Potential of Air Classification in Process-Plant Dust Recycling: A Mini-Review

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Abstract. Steel and cement plants, as well as biomass-based combustion plants, generate substantial amounts of fine dust that are removed from off-gases by de-dusting systems. The resulting residues are typically enriched in components that are volatile under process conditions, such as zinc and alkali salts. Due to volatilization at high temperatures and subsequent re-deposition during off-gas cooling, these species preferentially accumulate in the finest particle-size fractions. The presence of such components often restricts the utilization and recycling potential of de-dusting residues. Particle-size classification represents an effective strategy to address this challenge, as it enables the selective separation of the enriched finest fractions, thereby reducing the concentration of volatile components in the coarser bulk material. In addition, the fine fraction enriched in volatile species may, in certain cases, constitute a suitable feedstock for their targeted recovery. Owing to the characteristic cut sizes in the micrometre range, air classification is particularly well suited for this purpose, offering precise separation under dry processing conditions. This mini-review discusses the potential of air classification as a key processing step in the utilization and recycling of dust residues from industrial process plants, with a focus on applications in metal and mineral production.

1. Introduction

Large quantities of dust are generated in the minerals and metals industry as well as during the combustion of solid fuels (Table 1) [1-5]. The residues collected during off-gas de-dusting consist of fine granular materials that must either be valorized or disposed of in landfill sites. These residues are typically enriched in components that are volatile under process conditions, particularly heavy metals such as zinc and lead, as well as alkali salts. During high-temperature processing, these species vaporize and subsequently re-deposit onto existing particles as the off-gas temperature decreases. Because finer particles exhibit a higher specific surface area, the concentration of re-deposited material increases with decreasing particle size [6].

In recycling applications, such volatile components are generally undesirable because they tend to accumulate within the process through internal recirculation. However, for external utilization, for example for the targeted extraction of volatile components, their particle size–dependent enrichment can be advantageous for downstream recovery processes. Owing to the pronounced dependence of volatile component concentration on particle size, classification represents a viable approach to reducing their content in the bulk material by separating the enriched finest fractions. A well-established example is the treatment of sludge from wet off-gas cleaning of blast furnaces using hydrocyclones, where a zinc-enriched fine fraction is separated from the coarser sludge fraction [7,8]

Table 1. De-dusting residues in the process industry; quantities calculated from production volume and mean specific dust emission rates

Process	*Quantity of de-dusting residues [10^6 t/a]*	Source
Sinter plant	0.18 (EU, 2004)	[1]
	1.5 (China, 2010)	[2]
Blast furnace (BF)	1.9 (EU, 2004)	[1]
	18 (China, 2010)	[2]
Steel converter (BOF)	1.5 (EU, 2006)	[1]
Electric arc furnace (EAF)	1.6 (EU, 2006)	[1]
Biomass combustion plants	3 (EU, 2003)	[3,4]
Cement mill	33 (EU, 2006)	[5]
	320 (World, 2006)	[5]

For dry de-dusting residues, air classification has been proposed previously [9,10]. In one study, also technical

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realization of air classification unit for zinc enrichment and depletion of BF dust has been reported [11].

2. Possible fields of Application

2.1. Dust recycling in Integrated Steel Mills

In integrated steel mills, dust streams arising from the sinter plant, the blast furnace (BF), and the basic oxygen furnace (BOF) must be recycled to ensure resource efficiency. The primary internal recycling route is via the sinter plant. However, the recycling capacity of the sinter plant is limited by the acceptable input levels of zinc and alkali chlorides. Consequently, substantial amounts of dust are still disposed of in landfills.

Air classification offers a suitable method to overcome these limitations by separating dusts into size fractions with different chemical compositions. For sinter plant dust, air classification can be used to produce a coarser particle size fraction with a reduced alkali chloride content, enabling increased recycling via the sinter plant [12]. Similarly, BF and BOF dusts with low to medium zinc concentrations can be air classified to obtain coarser fractions with reduced zinc contents, which are suitable for internal recycling [13,14].

In contrast, BOF dusts with high zinc concentrations cannot be recycled via the sinter plant due to restrictive zinc limits. These dusts can either be processed in external pyrometallurgical recycling facilities [15,16] or recycled internally via the BOF after appropriate agglomeration. In both cases, air classification can be applied to optimize the overall material flow by selectively separating zinc-rich fine fractions. This approach reduces the number of zinc volatilization and redeposition cycles within the steelmaking process, thereby lowering energy demand and process inefficiencies, while simultaneously producing fine fractions with elevated zinc concentrations that are suitable for secondary zinc recovery [17].

2.2. Dust recycling in mini mills

In mini mills (EAF steel mills), the zinc concentration in dusts varies widely, primarily depending on the composition of the scrap charge. Under these conditions, air classification can be applied in a manner analogous to the treatment of high-zinc dusts in integrated steel mills, enabling selective routing of zinc-rich fine fractions to external recycling and improved internal material utilization [18]

2.3. Dust recycling in cement mills

In some cement plants, cement kiln dust (CKD) or cement kiln by-pass dust (CKBD) can be reintegrated into the production process, whereas in other plants these dusts are discharged to landfill sites [3]. The reintegration of CKD and CKBD is primarily limited by their high chloride content, as the maximum permissible chloride concentration in cement is typically 0.1%. CKBD is particularly enriched in chlorides, with reported contents ranging from approximately 7.5% to 17% [19,20], which often prevents its direct recycling. In some plants, CKBD is therefore used as a raw material for the production of potassium chloride fertilizers [20,21]. Laboratory studies have shown that air classification can significantly enrich potassium chloride in the fine fraction while simultaneously reducing the chloride content of the coarse fraction [22]. This approach can improve both the economic efficiency of the leaching process and the potential for recycling the chloride-depleted coarse fraction into the cement manufacturing process.

2.4. Fly ash from biomass combustion

Fly ash from biomass combustion is increasingly recognized as a potential secondary resource for potassium fertilizer production. Biomass fly ash often contains substantial amounts of water-soluble potassium compounds formed by the volatilization of alkali metals during combustion and their subsequent recondensation on fine particles. Several studies have shown that potassium can be recovered from biomass fly ash by water leaching, yielding potassium-rich solutions suitable for fertilizer production. However, experimental results indicate significant limitations of this approach. In a study with straw combustion fly ash potassium leaching efficiencies with water of less than 50% with only moderately higher recoveries under acidic conditions were reported [23]. Such low extraction efficiencies question the feasibility of producing potassium fertilizers via leaching compared to the direct agricultural application of fly ash. As an alternative, air classification has been demonstrated to enrich potassium in the fine particle fraction of biomass combustion fly ash. This approach has been successfully validated both in laboratory experiments [24] and at industrial scale [25], improving the potential for targeted potassium recovery while supporting circular economy strategies.

3. Conclusions

Industrial de dusting residues from steelmaking, cement production, and combustion processes present both challenges and opportunities due to their enrichment in volatile constituents such as zinc and alkali chlorides. As discussed in this mini review, the pronounced particle size–dependent enrichment of volatile components provides a systematic basis for optimizing recycling and utilization pathways for these materials. Air classification represents a technically robust and flexible dry separation method that enables the selective separation of fine fractions enriched in volatile components - particularly zinc and potassium salts - while simultaneously depleting the coarser bulk material. Across integrated steel mills, mini mills, cement plants, and biomass combustion systems, air classification has demonstrated clear benefits in reducing process limitations, improving resource efficiency, and enabling targeted recovery of valuable components. Both laboratory scale studies and industrial applications confirm its technical feasibility. Overall, air classification constitutes a versatile and scalable process that can support circular economy strategies by improving residue utilization and reducing landfill disposal.

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