Materials Processing Institute

A UK-WIDE SOLUTION FOR THE RECOVERY OF ZINC FROM ELECTRIC STEELMAKING WASTE

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Abstract

Between 10 and 25 kg of dust is produced per tonne of steel manufactured by an Electric Arc Furnace (EAF) and while the composition of this dust varies based on the composition of the charge, operating conditions, and the steel being produced, it has a relatively high proportion of zinc which is the most valuable component. The zinc is present as zinc ferrite (ZnFe2O4) and zincite (ZnO).

The high zinc content of this waste means that it cannot be recycled back into the steelmaking process due to the accumulation of zinc in the Blast Furnace, leading to poor processing conditions. High zinc containing wastes are known to be stored across the UK with no economically feasible method of recovery.

Zn recovery is the economic driver for EAF dust recycling, and the environmental drivers relate to Fe recycling and the impact of local stockpiling. Extensive research has been carried out into potential recovery methods, including the use of Rotary Hearth Furnaces, Sinter Plants, and Shaft Furnaces. This review paper provides a summary of existing (high technology readiness level) and potential future (low to medium technology readiness level) methodologies for Zn recovery from EAF dust. This includes landfilling/stockpiling, external recovery, Rotary Hearth Furnaces, Sinter Plants, hydrometallurgy, Micro Cavitation Ducts, and Oxidative Ionothermal Synthesis. Finally, the future work required to tackle this UK-wide issue is outlined. This includes technological, economic, and environmental analysis of the potential recovery methodologies, and the installation of a Pilot Plant to serve the industry.

The aim of this review paper is to provide stakeholders will the information required to make an informed decision on how to tackle this waste in a sustainable manner. The authors also aim to establish of a UK-wide steel industry focus group to address this issue

Introduction

Zinc waste arising from steelmaking is sent to landfill in considerable quantities in the UK because of a lack of recycling infrastructure, coupled with an under-developed market for the recycling of zinc.

Most of this zinc waste arises in the form of dusts and sludges from Basic Oxygen Steelmaking (BOS) due to operational constraints restricting blast furnace zinc recycling. Legacy waste quantities in the UK exceeds 5 million tonnes.

Proven technology exists in operational plants outside the UK to handle both Electric Arc Furnace (EAF) and BOS zinc recovery from waste. The reasons why this has not been implemented in the UK are commercial and regulatory related.

The way forward to this impasse, allowing operators to embrace Best Available Technology (BAT) principles, is to de-risk the decision-making process by a change of focus to a national level. This will move the decision thinking away from the parochial view of single operational plants or legacy sites. This can only be achieved by the bringing together of industry and government, with the objective of creating a national recycling asset for metallurgical wastes. This could be commercially incentivised along similar lines to those employed in the power industry but with the focus on circular economy performance and environmental sustainability metrics.

Summary of existing processes for zinc recovery

From a technology standpoint, zinc recovery processes are well proven for EAF steelmaking waste [1]. This has been driven by the stainless steel and zinc galvanising industrial sectors where large zinc concentrations in the furnace fume emissions incentivise the recovery.

The technology is dominated by the rotary Waelz kiln [2] which recovers both zinc and iron from EAF steelmaking wastes.

In mainland Europe, the technology is aligned to a mature market which is highly integrated across the metallurgical industries and operated by several large multi-national companies including Glencore, Nystar, ArcellorMittal, and Thyssenkrupp. Well established markets exist for Waelz crude zinc oxide and the supply chains to special high-grade zinc production processes using roasting, leaching, and electrolysis.

In contrast, zinc recovery from steelmaking wastes from Linz-Donawitz (LD) or BOS processes are much less developed, primarily because the commercial incentivisation is considerably less than in EAF steelmaking.

There are primarily two reasons for this. The first being that the concentrations of zinc are considerably less. This has an impact on capital cost outlay, operating costs and the price achieved for a crude zinc oxide. The second arises from the first and that is the historical low cost of disposal to landfill, so disincentivising zinc recovery.

To address the issues for zinc recycling from steelmaking wastes from BOS process, where zinc content alone cannot justify the capital outlays required, industry has developed processes that are optimised for overall metals recovery. Due to the relatively high iron content in BOS waste, this is recovered in a form that can be recycled to the EAF in addition to the ironmaking blast furnaces.

The economics of this approach to LD/BOS waste material recovery is that the scale of operation is significant requiring major capital outlay.

The mature technologies for the treatment of LD/BOS iron oxide containing waste streams are those of the shaft furnace and the rotary hearth furnace (RHF). These both produce a sponge iron product from a reduction process that brings the hot pelletised mixed oxide material into contact with a reducing gas (typically products from methane steam reforming) below the liquidus temperature of iron maintaining the structural integrity of the pellet. The metal products that are produced are known as Direct Reduced Iron (DRI). DRI has a well-established global market, but its traded price is highly dependent on quality. For ease of transport, the direct reduced iron is briquetted and is commercially traded as Hot Briquetted Direct Reduced Iron (HBI). HBI is sold to EAF operators.

The major suppliers of shaft furnaces are Midrex and HYL/Energiron with the former having 80% of the DRI production market.

To ensure compliance with the DRI product quality specification and so command the highest price, DRI is most commonly produced from pelletised iron ore. Any co-mingled LD/BOS waste material has to be strictly regulated in order to ensure adherence to the required quality specification.

RHFs are similar to sinter plants in that they have a moving bed with hot reducing gases passing counter-currently to the flow of pelletised metal oxide material. As in the shaft furnace, the operation takes place below the liquidus temperature of iron.

RHFs were originally developed to produce DRI by combining iron ore with pulverised coal in a pellet. The DRI market moved to be mainly sourced from shaft processes and RHFs were later developed to handle steelmaking wastes.

RHFs are currently not widely used for the production of DRI from iron ore but are used for the production of a pseudo-DRI product from steelmaking waste material. The RHF comprises a flat circular hearth rotating inside a large diameter stationery furnace. This process has the ability to handle sludges and slurries from the LD/BOS plants, mill-scale from rolling mills, and dusts from EAFs. The majority of the operational plants are located in Asia and the USA.

The market penetration of RHF produced pseudo-DRI is relatively small compared to the shaft process because it is difficult to achieve the DRI quality required by the market. Also, the capex required for a RHF is very significant due to the scale of operation required for economic viability. The throughput of a RHF for handling steelmaking waste is typically several hundred thousand tonnes per annum. Ensuring quality on feedstock is a significant challenge given the variability of steelmaking wastes, particularly if handling legacy wastes.

A RHF can recover volatilised metals, such as zinc, to produce a crude zinc oxide for sale to zinc refiners. Unlike the Waelz furnace, the revenue streams from the RHF are generally biased towards iron production rather than zinc due to the lower zinc concentrations arising in the steelmaking wastes.

A UK perspective – current position

In contrast to mainland Europe, the zinc recycling market is much less developed in the UK. Most of the commercial activity is undertaken at relatively small scale. Currently, there are no operational zinc refiners in the UK. Existing EAF operators are also of relatively small scale with some but limited integration into the UK market for recycled zinc products.

The large steelmaking companies have not undertaken recovery of the excess zinc that, for operational reasons, cannot be recycled to the blast furnace and have stockpiled the waste at site. It is estimated that there is in excess of 5 million tonnes of steelmaking wastes in the UK with significant amounts of BOS oxides dusts and sludges included in this.

The legacy site accumulations of steelmaking wastes are frequently classified as hazardous waste material due to the high concentrations of heavy metals. This is of particular concern where the materials are deposited in unbunded areas, such as lagoons and on low lying areas such as coastal flats subject to water borne dispersion. There are no DRI/HBI production facilities in the UK nor is DRI/HBI imported to any great extent by existing steelmaking operations unlike their European counterparts.

The major UK steelmaking companies are not incentivised to change course from stock-pilling their wastes because there is no developed market for the products. Penetration of the mainland European markets for DRI and zinc would be difficult given the maturity of those markets and the degree of integration of the production processes.

A UK perspective – the future

In addition to the legacy steelmaking waste stockpiles, there are annual arisings of 100,000 tonnes of steelmaking plant sludges and dusts from the existing operational steelmaking plants.

As a project partner in the NE Interreg European Regional Development Funded REGENERATIS project, the Materials Processing Institute (the Institute) is the project partner leading on the circular economy assessment and material recovery from the Teesside iron and steelmaking site [3]. This is now a past metallurgical site (production stopping in 2015) with deposits associated with the iron and steel industry over a 150-year period. The Institute is also advising on the benchmarking of pyrometallurgical processes for metals recovery.

For existing EAF operators, recovery of zinc is very much tied to the metal composition in the waste streams. For stainless steel manufacturers such as the Stainless Melting and Continuous Casting (SMACC) EAF operated by Outokumpu in Sheffield, there is a clear value proposition to the recovery of the waste metals. This is executed through a plasma arc furnace that in addition to producing a valuable alloy product for recycling back to the process and/or selling to a smelter, also includes two by-products. The first comprises a re-sublimated metal dust of zinc and other volatile metals. The other by-product is a low leachability grade slag that can be sold into the cement and construction products markets.

The Outokumpu commercial model is also replicated in Terni, Italy at Thyssenkrupp's stainless steel production plant, where a similar range of products and by-products are produced.

For LD/BOS plant wastes and including mill-scales and other metal rich deposits, the Institute and collaborative partners are developing a REGENERATIS concept process for a way of processing the mineral wastes in addition to the recovery of metals. The ability to deal with all waste material is particularly important for sites of limited acreage but also for sites undergoing remediation where transport off-site is uneconomical due to gate fees and landfill costs. This was the case for Thyssenkrupp at Terni. Economic regeneration requiring land remediation, and particularly for sites having significant pollution with material contamination of soils and water courses, has to be well managed and address the environmental risks.

The REGENERATIS concept process comprises a mineral processing plant followed by a metallurgical processing plant. Metals are recovered in both plant areas but most of the iron content is removed in the mineral processing plant. The reducible oxides of high value metals (such as chromium, nickel and manganese) are processed in a reducing furnace. Volatile metals such as zinc and lead are recovered from a fume dust extraction processing facility.

The REGENERATIS concept design basis would be to handle a broad range of materials arising from both existing operational and legacy sites. This would include hazardous waste materials such as heavy metals and accompanying hydrocarbon species.

Such a facility would require a significant capital investment and should be seen as a project of national interest.

There are several reasons why it should be a nationally funded asset. The economic viability of a REGENERATIS concept process depends on the development and integration of differentiated markets for its products and

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by-products. The highest market prices for those products and by-products requires significant investment in refining and post-processing technologies. For example, high-grade ceramic products can be produced in tandem with construction grade by-products that would generate additional revenue streams. Similarly, high added-value metal products can be produced alongside mainstream alloy products. However, this would only happen where the supporting infrastructure was in place. The ability to develop niche high-value products is a risk that most existing operators of steelmaking sites would not entertain.

In addition to handling legacy wastes, it would also be used for processing waste streams from the operational steelmaking plants in the UK. The impact of a nationally funded asset would ease the strictures of the time-limited BAT derogations currently in force for the management of metallurgical waste stockpiles.

Given the very significant legacy deposits of metallurgical and mineral deposit wastes, the asset economic life of a national facility would be at least 20 years and be able to process a six-figure tonnage annual throughput. Its establishment would not be without a negative impact on the many smaller niche operators recycling similar material. A UK government study should be undertaken to address this and the wider impact of such a facility supported by the formation of a UK-wide steel industry focus group of existing metallurgical processing companies.

The decision process for capital and operational investment in a recycling asset could be incentivised in a similar way to that of the power industry where successful schemes such as Combined Heat and Power Quality Assurance assessment and Contracts for Difference have brought about structural change.

While established on existing proven technologies, a REGENERATIS concept process will require pilot plant test facilities to optimise its asset configuration and process performance characteristics. The Institute is currently planning the creation of a new Circular Economy Technology Centre, including pilot plant facilities which will address many of these issues. The Institute is also working with collaborative partners on the development of new technologies for the recovery of zinc including hydrometallurgy, micro-cavitation ducts and oxidative ionothermal synthesis [4, 5].

Conclusion

A review of recycling technologies for zinc bearing wastes from steelmaking processes and a market assessment for the products arising has identified some of the barriers to the establishment of metallurgical waste recycling facilities in the UK.

The challenge is focused, primarily, on the legacy stockpiles of materials and current operational arisings where the metal compositions are low. For the existing owners of these sites, there is currently no viable commercial strategy for a change in direction.

For sites where metallic concentrations are relatively low in the waste materials, non-metallic products derived from the accompanying minerals have been successfully sold into a broad range of markets for many years. This has been seen by the metal producing industries as non-core to their businesses and has been outsourced primarily to the construction materials sector.

A significant factor for perpetuating the current position is the amount of capital required for adopting a diversification strategy beyond the core metals producing businesses. This is accompanied by the risk of such a venture.

To address these concerns, a national focus governmental-industry group should be established supported by universities and research institutes. The objectives of the group would be to propose the construction of a national asset for the processing of metallurgical wastes including both legacy wastes and wastes from current operational metal production sites.

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