Injection of BOF Slag-Coal Mixture in Blast Furnace Through Tuyeres for Better Process Control

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The recent years have seen a surge in the attempts to reutilize the waste worldwide. The ever-stringent environmental norms and huge pressure on cost and productivity have been the major triggers for creating value from waste. LD slag generated at steel melting shop is a nuisance of all integrated steel plants across the world. This by-product of LD steelmaking process possesses high proportion of free lime, %P2O5, P_2O_5 and % FeO which render it worthless for utilization in the process. Therefore, Tata Steel disposes sixty percent of the slag generated in lands bought solely for dumping the waste, causing degradation of fertility of land and reducing water adsorbing properties of land. Numerous trials have been initiated to recycle this material into the iron making process but could not be a success in long run. This paper elaborates on the conceptualization, planning and execution of extensive trials carried out at 'G' Blast furnace Tata Steel Jamshedpur for co-injection of LD slag-coal mixture through tuyeres. LD slag is a hard and dense material with density three times that of coal. Grinding it by mixing it with coal and pushing it through N_2 attracts various operational and equipment related challenges. Various other challenges such as thermal fluctuations of furnace were overcome to sustain the trials with the same quality and obtain favorable results. The comprehensive trials established various operational boundaries with regards to the optimized extent of co-injecting the LD slag-coal mixture to the furnace and attaining stable and improved results with respect to the quality of the hot metal.

Keywords: Iron making, Quality, LD slag, waste utilization, co-injection

1. Introduction

Blast furnace Iron making is a complex process involving several simultaneous reactions such as reduction, dissolution, melting, solution loss reaction, carburization and desulphurization. An efficient process is one which stays in equilibrium for long with seamless counter-movement of gas and raw material. Of the many factors that affect the equilibrium, cohesive zone is of utmost importance. Injection of LD slag through tuyeres offers an alternative solution to inject basic fluxes instead of charging, thereby improving process performance.

1.1 Characteristics of BOF Slag

BOF slag also known as LD slag is a secondary product of Steelmaking process. Unlike BF slags, LD slag is still dumped and landfilled, leading to soil, water and land pollution. It also reduces the ability of the land to adsorb water. High concentration of Iron oxide and free lime restricts its use in cement industry and in ballast making. Very low concentration of phosphorous makes it unfit for using as fertilizer. In order to process it several methods were used such as leaching, bio chemical processing, bio-leaching, aging but the most effecting is reduction. Indian LD slag is typically hazardous because varying concentration of lime makes it unfit to use any field. Table-1 Shows a typical composition of LD slag.

Table-1 Composition of LD Slag

Oxide of LD slag	CaO	MgO	Al_2O_3	SiO_2	FeO	Fe (met)	MnO	P_2O_5	S	Tramp elements
Composition (%)	48-50	0.5-1	1-5	15	18-20	0.5-1	0.5-2	0.5-1.8	0.09-0.3	1-2

With 48-50% of lime, LD slag is a rich source of basic flux for the blast furnace. In order to achieve slag basicity blast furnace use Calcium carbonate which adds to load for increasing fuel rate, significantly adding to production costs. LD slag offers suitable alternate in the sense that it has low melting point (Figure-1)and has lime, thus reducing heat requirement for reduction. However, High concentration of oxides of iron leads to increase in direct reduction in process. High concentration of iron oxide also decreases possibility of mixing, grinding and injecting with coal. Density of LD slag is three times the density of coal. LD slag has lower melting temperature. From the phase diagram (Fig-1), it's clear that when CaO is 50%, melting temperature of slag drastically reduces to 1200 deg C

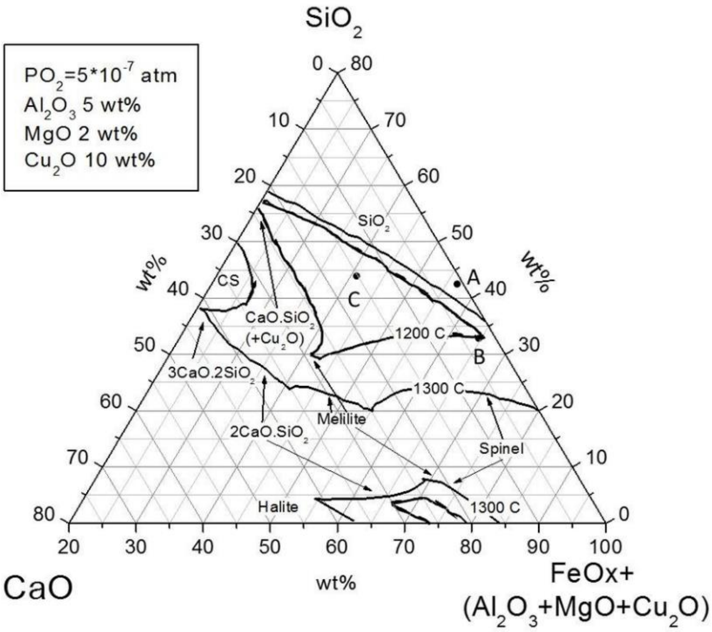

Fig-1 Phase Diagram

1.2 Apprehension with LD slag

Since LD slag is three times denser than coal, grinding it in roller mill needed to be evaluated. BWI testing showed that it is comparable to that of coal. BWI for LD slag came out 10.5KWh/tone. Also, LD slag is hygroscopic in nature. When injected with Coal, high moisture in slag might lead to choking in injection lines. LD slag has 15% silica, glassy structure of calcium silicate might lead to erosion lines primarily meant to inject coal.

1.3 Effect of Blast furnace process

It is expected that when basic flux is injected in the furnace instead of charging, melting temperature of cohesive zone decreases, thereby contributing to increase in permeability of furnace. It is also expected that injection of LD slag-coal mixture help in instant control of Hot metal quality.

2. Effect of Injection on Blast Furnace Process

2.1 Low Melting temperature

Basic fluxes such as lime, dolomite and Calcium carbonate have high melting temperature. When such fluxes mixed with Sinter are charged in the furnace, the melting temperature of cohesive zone increases. Hence, furnace losses permeability. In contrast, LD slag has mixed oxides along with oxides of Silica and hence relatively less melting temperature. Less melting temperature also reduces the burden for heat demand. From phase diagram in Fig-2, with 50% lime and 18% FeO, melting temperature drastically reduces

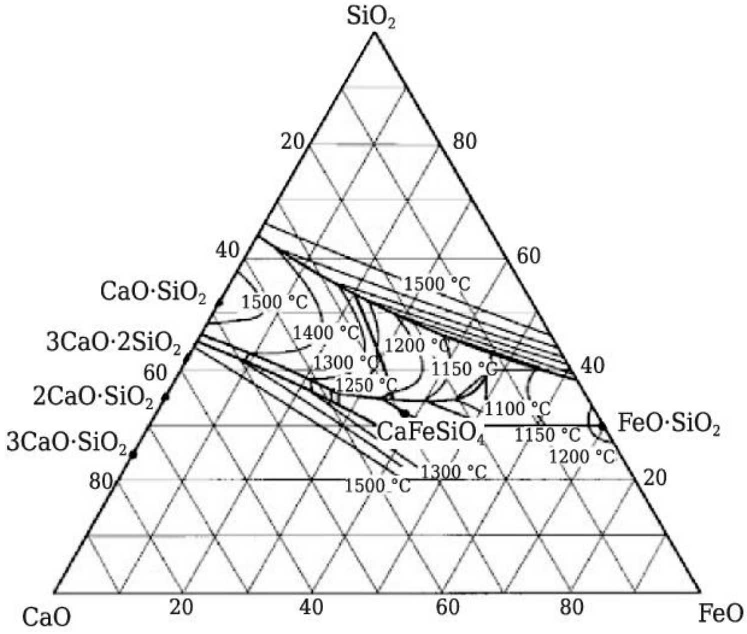

Fig-2 Phase Diagram

2.2 Change in Bosh slag Characteristics

Fluxes are charged in the furnace primarily to react with the ash of coke. But coke disintegrates in front of tuyeres. Hence, charging of basic fluxes merely loads the cohesive zone, increasing the basicity of bosh slag and not reacting before reaching the tuyeres. By injecting the slag, bosh slag volume decreases by fifty percent, considerably contributing to increase in scope for production and permeability of furnace[2].

2.3 Increase the basicity of Tuyere slag to a proper level

The basicity of the Tuyere slag increase form <0.1, a very acid slag with very high viscosity, formed only by the ash of the fuels for a normal operation, to about 0.8 – 1.10 for injection operation. When BOF slag is injected, the Tuyere slag composition is in fact very close to a normal final slag but with a slight low basicity, therefore, the melting properties of the Tuyere slag as well as the raceway conditions will be improved[1].

2.4 Unchanged final slag basicity

The basicity B2 of the final slag, mixture of Tuyere slag and bosh slag, is maintained at 0.9 to 1.0.5, as expected, after the reduction of SiO_2 to Si, mostly occurred at high temperature in front of the Tuyere in the form of disproportion reaction

$$SiO_2 + C = 2SiO + CO \qquad [2].$$

3. Theoretical Estimations

3.1 Phosphorous Calculation

Every 5kg/thm of injection contributes to increase in phosphorous in hot metal by 0.0065%. Increasing the injection in furnace till 15kg/thm will lead to increase in Hot metal phosphorous by 0.026%. The author assumes that no rejects are generated through mills and all the phosphorous goes to hot metal. This is evident from the following calculation: -

$$5Kg/thm \longrightarrow 5*1.3\%\ P \longrightarrow \frac{0.065*100 \text{ (in \% tons)}}{5*1.3\left\{\underline{1000}\right\}\text{(per ton hot metal)}} = 0.0065\% \qquad (1)$$

Table-2 Increase in Phosphorous with increase in injection

LD Injection rate	% Increase in Phosphorous
5 kg/thm	0.0065%
10 kg/thm	0.0130%
15 kg/thm	0.026%

3.2 Lime Calculation

LD slag has fifty percentage of lime in it. Hence injection of 5kg/thm of LD slag results in 2.5kg/thm injection of lime in the furnace. The underlying assumption is that the concentration of lime is fixed. Injection of five kg/thm of slag reduces lime addition in Sinter by 0.2%.

$$5\text{kg/thm} \longrightarrow 5*50\%\ \text{CaO} \longrightarrow 2.5\text{kg/thm.} \qquad (2)$$

Table. 3 decrease in Sinter Cao with increase in injection

LD Injection rate	Increase in CaO of sinter
5 kg/thm	0.2%
10 kg/thm	0.4%
15 kg/thm	0.6%

3.3 Increase in Direct Reduction

LD slag has 18% Iron oxide in it. Injection of LD slag increases the direct reduction of iron oxide, leading to increase in fuel demand based on the energy requirement. Consider the following reaction:

$$FeO + C = Fe + CO \qquad (3)$$

Heat Requirement per kg FeO is 2800 kJ/kg

Therefore, $5\text{kg/thm} \longrightarrow \frac{5*18}{100} \longrightarrow 0.9\text{kg FeO}$ (4)

Therefore, Energy required is 2520kg/thm.

1kg of coal produces 7500kJ/kg .

Therefore, 5kg/thm would require 0.336kg increase in coal requirement.

Table-3 increase in coal rate with increase in injection

LD Injection rate	Increase in coal rate due to FeO
5 kg/thm	0.3 kg/thm
10 kg/thm	0.6kg/thm
15 kg/thm	0.8kg/thm

3.4 Fuel Increase due to False Reading of Injection rate

200 kg/thm shall be read as 200kg/thm of coal. This value will be (195kg/thm Coal + 5kg/thm LD slag). Therefore, to maintain actual 200kg/thm, 5kg/thm increase in fuel rate needs to be done.

3.5 Tuyere Basicity Slag Calculation

Basicity of Tuyere slag shall increase due to injection. Basicity of Tuyere slag increases from 0.006 to 0.27. Therefore, for every 5 kg/thm injection, increase in Tuyere slag basicity by 0.264.

Table. 4 Tuyere Basicity Calculation

Coal	Value
coal rate (kg/thm)	200
Ash (in %)	10
SiO2 (in kg after considering factor)	8.4
CaO	0.056

LD slag	Value
slag rate (kg/thm)	5
CaO/ SiO2	50%/ 15%
SiO2	0.75
CaO	2.5

4. Experiment

Trial was planned to mix LD slag and coal in the coal receiving circuit, grind it in roller mills and then push it through tuyeres by using nitrogen as medium. Since, LD slag is denser than coal, the feasibility study of equipment was done. Accordingly, trial was carried out in three phases.

Table-4 Tuyere Basicity Calculation

	No. of mills	Target Injection (kg/thm)	Actual Injection (kg/thm)
Phase-1	1	5	3.2
Phase-2	2	10	4
Phase-3	3	15	5.2

Since the process of grinding involves reject generation, actual composition of the grinding mixture was calculated by measuring the composition of rejects. Another measuring point was at tuyere platform. Sample of coal-slag mixture was taken for composition testing.

In order to ensure that the mixing is uniform, and grinding is efficient, grinding parameters were consistently measured (table-5). Similarly, in process, different parameters were consistently monitored.(table-6)

Table-5 mill parameters

Mill parameter	Target Range	UOM
Mill Differential Pressure	150-220	mmWC
Bagfilter Differential Pressure	70-100	mmWC
Reject Generation	2	no. of trolley
Mill Outlet Temperature	85-92	degC
Grinding rate	15-18	tph
ID fan Flow	28000	nm3/hr

Table-6 Process parameters

Parameters	UOM	Range	Action Plan
Average Silicon per cast	%	0.5-1.1	Decrease fuel rate, burden adjustment
Average Phosphorous per cast	%	< 0.18	Decrease LD slag addition
Furnace DP	kg/cm2	<1.5	Decrease wind volume
K-value	ratio	<4.3	Increase steam
HMT	deg C	1485-1505	Increase fuel rate if HMT falls below the range
Distributor pressure	bar	3-4.5	Check lance choking. Lances choked >10. Stop the trial.

5. Observations and Results

Injection of BOF slag-coal mixture had several observations: -
a. Despite comparable BWI, feasibility of grinding LD slag-coal mixture in mills is less since LD slag is elastic in nature (as it has complex oxide structure). Crushing it using roller mills was a tedious process.
b. Since LD slag is heavier than coal, mixing even less quantity of coal lead to substantial rejects generation. Approximately 65% of rejection occurred.
c. Maximum effective injection was only 5.2kg/thm. Hence, much change in process could not be observed. However, it was observed that during the trial, Hot metal Silicon reduced from its normal average by 0.02%.

6. Conclusion

Injection of LD slag-coal mixture through tuyeres is tedious process as high density of coal made it deterrent to push the mixture through the coal conveying and grinding circuit, resulting in increase in reject generation. Hence, against the target injection rate of 15kg/thm, only injection of 5.2kg/thm can be achieved.

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