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Effective Utilization of Blast Furnace Flue Dust of Integrated Steel Plants

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ABSTRACT

Investigations were carried out on the effective utilization of blast furnace flue dust samples obtained from the two integrated steel plants at Rourkela and Jamshedpur. The samples essentially contained unburnt coke and iron rich grains as the value added products. Flotation technique was employed to recover the carbon values present in the sample. It was possible to obtain a product containing around 80% carbon with more than 90% recovery from both the flue dust samples using diesel oil and MIBC as the collector and frother respectively. The results obtained by the column flotation technique were quite encouraging due to its obvious advantages over conventional cells. Iron rich grains (magnetite, hematite, wustite & Fe metals) were recovered by low intensity magnetic separation (LIMS) technique. Magnetic separation of flotation tailings gave an iron concentrate of 61-64% Fe with 50-56% over all recovery. Studies were carried out also to remove the alkali content of the flue dust sample by scrubbing and washing, so that the material as a whole could be recycled for sinter making. However, total recovery of potassium was not possible because of its complex nature of association with other elements.

Keywords: Steel plant; Solid waste; Flue dust; Flotation; Magnetic separation

1. INTRODUCTION

Integrated steel plants in general, produce large amounts of solid wastes during iron and steel making process. These solid wastes have many valuable products, which can be reused if recovered economically. Many steel plants throughout the world have already taken up innovative measures for 100% utilization of these wastes with the ultimate objective of improving the operational efficiency and economics of steel industries. This not only reduces the cost of waste disposal and environmental pollution but also gives substantial amount of iron ore flux material as well as fuel rate benefits to the existing process, thereby conserving matching amounts of raw materials (Chaudhary *et al.*, 2001).

Significant quantities of flue dust have always been concomitant part of blast furnace operation. A substantial amount of the dust has been dumped inside the plant premises causing environmental and space problem. Blast furnace flue dust is generally contained of fine solid particles recovered from wet cleaning of the gases emerging from blast furnace operations. Due to its inherent moisture content, it becomes sticky and agglomerated after long exposure to the atmosphere. Chemical analysis of blast furnace flue dust sample indicates that it contains high values of iron and carbon accompanied by harmful elements like Na, K, Zn, and Pb etc. These elements are considered a major concern for sustaining stable operation of a blast furnace. However, this material can be used if both carbon and iron are recovered economically through a cost effective technology. The approach to solve the problem of alkali management should be taken to recycle the material as such in sinter making to a great extent. Efforts are being made to utilize the waste materials by proper characterization, beneficiation and agglomeration

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techniques (Nivedita *et al.*, 1999; Reddy *et al.*, 1996; Roy *et al.*, 1998). As the treatment of blast furnace sludge/dusts is still an unsolved problem in many countries of the world (Fosnacht, 1981; Uno *et al.*, 1979), the present study has two objectives: (i) to recover the carbon and magnetite values by flotation and magnetic separation techniques, which have the utility in domestic fuel mix and as a medium in coal washeries (ii) recycle the whole material as such in sinter making after removal of alkalis. These investigations have been carried out on two samples being generated at Rourkela Steel Plant and Tata Steel Plant. Detailed physical beneficiation supported by characterization studies has evolved a technology to utilize the material in an effective way.

2. EXPERIMENTAL

The blast furnace flue dust samples used in this investigation were obtained from Tata Steel, Jamshedpur and Rourkela Steel Plant, Rourkela, India. Each sample was thoroughly mixed and a representative sample was drawn for detailed investigation. Studies were carried out either on the sample as received or after classifying the sample to a suitable size. Batch flotation studies were carried out in Denver D12 sub-aeration flotation machine and the column flotation studies were carried out by using 100mm diameter flotation column designed and fabricated by the Regional Research Laboratory, Bhubaneswar, India. The sample was conditioned with predetermined amounts of the reagent and frother. All the studies were carried out as per standard procedures. Diesel oil and MIBC were used as the collector and frother respectively. All the products were collected separately and analyzed for iron and carbon. The flotation tailings were subjected to low intensity magnetic separator to remove the magnetite. A low intensity magnetic separator supplied by Sala International, Sweden was used for this purpose. Scrubber fitted to the flotation machine was used for the removal of alkali from the dust samples. In some cases leaching of the sample was also carried out by different leachants.

Size distribution of the blast furnace flue dust sample was carried out by standard wet sieve methods. Mineralogical and chemical compositions of the samples were determined by XRD, optical microscopy and wet chemical analysis respectively. Carbon content was ascertained after weight loss on ignition of the sample at 950°C. Trace elemental analysis was carried out by ICPA- (AES) techniques while charge density of the samples was examined by using a particle charge detector, PCD-03, pH supplied by Mutech, Germany and the technique of electron probe analysis was used to know the complex composition of the element potassium present in the flue dust samples.

3. RESULTS AND DISCUSSION

3.1 Characterization studies of flue dust samples

Chemical analysis of the blast furnace flue dust samples obtained from the Rourkela and Tata Steel Plant is shown in Table 1. Both the samples contain more than 30% of carbon and iron showing very abnormal accumulation of these two elements. Samples obtained from Rourkela Steel Plant contain higher amount of alkalis compared to those of Tata Steel. This may be due to difference in quality of the raw materials used by the plants. Both these samples, however, do not contain appreciable amounts of Pb & Zn as reported in other parts of the world. The harmful component in many plants abroad generally comes from the recycled scrap. The volatility of zinc at moderate temperatures and its condensation in the cooler region of the blast furnace poses severe problems.Rare earth elemental analysis of the samples is shown in Table 2. The associated rare earth elements in flue dust are La, Ce, Nd, Pr, Y, Er, Dy etc. Concentration of La and Ce was higher in comparison to other elements. Measurement of charge density values of the flue dust sample at different pH are shown in Figure 1.

The results indicate that Rourkela sample acquire zero charge at pH 6.0 and Tata Steel sample at pH~3.5. In view of this, flotation studies with non-ionic reagents should be carried out at slightly acidic pH values for achieving better separation of carbon values.

Table 1
Chemical analysis of the blast furnace flue dust

Constituents, %	Rourkela Steel	Tata Steel
Carbon	28.90	33.62
Fe_2O_3	51.10	50.93
SiO_2	6.30	8.3
Al_2O_3	5.12	2.54
CaO	4.90	1.96
MgO	0.88	1.55
Pb	0.024	0.019
Zn	0.042	0.028
MnO	0.58	0.20
K_2O	1.22	0.024
Na_2O	0.47	0.078

Table 2
Rare earth elemental analysis of blast furnace flue dust samples

Constituents ppm	Rourkela Steel	Tata Steel	Constituents ppm	Rourkela Steel	Tata Steel
La	15.25	9.01	Y	0.60	1.05
Lu	0.07	0.10	Er	ND*	ND*
Tb	0.10	0.17	Dy	ND*	0.62
Ho	ND*	ND*	Gd	0.28	ND*
Tm	0.30	ND*	Eu	ND*	0.17
Yb	3.46	3.0	Nd	1.55	3.07
Ce	24.39	18.88	Pr	4.43	ND*
Sm	0.60	1.05			

* not detected

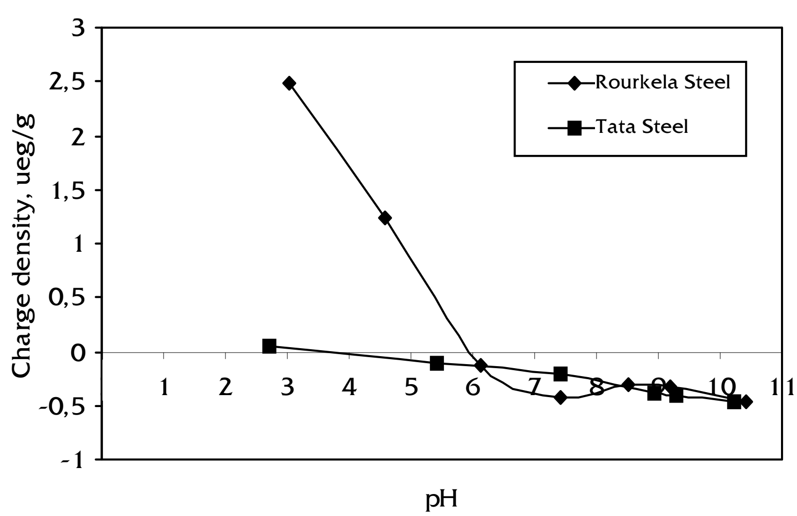

Figure 1. Charge density of blast furnace flue dust of Rourkela and Tata Steel at different pH

XRD result on the sample is shown in Figure 2 and 3. Blast furnace dusts generated at Rourkela Steel plant comprises prills of Fe metal, gehlenite ($Ca_2Al_2SiO_7$), hematite, magnetite and wustite in order of abundance, while the dusts of Tata Steel constitute only limited phases like quartz, hematite and magnetite. Unburnt coke fragments mostly in coarse size ranges are common in both these dusts. Mineralogical variation between these two dusts reveals distinct difference in flux material composition in corresponding blast furnaces. Further, the presence of wustite and iron metals at Rourkela Steel plant attests to the dust generation till metallisation.

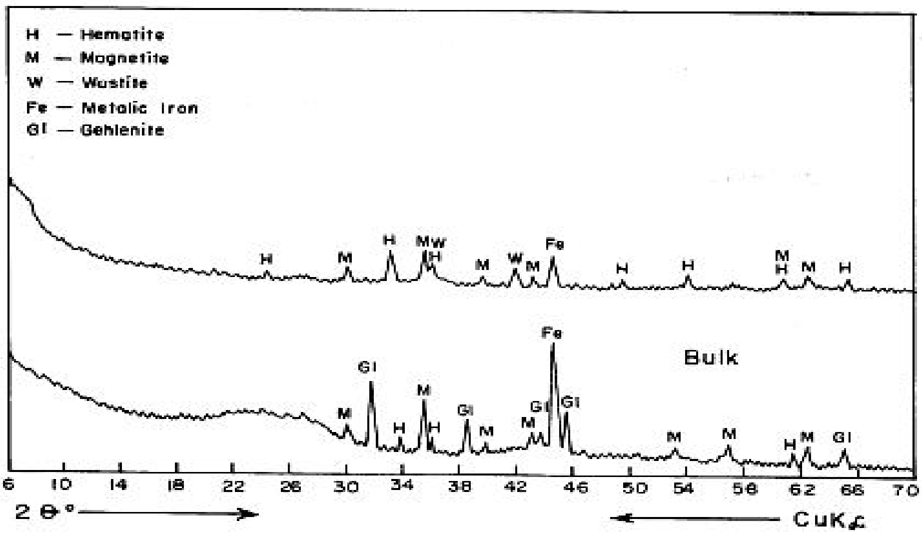

Figure 2. X-ray diffraction pattern of blast furnace dust sample (Rourkela Steel)

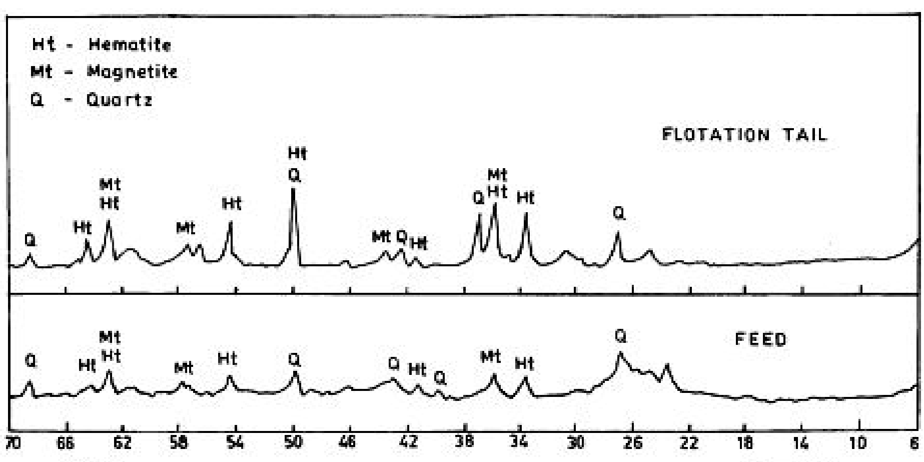

Figure 3. X- ray diffraction pattern of blast furnace dust sample (Tata Steel)

3.2. Recovery of carbon and magnetite from the flue dust

Both cell and column flotation techniques were employed to recover the carbon values present in the flue dust samples. Different variables studied in the cell were pH, reagent concentration, dispersant, grinding time etc. Natural pH of the slurry sample was found to be highly alkaline, i.e. pH 9.0, which is mainly attributed in both the cases due to the presence of alkali and alkaline earth metals in the sample. Flotation studies indicated that it was possible to obtain a carbon grade of 75-80% with more than 90% recovery at natural pH by adding around 400g/t of diesel oil. As coke particles are hydrophobic in nature, it was possible to recover the same at all pH values. A small dosage of MIBC was used as the frother. The carbon grade was further improved by the flotation techniques after grinding the material to different intervals of time. At 10 minutes of grinding time 80% carbon with more than 85% recovery was obtained in both the cases. The quality of carbon concentrate obtained by cell after two stages cleaning is shown in Table 3. Flotation rate recovery for both the samples were evaluated and plotted in Figure 4. It can be seen that initial kinetic of Tata Steel sample is very fast compared to the Rourkela Steel sample. In both the cases the flotation completes within three minutes of time. Recovery by flotation is slightly more in the case of Tata Steel.

Table 3
Quality of carbon concentrate obtained from blast furnace flue dust by flotation techniques

Constituents, %	Rourkela Steel	Tata Steel
Carbon	81.9	80.85
Fe_2O_3	4.52	4.29
SiO_2	8.52	12.73
Al_2O_3	2.12	1.29
MgO	0.12	0.028
CaO	0.07	0.02
Na_2O	0.10	0.04
K_2O	0.56	0.10

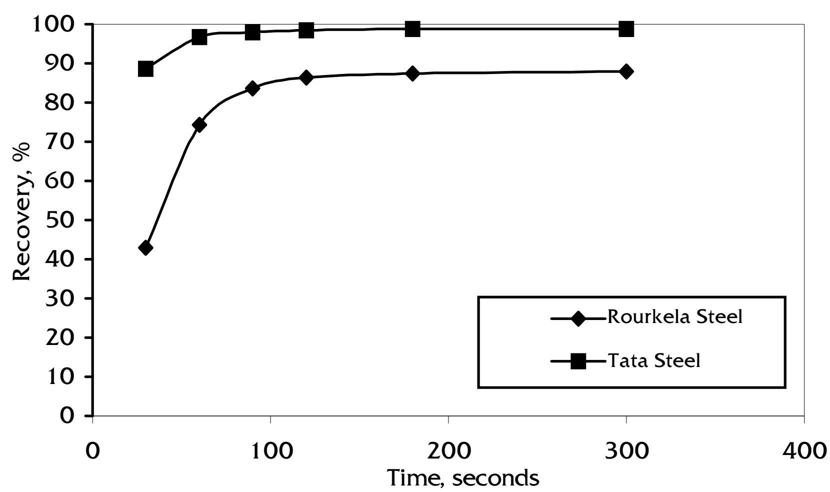

Figure 4. Flotation Recovery vrs. time plot for the Roukela Steel plant and Tata Steel flue dust samples (cell flotation)

The results of the column flotation studies are shown in Table 4. It can be seen that a carbon grade of >80% with more than 85% recovery could be obtained. The earlier optimized conditions used for cell studies were employed in column flotation studies. The airflow rate was varied from 3 to 7 liter/min. The results revealed that a good grade concentrate could be obtained by adopting the flotation techniques.

Table 4
Recovery of carbon values by column flotation technique

Sl. NO.	Air rate	Rourkela Steel		Tata Steel	
	liter/min	Carbon, %	Carbon Rec., %	Carbon, %	Carbon Rec., %
1	3.5	85.2	34.3	-	-
2	4.5	84.9	60.3	-	-
3	5.0	82.9	72.3	80.0	97.2
4	6.0	81.3	84.0	80.2	98.9
5	6.5	79.0	95.3	80.7	99.0
6	7.0	76.4	94.2	79.6	91.2
7	7.5	75.0	95.0	78.2	89.2

In order to recover the magnetite values, flotation tailings after carbon recovery were subjected to low intensity magnetic separation studies. Results of these studies are presented in Table 5. It can be seen that an iron grade of 60.9-65.1% with overall recoveries of 48 to 55% was obtained. The grade of magnetite as well as the specific gravity, which is an important factor for the quality of magnetite, was found to be better in the case of Tata Steel sample.

Table 5
Quality of magnetite recovered from flotation tailings

Constituents, %	Rourkela Steel	Tata Steel
Fe (T)	60.9	65.1
Fe_2O_3	87.1	93.1
SiO_2	2.73	1.81
Al_2O_3	3.82	1.80
MnO	0.36	-
Na_2O	0.065	0.015
K_2O	0.057	0.0475
LOI	2.7	-
CaO	0.91	0.94
Sp.gr	3.73	4.03

3.3. Removal of alkalis from flue dust

Utility of blast furnace flue dust as the raw material for sintering plant has so far been curtailed mainly due to the presence of Na and K oxides, which have a negative effect on the effective functioning of the blast furnace. Alkaline elements accumulate in the blast furnace owing to a mechanism of cyclical reactions. These alkalis hinder the normal operations, loss of permeability of the burden while attacking the refractory bricks of the furnace to cause cracking and chipping (Formose *et al.*, 1997). Further these alkalis swell the agglomeration iron ore fines and catalyze the gasification of coke. These phenomena increases also the coke rate of 15kg/thm for every kg/thm extra alkali in the raw material burdens (Alam and Debray, 1985).

Several attempts such as use of dunite as fluxing material, increasing the slag volume, increasing the slag acidity on addition of $CaCl_2$ in the raw mix have been studied to remove the alkalis in the blast furnace operations (Aydim and Dikec, 1990). In the present study techniques such as scrubbing, washing, leaching with $CaCl_2$, NH_4Cl etc. have been investigated to remove the alkali content from the flue dust. Some of the important findings after simple scrubbing and washing followed by classification at 45μm are shown in Table 6. It was possible to remove ~75% of Na values from the sample as received. This has been improved up to 95% by reducing the dust size to around 150μm. However satisfactory removal of the potassium could not be achieved on the sample as received and the removal varied from 22-32% only at different conditions. The removal of potassium has gone to 60% by reducing the particle size to -150μm size. Sodium and potassium normally exist in the raw materials in the form of alumino silicates. These are stable compounds and no chemical reaction takes place until very reducing conditions are reached. Such condition prevails in the high temperature zone of blast furnaces near the tuyeres zone. Potassium is eliminated from the furnace in the form of non-decomposed silicates. Electron probe analysis of the flue dust samples given in Table 7 also shows high accumulation of K in the flue dust sample. Most of the countries in the World have therefore started using dunite as the fluxing material to remove the alkali elements (Formose *et al.*, 1997). Dunite maintains its physical structure and absorption capacity over a wide temperature range permitting its use in blast furnaces.

Table 6
Removal of alkalis from blast furnace flue dust by scrubbing (Rourkela Steel plant)

Solid-liquid ratio	Scrubbing time min	Particle size of the sample, μm	Na removed %	K removed %
1:1	30	as received	75.1	21.6
1:1.5	30	as received	72.0	34.9
1:2	30	as received	70.9	29.3
1:1	60	as received	76.3	22.0
1:1	240	as received	80.3	32.1
1:1	30	-300	84.4	60.0
1:1.5	30	-300	85.0	57.5
1:1	30	-150	95.0	60.2
1:1.5	30	-150	95.1	60.1

Table 7
Electron probe analysis of few flue dust grains

Constituents %	Grains Number		
	1	2	3
SiO_2	31.32	51.93	28.87
Al_2O_3	3.81	13.81	19.28
FeO	3.30	2.95	1.38
MgO	14.50	9.67	25.0
MnO	6.67	1.37	-
CaO	22.19	7.60	4.63
K_2O	4.08	14.16	9.85
Na_2O	-	0.127	0.163
TiO_2	2.67	0.02	0.01

4. CONCLUSIONS

Solid waste material generated at steel plants should be well characterized with respect to undesirable as well as valuable components. The extent of recovery of values or recycling within the steel plants can be enhanced by beneficiating the wastes.

Studies carried out on blast furnace flue dust generated at steel plants have indicated that most of the carbon values can be recovered by cell or column flotation. Magnetic portion of the sample can be separated by low intensity magnetic separator techniques.

Harmful components such as alkalis present in the flue dust sample should be removed for its effective utilization in sinter making. It is found possible to remove ~85% Na and 60% K values by simple scrubbing, washing and classifying the products at a finer range

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