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Technical Note

Recovery and utilization of iron and carbon values from blast furnace flue dust

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ABSTRACT

Waste recycling in integrated iron and steel plant is important with regard to environmental and economic consideration. However, recycling of the waste needs to be supported by metallurgical studies to reap the maximum economic benefit. In this article, a typical flue dust sample obtained from Egyptian iron and steel company was characterized and the amenability of recovering iron and carbon values from it, was investigated. Flotation was used to recover carbon values while magnetic separation was employed for iron values recovery. It was possible to recover about 99% of carbon values with 87.18%. Besides, high intensity magnetic separation was adopted to recover clean magnetic fraction with 79% recovery and assayed 52.40% Fe.

Keywords: Flue dust; Magnetic separation; Froth flotation

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. This gives substantial amount of iron ore flux material as well as fuel rate benefits to the existing process, thereby conserving matching amounts of raw material, (Rubinstein and Hall 1996; Roy *et al.*, 1998, Wu-L, 1999, 2000).

Egyptian iron and steel company generates a lot of the blast furnace flue dust, (20,000-30,000t/y). Most of it is directed to the cement industry and the rest is recycled in the sintering unit. A typical analysis of the blast furnace dust shows that it contains 33.30% carbon and 27.20% Fe.

This paper deals with the characterization and recovery of iron and carbon values from blast furnace flue dust being generated from iron and steel company. Flotation technique was adopted to recover carbon values while low and high intensity magnetic separations were employed for iron recovery. These techniques were carried out based on earlier experience. However, the objective is to produce a feedstock that can supplement and compete with the virgin materials presently available on the market.

2. EXPERIMENTAL

The blast furnace flue dust sample was kindly supplied by Egyptian Iron and Steel Company. Sampling of the thoroughly mixed dust was conducted by a “Denver” Jones riffler to about 250g batches. 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. Kerosene was used as a carbon collector. The flotation tailings were subjected to wet low intensity magnetic separator “Boxmag Rapid” to separate the iron values. The “Dings” cross belt separator was used as a pick up separator with an auxiliary permanent magnet, for the separation of ferro-magnetic material, ahead of the electromagnet. Petrographic, XRD and chemical analysis were used for the characterization of the flue dust sample. Heavy metal ions removal experiments was carried out in 100ml round flask. A known weight (2.0g) of solid was added to a solution containing a fixed concentration of metal ion at natural pH (≈7). The flask was shaken in a rotary shaker at 200rpm till equilibrium was attained. The slurry was centrifuged at 12000rpm for 15 minutes.

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The clear supernatant was analyzed for metal concentration using Atomic Absorption (Perkin Elmer Analyst 200). The amount of metal, taken up by solid, was calculated as the difference between the initial and final concentrations of the metal in the aquous solution.

3. RESULTS AND DISCUSSION

3.1. Sample characterization

The size analysis of the original flue dust sample was carried out down to 63 microns. The results are shown in table (1).About 74% of the sample is below 210 microns indicating the fine nature of the material. The chemical analysis of different size fractions are given in Table 1. It reveals that the carbon values are found in the coarser sizes (plus 210 microns), and the iron values are found in the finer sizes (minus 210 microns).

3.2. Mineralogical characteristics

Microscopic examination of the flue dust sample indicates that the coke particles form its most dominating constituents and therefore the overall colour of the sample appears black. Its x-ray diffraction analysis reveals that the other associated phases to be magnetite (2.53Å) hematite (2.69Å), qauartz (3.33Å) and wüstite (1.51Å). The Microscopic study shows a wide variation in its constituents grain size and morphology. The coke particles are generally larger in size though some fine particles are also present. These are mostly irregular in shape. Magnetite and other iron particles (ferrites) mostly occur either free or sintered as iron aluminum silicates. In addition, subordinate amount of aluminium silicate and potassium aluminium silicate were detected through X-ray image mapping.

3.3. Flue dust beneficiation

3.3.1. Application of froth flotation

Mineral processing and industrial waste treatment constitute the bulk of commercial applications of flotation technology. However, flue dust beneficiation has been an area of increasing interest in recent years. Dos *et al.* (2002) found that carbon could be separated from flue dust by conventional flotation.

Table 2, shows that the unburned carbon is separated from the classified flue dust (-0.600+0.074mm) slurry by adding an effective amount of kerosene (3kg/t). The pH of the slurry was between 7.5-8, at retention time 20min and impeller speed 2000rpm. The kerosene coats the unburned carbon grains forming a hydrophobic film. Controlled air is introduced into the system for frothing the pulp mixture. The hydrophobic unburned carbon froths to the surface and is removed by skimming off the frothing layer. The flotation retention time was relatively long (20min). A float product containing around 87.18% carbon with about 99% recovery was obtained, Table 2.The sink product was directed to low wet intensity magnetic separation using Boxmag Rapid at 15% solid, 0.25kg/t sodium hexametaphosphate, as a dispersing agent and 60rpm Drum speed. The results are tabulated in Table 3. By applying the two techniques (Table 4), we got two valuable products; high carbon product with 87.18% L.O.I. and iron product with 49% Fe. However, it is observed that some iron values were lost in the non magnetic fraction (~17% Fe). These loses are due to the presence of other iron phases of low magnetic properties. On the other hand, flotation technique has some drawbacks, such as:

- It is a wet process that would ultimately requires dewatering and drying.
- High maintenance.
- Long retention time was frequently required for effective carbon removal.

However, dry high intensity magnetic separation technique was employed as shown in the following section.

3.3.2. Dry high intensity magnetic separation

Dry high intensity magnetic separation:

High intensity magnetic separation tests were carried out on the deslimed dust sample (-0.6mm+0.074mm) to recover the iron values. The “Dings” Cross belt magnetic separator was used in this study. Since most of the iron particles were in the reduced state, the iron values were captured by the permanent magnet part of the Dings separator. The results of this study are presented in Table 5. It indicates that good grade of iron product assaying 49.5% Fe with 75.22% recovery can be obtained from the flue dust. It was also possible to get a carbon product, with 85.42% loss on ignition and 96.61% recovery, in the non magnetic fraction.

In a trial to get a better magnetic separation results, the bulk size (-0.6 +0.074mm) was fractionated into three size cuts: -0.60mm+0.21mm, –0.21mm+0.074mm and –0.074mm. The results are presented in tables (6, 7 and 8). It is obvious from these results that a magnetic product 48.75% Fe with 74.88% recovery and a non magnetic product assaying 91.31% carbon with 41.09 % recovery were obtained from the size fraction –0.6+0.21mm. On the other hand, a better iron value product assaying 49.40% Fe with 59.27% recovery is obtained with the size fraction –0.21 +0.074mm. Also, a carbon grade of 94.08% with 61.72% recovery is obtained in the non-magnetic fraction. This improvement in separation was due to the increased mineral liberation of this size. Besides, using a finer feed i.e. –0.074mm, where the iron value is accumulated in this fraction, a magnetic product with 78.99% recovery and assaying 52.40% Fe, was obtained. This confirms the shielding effect of coarse particles and necessitates using very closed size feeds with kind of separators. However, it is suggested to grind the bulk sample to minus 0.074mm.

Table 1
Size and chemical analysis

Size, mm	Cum.	Fe		I.R.		L.O.I.	
	Pass.%	Assay %	Dist. %	Assay %	Dist. %	Assay %	Dist. %
+0.600	100	7.93	0.14	9.79	0.65	68.39	0.90
-0.600 + 0.500	99.52	8.90	0.14	9.59	0.57	65.52	0.84
- 0.500 + 0.400	99.08	10.86	0.35	9.59	1.22	60.41	1.64
-0.400 + 0.250	98.17	16.22	7.53	9.41	16.89	50.51	20.01
-0.250 + 0.210	84.90	20.93	7.19	8.86	11.76	40.39	11.86
- 0.210 + 0.130	75.08	28.45	36.64	7.85	39.05	35.48	38.99
- 0.130+ 0.110	38.29	34.82	13.80	6.91	10.54	32.69	11.05
- 0.110 + 0.090	26.97	35.28	6.85	6.03	4.46	21.14	3.50
- 0.090 + 0.075	21.42	35.89	5.87	5.91	3.65	20.72	2.90
-0.075+ +.0.063	16.76	36.14	5.59	5.18	3.11	18.89	2.48
- 0.063	12.36	36.89	15.93	4.85	8.11	15.55	5.71
Total	100.00	28.53	100.00	7.39	100.00	33.47	100.00

I.R. = Insoluble Residue L.O.I = Loss On Ignition Dist. = Distribution

Table 2
Flotation separation of the flue dust sample

Product	Wt.%	Fe		I.R.		L.O.I.	
		Assay %	Dist. %	Assay %	Dist. %	Assay %	Dist %
Float	41.59	3.32	5.13	4.32	22.77	87.18	99.17
Sink	58.41	43.720	94.87	10.43	77.23	0.51	0.82
Total	100.00	26.92	100	7.89	100	36.56	100

Table 3
Low wet intensity magnetic separation of sink fraction

Product	Wt.%	Fe		I.R.		L.O.I.	
		Assay %	Dist. %	Assay %	Dist. %	Assay %	Dist %
M	48.60	49.02	54.49	7.99	37.23	0.00	0.00
NM	9.81	17.45	3.92	23.26	21.88	3.04	58.48
Total	58.41	43.72	58.41	10.43	58.11	0.51	58.48

M= Magnetic fraction NM = Non magnetic fraction

Table 4
Flotation and wet low intensity magnetic separation of the flue dust sample

Product	Wt.%	Fe		I.R.		L.O.I.	
		Assay %	Dist. %	Assay %	Dist. %	Assay %	Dist. %
Float	41.59	3.32	5.13	4.32	22.57	87.18	99.17
M	48.60	49.02	88.51	7.99	48.77	0.00	0.00
NM	9.81	17.45	6.36	23.26	28.66	3.04	0.83
Total	100.00	26.92	100	7.96	100	36.56	100

Table 5
High intensity magnetic separation of the flue dust sample for the size (-0.6+0.074mm)

Product	Wt.%		Fe		I.R.		L.O.I.	
	Exp.	Actual	Assay %	Dist. %	Assay %	Dist. %	Assay %	Dist %
Magnetic Concentrate	40.91	34.06	49.50	75.22	6.14	31.84	0.00	0.00
Middling	17.74	14.77	35.66	23.50	13.04	29.32	7.00	3.39
Non Magnetic	41.35	34.43	0.83	1.28	7.41	38.84	85.42	96.61
Total	100.00	83.26	26.92	100.00	7.83	100.00	36.56	100.00

Conditions: Field intensity of 10,000 Gauss, Feeding rate of 10.5 kg/h, belt speed of 4m/min and the minimum air gap.

Table 6
High intensity magnetic separation of the flue dust sample for the size (-0.6+0.21mm)

Product	% Wt.		Fe		I.R.		L.O.I.	
	Exp.	Actual	Assay %	Dist. %	Assay %	Dist. %	Assay %	Dist %
Magnetic Concentrate	26.68	6.65	48.75	74.88	7.54	21.82	0.00	0.00
Middling	51.91	12.95	8.09	24.14	10.75	60.54	53.89	58.91
Non Magnetic	21.37	5.33	0.81	0.98	7.61	17.04	91.31	41.09
Total	99.96	24.93	17.38	100.00	9.22	100.00	47.49	100.00

Conditions: Field intensity of 10,000 Gauss, Feeding rate of 10.5 kg/h, belt speed of 4m/min and the minimum air gap.

Table 7
High intensity magnetic separation of flue dust sample for the size (-0.21+0.074mm)

Product	% Wt.	Fe		I.R.		L.O.I.	
		Assay %	Dist. %	Assay %	Dist. %	Assay %	Dist %
Magnetic Concentrate	37.12	49.40	59.27	5.38	27.29	00.00	00.00
Middling	41.64	29.48	39.61	8.37	47.59	29.77	38.28
Non Magnetic	21.24	1.64	1.12	8.67	25.16	94.08	61.72
Total	100.00	30.94	100.00	7.37	100.00	32.38	100.00

Conditions: Field intensity of 10,000 Gauss, Feeding rate of 10.5 kg/h, belt speed of 4m/min. and the minimum air gap.

Table 8
High intensity magnetic separation of the flue dust sample for the size (-0.074mm)

Product	% Wt.	Fe		I.R.		L.O.I.	
		Assay %	Dist. %	Assay %	Dist. %	Assay %	Dist. %
Magnetic Concentrate	53.30	52.40	78.99	3.15	31.39	0.00	0.00
Middling	29.40	25.87	20.73	7.75	48.58	6.90	12.55
Non Magnetic	15.30	0.64	0.28	6.14	20.03	94.08	87.45
Total	100.00	36.68	100.00	4.68	100.00	16.36	100.00

Conditions: Field intensity of 10,000 Gauss, Feeding rate of 10.5 kg/h, belt speed of 4m/min. and the minimum air gap.

3.4. Suggested Flowsheet Design

Based on the results obtained from laboratory investigations, a simple flowsheet design was developed to process the flue dust sample. The design includes; classification and magnetic separation. The final step involves collecting the remaining fractions of flue dust. The products are then prepared for shipment to their respective markets.

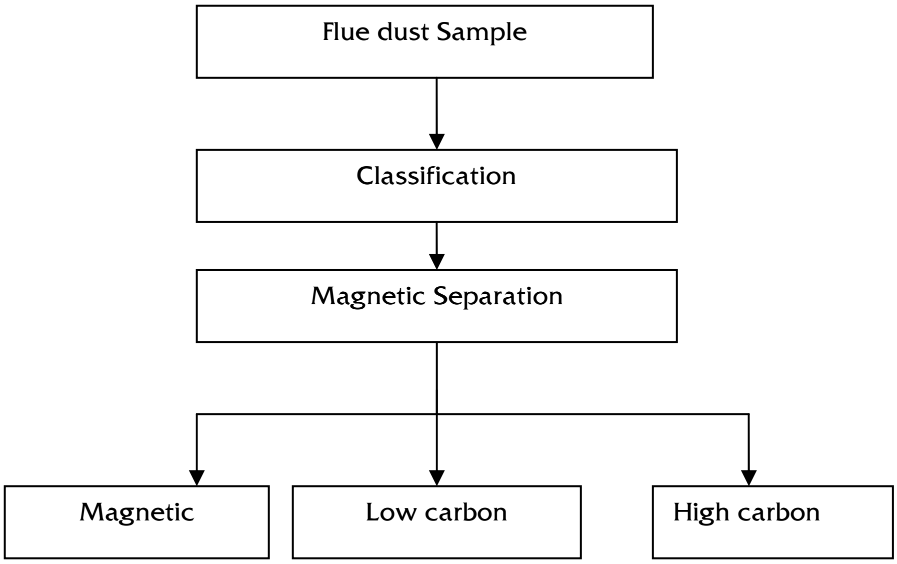

Figure 1. Flowsheet of beneficiation of flow dust

The above flowsheet recovers three principle products from the feed material; iron concentrate, low carbon, and high carbon, figure 1.

3.5. Maximum utilization of Blast Furnace Flue dust

3.5.1. Magnetic product

The usage of magnetically separated product, from flue dust, in sinter making has not been found to affect the sinter quality or productivity (Rubinstein and Hall, 1996). It is expected that metallic iron, present in the magnetic product, would reduce the fuel consumption i.e. coke breeze in sinter making unit. It was reported that Inland steel (Roy *et al.*, 1998) experienced a reduction in fuel rate with the usage of similar kind of magnetic separated out of wastes. It was found that the addition of 21% magnetic and 22% mill scale to the sinter burden of Inland steel has resulted in the lowering of externally added carbon rate from 55kg/t of sinter to 11kg/t of sinter.

3.5.2. High carbon product

The unburned carbon is a valuable product which can be returned to the sinter unit, or used in other sectors: as a sorbent, or for the production of carbon black. Preliminary experiments, on using the high carbon product for heavy metal removal from solution, were successful and allow the elimination of more than 87% of these metal ions. The results of synthetic solutions treatment are presented in table(9). It is shown that the metal removal reached 98.83% for Cu^{2+}, 99.56% for Pb^{2+} and 87% for Co^{2+}. Besides, a waste water sample, obtained from the Egyptian metal coating company, was also treated using the high carbon product, table(10), at the aforementioned conditions. It can be seen that the removal of Cu^{2+} and Zn^{2+} ions reached ~ 98% where the removal of Pb^{2+} ions was 80%. The results, obtained above, clearly demonstrate the potential of using the high carbon product for the removal of heavy metal ions from polluted industrial waste effluent.

Table 9
Removal of heavy metals from synthetic solution using high carbon product

Ions	Equilibrium Concentration, ppm	% removal
Pb^{2+}	0.09	99.56
Co^{2+}	0.762	87.00
Cu^{2+}	0.068	98.83

Conditions: Initial concentration =10^{-4} molar, equilibrium conditioning time=10 minutes, pH=7 and solid/liquid ratio =2%

Table 10
Treatment of Industrial Wastewater Using High Carbon Product

Ions	Initial Concentration	After Treatment	
		Equilibrium Concentration, ppm	% Removal
Cu^{2+}	10.00 g/l	149.00	98.51
Pb^{2+}	3.91ppm	0.77	80.30
Zn^{2+}	426.5ppm	7.98	98.13

3.5.3. Low carbon product

The mineral components of flue dust waste represent valuable raw materials for different industries, and the construction materials industry in particular. Attempts to use the flue dust directly in the production of building materials have failed in many cases. The reason for these failures was due to the presence of unburned carbon in the flue dust. However, the low carbon fraction can be used as an additive to cement in the production of aggregate ceramics, bricks, decorative tiles and other construction materials. Besides, this product can be used as an inert filler for plastic (Weinecke and Faulkner, 2002).

4. CONCLUSIONS

Solid wastes materials generated at Iron and Steel plant, should be well characterized with respect to valuable component. The extent of recovery of values or recycling within the iron and steel plants can be enhanced by beneficiating the wastes. Blast furnace flue dust sample was benefited using flotation, to separate the unburned carbon values and magnetic separation to separate the iron values. It was recommended to use dry high intensity magnetic separation for the beneficiation of the sample. However, from a material containing 28.53% Fe and 33.47% L.O.I., three products were obtained include; magnetic, high carbon and low carbon product. These products can be utilized as follow:

- magnetic product having 52.4% Fe, can be recycle to the sintering machine;
- high carbon product is suitable for reburning, waste water treatment or production of carbon block;
- low carbon product can be used as an additive to cement, bricks or as an inert filler for plastic.

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