Ironmaking under Indian conditions

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SYNOPSIS

Indian ores have a high alumina content, the coke has a high ash, and the limestone is siliceous. Mechanical mining, crushing, and screening lead to more gangue in the ore and a higher proportion of fines which ought not to be discarded.

These all produce special problems in present-day ironmaking and pose serious questions for the future because coking coal and good limestone are scarce, capital availability is limited, and yet iron production must be increased considerably. Any natural low gangue material such as blue dust should be exploited urgently.

Calculations are made on the technical effects of deterioration of the ore and coal, sintering, fuel injection, mineral dressing, etc. on the coke rate, iron make, slag weight, and flux requirements.

It is thought probable that classical mineral dressing, agglomeration incorporating limestone, oil (or gas) injection, and high blast temperatures will be the correct long-term solution to India's blast-furnace problems. SR78E

INTRODUCTION

EARLY IN 1962 the Durgapur Chapter of the Indian Institute of Metals held a symposium entitled 'Ironmaking in India'. The author contributed a paper, and as the proceedings of the symposium have not yet been published some of that paper is reproduced here.

Based on known Indian raw materials analyses and typical blast-furnace operation, an attempt was made to predict the effects of deterioration of ore, sintering fines, etc. on the furnace performance. This type of calculation is now extended to include the effects of coke with different ash content, oil injection, changes in slag basicity etc. To make these calculations, many assumptions have to be made on the relationships between cause and effect. These are arguable in detail but it is believed that the resulting predictions constitute a useful basis for detailed assessment.

TYPICAL BLAST FURNACE RAW MATERIALS

Fluxes

Limestone in India is expensive (usually dearer than 60%Fe ore) and of poor quality; it frequently contains 10–12%SiO_2. Dolomite contains less silica but is also expensive. Flux usage in the blast-furnace tends therefore to be minimized, and in consequence slags in India become high in alumina, around 30%, and this is very different from the 10–25% in other countries.

Blast-furnace coke

Typically, coals are washed to yield a coke with about 24% ash (52%SiO_2, 28%Al_2O_3). While it is appreciated that a great deal of study and research is being devoted to this important subject, it may well be that little improvement is in fact possible. Improved techniques may only keep pace with increased demands, bearing in mind particularly the greater coal losses normally associated with better cleaning.

Ores

While an iron content of about 60% suggests that the ores are rich, they seldom contain any lime and often have a 2:1 alumina/silica ratio. Good lump ore can have 4–6%Al_2O_3 and screened fines can double this quantity.

Manganese ores are little dearer than fluxes and are in good supply, so small additions are of little consequence to iron costs.

Strategic reserves

Papers at the Durgapur Chapter stressed the alarmingly small reserves of coking coals in India. Lahiri, Menon, and Das Gupta frequently draw attention to this and urge the iron industry to cooperate with the coal industry to conserve supplies.

Whenever a reduction in coke rate is indicated in this paper it is important to remember this and give a 'national resources' credit as well as a cost sheet credit.

The same applies to limestone but to a lesser extent. Lower grade limestone might eventually have to be used, this will require mineral dressing and will be more expensive but is not likely to stop ironmaking in the blast-furnace whereas running out of coking coal could.

TYPICAL BLAST-FURNACE PRACTICE

As a basis for the first series of calculations the following was taken to be typical good Indian practice using raw but well sized ores in a 28 ft dia. furnace:

Iron make	tons/d	1 300	
Coke burned	tons/d	1 240	
Coke rate	lb/ton	2 135	(19·1 cwt)
Flux (3 parts limestone, 1 part dolomite)	lb/ton	1 030	(9·2 cwt)
Blast temperature	°C	690	
Top pressure	lb/in²	1–2	
Slag weight	lb/ton	1 290	(11·7 cwt)
CO/CO_2 in top gas		1·8	

Ore	Fe	59	Slag	Al_2O_3	28	Coke Ash	25
	SiO_2	2·7 } 8·0		SiO_2	30	Carbon	74
	Al_2O_3	5·3 }		CaO	34·5		
				MgO	5		
					97·5		

The coke rate looks high to Western eyes but when it is adjusted for its low carbon content and it is realized how much raw stone is used then it appears much more reasonable. Indeed the CO/CO_2 ratio of 1·8 emphasizes that the coke utilization is good for the thermal requirements of the practice. Also, the coke burned per day is excellent – about 110 Rice rating, even after correcting for the low carbon content. The burden must, therefore, already be well prepared physically. This means that any agglomerate, if not well sized, would be expected to harm rather than improve the furnace stack permeability.

PREDICTIONS FOR SOME ALTERNATIVE PRACTICES

In the last few years many burden changes have taken place throughout the world and fortunately the results have been presented in the literature.

The method of the Durgapur symposium paper was to pick out some of the better established blast-furnace

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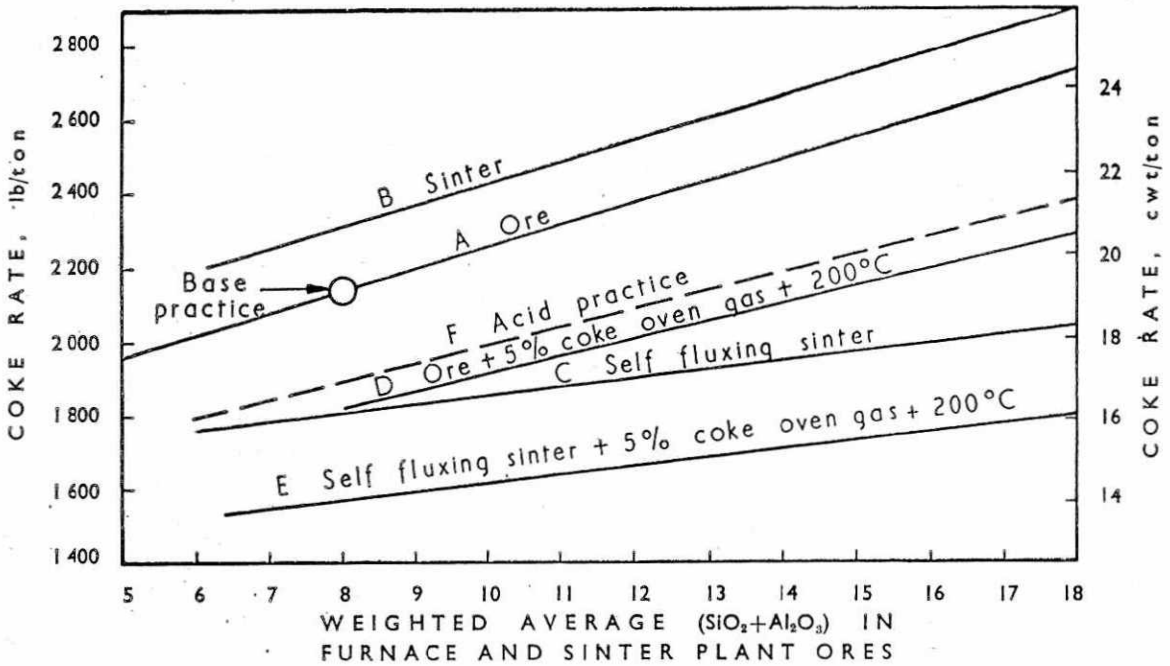


1 *Effect of ore acids and practice on coke rate*

coefficients and to apply them to the base practice described above. The effect on coke rate and iron make was calculated for an increasing acids content ($Al_2O_3+SiO_2$) in the ore for the following types of practice :

(i) the normal base practice of sized raw ore
(ii) 100% sinter made with coke breeze having 32% ash
(iii) 100% sinter ores with all fluxes incorporated in the sinter
(iv) 5% coke oven gas injection and a 200 deg C increase in blast temperature
(v) fluxed sinter with 5% coke oven gas plus 200 deg C [i.e. combining (iii) and (iv)]
(vi) an acid practice with slag analysis, say, Al_2O_3 25–30%, SiO_2 50–55%, MgO 10%, CaO 10%. This assuming for the present that operation with such a slag is operable.

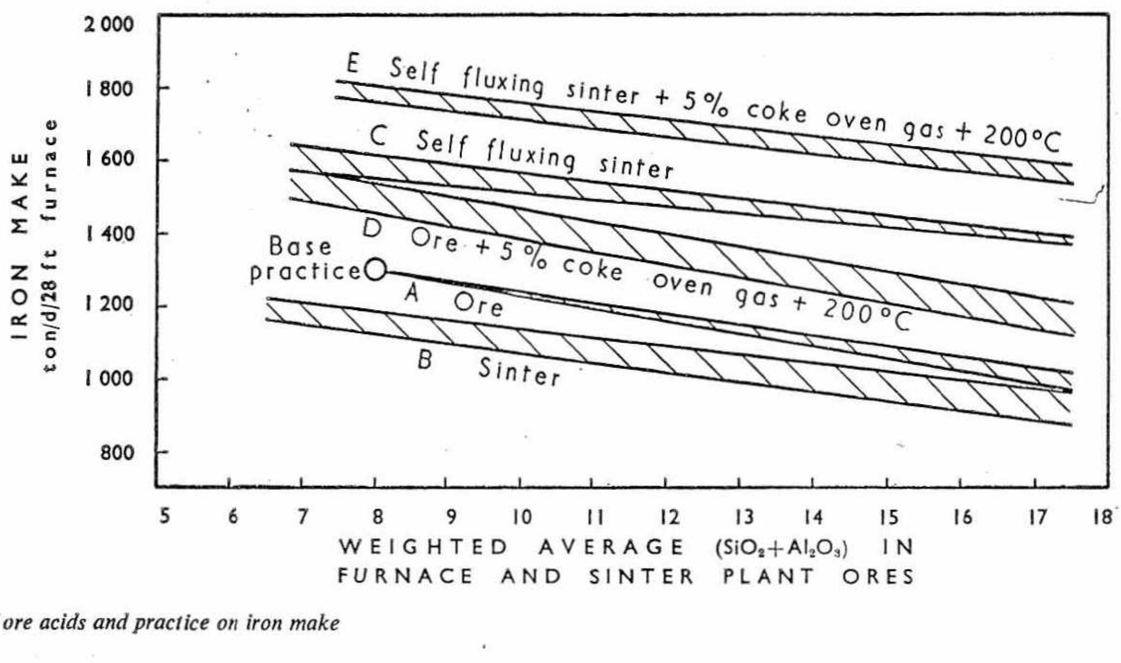
Discussion

Figures 1 and 2 show the results obtained. The derivation and full conclusions were presented in the Durgapur paper. It is clear that for constant basicity furnace slag any increase in the acids content of the ores produces a marked increase in coke rate and reduction in iron make.

Unfluxed sinter is predicted to behave worse on the furnace than the clean raw ore it replaces, whereas sinter which incorporates all the furnace fluxes should behave better than the ore it replaces.

Increased blast temperature plus coke-oven gas (or oil) injection should reduce the coke rate and increase iron make appreciably.

High top pressure has not been included mainly because it is unlikely to affect coke rate or flux additions or to depend on the ore acids. It would, however, increase iron make.



2 *Effect of ore acids and practice on iron make*

TABLE I Changes in consumption rates

	Changes in consumption rates over base practice											
	Base practice *A* (Ore)		*B* (Sinter)		*C* (Fluxed sinter)		*D* (Ore+coke-oven gas)		*E* (Fluxed sinter +coke oven gas)		*F* (Acid practice)	
Acid	8	17½	8	17½	8	17½	8	17½	8	17½	8	17½
Coke, lb/ton	2 130	2 705	+180	+170	−270	−675	−325	−435	−565	−915	−245	−345
Fluxes, lb/ton	1 030	1 950	+194	+150	+70	+100	−90	−230	0	+28	−580	−1 030
Silica, lb/ton	...	...	...	...	...	...	...	...	...	...	+230	+650
Coke oven gas for injection ft^3/ton	...	...	...	...	...	...	+4 050	+5 250	+3 300	+3 800	...	...
Coke breeze, lb/ton	...	...	+480	+535	+620	+780	...	...	+615	+770	...	...
Slag make, lb/ton	1 280	2 350	+230	+250	+130	+10	−150	−270	...	−100	−190	+30
Iron make, tons/day	1 300	1 000	−250	−80	+280	+375	+190	+160	+180	+550	+185	+65

Acid practice was thought to be interesting and worthy of more study. Finally, any low gangue material such as blue dust should be incorporated in sinter mixes, or it should be considered in terms of pellet production.

CHANGES IN CONSUMPTION RATES AND PRODUCTION

Comparison of processes

While Figs. 1 and 2 show changes in coke rate and iron make for the various conditions, they do not show changes in flux requirement, coke breeze, etc. It is useful to list these because they are helpful when costing the different practices discussed.

Table I shows the coke, flux, etc. requirements for the base case of raw ore for 8 and 17½% acids, (Al_2O_3+SiO_2), in the ore and the changes in these requirements for the other practices.

Practice *B* (sinter) costs extra coke, flux, and coke breeze, and gives a lower iron make. This is clearly not in India's interest.

Practice *C* (fully fluxed sinter) saves furnace coke (especially with low grade ore), demands coke breeze and some additional flux compared with practice *B*, but gives a useful gain in iron production.

Practice *D* (ore+coke-oven gas injection+200 deg C blast heat) requires coke-oven gas for the furnace and more blast-furnace gas for the stoves, but saves a large amount of furnace coke, some fluxes, and gives a useful increase in make over the base practice.

Practice *E* (fluxed sinter+coke-oven gas injection+200 deg C) saves much more coke than *D* and yields more iron output but requires an appreciable quantity of coke breeze.

Practice *F* (acid slag), if operable, would save coke and large quantities of limestone and give a useful increase in iron make.

It would be interesting if a works accountant calculated hot metal costs for these practices.

Table I highlights which processes have the least coke and/or flux requirements, and emphasizes the advantages of rich ores rather than lower grade ores.

Effects of mineral dressing

Let us consider the difference between the flux, coke, etc., requirements for each practice for a reduction of ore acids from, say, 10–8%. A change of 2% in total acids may be taken to involve a change of 1·33% in Al_2O_3. These figures can then be used to show the savings in coke, flux, etc. and increase in iron make if ores are selectively mined or subjected to mineral dressing to reduce the Al_2O_3 by 1·33%.

The practices using raw stone save 100 lb or so of coke whereas fluxed sinter saves about half this. There is also a decrease of nearly 200 lb limestone and an increase of around 5% in iron make. In every case upgrading the ore can be seen to reduce appreciably the coke and fluxes.

EFFECTS OF CHANGES IN COKE ASH

A similar base case of sized raw ore has been taken and computations made of the effect of different coke ash contents on the flux rate, coke rate, etc. Table III gives the results : it is not claimed that the numbers are accurate to four figures but the computer likes it this way !

A rise of 4% in coke ash costs over 200 lb of coke and over 200 lb of fluxes and reduces iron make by about 5%. There is a slight reduction of Al_2O_3 in the slag which should improve furnace operation.

It can be argued that if a 4% decrease in coke ash involved a loss of coal yield of as much as 10%, then there would still be no change in the amount of raw coking coal per ton of iron, while limestone could be saved and an increase in production obtained.

The acid slag contemplated for practice *F* was known to have a reasonable liquidus temperature but it was suspected to be rather viscous. Calculation of its viscosity suggests that 'rather' should be replaced by 'impossibly. However, the slag diagrams suggest that there is a constant liquidus valley along which one can travel for increasing acidity and it is interesting to calculate furnace burdens and slag viscosities at a number of points.

The results are shown in Table IV. The base practice is again sized raw ore with a typical Indian slag. Burdens

TABLE II Effects of ore beneficiation on consumption rates

	Change in requirements for a reduction of 2% in ore acids (1·33% in Al_2O_3)					
	A (Ore)	*B* (Sinter)	*C* (Fluxed sinter)	*D* (Ore+coke oven gas)	*E* (Fluxed sinter + coke oven gas)	*F* (Acid practice)
Coke, lb/ton	−114	−114	−45	−92	−44	−94
Fluxes, lb/ton	−184	−174	−190	−156	−190	−110
Silica, lb/ton	...	...	...	...	...	−75
Coke oven gas for injection, ft^3/ton	...	...	...	−240	−100	...
Coke breeze, lb/ton	...	−11	−33	...	−31	...
Slag make, lb/ton	−214	−218	−190	−190	−194	−260
Iron make, tons/day, 1300 base	+60	+47	+40	+65	+45	+84

TABLE III Prediction of coke, stone, slag, and production rates with changes with coke ash

Base case

Material	wt. (lb/ton) wet	wt. (lb/ton) dry	H_2O % (wet)	C (% dry)	Ash (% dry)	SiO_2 (% dry)	Al_2O_2 (% dry)	MgO (% dry)	CaO (% dry)
Coke	2 135	2 062	3·4	73·92	24·66	...	...	...	...
Coke ash	...	...	...	...	...	52	28	1·5	1·5
Stone	...	1 030	...	...	...	7·48	2·25	7·95	41·83
Ore	...	3 520	...	...	...	2·67	5·48	...	...
Flue dust	...	75·6	...	...	...	11·2	11·1	...	...
Slag	...	1 263·7	...	...	...	28·1	27·7	7·1	34·7

Production = 1 300 tons/day on 28ft dia. furnace
Metal Si = 1·5%

Assumptions

Coke ash+carbon = constant = 98·58% (dry)
Coke moisture = constant = 3·4% (wet)
Ore and flue dust wt. and analysis = constant
$\frac{CaO+MgO}{SiO_2+Al_2O_3}$ Slag basicity = constant = 0·7491
Slag $SiO_2+Al_2O_3+MgO+CaO$ = constant = 97·6%
Stone analysis is constant (i.e. Limestone and Dol. proporions are fixed)
Coke ash analysis is constant
Coke carbon burning rate is constant
Metal analysis is constant

Predictions

Coke analysis (dry) %C	Coke analysis % Ash	Stone rate, —lb/ton(dry)—	coke rate, —lb/ton(dry)—	slag rate, —lb/ton(dry)—	Production tons/day	Slag analysis % SiO_2	Al_2O_3	MgO	CaO
76·00	22	916	1 923	1 122	1 346	26·95	28·85	7·06	34·74
72·58	26	1 095	2 140	1 344	1 276	28·65	27·15	7·1	34·7
68·58	30	1 320	2 413	1 623	1 197	30·12	25·68	7·13	34·61

1, 2, and 3 are designed to increase progressively the slag acidity (by adding quartz) whilst preserving the liquidus temperature. These are then repeated using BHQ instead of quartz (Burdens 1*a*, 2*a*, 3*a*). Calculations are then made assuming that burdens base, 1, 2, and 3 are partly sintered using coke breeze and that all the fluxes are incorporated. It is thought that the sinter compositions are not unreasonable.

Viscosity and liquidus predictions are as follows :

Practice	*Viscosity (poises) at 1 500°C*	*Liquidus temp.,°C*
Base practices	3·8	1 500
No. 1, 1*a* and 1*b*	9	1 450
No. 2, 2*a* and 2*b*	20	1 400
No. 3, 3*a* and 3*b*	47	1 400

In order to interpret the viscosity values, the following figures are given for UK furnace slags, and also for the slag made in the 'hyper-acid' process tried at Watenstedt in Germany.

Viscosity (poises) at 1 500°C

UK slags Minimum	Average	Maximum	Watenstedt slag
2·3	3·6	4·9	13·8

The Watenstedt hyper-acid practice experienced a number of difficulties, some of which may well have been due to the high viscosity of the slag.

Unfortunately it looks as if only a small increase in acidity would be possible. The use of BHQ is preferable to quartz but even if the burdens 1, 1*a*, or 1*b* were used, the savings in coke rate and increase in iron make would be very small. There is, of course, an appreciable saving in limestone.

TABLE IV The effects of changes in slag basicity

Raw ore

Practice	Slag composition SiO_2	Al_2O_3	CaO	MgO	Slag volume lb/ton pig	Burden ore*	Limestone	Dolomite	SiO_2 rock	BHQ ore†	Burden weight lb/ton pig	Coke rate lb/ton pig	Production ton pig/d
Base practice	28·0	27·8	34·7	7·1	1 260	3 520	770	260	...	...	4 550	2 140	1 300
1	36·2	27·8	26·6	7·0	1 220	3 520	500	295	115	...	4 430	2 055	1 355
2	43·1	27·8	19·6	7·0	1 185	3 520	285	330	215	...	4 350	1 985	1 405
3	50·2	27·8	12·5	6·9	1 150	3 520	80	350	305	...	4 255	1 915	1 455
1a	36·5	28·5	25·6	6·9	1 150	3 375	455	265	...	235	4 330	2 010	1 385
2a	43·0	28·2	19·4	6·9	1 125	3 270	265	305	...	420	4 260	1 960	1 420
3a	50·0	28·4	12·4	6·9	1 070	3 175	70	325	...	585	4 155	1 885	1 475

*Composition of overall ore : Fe, 58·8% ; SiO_2, 2·67% ; Al_2O_3, 5·48%
Overall ore comprises : Iron ore, 96·5% ; BHQ ore, 1·3% ; manganese ore, 2·2% ; Coke ash, 24·7%
†Composition of BHQ ore ; Fe, 35·6% ; SiO_2, 47·0% ; Al_2O_3, 0·84%

Sintered

Practice	Slag composition SiO_2	Al_2O_3	CaO	MgO	Slag volume lb/ton pig	Burden ore	Limestone	Dolomite	SiO_2 rock	BHQ ore	Burden weight lb/ton pig	Sinter weight lb/ton pig	Coke rate lb/ton pig	Production ton pig/d	Amount sintered Ore	Sinter composition Fe	SiO_2	Al_2O	CaO	MgO
Base practice	29·1	27·6	33·9	6·9	1 355	3 505	805	250	...	...	4 280	3 115	1 800	1 550	2/3	44·5	7·0	6·2	14·3	2·7
1b	35·8	28·0	26·6	7·0	1 280	3 505	530	295	95	...	4 225	3 060	1 785	1 560	2/3	45·3	9·5	6·1	10·9	2·7
2b	42·9	28·1	19·5	7·0	1 195	3 510	285	320	200	...	4 145	1 805	1 765	1 980	1/3	38·4	17·4	5·5	12·4	4·2
3b	49·9	28·1	12·5	7·0	1 180	3 510	75	355	295	...	4 125	1 785	1 760	1 585	1/3	38·8	21·8	5·8	7·7	4·1

TABLE V Prediction of coke, stone, slag and production rates with oil injection

Burnpur base case

Material	Wt (lb/ton) Wet	Wt (lb/ton) dry	H_2O % (wet)	C (% dry)	Ash (% dry)	SiO_2 (% dry)	Al_2O_3 (% dry)	MgO (% dry)	CaO (% dry)
Coke	2134·92	2062·35	3·4	72·35	24·66	12·82	6·9		
Coke ash		508·58				52	28		
Stone		981·86				7·46	2·25	8·0	41·78
Ore		3560·5				2·69	5·48		0·14
Flue dust		75·78				11·2	11·1		2·88
Slag		1226				28·64	28·81	6·36	33·69

Production = 1 300 tons/d
Metal Si = 1·5%

Assumption

Coke moisture = constant = 3·4%
Ore and flue dust, weight and analysis = constant
Slag basicity = constant = 0·698
Slag CaO + MgO + SiO_2 + Al_2O_3 = constant = 97·5%
Stone analysis is constant (i.e. limestone and dolomite proportions are fixed)
Coke analysis is constant
Total carbon burning rate = constant
Metal analysis is constant

Predictions

Wt. of oil/ton	Temp. compensation, °C	Slag wt (lb/ton dry)	Coke wt (lb/ton dry)	Stone wt (lb/ton dry)	CaO (Slag analysis)	MgO (Slag analysis)	SiO (Slag analysis)	Al_2O_3 (Slag analysis)	Prdn tons/d
50 lb	0	1 191	1 976	954·1	33·68	6·4	28·52	28 90	1 367
50 lb	100	1 167	1 916	935·0	33·68	6·4	28·32	29·1	1 357
50 lb	200	1 153	1 880	923·3	33·68	6·4	28·2	29·23	1 382
100 lb	0	1 172	1 927	938·4	33·68	6·4	28·35	29·07	1 311
100 lb	100	1 129	1 820	904·2	33·68	6·4	27·98	29·44	1 382
100 lb	200	1 092	1 728	874·7	33·68	6·4	27·64	29·78	1 452
200 lb	0	1 134	1 832	908·2	33·68	6·4	28·03	29·39	1 295
200 lb	100	1 080	1 697	864·8	33·68	6·4	27·52	29·9	1 386
200 lb	200	1 034	1 580	827·6	33·68	6·4	27·04	30·38	1 475

EFFECTS OF OIL INJECTION

In the earlier calculations, coke-oven gas was chosen for fuel injection because it was known that oil was expensive. However, coke-oven gas appears to be in short supply and it is possible that increases in iron output can justify increased fuel costs. Fuel costs are almost bound to rise with oil injection because oil costs, today, three to four times that of coke (on weight basis).

A base case has been taken and computations made of the effect on output and coke rates for various combinations of extra blast heat and oil injection.

Table V gives the computer results; which combinations of temperature and injection rate will be acceptable to the furnace only full-scale experiments will tell.

Supposing a 200 lb injection rate is possible with 100 deg C blast temperature rise, then the accountants can compute the extra cost of 200 lb oil and 100 deg C blast temperature compared with a saving of 365 lb coke, 117 lb stone and making allowance for extra 86 tons metal/d.

This increase of $6\frac{1}{2}$% production would be worth about 4 rupees/ton if, for example, the conversion costs, depreciation, and profit total 65 rupees/ton metal, so there is a possibility that oil injection might pay on hot metal costs. It appears unfortunate that oil is so heavily taxed because otherwise it could help more to reduce the consumption and transport of coking coal and limestone. Oxygen enrichment would enable larger replacements of coke by oil with or without extra blast temperature.

PREDICTED PERFORMANCE WITH 100% RICH PELLETS AND INDIAN COKE AND FLUX

Recently information was obtained on heat hardened pellets made from Goan ore. These analysed 66·1%Fe, 1·8% Al_2O_3, and 2·0%SiO_2, and appeared to be of an excellent material. Presumably these were gas or oil-fired and not loaded with the high ash from coke breeze.

These have not, to the author's knowledge, been smelted exclusively in a blast-furnace with Indian coke and fluxes, so there is no established base practice using them.

An attempt has been made in Table VI to predict operating data considering a furnace of hearth diameter 28 ft and a blast temperature around 800°C. Line *A* suggests that the high coke ash still demands large flux additions but that the coke rate would be 1 700 lb/ton. At the previously assumed coke burning rating of 108% Rice the iron made would be over 1 600 tons/d. In view of the reported high driving rates possible with 100% pellets, nearly 2 000 tons/d might well be obtained.

Line *B* assumes that the fluxes are incorporated in the pellets in some manner. The coke rate could well come down to about 1 500 lb/ton and the iron make could be as much as 2 200 tons/d.

The alumina in the slag would be 18 or 19% and this would be welcomed by operators. Lower silicon, low sulphur iron should be possible and this would be appreciated by the steelmaker.

The savings in coke and stone together with considerably reduced conversion cost, depreciation charges (because of increased make), etc. should be calculated in order to estimate whether they would cover the cost of crushing, mineral dressing, and pelletizing.

MINERAL DRESSING: ARGUMENTS FOR AND AGAINST

It is established that high coke ash and high alumina in the ore result in high flux rates, high coke rates, low iron makes and difficult furnace operation with about 30%Al_2O_3 in the slag and about 1·5%Si in the metal.

The National Metallurgical Laboratory at Jamshedpur has made extensive ore dressing studies and a cursory examination of their data suggests that cheaper hot metal from beneficiated ores should be possible provided reasonable credit is taken for the increased iron make which would result. Iron losses in the tailings are appreciable but are not very much greater than those incurred in rejecting the fines today.

Limestone beneficiation looks sensible for steelmaking but while coke ashes are so high the case for upgrading

TABLE VI Predictions for rich pellet practice

	Slag composition SiO_2	Al_2O_3	CaO	MgO	Slag volume lb/ton pig	Burden pellets	limestone	Burden weight lb/ton pig	Coke rate lb/ton pig	Production 108 RR	130 RR	Viscosity at 1500°C, poises	Liquidus temp., °C
A unfluxed	34·7	18·8	42·3	4·3	980	3 150	890	4 040	1 700	1 630	1 960	3·5	1 475
B if fluxed	34·4	18·7	42·7	4·2	920	3 665	(845)*	3 665	1 520	1 830	2 200	3·5	1 475

* Based on using Indian coke and fluxes added to the concentrate before pellet firing.

limestone for ironmaking is less strong. As reserves diminish, however, it may then be necessary.

Studies should be made by the coal and ironmaking experts to establish the optimum degree of coal washing which will produce the maximum iron make per unit of raw coking coal. If necessary, cost sheets may have to be of secondary importance to that of the life of the industry.

CONCLUSIONS

High coke ash and ores with high alumina complicate ironmaking in Indian blast-furnaces. Any appreciable increase in either would have serious consequences. To reduce alumina by mineral dressing methods involves extra expense but would increase iron productivity and save coke. Hot metal costs will not necessarily increase.

Fuel injection and the use of higher blast temperatures will reduce coking coal and flux requirements and increase iron makes. It is most unfortunate that fuel oil is not indigenous and is expensive because the management will be reluctant to encourage the maximum possible replacement of coke by oil.

With lower alumina in the slag lower silicon metal can be produced. Dilution of alumina with silica and limestone requires extra fuel, fluxes, etc. and reduces iron output, whereas removal of alumina from the input materials is beneficial all round.

High top pressure should increase iron makes but cannot be expected to reduce fuel or flux requirements.

The paper gives much data on the different quantities of fuel and fluxes, etc. necessary to make iron with different practices, ore and coke analyses etc. With mineral dressing data from the NML and operating costs from plant makers the works accountants can therefore make useful forecasts of materials costs and total hot metal costs.

Rough calculations suggest that for a cost-free reduction of 1%Al_2O_3 in the input ores the hot metal total cost would be reduced by about 6 rupees/ton. This is probably more than sufficient to cover the operating and capital costs of beneficiating ores by this amount at the mines.

Normal sintering is not recommended because it will increase fuel rates and reduce output. It would be even less desirable if lower grade fines were used. Fluxed sinter would, however, be advantageous.

The time may come when hot metal costs must be secondary to conserving coking coal. If it does, the answer will probably be to practise maximum mineral dressing and to produce a fluxed agglomerate for smelting in furnaces with high blast temperatures and oil or gas injection in the tuyeres. Oxygen enrichment of the blast would enable a greater replacement of coke by oil, increase iron make, and may well be worthwhile. Alternatively, low ash coke may have to be imported.

ACKNOWLEDGMENTS

My thanks are due to all the furnace operators who have encouraged burden changes on their furnaces and have had the courage to write up their experiences.

I am particularly grateful to Dr R. Wild, and Messrs K. Dixon, L. Reid, and J. Monson for so many calculations and for their valuable advice throughout.

I readily acknowledge the help of many friends at Jamshedpur, Burnpur, Rourkela, and Durgapur in patiently explaining to me so many of the problems which arise when making iron in blast-furnaces in India : I can only hope I have not seriously misunderstood them.