ABSTRACT

The work discusses the current status of steel mill dust recycling and tries to give an outlook to the upcoming two decades. Due to the fact that after 25 years intensive research and development - up to the industrial scale - in this field, the Waelz technology is more dominant than ever, this option is evaluated in detail. However, there are interesting movements within the Waelz kiln process, e.g. the combination with Solvent Extraction and winning electrolysis, which is already implemented partly. This approach makes the Waelz kiln a competitor to the primary metallurgical industry producing high grade zinc from the Waelz oxide. Especially if primary operations are not available any longer in parallel, where the dusts could be used as ore substitute. Another important development is the utilization of the slag which would turn the Waelz technology more into a zero waste solution. The paper also includes an outlook concerning the future role of low zinc containing steel mill dusts from the BOF as well as an overview about the world-wide generation of steel mill dust and possible future solutions.

INTRODUCTION

For about three decades, the research in the field of steel mill dust utilization has been an important part of metallurgical recycling activities. Numerous process developments based on hydro- as well as pyrometallurgical principles characterized these efforts in this sector. While especially hydrometallurgical attempts showed partly unsolvable problems, not leading to successful concepts, pyrometallurgical principles allowed the establishment of various processes in pilot and industrial scale. The common aim of this review was to find a possible alternative technology to the dominating Waelz kiln process, which was seen as old fashioned, not efficient and not forward looking concept. [1, 2]

Due to this, it is astonishing that the Waelz process nowadays is more dominant than ever before while other developments more and more move into the background or disappear completely from the market. On the other hand, the Waelz technology itself shows interesting innovations and optimizations which would probably allow it underlining and fixing its status as the so called best available technology also for the upcoming 25 years.

Roughly 50 % of the world zinc production is used for galvanizing purposes. After the lifetime of such galvanized steel products like car bodies or construction elements they return, if recycled, to the steel mill as scrap. Worldwide approximately 1.6 billion tons of steel are produced per year. Depending on the process type, a higher or lower ratio of scrap is used for steel production. While the integrated route via the basic oxygen furnace uses pig iron – as hot metal - and only up

DOI: 10.26649/musci.2015.018
to 30 % scrap as cooling agent, the electric arc furnace is the typical recycling facility and therefore often makes use of up to 100 % scrap. Accordingly, the zinc input is relatively high. Between 15 and 23 kg dust per ton of steel are generated where zinc, due to its high volatility, accumulates as oxide in the dust together with other volatile compounds and mechanical carry over. Up to 40 % zinc concentrations are possible to find in such secondary material. Compared to this, the integrated route via the BOF only allows maximum values of 8-10 %. [1], [2]

The electric arc furnace route represents about 29 % (2013) of the world’s steel production [3]. The generated dust out of this is recycled only to 45-50 % while the rest is still landfilled [1], [2]. Table 1 shows the available, treated and dumped amount of high zinc containing dusts as well as the related amounts of contained zinc and it’s relation to the world zinc production (based on 2013 figures).

Table 1: Amount of generated, treated and landfilled steel mill dust (EAF) and the calculated zinc content, related to the world zinc production [3]

<table>
<thead>
<tr>
<th></th>
<th>Amount of dust</th>
<th>Contained zinc</th>
<th>Ratio related to world zinc production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>8.5 mio t</td>
<td>1.7 mio t</td>
<td>13.0 %</td>
</tr>
<tr>
<td>Recycled</td>
<td>4.0 mio t</td>
<td>0.8 mio t</td>
<td>6.0 %</td>
</tr>
<tr>
<td>Landfilled</td>
<td>4.5 mio t</td>
<td>0.9 mio t</td>
<td>7.0 %</td>
</tr>
</tbody>
</table>

Interesting to consider is the role of China in the particular case of steel mill dust recycling. While China plays a dominant role in most of the produced metals, as well as their residues, the situation appears different in the case of steel mill dusts. Even China meanwhile is responsible for more than 50 % of the world’s steel production only 12-14 % of the high zinc containing dusts are produced in China, due to the dominance of integrated production routes (low scrap addition) which came up during the last ten years [3].

STATE OF THE ART RECYCLING TECHNOLOGIES

The dominating process for steel mill dust recycling is offered by the Waelz-kiln today. Here, the dusts together with different additives, especially carbon based reducing agents, are heated up to ~1100 °C for reduction. In course of this reduction zinc gets vaporized and re-oxidized by air introduced in the upper part of the kiln. With this process the main part of the zinc becomes separated from the rest of the charged material. Unfortunately, halogen compounds and some other unwanted impurities follow zinc. Also lead compounds are mainly accumulated in the formed dust. Figure 1 shows the scheme of the Waelz-process [4].
This concept for the treatment of steel mill dust is applied in approximately 30-35 instances worldwide not considering China. The general pros and cons of the Waelz-process can be summarized as follows:

Pros:  
- low energy consumption compared to alternatives  
- well known and already optimized principle  
- simple and basically „one step type“ process

Cons:  
- low product quality (use as ore substitute in primary zinc metallurgy)  
- high amounts of newly generated residues (appr. 700-800 kg per ton of charged dust)  
- only one valuable metal is recovered

The alternative concepts are mainly based on pyrometallurgical techniques. Because of the bonding of zinc to iron oxide in the form of hardly soluble zinc ferrite, most of the approaches based on leaching did not show success, due to rather poor yields. Therefore, the obvious advantage of low energy consuming hydrometallurgical principles, cannot be utilized. Combinations with pyrometallurgical concepts may allow a sufficient yield but have no advantage with respect to energy consumption, product quality and operational costs and would also lead to higher investment. The pyrometallurgical concepts are generally based on carbothermal reduction and differ only concerning the used facilities and operational techniques [1], [2].
Those processes which reached industrial scale within the last 20 years are listed and specified concerning their locations as follows:

- Multiple Hearth Furnace, Primus Process (Paul Wurth), one facility in operation in Taiwan
- Rotary Hearth Furnace (ZincOx Resources), one facility in operation in South Korea, some more are in operation treating steel mill dust as a part of the overall feed
- Induction Furnace Technology (PIZO) one facility in operation in the United States
- Electric Arc Furnace Technology (JP Steel), at least one facility in operation in Japan
- Combination of leaching with Electric Arc Furnace, Ezinex (Engitech), one facility in operation in Italy

One advantage of most of these processes can be found first of all in the opportunity to recover the iron value parallel to that of zinc. Furthermore, some of them are able to be economically operated in a so called mini mill concept, where the process serves mainly only one steel mill and for this can be perfectly adapted to the requirements and characteristics of this specific plant, which would allow a much higher optimization potential. With this, centralized solutions could be avoided allowing a higher independence. [1], [2]

The disadvantages can be found in the high energy consumption, the partly low yield and the low product quality of the produced zinc oxide as well as that of the iron phase. Furthermore, in some of the cases the throughput is low and there are strong interactions with the refractory lining.

The combined Technologies (hydro- and pyrometallurgy) unite the disadvantages of both basic principles without showing groundbreaking advantages compared to the Waelz kiln.

Another current development, are processes with a two-step pyrometallurgical concept. Here the goal is to generate a high quality zinc oxide beside the recovery of iron, as well as producing a remaining slag that could be utilized e.g. in cement industry. One example is the so called RecoDust process, which has been in discussion for more than 15 years but has never been brought to the pilot scale. Reasons for that might be found in the proposed facilities which are new concepts and therefore not fully developed yet. Also the high energy consumption and problems with the refractory material could be the reason for the still missing success. However, other pyrometallurgical two step concepts are upcoming that might show more success in future.

Summarizing the described situation, the Waelz kiln technology is absolutely dominating which is also underlined by the erection of new facilities in Europe, South East Asia and Middle East.

NEW DEVELOPMENTS IN THE WAELZ KILN SECTOR

While alternative concepts for steel mill dust treatment are showing less success, as described in the previous chapter, different interesting developments can be found within the Waelz kiln technology. The most important, forward looking improvements are described in the following:

Combination Waelz Technology, Solvent Extraction and Winning Electrolysis

To avoid an introduction of fluorides and chlorides as well as other impurities into the winning electrolysis the combination of Waelz kiln technology and solvent extraction has been developed. With this, the previously dominant option of transferring the Waelz oxide into the primary zinc
metallurgy can be avoided, and the necessity to charge the material into the roster first becomes obvious. Especially the positive aspects of the Waelz oxide compared to primary concentrates, such as low iron contents and high lead values can be used in a more advantageous way.

This combination has already been widely successful implemented by Horsehead (US), Glencore (Italy) and Akita (Japan).

The disadvantages of this concept can be summarized as follows:
- high investment costs
- no iron recovery so far
- a washing step for the minimization of contained fluorine and chlorine after the Waelz process, prior to solvent extraction is still necessary
- the required zinc quality in the electrolysis usually cannot be reached due to non-sufficient removal of impurities

However, the important advantages are:
- chlorine and fluorine removal to a minimum level
- independence from primary zinc smelters
- production of metallic zinc
- lead- and silver recovery possible

The interesting scenario:

If all of the Waelz kilns would go for the combination with solvent extraction and electrowinning, assuming the availability of the necessary investment, the following changes would appear in the steel mill dust treatment business:

With such an approach, 600 000 to 750 000 t less input material (substitution for ore concentrate) would be available for the primary zinc smelters and in parallel 400 000 to 500 000 t of zinc would come to the market not originating from primary zinc producers but from secondary sources.

Simultaneous Iron Recovery:

In times of strict environmental legislations, especially in European countries, a special focus lies on the minimization of materials that have to be landfilled. Based on this fact as well as on the intention to recover as many valuable materials as possible, iron recycling out of Waelz slag is one important challenge for waelz kiln operators in the future. A further aspect of Waelz slag treatment is the option to recover also remaining zinc leading to a higher overall zinc yield, which is important from the economical point of view.

Two possible concepts of slag treatment:
- Reduction within a gas-solid reaction leading to a separation of zinc and the generation of an iron sponge, which is of relatively low quality.
- Melting and reduction with carbon causing a separation of zinc and the generation of an iron alloy, e.g. performed in an electric arc furnace or a Top Blown Rotary Converter
These concepts have been and are still in evaluation. A successful implementation will depend on the question if the necessary energy consumption for iron reduction is justified by the value of the recycled zinc as well as the generated iron alloy and its quality and market opportunities [5].

**Improvement of Waelz Oxide Quality**

Waelz oxide is the main product of the process. As already mentioned, a washing step is necessary to remove most of the halides. This works sufficient for chlorine but does not really prove success in the case of fluorine. The remaining concentrations make a roasting - in primary smelters - before the leaching necessary where some of the remaining halides are removed but still too high to allow an unrestricted use in winning electrolysis. Therefore, still a maximum amount of 15 % of the overall input of a primary zinc plant must be seen as a limit. There are no simple methods to remove these remaining amounts of halides when they are introduced into the primary process. However, if the different market values of Waelz oxide and alternatively a high grade zinc oxide are compared, there is a lot of potential for a purification step that allows such an upgrading. Further advantages can be found in the independence from primary zinc smelters and the prevention of high energy consumptions to get at the and to SHG-zinc [6]. There are two other options for a possible product upgrade:

- Clinkering: special form of thermal treatment under oxidizing conditions to form e.g. a possible input material for the production of high quality zinc oxide - via the American process
- Production of zinc sulphate via a hydrometallurgical treatment

Similar approaches are made by the above described combination with solvent extraction.

**Future Developments in Steel Mill Dust Recycling**

One important question for the future will be what will happen with low zinc containing dusts from integrated steel production, especially because statistics show that the zinc values in these dusts are steadily increasing.

Today less than 10 % of these low zinc containing dusts are recycled. Due to more and more zinc input based on scrap utilization especially in “b-r-i-c-k” countries lead to concentrations up to 10 %. New technologies in the off-gas treatment, as for example Voest-alpine in Austria has already implemented, allows better separation and therefore enables zinc concentrations of more than 18 % for a certain part of the dust. With this, the zinc content reaches a value which makes it suitable for the treatment in a waelz kiln, which was until now only dedicated to electric arc furnace dust. Also here an interesting scenario could be figured out:

If only 30 % of the integrated steel plants would generate a dust (estimated 50 % of the specific amount) by such a technology, reaching 17 to 20 % zinc, that could be treated efficiently in a Waelz kiln, this would mean 3.5 Mio tons more available dust at the market whereof 800.000 t more Waelz oxide could be produced. This leads to additional 500 000 t of zinc from secondary resources increasing the overall recycling rate.
Other proposed scenarios for the future influencing steel mill dust treatment

Stricter environmental legislation as well as higher prices for iron scrap would lead to efforts to promote the simultaneous iron recovery.

The already high but probably rising zinc prices in future would favor developments like the combination with solvent extraction or alternative methods for the increase of the product quality to avoid the simple input into the primary zinc route. This allows a higher independence but also a lower availability of secondary concentrates for the zinc smelters.

Even though, the Waelz process is more dominant than ever, special concepts for so called mini mill solutions like the two step concept would allow tailor made processes. The success of such technologies would cause a lower available amount of dust for Waelz kiln operations.

SUMMARY

The present and future situation in steel mill dust recycling can be summarized by the following statements:

- Still only 45-50 % of high zinc containing dusts are recycled worldwide.
- The Waelz kiln technology is more dominating than ever before.
- New developments suffer from high energy demands and low product qualities
- Hydrometallurgical methods are still insufficient.
- The combination of Waelz kiln technology and solvent extraction has been implemented successfully at some sites in America, Europe and Asia and could be the dominating trend for the future. However, this is only realistic if the zinc prices are stable or even rising due to the high investment costs.
- New technologies will allow higher amounts of treatable dusts from the area of integrated steel production.
- Stricter environmental legislation and higher steel scrap prices will have an important impact on new process developments.
- The development of new markets with high ZnO-qualities could promote avoiding the primary zinc smelter route.

REFERENCES