

Feasibility of Air Classification in Dust Recycling in the Iron and Steel Industry

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The potential of air classification of dusts from dry off-gas cleaning for improved recycling of these dusts is investigated. By air classification, a dust can be separated into a coarse fraction and a fine fraction. Some components which are usually unwanted in recycled dust like alkali chlorides and Zn and Pb are often enriched in the fine dust fraction. Thus, air classification of dust before recycling will allow recycling of an increased amount of dust and, thereby reduce the amount of dust which has to be sent to landfill. The feasibility of such treatment is studied on the basis of estimated investment costs and operating costs. The main factors affecting the feasibility of such a treatment are the capacity of the unit, the cost of landfill of the respective dust, and the fraction of dust which can additionally be recycled after the treatment. The investigation of classification of BF dusts and sinter plant dust shows that economic operation can be reached under the assumed conditions at landfill costs above 35–60 EUR/t for BF dust and 90 EUR/t for sinter plant dry desulfurization and de-dusting residue. The integration of air classification into EAF dust in-plant recycling can be feasible, too.

not efficient.^[5] Zn in the sinter causes problems in the downstream BF process, where it forms crusts in the upper part of the BF and accumulates in the furnace lining, which consequently deteriorates.^[6,7] For this reason, the total amount of Zn in the charge of a BF is usually restricted to 100–150 g t⁻¹ of hot metal produced.^[1] As a result, large amounts of dusts cannot be recycled via the sinter plant.^[8] For the treatment of such dusts various hydrometallurgical and pyrometallurgical processes have been developed in the past to separate Zn and Pb from these dusts.^[9–11] However, only dusts with a high Zn content like the dusts from electric arc furnace steelmaking are usually processed via these process routes.

In the case of sinter plant dust, the limitations arise from an increased content of the alkali chlorides KCl and NaCl.^[1,12] Recycling of chlorides can lead to an up-cycling of chloride in the sintering process.


The resulting higher alkali chloride concentrations in the off-gas dust negatively influence the performance of the electrostatic precipitator (EP), thereby increasing the dust concentration in the cleaned off-gas.^[13,14] To be able to operate the sinter plant below the dust emission limit, EP dust with a higher chloride concentration cannot be recycled but is disposed of in landfill sites.^[14] Leaching of this dust for removal of the alkali chlorides has been investigated.^[15] However, the salty waste water produced might be a hindrance to the application of such processes on an industrial scale.

In several studies, it has been shown that these unwanted components are especially enriched in the fine fractions of the dusts. This effect has been reported for BF top-gas dust,^[16–18] for BF cast house dust,^[19] for BOF secondary dust,^[20] for electric arc furnace (EAF) dust,^[21] and also for sinter plant dust.^[22] Therefore, classification by particle size could be a feasible process to reduce such components in the bulk of the dust by separating off the finest fractions. Because of the fineness of the dusts^[19–23] it is not possible to apply sieving for classification. However, air classification can be used to classify such fine dusts.^[24,25] Classification of sludge from BF wet off-gas cleaning by hydro-cyclones is a well-established process.^[26,27] Thereby, the fine fraction enriched in Zn is separated from the coarser fraction of the sludge. In a similar way, air classification could be used for treatment of residues from dry off-gas de-dusting.^[28] However, the treatment costs are expected to be somewhat higher in the case of air classification

1. Introduction

The residues from dry air pollution control processes in integrated steel mills are fine-grained material. These residues have to be recycled in some way or have to be disposed of on landfill sites. The dusts separated from off-gas at the blast furnace (BF), the basic oxygen furnace (BOF), and the sinter plant are rich in Fe^[1,2] and, therefore very often recycled inside the steel mill. Other valuable components are, for example, carbon in BF dust and Ca in sinter dust. However, limitations for recycling of these dusts usually arise from high Zn and Pb or alkali chloride content.^[1,3,4] The amount of Zn in the sinter plant feed is limited because Zn removal in the sinter plant is

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because in contrast to air classifiers hydro-cyclones are well known for their low cost.^[29]

In this study, the feasibility of air classification was investigated for some applications on the basis of the treatment cost compared with typical landfill costs for such dusts or with cost savings in recycling. Section 2 describes the concept for an air classification plant in a steel mill for the classification of three different capacities between 300 and 3000 kg h⁻¹ including estimated investment and operation costs. In Section 3, the feasibility of the classification of various steel mill dusts is discussed on the basis of treatment costs and expected savings in landfill costs or reduced recycling costs.

2. Air Classification of Dusts

2.1. Plant Concept

The concept for the classification plant (CP) in the evaluation was a green-field plant installed in an existing steel works.^[30,31] The dust is transported by silo truck to the CP and filled pneumatically into the storage silo. The core component of the plant is an air classifier with a speed-controlled classifier wheel. The granular dust material is fed to the classifier by a mechanical conveyor. Additionally, air is fed to the classifier to disperse the dust. The dust particles enter the classifier wheel and there they are classified in the centrifugal field. Coarse particles have a higher impact and are rejected toward the side walls, from where they fall by gravity to the coarse material outlet. The fine particles can pass through the classifier wheel. Subsequently, they are separated from the air flow in a bag filter. The split between coarse and fine fraction, characterized by the cut size is managed by adjusting the speed of the classifier wheel. The fine and coarse fraction are stored in separate silos. **Figure 1** shows the flow diagram of the process.

The coarse fraction is to be recycling in the steel works, whereas the fine fraction with the bulk of unwanted elements – Zn, Pb, or alkali chlorides, depending on the treated dust – is either transported to landfill or utilized in some way outside the steel works.

For the evaluation the design capacity of the CP was sized according to the expected dust requirements. **Table 1** gives an overview of the specific dust generation rates of the various process steps of a steel works. In the table, average values are shown which are taken from the BAT reference document for

iron and steel production.^[1] The values for dust generation reported vary within a wide range. Therefore, three values (300, 1000, and 3000 kg h⁻¹) for the capacity of the CP were selected. Thus, the capacity covers the whole typical range from sinter plant electrostatic precipitator dust, the dusts from a BF (dust catcher, cast house de-dusting) up to the dust from steelmaking.

According to published data, the required cut size in the classification is expected to be in the range of 1–10 μm.^[16,18–22] However, this value can only be given in a range. In a specific case trial runs using the actual dust would have to be performed.

In the selection of the silo storage capacity, an important parameter is the bulk density of the dust. Reported data for the bulk density of dusts from sinter plants, BFs and BOFs are 500–1500 kg m⁻³, while the material densities are in the range of 2500–4000 kg m⁻³.^[32–34]

2.2. Cost Estimation

To provide the cost calculation in a comprehensible manner, the investment costs for the main components were estimated on the basis of quotations. The required basic engineering for the CP was elaborated on the basis of the flow diagram and the mentioned design data. An overall layout of the CP was worked out for a proper estimate of site costs. In the layout, a location of the CP beside a road was assumed. The required area for the site is 600 m². The 50 m² – building for the classifier and the compressed air supply with an eave-height of about 5 m is of standard industrial prefabricated type. It is placed on a concrete base. The storage silos are the tallest buildings with a height of approximately 18.5 m over ground level.^[30] In cost estimation, a site location in Central Europe was assumed.

The size of the site and the building as well as the capacity of the silos and the compressed air supply was the same for all three size versions of the CP, while the other equipment was adapted to the capacity of the CP.

The main equipment in the CP is the air classifier. The search for suppliers of suitable air classifiers showed a number of capable companies. However, suppliers with references in the iron and steel industry are rarely to be found. The main difference between the air classifiers from different suppliers is the type of feeding, mechanical feeding, or pneumatic feeding. For the CP a classifier with mechanical dust feeding was selected. The engineering costs do not depend on the plant size. An estimate of 650 h was included in the calculation.

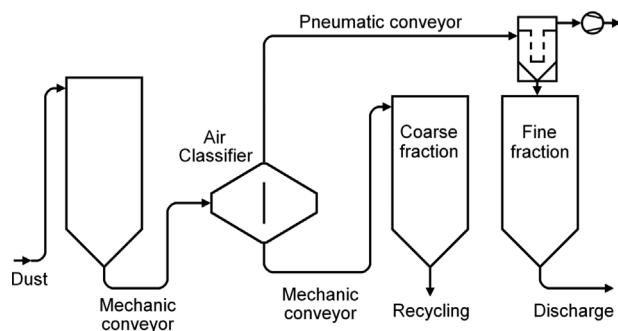


Figure 1. Flow diagram of the CP.

Table 1. Typical amounts of off-gas de-dusting residues produced.^[1]

	Average amount of dust produced	Typical production capacity
Sinter plant	1.5 kg per ton of sinter	200 t h ⁻¹
BF Top-gas cleaning 2nd stage	12 kg per ton of hot metal	200 t h ⁻¹
BF cast house	2.8 kg per ton of hot metal	200 t h ⁻¹
BOF (sum)	12 kg per ton of liquid steel	400 t h ⁻¹
EAF	20 kg per ton of liquid steel	100 t h ⁻¹

The calculated investment cost were 780 000 EUR, 850 000 EUR, and 1 050 000 EUR for a CP with a capacity of 300, 1000, and 3000 kg h⁻¹, respectively.^[31]

Operation of the CP was assumed to be by means of a remote station at another plant, for example the plant which generates the dust treated in the CP, so there is no necessity of direct local interaction. Therefore, in the estimation of the personnel costs sharing of personnel with other facilities was supposed. For CP operation, a 25% share of one full-time resource was assumed to be sufficient. Unloading of dust and loading of products are assigned to the transportation costs, which are excluded from this calculation. Three-shift operation of the CP with planned maintenance stops is proposed. Taking into account other reasons for stoppages such as shut-downs of the dust producing facilities, a net production time of 7900 h/a is assumed. Considering the operation time and the 25% share approximated, one person has to be calculated in total for CP operation independent of the plant capacity. A value of 57 000.- EUR per year was estimated for the chosen location based on local rates.

Besides the personnel costs, the biggest item in the operating costs is the power consumption. The calculated annual electric power consumption of the small, medium and large CP was 210, 480, and 870 MWh, respectively. Estimation of the cost for electric power is very much dependent on the location of the CP. In this evaluation, a figure of 120 EUR/MWh was used for all three plant sizes, which is an extrapolation for ten years based on 2014 figures.^[35] Annual maintenance costs for the classifier are derived from quotations obtained from specialized companies. A figure of 9000.- EUR per year was included in the calculation, independent of the size of the classifier. Other maintenance activities are deemed to be covered by the personnel costs.

In the calculation of the treatment cost, a payback period for the investment of 10 years was assumed and additionally financing costs of 5% per year. The resulting specific costs for air classification of a dust at a capacity of 300, 1000, and 3000 kg h⁻¹ were 73.0, 27.0, and 11.8 EUR/t, respectively.^[31] The detailed calculations are summarized in **Table 2**.

A further reduction of the investment cost of about 10% might be achieved if the CP is integrated into the air pollution control system, where the treated dust originates from. Thus, the storage silo for the dust before classification would be

eliminated. Additionally, the cost for operation personnel might be less, so the operation cost per ton would be reduced by 5% to 10%.

3. Results and Discussion

3.1. Possible Cost Savings by Air Classification

The profitability of a CP mainly depends on the two main benefits. The first benefit is saving of landfill costs or external treatment costs. After air classification only the fine fraction would be sent to landfill, while the coarse fraction would be recycled. The second benefit is the recycled valuable material, for example, Fe and carbon in the case of BF dust. The value of the second benefit is quite difficult to calculate because it depends greatly on the steel mill- specific operation conditions. In an extreme, case this benefit could also be negative if the recycling of the coarse fraction causes additional operation costs which exceed the value of the recycled elements.

The further considerations are based on the assumption that the cut size in the classification process is such that recycling of the coarse fraction is cost-neutral. Thus, the only benefit is saving in landfill cost. Saving of landfill costs depends on two factors: the specific landfill cost and the amount of material which can be recycled after classification instead of being sent to landfill.

Appropriate numbers for actual landfill costs of dust from steelworks are hardly found in literature as steel works do not publish such costs. Additionally, landfill costs also depend greatly on the specific location.

In the online service “Baupreislexikon.de” which is widely used in the construction business in Germany for price calculation, costs of approximately 80.- EUR/t can be found choosing the section “metallic waste loaded with zinc” together with “dust-tight loading at filling site”.^[36] In a recent study, the cost for landfill of untreated municipal waste incineration fly ash in Europe of 220.- EUR/t was used, whereas costs for inert fly ash after leaching were 36.- EUR/t.^[37] In another study nearly ten years ago costs for landfill of electric arc furnace dust of 125.- EUR/t in Turkey was used, whereas landfill from processes with an inert mixture of dust of this kind together with cement were said to be 20.- EUR/t.^[38] For the year 2000 landfill costs of 105.- EUR/t were used in a study for Belgium.^[39]

The amount of coarse material which can be utilized after classification depends on composition of the dust and the specific circumstances at the steel works. Therefore, it is used as a variable parameter in the further discussion.

The calculation of the processing cost per ton c_p in EUR is based on the cost function shown in Eq. (1):

$$c_p = a(w)^n + b \quad (1)$$

where w is the mass of dust which has to be air classified in t h⁻¹. The term $a(w)^n$ takes into account the influence of the capacity dependence of the operation cost, while b are the lowest possible operation costs per ton at very high dust throughputs. The parameters a , b , and n were derived from the estimated data for the three plant sizes. The values obtained for the parameters a , b and n were 24.5, 2.5, and -0.876, respectively. The sum of parameters a and b equals the processing cost at 1 t h⁻¹ feed,

Table 2. Processing costs per ton (10 years operation).^[30]

	300 kg h ⁻¹	1000 kg h ⁻¹	3000 kg h ⁻¹
Annual plant capacity	2370 t/a	7900 t/a	23 700 t/a
Investment cost (greenfield, in EUR)	780 000.-	850 000.-	1 050 000.-
Cost per year (in EUR)			
Depreciation	78 000.-	85 000.-	105 000.-
Financing	4000.-	4000.-	5000.-
Personnel	57 000.-	57 000.-	57 000.-
Electric power	25 000.-	58 000.-	104 000.-
Maintenance	9000.-	9000.-	9000.-
Total annual cost	173 000.-	213 000.-	280 000.-
Cost per ton	73.-	27.-	11.80

which was, as mentioned, to be 27 EUR/t. If the value of w decreases, the processing cost rise in an approximately exponential way.

Based on Equation (1), the minimum rate of utilization of the treated dust γ_R^* , above which the investment is feasible, results from Equation (2):

$$\gamma_R^* = \frac{a(w)^n + b}{c_L} \quad (2)$$

where c_L is the cost of landfill in EUR/t.

Figure 2 shows the calculated minimum utilization rate as a function of the mass rate of treated dust for different values of cost of landfill.

3.2. Feasibility of Air Classification in Some Applications

3.2.1. Application in BF Dust Recycling

As first example, the feasibility of air classification of the dusts from a BF as presented in a previous study^[28] is investigated. In this study the assumed rates of dust were: dust catcher dust: 7.0 kg t^{-1} hot metal (HM); dry second-stage filter dust: 7.0 kg t^{-1} HM; and cast house dust: 0.70 kg t^{-1} HM. The respective Zn content of the dusts was 0.3%, 1.5%, and 1.5%. The assumed limits for the amount of Zn fed to the sinter plant by dust recycling were 40, 60, and 80 g t^{-1} HM. Figure 2 shows a flow diagram of the BF plant with the three dusts. In this economic evaluation, a production capacity of the BF of 430 t h^{-1} HM was used which is an average value for BFs.^[1] The dust catcher dust is recycled in all cases because of its low Zn content. The actual situation is that the amount of second stage filter dust and cast house dust recycled results from the respective Zn limit, while the fraction which cannot be recycled is sent to landfill. In Scenario A, the filter dust is classified while all dust catcher dust is recycled. In Scenario B, both dusts are classified separately. The results of the evaluation are shown in Figure 3. In Scenario

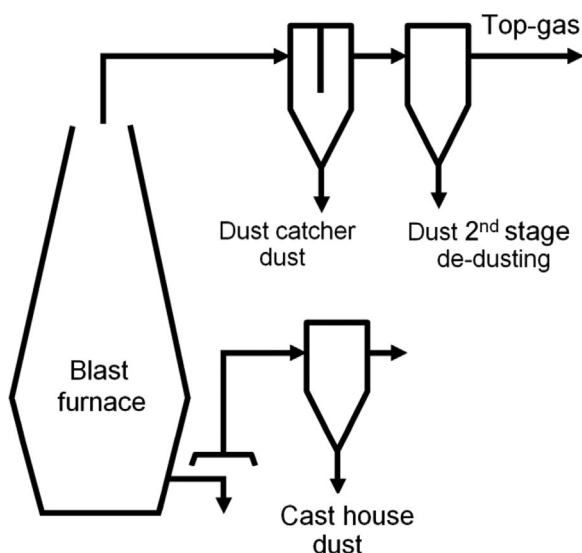


Figure 2. Flow diagram blast furnace de-dusting system.

A, 3.0 t h^{-1} of dust have to be classified while in Scenario B the amount is somewhat higher (3.3 t h^{-1}). Thus, the required capacity of the CP is on the upper end. The three data points of each scenario, representing the three different Zn limits investigated, show the fraction of dust which can be additionally recycled to the sinter plant at unchanged Zn rate due to air classification in the CP. The lower the Zn limit is, the lower is the fraction of additionally recycled dust. The results show that classification of both dusts (Scenario B) is more economic compared to classification of the filter dust only (Scenario A). For Scenario B classification is feasible at landfill cost above approximately 35–60 EUR/t depending on the Zn limit.

3.2.2. Application in Sinter Dust Recycling

The second example is the classification of the residue from a single-stage dry desulfurization and de-dusting system of a sinter plant. This new system comprises an entrained flow sorption process and a fabric filter, installed upstream of the fan. Thus, the investment costs for the off-gas cleaning system are reduced significantly compared to the conventional design where an electrostatic precipitator is installed upstream of the fan and additionally, a dry desulfurization and de-dusting system is installed downstream of the fan. However, the whole residue from such a system would have to be landfilled while in a conventional two stage system the dust from the de-dusting stage can be recycled and only the dust from the second-stage gas cleaning system has to be landfilled.^[40] In this study it was found that after treatment of the dust in a CP approximately 60% of the dust (coarse fraction) can be recycled at similar recycling rates of chloride and sulfur as in the actual situation with recycling of the dust from the de-dusting stage only. The mass ratio of dry desulphurization residue to dust from de-dusting in this study was 1:2.3. Assuming a sinter plant capacity of 200 t h^{-1} and a dust generation rate of 1.5 kg t^{-1} sinter (Table 1) the capacity of the CP is approximately 0.43 t h^{-1} . The resulting limit costs for landfill are approximately 90 EUR/t in this case (Figure 3).

3.2.3. Application in EAF Dust Recycling

Another example would be air classification of EAF dust in mini mills that utilize in-plant dust recycling. In these steelmaking

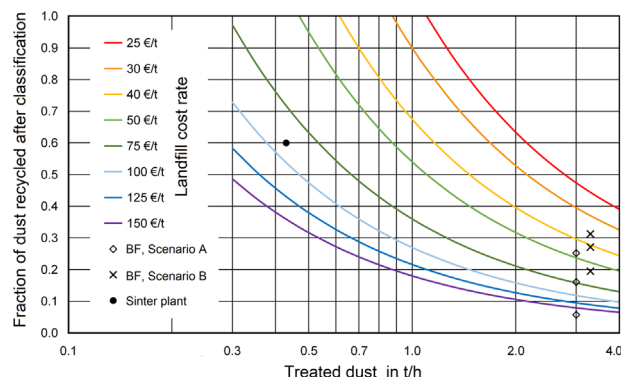


Figure 3. Minimum utilization rates after classification for feasibility.

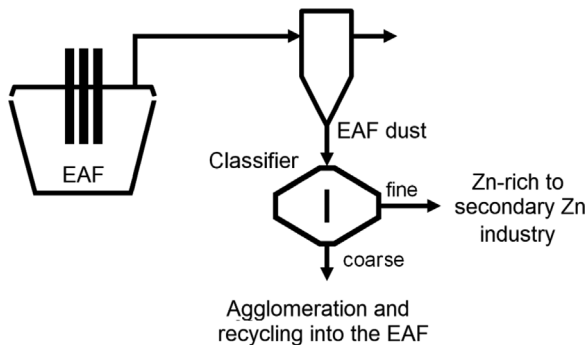


Figure 4. Flow diagram EAF dust recycling.

plants, part of the dust is recycled back into the furnace to decrease the amount of dust that has to be discharged and at the same time increase the Zn concentration of the remaining EAF dust, which is sent to landfill or is processed for Zn recovery.^[41–43] To compensate the required energy for reduction and vaporization of the recycled Zn, coke breeze is added to the recycled EAF dust. When air classification is integrated into such a recycling process (Figure 4), the amount of Zn, which has to be volatilized, can be reduced by more than 50% and the total amount of recycled dust is reduced by approximately 25%.^[21] Thus, in this application of air classification the benefit is a reduction in the costs for dust recycling instead of saving landfill costs. Assuming an average rate of EAF dust generation of 2.0 t h^{-1} (Table 1) the specific air classification costs according to Equation (1) are 15.8 EUR/t for this CP capacity. The total air classification cost would be 31.6 EUR/h. With a reported coke breeze addition of 22%,^[42] the reduction in the amount of recycled Zn of 50% would reduce the required coke breeze addition at a similar rate. Assuming the cost of coke breeze per ton is approximately half the cost of coke^[44] and using the average coke prize for 2017 of EUR 260/t,^[45] the cost savings by the reduced coke breeze consumption of 0.22 t h^{-1} result in savings of 28.6 EUR/h. These savings are slightly below the cost of classification. However, further benefits of the reduced amount of recycled dust in case of air classification like the reduced efforts for material handling could outweigh the somewhat higher cost of the air classification option.

4. Conclusion

The use of air classifiers can help to increase dust recycling and reduce the amount of landfilled dust from air pollution control in steel mills substantially. Even if moderate costs per ton for landfill are taken into account, economic feasibility of dust treatment by air classification has been demonstrated in different cases. Although recycling is not top priority in many steel companies a good reason for an investment in a CP could be that available space in the existing landfill site is limited.

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Conflict of Interest

The authors declare no conflict of interest.

Keywords

Classification, Cost of treatment, Dust recycling

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