

THE POTENTIAL USAGE OF STEELMAKING BY-PRODUCTS: ELECTRIC ARC FURNACE DUST

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Abstract. During the steel manufacturing processes, by-products such as electric arc furnace (EAF) dust, rich in metallic oxides, are generated. In Malaysia, EAF dust is presently dumped or landfilled. However, as we forge ahead to achieve Malaysia's Vision 2020 to be a fully industrialised nation, we should not lose sight of the various regulations to protect the environment.

EAF dust, presently listed as N201 and classified as scheduled waste under the Environmental Quality (Scheduled Wastes) Regulations, 1989, contains heavy metals such as zinc, lead, cadmium and chromium. Heavy metals are harmful substances which are prohibited from being dumped directly. They are also valuable mineral resources. The high percentage of zinc in EAF dust suggests the potentiality to extract this valuable metal.

In view of the difficulty in obtaining licence and land for dumping or landfill, and the tremendous increase in cost for present method of disposing EAF dust, a series of tests had been done to identify the potential usage of this by-product. This paper aims to direct iron and steel industry in Malaysia on the right path to the conversion of non-usable EAF dust into the recovery of valuable metals such as zinc, lead, iron, chromium, cadmium or nickel.

1 INTRODUCTION

This was a preliminary study to identify the potential usage of steelmaking by-product, EAF dust, from the iron and steel industry in Malaysia. In this study, a series of tests and analysis on the physical and chemical characteristics, chemical compositions, leachate, feasibility study and economical aspects were carried out. In view of the growing concern and stricter legislations on environmental issues, this study developed rational guidelines, solutions and proper methods to utilise, handle or dispose EAF dust.

With the five major steel producers and less than half a dozen of minor steel manufacturers in Malaysia, these steel mills generated about 77,000 tonnes of EAF dust in the year 1995. An annual growth of about 10% is expected due to the strong demand for steel products, since the generation of this by-product is directly proportional to the production of steel. With the industry going ahead for an increase in steel production to cater for the rolling of flat products in Malaysia, the generation of this by-product will undoubtedly increase sharply. Therefore, EAF dust which represents money worth millions of dollar has been thrown away every year [1].

2 WHAT IS EAF DUST?

The majority of particulate emissions EAF are generated during the melting and oxygen-blowing cycles. During charging and tapping, lesser amounts are generated by-products generated during the operation of electric arc furnace, especially dust rich in metallic oxides, are of growing worldwide interest and concern.

The main tonnage of EAF dust is collected from the direct extraction systems attached to each furnace. The product is either wet sludge, 25% to 40% moisture, or more usually a dry dust. Indirect extraction systems are installed in many plants to collect the fume that escapes within the melting shop. The rate of dry dust arising varies between 10 – 15 kg/t from direct extraction plus 3 kg/t from indirect extraction, totalling 13 to 18 kg/t of liquid steel. This means there is an average value 1.5% of dust generated as a percentage of crude steel tonnage or about 7.7% of EAF by-products is EAF dust.

The chemical compositions of dust vary considerably from plant to plant and mainly depend on variables such as the type and quality of scrap used, charging methods, oxygen-blowing rates, furnace-operating practices, and the type of steel produced.

EAF dust contains the heavy metals such as zinc (Zn), lead (Pb), chromium (Cr) and cadmium (Cd). Heavy metals are harmful substances which are prohibited from being dumped directly. They are also valuable mineral resources. As these heavy metals have very low solubility in melted scrap and high vapour pressure (boiling point for Zn : 907°C, Pb : 1074°C, Cd : 765°C), the heavy metals are evaporated and reoxidised to be exhausted as dust while the scrap is melted in the electric furnace. Lead's solubility is a bit higher and its boiling point is higher than the temperature of melted scrap, so a part of Pb contents settles at the bottom of the furnace (Baik, 1993). EAF dust particle sizes range from less than 1 µm to more than 300 µm. The majority of particles are 1 to 6 µm in diameter, but particles of 20 to 50 µm are not uncommon. (Hagni, Hagni and Demars, 1991).

2.1 Factors Influencing Developments in EAF Dust Management

Contamination of both surface and underground water sources is becoming a major concern to us. In the USA and Canada, three metals prominently present in baghouse dust have been established as being environmentally toxic constituents. They are lead, cadmium and chromium [6].

Due to environment concerns, disposal of EAF baghouse dust will be increasingly regulated and the costs of such disposal will significantly increase. In the USA, the cost of disposal of EAF dust is between US\$160 to US\$360 per tonne, depending on the plant location and method used. In view of these circumstances, the drive to minimise dust generation in the steelmaking process is great and justified. With increases in the price of zinc and lead, the recovery of metals from EAF dust has become economically favourable [11].

In the year 1990, about 30% of the world dust is processed to extract the heavy metals. Hence, approximately 160 000 tonnes of zinc per annum (8% of world zinc production) is recovered from EAF dusts. Assuming that all EAF dusts were processed, the current potential is estimated to be 500 000 tonnes of zinc per annum, or 25% of the world's production. By the year 2000, this could be increased to 700 000 tonnes of zinc per year due to the additional galvanised steel in motor cars and domestic appliances.

The cost of treatment for EAF dust to the steelmaker is in excess of US\$200 per tonne of dust [6]. Therefore, for a steelmaker producing one (1) million tonnes of steel, this represents an annual cost of approximately US\$3 million. This has triggered considerable research and development work to develop more effective technologies such as stabilisation, concentration and hydrometallurgical.

3 POTENTIAL USAGE OF EAF DUST

EAF dust is used mainly in the recovery of valuable metals such as zinc, lead, iron, chromium, cadmium or nickel. The Glassification process in the USA uses EAF dust to produce a wide variety of end products such as coloured glasses, glass ceramics that resemble natural rocks used for

architectural purposes and decorative articles, roofing granules, abrasive grit, brick and tile colourants, and filler. The Ezinex process (Italy) is an environmentally closed loop system which can be used to produce zinc slabs, lead cement, alkali chloride salts and iron oxide residue [9].

4 TREATMENT TECHNIQUES FOR EAF DUST

Recycling and recovery will play an important role. When the concentration of zinc in the dust reaches 24% or above, it is present at the same level as that found in natural zinc ores. Therefore, EAF baghouse dust could have a very significant market value because they can be utilised as valuable metals resources, or used as landfill or road construction material after stabilisation process.

For the treatment of EAF dust, pyrometallurgical processes have not gained wide acceptance due to high capital and operating costs. Among the hydrometallurgical processes, caustic soda leaching appears to be the most promising because it dissolves practically no iron.

IMS-Tetronics plasma is simple to operate, capable of handling a wide range of dust of particle size and chemical compositions. The power input to the furnace is controllable and is independent of furnace atmosphere and slag chemistry. It is suitable for an individual EAF dust generator, unlike Waelz kiln that operates on a regional basis. It is known that the Waelz process is the most popular recovery method, use for about 76% of all EAF dust treated [3].

Classification process (Oregon Steel Mills, USA) needs simple operation, low capital investment with return on investment possible in under two years and minimised manpower requirements through automation [4].

The Ezinex process from Italy is a new hydrometallurgical method which has the potential to grow. The payback period is two and a half years, with an investment cost of US\$7 000.00 [7].

Thus it is clear that stabilisation including chemical fixation and vitrification is to allow delisting and disposal or other usage, recycling is to minimise volume and maximise zinc concentration, hydrometallurgy is to recover zinc and remove heavy metals and pyrometallurgy is to recover zinc and remove heavy metals, including high temperature zinc recovery.

5 MATERIALS AND METHODS

Dust samples from major steel industries in Malaysia was collected and identified as dust 1, 2, 3 and 4. The sample was cleaned and air dried and its mineralogy was determined by X-ray diffraction techniques. In order to carry-out the microstructural study the sample was analysed and observed under Philip XL40 Scanning Electron microscope.

The concentration of heavy metals in sample was determined by leaching test conducted using Philip PU9200X Atomic Absorption Spectrophotometer.

6 RESULTS AND DISCUSSION

Testing had been carried out to determine the contents, leachate, microstructure and surface morphology of EAF dust collected from four different sources.

6.1 Chemical Composition Analysis

Based on analysis from a spectrophotometer on EAF dust samples, the average results on the chemical composition of EAF dust were obtained in Table 1, based on five tests.

Table 1 Results and Comparison of Chemical Compositions for EAF Dust.

Item	Chemical compositions (% wt/wt) on dry basis	Dust-1	Dust-2	Dust-3	Dust-4	SEAISI (1994)
1.	CaO	1.73	1.65	1.72	1.82	3.3
2.	MgO	0.92	0.95	1.13	1.47	2.0
3.	Al ₂ O ₃	0.76	0.82	0.54	0.68	2.7
4.	SiO ₂	5.64	6.20	5.52	6.55	4.4
5.	Total Fe (FeO & Fe ₂ O ₃)	59.64	55.70	54.81	56.83	41.6
6.	MnO	1.38	1.42	1.32	1.41	3.3
7.	PbO	0.94	1.25	1.59	1.12	-
8.	ZnO	11.73	17.38	22.45	15.05	22.5

The first and obvious, thing to note about the data tabulated is that two of the major compounds are total Fe and ZnO, follow by a significant amount of SiO₂ derived from the refractory and CaO. PbO also contributes to a small amount in dust contents although South East Asia Iron and Steel Institute (SEAISI, 1994) reported a negligible amount.

EAF dust containing about 55% of total Fe potentially suggests the possibility to recycle it in the steel making plants. The first recycling option uses a pelletiser to agglomerate EAF dusts into micropellets and charged into the electric furnace. This process involves lower capital costs, less dust generation and little adverse effect on steel or slag property. However the presence of high zinc content may affect the performance of the furnace.

The second recycling option is called direct injection technique where EAF dust mixed with screened coke breeze are fed separately into a high speed screw conveyor which then compresses the mixture into micropellets. During injection of these micropellets at United States Houston Works of Armco Inc., it was reported that nearly all of the Zn, Pb and Cd injected as micropellets returned to the dust during recycling and Zn content of the dust can reach 50%.

Alternatively, zinc contents in the dust can be extracted. Unfortunately, the zinc content of EAF dust-1 at 11.73% due to the use of DR iron as raw materials, will not be high enough for economic extraction. Comparatively, the zinc content of EAF dust-2, dust-3 and dust-4 at 17.38%, 22.45% and 15.05% respectively, due to the use of galvanised scrap as raw materials, will be more economical, with respect to zinc extraction. It is interesting to observe that the content of PbO generally increases with the increase of ZnO. This could be attributed to the use of galvanised scrap which contained zinc and lead.

6.2 Microstructural Study

EAF dusts were also observed under a Philips XL40 Scanning Electron Microscope-EDX. EAF dusts were passed through a 50 microns ISO 565 laboratory test sieve with ease. This indicates that a majority of dust particles are less than 50 microns in size.

As shown in Figure 1, it is evident that most particles are spheres in shape at about 2 microns or less, together with some angular fragments originated from broken spheres. It has been shown that a large number of EAF dusts particles are polyminerallitic and exhibit a variety of internal textures that are especially characterised by skeletal textures.

Observation made from a siemens D5000 XRD analysis showed that the presence of FeO and Fe₂O₃ (magnetite) is obvious in EAF dust depending on the oxygen potential of the flue gases. One of the most common minerals in Fe₂O₃.

6.3 Leaching Test

Based US EPA Toxicity Characteristic Leaching Procedure (TCLP), heavy metals were analysed by using a Philips PU9200X Atomic absorption Spectrophotometer. The average results of concentration of heavy metals (mg/L) in TCLP extract of dust-1, dust-2, dust-3 and dust-4 are tabulated in Table 2, based on three sets of test data.

Table 2 Result and comparison of concentration of heavy metals in TCLP extract for dusts.

Item	Concentration of heavy metals (mg/L) in TCLP extract	Dust-1	Dust-2	Dust-3	Dust-4	US EPA
1.	Arsenic	< 0.1	< 0.1	< 0.1	< 0.1	5.0
2.	Barium	0.637	0.745	0.536	0.731	100.0
3.	Cadmium	0.884	8.390	9.930	4.958	1.0
4.	Chromium	0.921	0.488	0.819	0.418	5.0
5.	Lead	1.985	29.36	38.48	13.51	5.0
6.	Selenium	0.196	0.139	0.210	0.197	1.0
7.	Silver	0.046	0.131	0.051	0.063	5.0

As shown in Table 2, although all the concentration of heavy metals for dust-1 is within the US EPA regulatory limit, the concentration of Pb and Cd for dust-2, dust-3 and dust-4 surprisingly exceeds the regulatory limit by many folds. Nevertheless, the presence of Pb leaching can be justified by the significant amount of Pb in the chemical compositions analysis discussed previously. These obtained results are also consistent with results reported by IISI [6].

Thus, we can conclude that EAF dust is unlikely to be accepted for landfill/dumping without prior treatment process to render it non-hazardous, as in the case of many developed countries worldwide.

6.3 General Discussion

For dust treatment, the dust should be collected at a place where the distance between dust generators and treatment site is as near as possible to cut down costs of transportation. An ideal location would be a site next to the dust generator and port. In this case, the use of ship to transport dust would certainly minimise the cost of transportation. A systematic transportation and collection system must be established to eliminate losses due to double temporary storage of transportation.

Therefore, it is felt that to select a most suitable technology for by-product treatment, cost alone should not be the only selection criteria. It appears that to successfully set up a treatment plant, the government may need to shoulder some of the costs, in order to make a proposal economically viable and to convince steel producers to take an active part. The establishment of a treatment plant will now get Pioneer Status incentive for 5 years, special allowance at an initial rate of 40% and an annual rate of 20% for all capital expenditures plus sales and equipment tax exemption [8].

7 CONCLUSION

This study has demonstrated the urgency to establish the potential usage of steelmaking by-product from the iron and steel industry in Malaysia. Out of the two major steelmaking by-product, EAF slag and EAF dust, the latter has a great commercial value.

It was found that the major contents in EAF dust are total Fe (FeO , Fe_2O_3), ZnO, SiO_2 , CaO and PbO. SEM analysis revealed that EAF dusts consist of many tiny sphere particles which come in different sizes, some as small as 2 microns or less.

This study has shown that EAF dust as a product is hazardous when subjected to the stringent United States Environmental Protection Agency (US EPA) drinking water requirement due to the presence of Lead and Cadmium in TCLP extract above the US EPA regulatory limit.

Thus, with the rapid increase in steel production and therefore the generation of its by-products, the most viable long-term solution lies in the utilisation of EAF dust for zinc, lead, cadmium and iron recovery. Apart from generating revenue and minimising mining of similar industrial materials, the usage of these by-products will contribute significantly to the preservation of our environment for future generations.

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1. INTRODUCTION

The steelmaking process is a complex and energy-intensive industrial activity. It involves the transformation of iron and scrap into molten steel, which is then cast into various products. This process generates a significant amount of by-products, including slag, dust, and gas. These by-products, if not properly managed, can pose environmental and health risks. However, they also represent valuable resources that can be recycled and reused in various ways. This paper explores the potential usage of steelmaking by-products, focusing on the recovery of zinc, lead, cadmium, and iron from electric dust. The study aims to identify the most appropriate contractual arrangements for implementing Total Quality Management (TQM) on construction projects and to establish the best practices for the Project Manager when implementing TQM.

2. RESEARCH OBJECTIVES AND METHODOLOGY

The objectives of the present research were: (i) identify the most appropriate contractual arrangements for implementing TQM on construction projects; and (ii) establish the best practices for the Project Manager when implementing TQM.

