table I gives an idea of the extent of degradation in size caused by transporting.

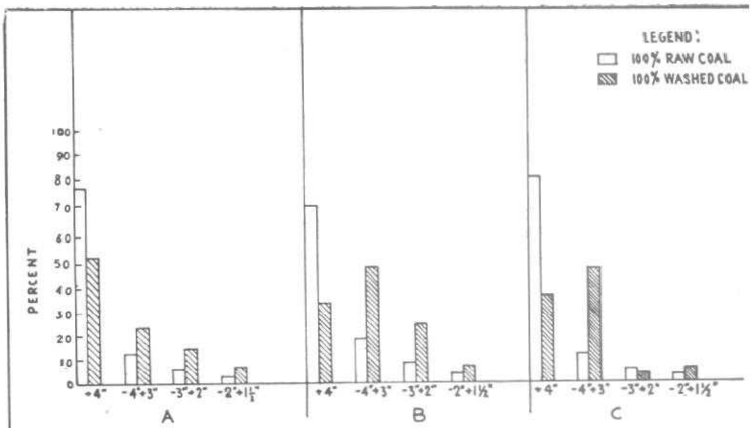

FIG. 6. EFFECT OF WASHING.

TABLE I

Effect of degradation of coke size in transit screen analysis of coke

Screen size inches	COAL TESTED A *I	A †II	A diff.	B I	B II	B diff.	C I	C II	C diff.	D I	D II	D diff.
6″ % Cum.	11·2	6·7	4·5	9·4	3·2	6·2	0.5	—	0·5	0·9	—	0·9
5″ ,,	20·0	11·1	8·9	15 3	8·1	7·2	2·9	0·6	2·3	3·3	1·1	2·2
4″ ,,	47·5	32·1	15·4	40·0	24·9	15·1	17·3	9·7	7·6	14·5	7·8	6·7
3″ ,,	69·6	59·8	9·8	68·8	58·3	10·5	50·4	39·8	10·6	42·4	32·5	9·9
2″ ,,	86·9	80·8	6·1	91·4	86·9	4·5	80·9	78·5	2·4	78·5	73·1	5·4
1½″ ,,	91·6	87·9	3·7	95·9	93·7	2·2	92·5	89·7	2·8	90·3	87·7	2·6
1″ ,,	95·8	93·1	2·7	97·4	95·5	1·9	95·4	94·1	1·3	94·6	93·5	1·1

* Before transit (tested at Coke Wharf) † After transit over a distance of 50 miles.

It is seen that by simply carrying the coke in a truck over a distance of 50 miles there is a decrease in the cumulative percentage on all the size.

For the 4 different cokes studied, the amount of undersize below 1½ inch is about 3 per cent on an average. Mott and Wheeler[7] have shown production of 3 per cent breeze (1½″) by carrying wagonloads of coke over 40 miles—and the possibility of the production of about 7½ per cent of breeze due to dropping of the coke on the wagon while loading.

Examples of the size of a coke of its handling between the ovens and the effect on the blast furnaces stock level have also been given by Mott and Wheeler[4] pertaining to different kinds of transport e.g. by rails, by aerial ropeway and conveyor belt. Out of the total expected fall of about 48 ft. the most severe fall was shown to be from the skips to the stock level. The coke breeze or smalls produced up to the skip could be eliminated as is usually done in normal blast furnace practice, but any breeze formed subsequently finds their way into the furnace.

The conventional shatter test done in the laboratory has been devised to simulate the probable breakage of coke during its handling and inside the blast furnace stock column.

One important point has to be considered in connection with the degradation of coke size on handling. The spongy, porous, weak and black looking centre-of-oven portions of the coke are knocked off in the earlier stages of handling together with the portions breaking along the major fractures and fissures in the coke. The remaining parts of the coke pieces generally become more and more resistant to impact or their hardness increases. Because of this characteristic behaviour of coke on handling it has been suggested that the coke should be subjected to rough handling prior to its supply to the blast furnace so as to eliminate as much of the fines as possible.

Table II shows the average screen analysis of run-of oven cokes produced in a steel plant and the corresponding figures for the coke as delivered to the blast furnace skip.

TABLE II

Screen analysis of coke in steel works

size	At coke wharf % by wt.	At blast furnace end % by wt.
+4″	55–60	28·2
Between 4″–3″ ...	11–20	30·8
Between 3″–2″ ...	13–17	30·7
Between 2″–1½″ ...	3–5	9·9*

* (2″ to 1″).

It may be seen that the percentage of plus 4 in. coke is considerably lower as tested at the blast furnace end, while the percentage of the intermediate sizes are higher. This is caused by the drops and slides the coke undergoes in its travel from the coke ovens over various belts and through screens and to a considerable degree due the deliberate crushing of the plus 2 in. coke to make the coke more closely graded.

Sub-standard coke for blast furnace

In certain plants in the western part of the U.S.A.[8,9] where there is local dearth of high class metallurgical coal, the coke produced from poorly coking high volatile coals has been used successfully in tall blast furnaces to give a production of over 1,200 tons of iron a day with a coke consumption of 1416–1778 per ton of metal. The quality of the coke has been improved to some extent by quicker carbonisation in narrower ovens and by blending with small quantities of low volatile coals, pitch and low temperature char. But the quality of the coke produced is still much below the standard of normal metallurgical coke both in respect of size, hardness and strength. The adverse effect produced in the blast furnace by the use of this softer coke has largely been compensated by improving the size consist of the iron ore which helps to keep the burden open and thus permits the use of inferior coke.

TABLE III

Blast furnace operation data. Properties of coke

	Fontana Steel Works, U.S.A.				INDIA	
	100% high volatile Utah coal		10–12½% low volatile coal (Oklahoma) 87½–90% high volatile (Utah) coal		100% high volatile (Raniganj) coals	100% Normal metallurgical coal
	Full oven test*	Actual plant data†	Full oven test*	Actual plant data†	Test oven data	Plant Data
Size of coke						
% +4" ...	0·5	—	6·3	4·6	40–60	55–60
4"–3" ...	—	—	—	—	18–24	11–20
3"–2" ...	—	—	—	—	7–18	13–17
+ 2" (Total) ...	44·9	42·9	68·4	66·4	70–85	89–93
Strength and hardness shatter index						
(Cumulative %) + 2" ...	11·4	9·2	49·9	37·6	60–75	80–85
Stability factor						
(Cumulative %) on 1" ...	6·8	5·7	27·7	20·4	10–20	45–50
Physical fuel value ...	16·1	15·2	38·4	31·5	27–32	53–60
Porosity % ...	53·0	54·7	53·5	54·1	50–55	40–45
Proximate analysis						
% V.M. ...		1·7	—	—	0·5–1·5	0·5–1·5
Ash ...		11·4	—	10·9	18–22	20–22

* See reference 8. † See reference 9.

Alteration in the coke handling technique prevents the production of too much fines prior to its supply to the blast furnace. Tables III and IV show the properties of coke from these poorly coking U.S.A. coals and their blends together with the properties of Indian metallurgical coke[10]. It may be seen that these U.S.A. cokes are inferior in all respects (barring the lower percentage of ash) compared to the Indian metallurgical coke, but the daily production of iron per furnace is higher and the coke rate conspicuously lower compared to Indian blast furnace practice. Thus reactive coke may indeed be more suitable for blast furnace practice, if other factors be brought under control. If this be found true, the available resources of coal for coking in India will be vastly increased, as much larger quantities of weakly coking coals will be used in blends than hitherto proposed.

TABLE IV

Performance of the blast furnace

	100% high volatile (Utah) coal*	10–12½% low volatile (Oklahoma) coal 87½–90% high volatile (Utah) coal†		Normal metallurgical coke India‡
Average daily tonnage ...	1,154	1,235	1,259	925
Average wind/min. (in cft.) ...	71,200	63,800	58,200	48,000
Average coke/ton of hot metal (in lb) ...	1,778	1,468	1,416	1,876

* See reference 8. † See reference 9. ‡ See reference 10.

Conclusion

It has been seen that in the course of the different steps unavoidably involved in the travel of run-of-oven coke to the blast furnace and in the deliberate crushing of the oversize on 4 in., the larger pieces of coke obtained from coke ovens are reduced in size to a considerable extent and this is certainly in the interest of better performance of the blast furnace.

Encouraged by the results of investigation on the blending and coking of Indian coals, the Central Fuel Research Institute has been persistently advocating the following measures in the interest of conservation of coking coals:

(*i*) addition of small quantities of finely crushed high temperature coke-breeze to the coking coal mixture,

(*ii*) washing of the higher ash coals to reduce their ash and to enable incorporation of higher percentage of inferior coking coals,

(*iii*) blending of standard coking coals with varying percentages of inferior coking coals,

(*iv*) adoption of quicker heating rate which would enable the production of better grades of coke from blends containing inferior coking coals,

(*v*) selective crushing of the coking coals to finer grain sizes to improve the coke quality.

Table V summarises the influence of different factors on the size of coke as produced in a coke-oven.

It is apparent that the net result of implementing the above suggestions is a reduction in the +4 in.

Table V

Effect of different factors on coke size

Treatment of the coking coal		Changes in the size of coke. +4″	4″–3″	3″–2″	2″–1½″
Addition of non-coking coal	...	Decrease	Increase	Increase	About the same
Fine crushing ...	...	Decrease	Increase	Increase	Increase
Addition of coke breeze	...	Increase	Decrease	Decrease	Decrease
Washing ...	...	Decrease	Increase	Increase	Increase
Quicker heating rate ...	...	Decrease	Increase	Increase	Increase
Overall effect ...	...	Decrease	Increase	Increase	Inorease

size coke, and the production of higher percentage of the intermediate sizes, the total percentage of blast furnace coke 1½″ remaining unaffected.

It is difficult to understand the logic behind the production of large sized coke (8″-9″) in the steel works, as at present, and subsequent crushing of the bigger lumps to smaller pieces for feeding into blast furnace. This is uneconomic both from the viewpoint of the cost involved in crushing the coke and the loss of the fines produced.

The coke plants built in India in recent years operate on average flue temperatures of 1,250–1,280°C. In contrast with this, most coke plants in the U.K. and the continent maintain higher flue temperatures in the region of 1,320°C. It is worth serious consideration whether the Indian coke plants should not be operated at higher temperatures than at present. This would mean a concomittant increase in the oven throughput by cutting down the carbonisation time and would result in coke of more uniform size, a factor of greater importance to blast furnace operation than the increase or decrease in the physical test indices by one or two points.

It is a happy augury that the projected Government Steel Plants including some of the existing ones in the private sector are taking active steps to beneficiate the iron-ore. This would demand still closer grading of coke in smaller sizes than at present in order that the required voidage in the blast furnace may be maintained. The exigency arising out of the scarcity of our coking coal reserves leaves us with no choice but to use substantial quantities of the poorer coking coals in the future coking mixtures. A serious note of the situation has to be taken and it is opportune to study in details the implications, both financial and technical, of the blast furnace technique evolved in the western part of the U.S.A. with a view to its adoption in the Indian steel industry. We have fairly large reserves of high volatile, poorly coking coals in the Raniganj and Karanpura field which are even superior to the Utah coals of the U.S.A. in respect of the quality of the coke obtainable from these coals and their blends with low volatile coals. It is needless to say that this will go a long way to alleviate the alarming situation that the dearth of coking coal may eventually create in the country, with the implementation of the successive Five Year Plans which aim at production of more and more steel.

Acknowledgement

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