Fuel Economy Index as a Criterion for Reduction of Coke Rate in the Blast Furnace

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The paper discusses the extent of coke saving possible in the blast furnace by a combination of oxygen enrichment of air and pulverized coal injection in the tuyere raceway under high top pressure operation.

Previous Work

Conventional blast furnace practice depends upon carbonization of premium fuels, coking, and blendable coal for manufacturing blast furnace coke. If a part of the blast furnace coke can be replaced by non-caking coal the measure would contribute appreciably to conservation of coking coal in view of its limited resources in India. The latest figures quoted by the Geological Survey of India puts the reserves of prime, medium, and semi-coking and non-caking coals of India as on 1 January 1999, as shown in Table 1, which indicates that prime coking and blendable coals form only 14.408 per cent of India’s total coal reserves of 208.751.89 million tonnes.

The blast furnace has for decades been producing about 95 per cent of the world’s pig iron because it is economically unmatched by any other process on account of its high production rate and economies of scale.

The specifications for hard metallurgical coke for blast furnaces in various countries are indicated in Table 2.

It can be noted from Table 2 that the major handicap of smelting iron ore in blast furnaces in India is the high ash content of hard coke which is more than double that in almost all countries. For this reason, coke rates on Indian blast furnaces are higher compared to many advanced countries in view of the high ash content of Indian cookes (about 0.70-0.95 kg coke/kg pig iron in India as against 0.55 kg/kg in the UK, 0.59 kg/kg in China, and 0.53 kg/kg in Germany). In Japan the reported coke rate is as low as 0.40 kg coke/kg pig iron which is due to import of very low ash coke, and advanced blast furnace technology. It has been reported that the new blast furnace No.2 at the Visakhapatnam steel plant has achieved a coke rate of 0.566 kg/kg which is comparable to the coke rates in advanced countries. The reason for this remarkable achievement is probably due to use of low ash content coke and consequently extremely low slag rate of 0.275 kg slag/kg pig iron (compared to 0.28 kg/kg in Germany and Japan) and also due to economies of scale with a blast furnace having an effective volume of 3200 m³ and a production rate of 4860 tonnes pig iron /d.

Another recent report states that the new 3 million tonnes/y steel plant coming up at Brahmani near Cuttack in Orissa will have a blast furnace having a capacity of 2200 m³ and equipped with modern coal injection system and will have a coke rate of less than 0.5 tonnes /tonne molten iron. Though the Brahmani blast furnace has a lower capacity than the one at Visakhapatnam the low coke rate possible can be attributed to coal injection which is elaborated further subsequently.

| Table 1 — Reserves of coking and non-coking coals of India on 1 January 1999 |
|-----------------|-----------------|-----------------|
| Type of coal    | Reserves in million tonnes | Per cent |
| Prime coking    | 5.313.06         | 2.545          |
| Medium coking   | 23.157.53        | 11.093         |
| Semi-coking     | 1.607.88         | 0.770          |
| Total coking + blendable | 30.078.47 | 14.408       |
| Non-caking      | 178.673.42       | 85.591         |
| Total coking + blendable + non-caking | 208.751.89 | 100.00        |

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As mentioned earlier, Indian coals are high in ash and these values are likely to increase in future. Hence, lowering the coke rate assumes great importance in India in order to conserve the limited resources of prime coking and blendable coals. Coal washing is one alternative for reducing the ash content of coke and thus lowering the coke rate, but in coal washeries, in India, it entails a loss of about 10-30 per cent of the coking coal in middlings and rejects depending on the ash content and the washability characteristics of the unwashed coal. Thus, coal washing is limited in its applicability because washing the coal to less than 15 per cent ash in the cleans is not viable. A further lowering of the coke can be effected by injection of non-coking coal in the tuyere raceway.

Other alternatives for conservation of coking coal are blending with non-coking coals and production of pig iron in low shaft furnace have been discussed by Sunavala. The results on blending carried out at Tata Iron & Steel Co., Jamshedpur (TISCO) are summarised in Table 3, and that done at Central Fuel Research Institute (CFRI), Dhanbad are shown in Table 4.

Work on low shaft furnace was carried out by National Metallurgical Laboratory, Jamshedpur, using semi-coke or low temperature coke or briquettes produced by CFRI, at the Kalinga Iron Works at Barbil, Orissa. The useful height of this furnace was only 5.9 m and it was possible to make foundry pig iron containing 3.25 per cent silicon with a blast temperature of 750°C. But the coke rate was quite high at 1.3 kg coke/kg pig iron.

Sangameswaran has made a statistical study of the various parameters affecting the coke rate \( R_c \) on a conventional blast furnace. He has put forward the following empirical Eq. (1):

\[
R_c = K + B_1X_1 + B_2X_2 + B_3X_3 + \ldots + B_nX_n, \quad \text{kg coke/kg pig iron,} \quad \ldots(1)
\]

where \( K, B_1, B_2, B_3, \ldots \) are constants and \( X_1, X_2, X_3, \ldots \) are various parameters studied like size of hard coke, per cent ash in coke, per cent sinter in burden, limestone rate, slag volume, wind volume, wind pressure, etc., but he
has not considered the effect of oxygen enrichment of the blast and the effect of injection of non-coking coal in the tuyeres on the coke rate which is discussed in this paper.

In earlier work, Sunavala had indicated that the coke rate in the blast furnace could be lowered by oxygen enrichment of the blast, but this coke economy was limited to an enrichment level of about 30-35 per cent oxygen in the blast necessitated by the requirement of maintaining the central reserve zone of the shaft at 1100°C in order to carry out the reduction of iron oxides by carbon monoxide. An enrichment value above 30-35 per cent oxygen led to the chilling of the shaft (reflected in the drop in the top gas temperature) and caused ‘hanging’ due to improper burden movement which made the blast furnace inoperable.

Two solutions were suggested for overcoming the limitations to fuel economy posed by oxygen enrichment of the blast, viz. (i) Steam injection coupled with high top pressure operation (0.5-3.5 atm gauge) and (ii) Recirculation of hot blast furnace gas through the tuyeres coupled with high top pressure operation.

Another alternative adopted for lowering the coke rate was injection of auxiliary fuels like pulverized coal and coal-oil or coal-water slurries in the tuyere raceway with or without oxygen enrichment. Other injectants like natural gas and heavy fuel oil have also been resorted to, but they are not of any economic interest in the context of the dwindling resources and escalating prices of these fuels. However, when auxiliary fuels are injected in the tuyere raceway, it would also be necessary to inject additional oxygen in order to maintain the per cent oxygen in the blast to at least the normal level of 21 per cent or even higher, if desired. The quantification of the degree of coke economy attainable in a blast furnace by a combination of oxygen enrichment and injection of auxiliary pulvzerized non-coking coal in the tuyere raceway is discussed subsequently.

**Present Work**

1. **Effect of Oxygen Enrichment on the Coke Rate**

Figure 1 shows the effect of the Fuel Economy Index, \( \phi \), given by the following Eq. (2) and the effect of oxygen enrichment of the air on the blast furnace coke rate, \( R_c \), for a typical Indian Haematite ore:

\[
\phi = \frac{\text{Volume fractions of corresponding gases in the blast furnace gas}}{\frac{\text{Volume fraction oxygen in the oxygen-enriched air blast}}{}}
\]

where \( \text{CO}_2, \text{O}_2, \text{CO}, \text{H}_2, \text{CH}_4, \text{and N}_2 = \text{Volume fractions of the corresponding gases in the blast furnace gas and } \rho_0 = \text{Volume fraction oxygen in the oxygen-enriched air blast.}

If the furnace is operated on a blast containing 100 per cent oxygen, then Eq. (2) simplifies to Eq. (3):

\[
\phi_0 = \frac{\text{CO}_2 + \text{CO} + \text{CH}_4}{\text{CO}_2 + \text{O}_2 + 0.5 \text{CO} - 0.5 \text{H}_2 - \text{CH}_4 - \frac{\rho_0}{1 - \rho_0} \text{N}_2}
\]

Further, if the \( \text{CO}_2 \) content of the blast furnace gas is removed in a scrubber and the remaining constituents (essentially \( \text{CO} \)) are recycled back and burnt in the tuyere raceway to generate extra heat and ballast gases in the shaft, the effective composition of blast furnace gas at exit will be 100 per cent \( \text{CO}_2 \) and the Fuel Economy Index, \( \phi_0 \), will be close to the critical minimum value of \( \phi_0 = 1 \) and the coke rate could be reduced drastically and brought close to the limiting thermodynamic coke rate. The limiting thermodynamic coke rates for various values of coke ash for a typical Indian haematite ore are shown in Table 5.
This use of recycled CO as the injectant and its combustion in the tuyere raceway is the basis of a new technique of operating the blast furnace on a blast of 100 per cent oxygen developed at the Central Research Institute of Ferrous Metallurgy, Moscow. The main difficulty encountered was that the tuyeres burnt away due to the excessive heat of the carbon monoxide-oxygen flame. The problem was overcome by leading the CO-O₂ flame deep into the centre of the furnace so that the heat is distributed uniformly in the shaft. It has been reported that by using this technique of operation of blast furnace on 100 per cent oxygen blast with CO recycle, it was possible to lower the coke rate by 25 per cent in the pilot plant of the Tula Steel Plant in the erstwhile Soviet Union.

2 Effect of Coal Injection in the Tuyere Raceway on the Coke Rate

In Figure 2 are shown the effects of coal injection rates (α) varying from 0.1 to 0.3 kg/kg pig iron on the corresponding coke rates (Rc) on the blast furnace. For reasons of clarity in reading from the graphs the results are depicted for coals having 0 per cent and 30 per cent coal ash only.

Table 6 shows that at coke ash content of 30 per cent coke rates of the order of 0.5-0.6 kg coke/kg pig iron reported as attained or attainable in the Visakhapatnam and Brahmami steel plants could be achieved with coal injection rates of the order of 0.2-0.3 kg coal/kg pig iron which would imply a reduction of 30-36 per cent below the present coke rates in the five integrated steel plants in India. If the coke ash could be reduced to 0 per cent
by coal washing, coke rates of the order of 0.4-0.5 kg coke/kg pig iron could be achieved with coal injection rates of the order 0.1-0.2 kg coal/kg pig iron. Such measures would contribute immensely to the conservation of coking coal in India.

Conclusions

In view of limited resources of coking coal in India the injection of non-coking coal into the tuyere raceway together with simultaneous operation of the blast furnace with oxygen enrichment of the blast and at high top pressure, accompanied either by recirculation of hot blast furnace gas through the tuyeres or steam injection, holds immense possibilities in reducing the coke rate on the blast furnace. Theoretical calculations have revealed that at coke ash content of 30 per cent, coke rates of the order of 0.5-0.6 kg coke/kg pig iron can be achieved by coal injection rates of the order of 0.2-0.3 kg coal/kg pig iron. If the coke ash is reduced to 20 per cent by coal washing, the same coke rates can be achieved with coal injection rates of the order of 0.1-0.2 kg coal/kg pig iron, depending upon the Fuel Economy Index.

References

5 News Item, “Rs 12,000 Crore Steel Plant to Come Up in Orissa”. *Indian Express* (5 May 1992) 14.