Blast Furnace Burden Preparation with Reference to High Ash Coke

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THE primary objectives in iron smelting are high output, low coke rate and smooth operation.

The aspect of coke economy is somewhat complex when working with an iron rich burden and a high ash coke since the ash of the coke contributes a major part of the total slag.

Where, as in India, the sulphur content of ore and coke is low, the minimum workable slag volume may be taken as 350 kg. of slag per metric ton of pig iron. It is worth noting that the Fairless works in America has successfully operated with slag volumes as low as 300 kg. per metric ton.

For an ore containing 62 per cent iron, 3 per cent silica and 4 per cent alumina the relationship between per cent ash in the coke and the coke rate necessary to give 350 kg. of slag is as plotted in Graph 1, line AOB. Also on this graph line COD represents approximately the coke rate likely to be attained with optimum practice. As the coke ash is reduced below 17·5 per cent it becomes necessary to add silica sand as a fluxing agent and this explains the reduced benefit of lower ash in the coke to the left of point O.

If a hypothetical furnace is operating at point P two steps are required to bring it to O, the point of optimum working. Firstly, the coke ash must be reduced from 21 per cent to 17·5 per cent (P to Q). This is a problem for the coal washeries and is already well appreciated and being dealt with. Secondly, it is necessary to lower the coke rate from Q to O and the present paper considers burden preparation as a means of achieving this aim.

The carbon requirement of the blast furnace

This is governed by two factors:

(*a*) the heat needed to calcine and reduce the burden and to produce molten iron and slag of the appropriate composition;

(*b*) the efficiency of utilisation of the carbon burnt at the tuyeres as measured by the CO/CO_2 ratio of the top gas.

The following means are available for lowering the amount of carbon needed:

(*a*) by the use of higher blast temperatures. Here a limit is set by the capacity and materials of construction of the stove and by the need to maintain smooth operation.

(*b*) by replacing part of the coke by liquid or solid fuels injected through the tuyeres. While theoretically promising, this technique may present practical difficulties.

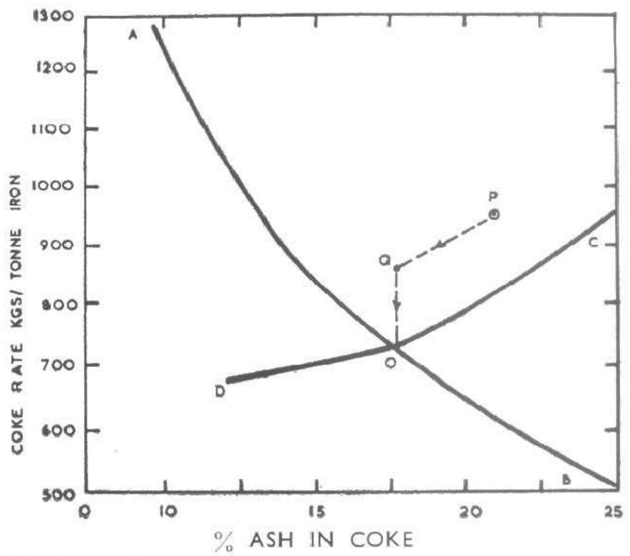
(*c*) by preparation of the burden outside the furnace so that the net heat requirement per ton of iron is lowered. Such preparation will also improve furnace efficiency through the improved permeability and reducibility of the burden.

Methods of burden preparation

Apart from beneficiation processes there are two main kinds of ore treatment:

(*a*) Physical processes such as the blending, crushing and screening of lump ores to produce a burden of uniform chemical composition and of the optimum size grading from the point of view of reducibility and permeability.

(*b*) Thermal processes such as drying, calcining, pelletising and sintering in which part of the work normally performed in the furnace is done externally using a lower grade of fuel than metallurgical coke.



Graph 1: The lines are approximate only and do not give exact values for minimum coke rate or optimum coke ash.

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Application of burden preparation to Indian ores

For high grade Indian ores the only relevant processes are crushing and sintering.

As mined, an ore will consist of lumps widely varying in size, the range being generally greater and with more fines when mechanical methods of mining are used. If such material is charged directly into the furnace it is very difficult to avoid segregation. This results in chanelling with poor gas/solid contact and high CO/CO_2 ratio in the top gas.

The presence of large lumps of dense hematite ore is also undesirable from the aspect of reducibility. The work of Wild and Saunders[1] has shown that the optimum size for such ores is around 30–35 mm. Larger lumps will arrive at the hearth inadequately reduced and will impair furnace efficiency.

The sintering process

The crushing of Indian ores to this optimum size will produce a fairly large portion, possibly 40% of−10mm fines which cannot be directly charged into the furnace.

It was to utilise such fines that the sintering process was originally developed but subsequent experience has shown that sinter offers many inherent advantages as a burden material namely :

(*a*) Any free or combined moisture in the original ore is driven off and carbonates are decomposed.
(*b*) A part of any sulphur present is removed, in amount depending on the lime content of the sinter.
(*c*) The gangue constituents of the ore can be pre-slagged by the addition of the appropriate fluxes to the sinter mix.
(*d*) The irregular surface of sinter lumps helps to maintain adequate burden permeability and permits high blowing rates.
(*e*) After screening at 10 mm a properly made sinter does not break down appreciably in its transport to the furnace. It is also not prone to suffer disintegration within the furnace, a defect of certain dense hematite ores. Flue dust losses are thereby reduced and permeability is maintained.
(*f*) Reducibility varies with sinter composition but is generally better than that of dense ores[2].
(*g*) It is generally possible to carry higher blast temperatures with sinter burdens.

In a modern strand sintering installation an accurately proportioned, conditioned and intimate mixture of fine ore, flue dust, coke breeze and return fines (the undersize produced when screening the finished sinter) is charged onto a set of horizontally moving pallets on the sinter machine to form a uniform bed generally 6′ or 8′ wide and 12″–18″ deep. This bed first passes under an ignition hood when the surface is heated to around 1,200°C by burning blast furnace gas of fuel oil at a rate to give a heat input of 4,000 B.T.U. per sq. ft of sinter surface per minute.

Situated below the pallets are a series of windboxes connected to a main fan which draws air down through the sinter bed and the grate bars forming the bottom of the pallets. This air performs two functions :

(*a*) It provides oxygen for burning the coke breeze in a thin layer of the bed which travels down through the bed at 1′-2″ per minute.
(*b*) It extracts heat from that part of the bed in which sintering is complete and is thus preheated when it burns coke on the lower region of the bed.

The success of sintering depends to a large extent on the matching of the rate of heat transfer and the rate at which the flame front travels so that a sharp peak temperature is generated in a narrow layer of the bed. Operating variables are normally adjusted so that sintering is complete at the penultimate windbox.

At the end of the strand the sinter cake is broken and screened at 3/8″ and the +3/8″ material is then cooled. This is generally done by means of a forced draught of air since water quenching has been found to impair sinter strength.

Output up to 5,000 tons per day can be achieved on a single machine.

Practical experience with sinter burdens

Although some of the most striking benefits have been obtained with low grade ores the following practical results, selected from a large volume of literature, show that even with rich ores the gains are impressive. In 1945 the South African Iron and Steel Corporation[3], faced with a physical deterioration in the quality of its dense hematite ores embarked on a programme of ore preparation involving crushing and screening together with washing and sintering of the fines produced. The results obtained are summarised in the following table :

TABLE I

Period	% sinter in burden	Production ton/day	Coke rate kg/ton
Ore crushed to−3″ charged in two layers	—	540	795
Minus−1/8 ore sintered with added limestone	37·9	551	741
Minus−1/8 ore sintered with limestone, rescreened at furnace	38·6	585	705
Minus−1/8 ore sintered with limestone, rescreened at furnace	75·0	672	588

Note: In all tests with sinter the remaining ore was charged as two layers−50 mm, + 20 mm, + 3 mm. The coke had 16–17 per cent ash. More outstanding results have been reported by the Steel Company of Canada[4]. By charging 100 per cent self-fluxing sinter containing 52 per cent iron the coke rate was reduced from 805 to 536 kg/ton of iron. Higher blast temperature became possible and flue dust was reduced from 27 kg. to 12·5 kg/ton. Even when taking the cost of the coke breeze used for sintering as equal to that of blast furnace coke there was still a net saving of 112 kg/ton of pig iron.

Swedish experience[5] confirms the advantage of sinter burdens in rich ore practice. Table II gives the results of several years' operation at a works using sinter without added limestone. Coke consumption decreased by 23–30 per cent with a simultaneous increase in production of 55–58 per cent.

TABLE II

Grade of iron		Sinter % of total ore	Relative coke % rate	Relative production rate %
Open hearth iron	...	0	100	100
1% Si ...	...	85	79	185
Foundry iron	...	0	100	100
1·5–2·5% Si	...	78	77	188
Foundry iron	...	0	100	100
2·5–3·5% Si	..	75	80	155

Finally there is the statistical study by Flint[6] of a large number of blast furnaces within the United States Steel Corporation. His figures are based on the saving in effective carbon which is defined as follows:

Effective carbon=(% fixed carbon)—(1·04 × % ash)—(3 × % sulphur). Each 10 kg. of sinter in the burden per ton of pig iron resulted in a saving of 0·5 kg. of effective carbon (or nearly 1 kg. of a 20% ash coke). The incorporation of 1 kg. of CaO+MgO in the sinter gave a further saving of 0·35 kg. of effective carbon (or 0·6 kg. of a 20% ash coke).

Sintering costs

The advantages discussed above are achieved with the use of a low grade fuel, coke breeze. Typical European sintering costs for an iron rich sinter mix and a production of 600,000 tons of sinter per year on an 8 ft. strand are itemised in Table III.

TABLE III

Item	Cost/ton of sinter	% of Total cost
Ignition fuel (c.f. gas) 1 Therm (100,000 B. Th. U.) ...	6d.	2·7
Coke Breeze 220 lb @ £3/ton	6/-d.	31·8
Main Fan 15 kWh @ 2d. ...	2/6d.	13·3
Auxiliaries (including coke crushing) 5 kWh	10d.	4·5
Operating labour	1/-d.	5·3
Maintenance	2/-d.	10·6
Capital charges at 15% for production of 600,000 tons per year	6/-d.	31·8
Total	18/10d.	100·0

These figures, particularly labour charges, would need modifying before application to Indian conditions but fuel and depreciation cost will remain the biggest items.

Self-fluxing and super fluxing sinter

When limestone is added to the sinter mix the gangue of the ore is charged to the furnace as a pre-formed slag of regular composition. Such a slag promotes less viscous conditions in the furnace bosh where the silica of the coke ash is not yet liberated.

Also there is less likelihood of compounds such as fayalite (2 FeO. SiO_2) which are less easily reduced than iron oxides being formed in the sintering process.

It has been found that self-fluxing sinters made from rich ores show a greater resistance to disintegration during reduction[7]. This may be due to the greater quantity of slag available as a bonding agent. Limestone also improves the sintering rate due either to increased bed permeability or to a decrease in the specific air volume. In some instances[8, 9] lime additions have led to a saving in sintering fuel, but this does not hold for all ores.

The calcination of limestone outside the furnace assists coke economy in two ways. First, the endothermic decomposition of carbonates is no longer effected in the furnace and second, the smaller quantity of CO in the upper stack favours the reduction of iron oxides by CO.

Although all these benefits remain applicable to rich ores, the low gangue content of the latter means that, when making a self-fluxing sinter only a proportion of the total limestone needed will be pre-calcined.

Interest is therefore directed towards the use of super fluxing sinter in which lime is added in excess of that required to flux the ore gangue.

It must be admitted that there are certain difficulties in making a sinter of adequate strength when the $CaO/(SiO_2+Al_2O_3)$ ratio is high. These derive from the presence in the finished sinter of free CaO of dicalcium silicate which is unstable at normal temperatures.

However with fine grinding and uniform mixing of the limestone it has proved possible to make a rich ore sinter with a $CaO/(SiO_2+Al_2O_3)$ ratio of 1·5 equal in strength to a normal sinter. Even when this ratio was raised to 1·8 the fall off in strength was not too great.

With this in mind we may consider a rich ore containing 65 per cent Fe, 3 per cent SiO_2 and 4 per cent Al_2O_3 and a coke with 20 per cent ash of composition 50 per cent SiO_2, 30 per cent Al_2O_3 and 3·5 per cent CaO.

Let the coke rate be M kg. per metric ton of pig iron and assume that a blast furnace slag with a $(CaO+MgO)/(SiO_2+Al_2O_3)$ ratio of 0·7 will give adequate desulphurisation with the raw materials involved.

The total gangue in kg/ton of iron is then made up as follows:

	SiO_2	Al_2O_3	CaO
From the ore	45	60	—
From the coke ash	0·1 M	0·06 M	0·007 M
Total =	(45+0·1M)	(60+0·06M)	(0·007M)

The required lime addition is then

$$0{\cdot}7\ (105+0{\cdot}16\ M)-0{\cdot}007\ M$$
$$=73{\cdot}5+0{\cdot}105\ M.$$

If 40 per cent of the ore consists of fines which are sintered with the addition of lime to give a ratio $CaO/(SiO_2+Al_2O_3)=1{\cdot}5$ then the weight of lime incorporated per ton of iron is

$$\frac{1{\cdot}5\times 40}{100}\times 105=63\ \text{kg.}$$

From these figures the proportion of the total lime needed which can be calcined can be calculated for various coke rates. Results for burdens with 20 per cent, 40 per cent and 60 per cent sinter are plotted in Graph 2. At moderate coke rates it is possible to pre-calcine 40 per cent of the total limestone when charging 40 per cent sinter in the burden and this should appreciably reduce the thermal load on the furnace.

For the conditions as stated the calculated slag composition at a coke rate of 800 kg. per ton of iron is:

SiO_2	Al_2O_3	CaO
32·0%	27·7%	30·3%

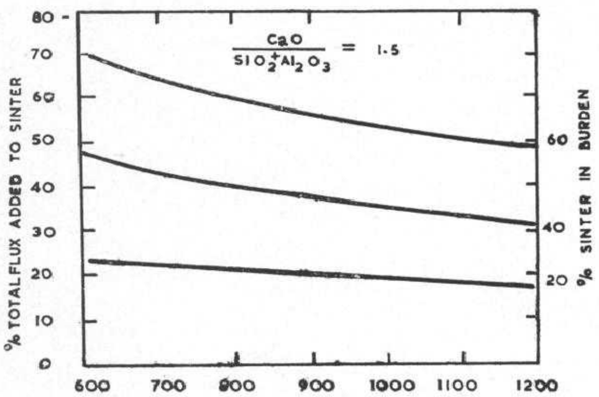
When allowing for 4 per cent MgO this slag has a liquidus temperature around 1,460°C and should therefore have adequate fluidity. The slag volume is 390 kg/ton of iron.

Control of the sintering process

When making sinter and in particular self-fluxing sinter which is to constitute a significant part of the burden it is vital to be in full control of the process variables so that a uniform product is made. This will save coke in the furnace by promoting more regular operation.

There are two factors in this problem of control:

(*a*) *Analysis*: When the raw materials are subject to variations in composition, rapid methods of analysis are needed if off grade sinter is to be avoided. Normal chemical methods are too slow for elements such as SiO_2, Al_2O_3 and CaO and it is probable that the future will bring the greater application of physical methods of analysis such as X-ray fluorescence spectography.



Graph—II Coke rate, kg/ton pig iron.

(*b*) *Control of operating variables*: Sinter mix composition and moisture content, bed height, strand speed and fan suction must be controlled to give optimum output and quality.

In the modern sinter plant all controls are centralised in a control room. From this room the feed rates of all materials involved can be set at the appropriate values and all important variables such as suction in each windbox, temperature in selected windboxes, quantity of ignition gas, etc. are either indicated or recorded. With uniform raw materials control is relatively simple once the correct mix has been established. This is illustrated by the fact that recently a sinter plant ran for 12 hours without any adjustment of the controls whatsoever.

Conclusions

(*i*) With coke of relatively high ash content the primary aim should be to reduce the coke rate until the slag volume is at the minimum workable limit.

(*ii*) The most promising means of achieving this and with a rich ore burden would seem to be to crush the ore as mined to approximately -35 mm and to screen out the -10 mm fines.

(*iii*) These fines could then be sintered with the highest possible lime content consistent with adequate sinter strength in order to minimise the addition of uncalcined limestone to the furnace.

(*iv*) Experience in other countries suggests that a burden with say 60 per cent crushed ore and 40 per cent super fluxed sinter will have good permeability and reducibility and will lead to high outputs and low coke rates.

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DISCUSSIONS

Dr. K. Wada, Director, Yawata Works, Japan: Messrs Jennings and Frankau have discussed very interesting aspects of Burden Preparation for the Blast Furnace and I thought I could add here some results obtained in our works in Japan. In 1957 the coke rate throughout Japan was 700 kg; in our Yawata Works, however, this figure was 687 kg. In November, 1958, No. 2 Blast Furnace of the Kukioka plant of Yawata Works gave a still lower coke rate of 525 kg., which I think will be the new international record.

Sizing is a process difficult to carry out exactly and correct screening of the sinter is in particular very important. Our average coke size is between 60 and 70 mm. I feel still better results would be obtained if the Blast Furnace could be operated at a blast temperature higher than 900°C, ensuring of course, that sizing of raw materials is carried out very strictly and referring to the graph contained in the paper showing the relationship between coke rate and coke ash, I just wonder if the inclination of the curve should not be steeper than what is seen in the figure.

Mr. A. M. Frankau (Author): I would like to congratulate Dr. Wada on the remarkably low coke consumption that he has been obtaining at the Yawata Works. With regard to his comment on Figure 1, the graph is purely a theoretical relationship between the percentage of ash in the coke and the coke rate necessary to give 350 kg. of slag. For any other slag burden, the scope of this graph would of course alter.

Mr. Charles Crussard, Director, IRSID, France: May I ask Dr. Wada what percentage of sinter is being used in his works.

Dr. Wada: About 50 per cent. The coke rate of 525 kg. mentioned by me was arrived at by blending about 100 per cent sinter with blended limestone. Limestone is however not indispensable and the same result could be obtained without using it.

Dr. A. Lahiri, Director, C.F.R.I., Jealgora: I would like to know what type of coke was used. Will Dr. Wada give us some details on its reactivity, composition, ash content and the percentage of Japanese coal used in the coal blend?

Dr. Wada: In the Yawata Works 50 per cent of American coal is blended and 10 per cent of domestic and Australian coal, so that we have about 45 to 50 per cent of low volatile coal whereas the remaining 60 per cent of blended coal is obtained from local sources.

The coke contains about 11 to 12 per cent ash. Besides hardness, size is another important factor. In Yawata, we keep to 60–70 mm, but no use is made of coke beyond 100 mm per inch, in which case we crush down and screen out. Recalling my experience 30 years ago in North Korea where I had to use high ash coke of about 22 per cent I had found that excessive size stops the movement inside the tuyeres; but when I reduced the size, the operation was very rapid and high temperatures were necessary so that I also had to carefully avoid the fines of the crushing.