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Dust arising during steelmaking processes

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ABSTRACT

Purpose: This paper describes the dust arising during steelmaking processes.
Design/methodology/approach: Steelmaking dusts may be a viable alternative for obtaining valuable and widely used metal which is zinc. On the other hand, heavy metals, it was as dangerous to the environment, and this in turn means that development of steelmaking dusts in the best possible way.
Findings: The analysis of the formation of steelmaking dust.
Research limitations/implications: Understanding the mechanism of steelmaking dusts will help to increase the participation of zinc recycling from wastes.
Practical implications: Contained zinc in the dust can be recovered from the positive economic effect, and neutralization of hazardous waste to the desired environmental effect.
Originality/value: Description of the mechanism of steelmaking dust, with particular emphasis on the distribution of zinc. The information is very important in the development of metal recovery technology from waste.
Keywords: Dust; Steelmaking process; Zinc; Mechanism

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1. Introduction

In electric-arc furnace (EAF) there arise 10-15 kg of dust per one Mg of product what gives 3.7 million Mg per year in scale of worldwide steel production [1, 2]. It will be received much higher projected quantities of dust when we consider data from the study [3] as well as data from statistical yearbook [4]. When we multiply 20 kg of dust per Mg of steel [3] by worldwide annual production of raw steel using EAF which was in 2010 410.726 million Mg we get value 8.2 million Mg of dust.

During steelmaking in oxygen converters (LD) there arise 8-12 kg of dust (sludge – converted into dry condition) per Mg of steel [5]. Authors of the study [6] have estimated total worldwide quantity of dust from LD converters at the level 5-7 million Mg. If we make the same forecast as for the EAF method and use quantity of production from LD converters in amount 988.592 million Mg – [3], the projected total quantity of dust from LD converters in 2010 would be 7.9-11.9 million Mg. It is noticeable that annual growth of dust quantities generated by main method of steelmaking i.e. LD converter was very large, in period 2003-2010 it was on average not lower than 10 %.

2. Zinc in steelmaking process

The dust from electric-arc furnace has much higher content of elemental zinc than sludge coming from oxygen converters. According to subjective literature concerning electric-arc furnace dust (EAFD) their chemical composition are significantly different especially in terms of zinc content. It depends on presence of galvanized scrap metal in charge material. If the charge material either has small amount of zinc coating or it hasn't it at all, then zinc content in dust would be relatively lower. Therefore, according to authors of studies [1, 7] zinc content is in a range 16 to 25%, and iron content is not lower than 30%. Authors of other study [8] analysed dust generated in six different electric steelworks and they found that zinc and iron content were 10.8 to 36.4% and 24.4 to 41.4% accordingly. They also found manganese content in quantity 0-2.8%. In another study [9] there is placed a synthetic data coming from 19 literature sources which gives confirmation of the thesis that quantity of galvanized scrap affects zinc content in EAFD. Zinc content in EAFD varies in range 13 to 46% and iron content varies in range 10 to 45%.

Converter dust contains much lower amount of zinc in relation to electric steelworks dust. It is caused by the fact that charge material for converters is composed of pig iron in 70-75% which practically doesn't contain zinc. In the nineties, zinc content in Polish steel converters was not lower than 1.5% [10] , whereas after put continuous steel casting into operation the zinc content grown up to 3.2% [11] and later up to 5.2% [1]. At the same time, in foreign steelworks zinc content was up to 7% as it was synthetically demonstrated in the study [12]. Although LD converter dust contains much lower amount of zinc it contains much higher than EAFD amount of iron which can be as high as 70% as provided by authors of the study [13]. Due to the high content of iron in LD converter dust, sludge coming from wet dedusting was dehydrated and briquetted and then turned back to the process as an addition to the bath after first lime portion. After several cycles of this process zinc content in dust was 20% and more [13].

Considering amounts of zinc in steelmaking dust it should be pointed out that they are higher than zinc content in zinc raw materials. Zinc and lead ores may be divided into: rich 8-15% Zn and 4-15% Pb, medium 4-8% Zn and 2% Pb, poor 2-4% Zn and 1-2% Pb [14]. In Poland, there are mined poor ores in Z.G. "Trzebionka" S.A containing 3.0÷3.3% Zn and 1.32-1.67% Pb, in Z.G.H. "Bolesław" S.A. the values are 4.0.4.2% and 1.45-1.69%. Moreover, Polish resources are becoming exhausted. Worldwide, if there is no zinc recycling, the resources will be exhausted in next 38 years [15].

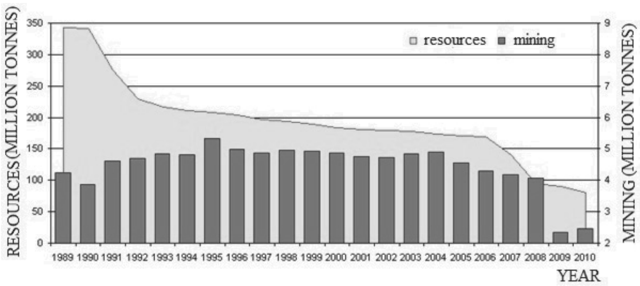

Fig. 1. Resources and mining quantities of zinc and lead ores in Poland during period 1989-2010 [16]

According to the data above concerning ores and the information about steelmaking dust, it can be a real alternative as a source of valuable and widespread metal that zinc is. On the other hand, zinc as a heavy metal is considered as dangerous to environment. It makes steelmaking dust to be managed in the best possible way. In Figure 1 there are presented quantities of resources and mining of zinc and lead ores in Poland during period 1989-2010.

3. Dust arising during steelmaking processes

Worldwide research centres intensively work to know steelmaking dust arising mechanisms. The results of the analyses concerning EAF furnaces are presented in the studies [2, 3, 8, 9], whereas results of the analyses concerning LD converters are presented in the studies [6, 13]. It is worth to notice, that there is being performed the work using laboratory facilities, which gives results of thermodynamic modelling.

Mainly, there are being explored two theories during research of steelmaking dust arising. The first is "evaporation theory" and the other one is "bubble theory". It should be emphasized that this approach is used to formulate mechanisms related to EAF furnaces as well as to oxygen converters.

It appears that the most representative study concerning EAF furnaces is proposition to identify steelmaking dust process by using the following five mechanisms – [3], presented in Figure 2:

1) Evaporation, especially in high temperature areas i.e. in electric-arc zone (1) and oxygen injection zone (1'),
2) Metal drops are mechanically thrown out in the result of electric-arc blow (2) and oxygen injection (2') into the melt surface,
3) Small metal drops are thrown out in the result of blowing out CO bubbles (3) which are generated during melt decarburization,
4) Metal drops burst (4) in the result of contact with oxidizing gaseous phase; immaterial in EAF furnace;
5) Directly emission of solid particles (5) during charging the furnace with powdered materials (slag making additions, coal for foaming the slag, turned back dust).

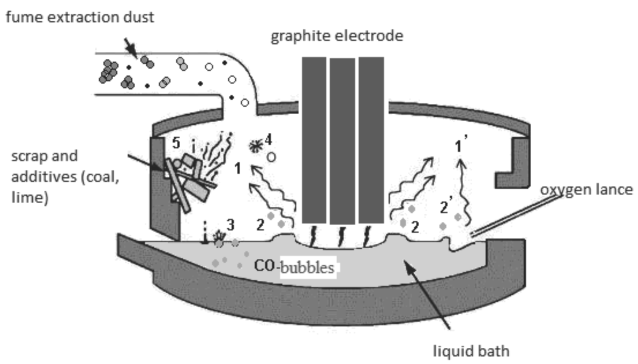

Fig. 2. Dust emission after charge melting in electric-arc furnace [3]

Authors of the study [3] assumed that dust emission in EAF furnace mainly occurs in the result of throwing out liquid steel drops and slag during blowing out CO bubbles , which is presented in Figure 3. The scheme was made on the basis of numerous works where the cold model in air-water system was used. Result of the works were summarized by authors of the study. They also performed a similar research using original station i.e. hot model in argon-liquid steel system. With the use of high speed video camera they recorded process of blowing out argon bubbles as well as process of throwing out liquid metal drops.

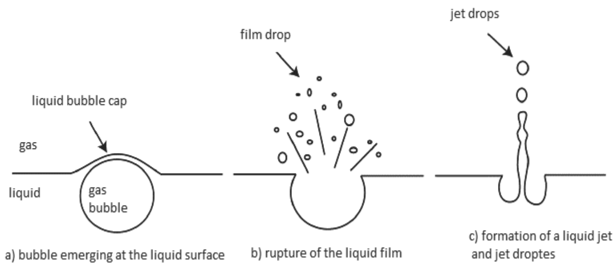

Fig. 3. Scheme of blowing out bubbles on a liquid surface [3]

According to the study [3], only argon bubbles smaller than 4.5 mm throw out metal drops permanently. When the bubbles are bigger than 4.5 mm metal drops are to big so they fall to metal bath. Therefore, they don't emit dust.

The more complex experiment was performed in 2011 by authors of the study. They also used hot model. In contrast to using inert gas in the study [3] they performed oxygen metal bath blowing. In first group of experiments they used scrap steel as charge, in the second group they used pig iron as charge. Therefore, the results are representative for EAF furnace (first group), and also for oxygen converter (second group). Moreover, metal-bath was supplemented by manganese and molybdenum which is an element with higher than iron vapour pressure.

According to the study [17], microscopic analyses of structure, granulation, elements distribution, SEM and ratio Mn/Fe show that dust arising mechanism is mixed i.e. dust are generated partially according to "evaporation theory" and partially to "bubble theory". The dust which arose during evaporation is uniform, and ratio Mn/Fe in dust is much bigger in comparison with quantities of these elements in metal bath. Moreover, composition of the dust is dependent on vapour pressure. In case of the "bubble theory" it is non-uniform, and the ratio Mn/Fe in dust is equivalent to the ratio in metal bath. It should be noticed, that these findings confirms the results of much earlier study [18] performed on industrial objects i.e. oxygen converters with mixed blow. Authors of the study [18] came to conclusion that in workspace of converter dust generated by evaporation is mixed with dust arose in the result of blowing out CO bubbles. A fraction of particles generated by blowing out bubbles is relatively big during first phase of blow and it decreases as much as the duration of oxygen blow is longer. In reverse, the longer is phase of blow the larger is fraction of vapour condensates in dust. According to the study [13], in case of oxygen converter, about 17% of dust is generated during first phase of blow in the result of metal bath components evaporation. During second phase of blow there is generated about 32% of dust. It should be also noticed, that the subjective literature includes opinion saying that in oxygen converter the dust arises only according to the "bubble theory" because fraction of dust generated in result of metal bath components evaporation is unnoticeable so it may be omitted. This conclusion was given in the study, which concerned research of dust in industry conditions, the dust was taken from dedusting system pipeline located at distance not closer than 50 m from place of dust generation. Therefore, conclusion of dust arising mechanism on the basis of their composition, structure and granulation is risky, though the results may be valuable as regards to dust utilization.

The another important opinion dispelling some concerns regarding dust arising mechanism is discussion of author of the study [19] with argumentation and conclusions from the study [20]. Authors of the study [20] discovered that 92-94% of fine dust is generated in the same way as coarse dust – mechanically i.e. metal is thrown out by CO bubbles created in metal bath. According to this opinion, a quantity of fine dust generated in the result of evaporation is constant during all the period of blow and is on average about 5%. Author of the study [19] on the basis of argumentation from the study [20] shows that the same data may be considered as proof for arising a fine dust in result of evaporation, especially zinc, manganese and iron. As a proof for the above is the fact that the amount $(Mn/Fe)_{dust}$ / $(Mn/Fe)_{metal\ bath}$ varies from 2-5 at beginning of oxygen blow to 10-15 at the end, which was discovered by authors of the study [20].

Steelmaking dust may be an alternative charge material in zinc production using secondary materials in place of natural raw materials, which is significant from the ecological point of view. However, non-ferrous metallurgy expects a relative high content of this element in dust. Very often in Poland, there is required higher than 20% elemental Zn content, as it is given in doctoral thesis [21] referring to data from the studies [23]. The requirement is met in case of dust from arc furnaces, unlike to dust from Polish oxygen converters. As already described, Zn content in dust from converter process can be raised in the result of several cycles of turning it back and adding to charge material – in form of specially prepared briquettes made from dust. After reaching required Zn content the dust is removed from production process. However, the technology generates large quantities of waste. The waste material has also complicated chemical composition, therefore a further processing of them may be costly. It appears that the data included in the study [23] as well as the materials of VAI company may be an alternative solution. In figure 4, there is shown how zinc content in dust from specific oxygen converter is changing during the period of oxygen blow. It is clearly visible that the highest zinc content occurs during first phase of blow, and then, after next 5 minutes the zinc content decreases suddenly, coming closer to 0 at the end of blowing.

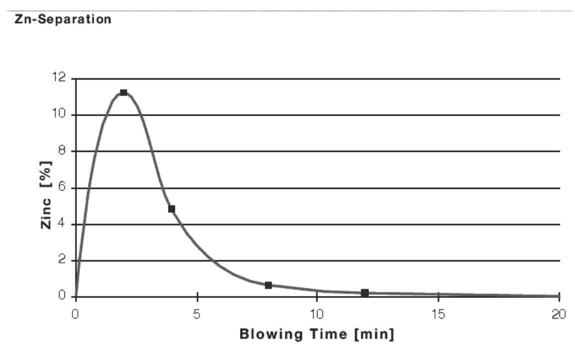

Fig. 4. Change of zinc content in dust from converter process during blowing time [24]

It is probably, that the tendency showed in Figure 4 was a basis to making conception of VOEST-ALPINE Industrie-anlagenbau. It concerned separating dust generated during first phase of blow (dust “rich in zinc” and “poorer in iron”) from the dust generated during second phase of blow (dust “rich in iron” and “poorer in zinc”). The idea is presented in Figure 5.

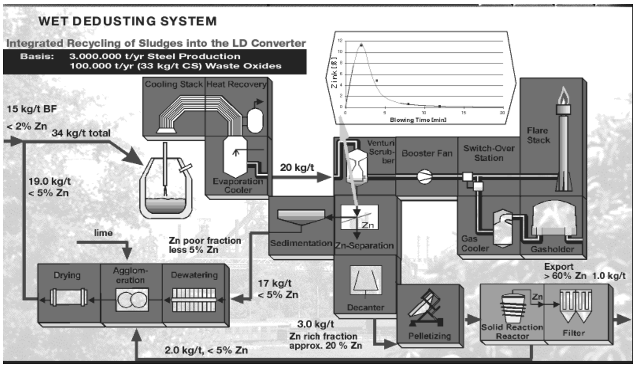

Fig. 5. Diagram of new dedusting system in converter steelworks

According to the Figure 4 and Figure 5, in case of use of this conception in industry conditions, the amount of utilized to zinc recovery materials would be lower. It would also have less complicated chemical composition (shorter period of process factors influence) and be easier to utilize iron from the remaining dust.

4. Conclusions

From the point of view of steelmaking processes generating dust is disadvantageous because it decreases metallic yield, it is a source of unintended product. Moreover, according to the study a very important and often ignored in metallurgical publications aspect is loss energy caused by iron evaporating in high temperature zone in welding puddle under electrodes in EAF furnace, and also heat loss in the result of its carrying up by the dust.

Both of the approaches to steelmaking dust i.e. limitation of its occurrence – process economics from the first side, and its good management – recycling from the other side, require to know the mechanism that generates the dust in specific process conditions. Due to the different specificities of EAF furnace and LD converter there should be expected different elements of the mechanisms as well as common elements.

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