

Electric arc furnace dust waste management: A process synthesis approach.

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ABSTRACT

The electric arc furnace dust (EAFD) is the residue from the gas collection system of steel mills which contains significant amounts of iron, zinc, and lead. The EAFD management presents scientific and technical challenges, due to its classification as hazardous waste, which significantly impacts the economics of steelmaking. Normally, this kind of waste is treated by specialized waste management companies; however, valuable metals can be recovered. In collaboration with a steel manufacturer, this work studies the management of steel mill residue with a process synthesis approach using mathematical programming. The results show that savings of 23 USD per ton of dust can be achieved by recovering pure Zn and Pb through hydrometallurgical dissolution and electrodeposition. Finally, this work provides a decision-making management tool for toxic waste that combines data from both pilot-scale operations and metallurgical companies, and insights from expert judgment, thereby offering a comprehensive framework for informed decision-making.

Keywords: Steelmaking process, Process synthesis, Waste management, Mathematical programming

INTRODUCTION

The residue from the gas collection system of steel mills is known as electric arc furnace dust (EAFD). It contains significant amounts of iron (Fe), zinc (Zn), and lead (Pb) in the form of oxides, silicates, and carbonates. [1,2] Therefore, most countries classify this residue as hazardous waste, so, its management presents challenges that significantly impact the economics of the steelmaking process. Normally, steel making companies rely on a third-party company for EAFD management.

Lead could be separated or immobilized, and valuable metals could be recovered from this residue. Zn and Pb have amphoteric properties so alkaline extraction solubilizes both metals simultaneously in a liquid stream, leaving iron compounds in an insoluble form (solid stream). The solid can be stabilized by incorporating it into a geopolymer that captures the heavy metals allowing the disposal in a sanitary landfill, or it can be managed by a third party. Meanwhile, the liquid stream is a zinc-rich solution from which Zn could be electrochemically

recovered as a valuable product. To avoid lead contamination of the product of interest (pure Zn), the liquid can go through a precipitation process with sodium sulphide, removing the lead as lead sulphide or electrodepositing pure lead. Each step generates different costs and alternatives for managing this residue. Therefore, the process synthesis approach is suitable, allowing for the simultaneous analysis of these alternatives and the selection of the one that generates the greatest benefit.

The management of steel mill residue from a steel making company in the Uruguayan department of Montevideo was studied combining experimental data from pilot-scale operations, data collected from metallurgical companies, and expert judgment.

SUPERSTRUCTURE MODEL

We adopt the unit-port-component model for a general operation unit from bibliography [3,4,5]. For each unit operation, the model depends on the separation efficiency of each individual metallic component. This

information has been gathered from prior experiences [6], real scale data provided by a metallurgic company and from literature [7]. Operational costs encompassing energy, reactants, and other resources, as well as operational limitations, are considered. Subsequently, logical constraints for the model were established based on empirical knowledge. Finally, a techno-economic analysis was conducted, and the objective function was defined as the benefit per ton of EAFD. A general disjunctive programming model was formulated and then reformulated using the big-M reformulation in a mixed-integer nonlinear problem (MINLP) and implemented in GAMS. [3,4,5,8]

In order to model all the interactions between the different stages we propose the use of artificial streams. The artificial streams have the function of representing different paths and connections between different stages to represent this process synthesis network. The superstructure model is shown in Fig. 1.

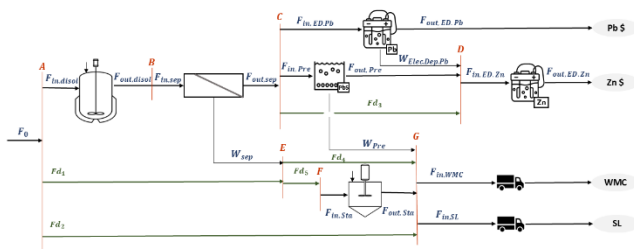


Figure 1. Superstructure of the EAFD management problem. Zn \$: zinc sale, Pb \$: lead sale, SL: sanitary landfills, WMC: waste management company.

The alkaline hydrometallurgical dissolution process (disol) dissolves the Zn and Pb content in water obtaining an aqueous stream rich in Zn and Pb, along with residual dust that did not solubilize. This residual dust must then be managed, either by an external company (WMC) or through stabilization (Sta) and sanitary landfill disposal (SL). Since Zn has a higher electrodeposition voltage compared to Pb, pilot-scale tests resulted in Zn contaminated with lead, which has a lower market value. Therefore, two additional operations were included to remove lead from the solution: precipitation using sodium sulfide (Pre) and lead electrodeposition at a lower voltage (ED, Pb). Lead can be recovered separately from Zn, enabling the sale of both metals in pure form (Zn \$, Pb \$).

RESULTS

The models are formulated in GAMS V47.5.0 and solved using SCIP V9.1 on an Intel(R) Core(TM) i3-1005G1 CPU @ 1.20GHz 1.20 GHz processor with 2 cores and utilizing a maximum of 8 GB RAM. The EADF waste management optimization model consists of 1354 equations, 718 continuous variables, and 13 discrete variables. The nonlinearities in the problem are due to constraints governing the

concentration of key metals in the product and the waste stream, particularly the restriction on the allowable mass percentage of lead in landfill disposal. For more model details see the supplementary information section. The top 5 alternatives for the valorization of steelmaking residue are presented below in table 1, along with their costs per ton of dust. The most economical alternative involves the electrodeposition of pure Zn and pure Pb, with the residual dust being disposed of by the external waste management company, followed by the current management alternative.

Table 1: Ranking of the optimal solutions

Alt.	Management alternative	Profit (USD/ton)
1	Obtaining Zn and Pb separately by electrodeposition (residual dust to WMC)	-216
2	Direct to WMC (base case)	-239
3	Obtaining Zn (96 %) by electrodeposition (residual dust to WMC)	-259
4	Obtaining pure Zn and precipitate PbS (residual dust to WMC)	-601
5	Obtaining Zn and Pb separately by electrodeposition (residual dust stabilized to WMC)	-614

CONCLUSION

A model was developed using the process synthesis approach to support decision-making in the management of electric arc furnace dust. The results indicate a cost reduction compared to the actual management alternative can be achieved by recovering pure Zn and Pb through hydrometallurgical dissolution and electrodeposition.

DIGITAL SUPPLEMENTARY MATERIAL

The general disjunctive programming model and the parameter descriptions are provided [here](#).

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