

THE NATURE OF PARTICLES AND FINES IN POTROOM DUST

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Abstract

Potroom dust or particulates are major contributors to a smelter's total environmental burden. A wider study on the environmental contribution of these particulates was conducted across multiple prebake smelters, part of which was to determine the composition and particle size distribution of this dust and its material sources. This has provided an understanding of the fate of particles within the potroom, after the point of emission. In general, anode cover material and feed alumina were found to be contributors of coarser dust that tends to settle on various surfaces in the potroom (floor, pot superstructures, rafters), thereby becoming a source of recirculating dust. In contrast, bath fume was found to be the dominant contributor to fines/ultrafines, from operations involving open cells and hot, fuming materials in the potroom. Such fines are fluoride-based, highly mobile and readily emitted from the potroom. Particles also tend to decrease in size at higher potroom elevations.

Introduction

'Potroom dust', the air-suspended particulate in the potrooms of aluminium smelters, is typically process-related material that has escaped confinement. Components of dust can include: alumina, bath-based compounds (crushed bath, bath droplets and fume), anode cover material, carbon dust, sulfur and metal impurities [1, 2]. Such particulates can range in size from the nanometer-scale up to 100 μ m and beyond [2]. Particulates not specifically related to the smelting process (rust, silicates, marine salts) can also be found in potroom dust, albeit at more minor levels [3].

Typically, potroom dust forms a significant component of the total particulates emitted from a smelter site (e.g. up to 85% of all PM_{2.5} or <2.5 μ m particulates from a smelter [4]). In order to meet increasingly strict regulatory limits for emissions, the industry has a pressing need to understand and address the problem of potroom dust. This has led to a major study on potroom dust commissioned by *AMIRA International* (project P791a) and aimed at understanding its overall sources and generation mechanisms to identify strategies to reduce dust. The study spanned across four pre-bake, point fed aluminium smelters each with varying pot

technologies, operating practices and raw materials. Incorporating these factors provided depth to the study and an ability to identify factors behind potroom dust that are applicable to the industry as a whole. This paper focuses on the particle size distribution (PSD) of potroom dust and its various sources, and hence the fate of particles following their point of emission.

Composition & Sources of Potroom Dust

The composition and sources of both settled and airborne dust have been previously reported [5, 6] for the four case study smelters whereby dust was collected from multiple locations and elevations in each potroom. For ease of reference, a summary of these findings has been provided in Table I.

The composition of *settled dust* showed variations depending on the granulometry of anode cover material and the delivery mechanism for feed alumina used at each smelter (Table I). At smelters with relatively '*fine*' cover and alumina delivered to pots by *conveyors*, settled dust tended to be dominated by cover material (Smelters A and B). However, in smelters with '*coarse*' cover and *crane-loaded* alumina, feed alumina also became an important contributor to settled dust. For example, at Smelter D, settled dust resembled a roughly 50/50 mixture of cover and feed alumina. In contrast, *airborne dust* was shown to be considerably different in composition from settled dust, being high in bath content (Table I) and therefore linked to crushed bath fines (from cover) and bath fume. This general trend applies across all four smelters, regardless of technology, practices and raw materials.

These findings provided a good compositional basis for relating samples of dust at each smelter to their suspected material sources. However, the overall picture of how potroom dust is actually generated and dispersed is still incomplete without a consideration of the PSD of dust and its sources.

Particle Size Distribution & Potroom Air Flow

Tracking the PSD of dust at different potroom locations and elevations, both in settled and airborne forms, provides further insights to understanding the dust problem.

Table I: Composition of settled and airborne dust across four case study smelters categorised in terms of the delivery method for feed alumina and the granulometry of anode cover material. Reproduced from a previous publication [6].

Smelter	Delivery Mechanism for Feed Alumina to Pot	Granulometry of Cover Material	Composition of Settled Dust	Composition of Airborne Dust
A	Conveyed to Pot	'Fine'	Predominantly Cover Material	Mostly Bath Fines + Fume
B	Conveyed to Pot	'Fine'	Predominantly Cover Material	Mostly Bath Fines + Fume
C	Loaded by Crane to Pot	'Coarse'	Mostly Cover + some Feed Alumina	Mostly Bath Fines + Fume
D	Loaded by Crane to Pot	'Coarse'	50% Cover + 50% Feed Alumina	Mostly Bath Fines + Fume

First, it confirms the compositional links between dust sources and collected dust samples. Second, it provides a means to track the fate of particles starting from (i) the point of dust release into the potroom, (ii) to transport or dispersion around the potroom, and (iii) whether particles settle in the potroom or escape through the potroom roof as a fugitive emission.

In conventional particle mechanics, the fate of an emitted particle – i.e. whether it settles or continues to be suspended in air – is governed by whether upwards air flow velocities (v_{air}) exceed the particle's terminal velocity ($v_{particle}$) due to gravitational settling. The terminal velocity of a particle is dependent on its particle size, shape and density, as well as the air flow regime past the particle (laminar or turbulent) [7]. Figure 1 shows an illustration of how particle terminal velocity varies as a function of particle size [8] whereby particles settle when $v_{air} < v_{particle}$ or remain airborne if $v_{air} > v_{particle}$. In general, larger particles tend to settle closer to their points of emission (i.e. the potroom floor level), whereas smaller particles tend to be more easily suspended and carried away by air currents flowing through the potroom. For very small particles ($<0.5\mu\text{m}$), motion is governed more by Brownian diffusion and less by gravitational settling. Note that as the particle densities and the air flow regime assumed in Figure 1 have not been explicitly stated, care should be taken when reading off particle 'cut-off' sizes for settling vs. entrainment.

In a typical potroom, upwards air velocities at the roof vent are in the range of 0.5-1.5m/s [9, 10]; for reference, these are indicated in Figure 1 as horizontal lines. At such velocities, one might deduce that particles larger than $>100\mu\text{m}$ are likely to settle and remain inside the potroom, whereas smaller particles are more likely to remain airborne. Clearly, the mobility and therefore the propensity of particles to escape through the potroom roof as fugitive dust increases with decreasing particle size. Considering these factors, one might expect to see a *natural stratification* or separation of dust as a function of particle size within the potroom where larger particles settle at lower elevations in the potroom and finer particles settle at higher elevations or are ultimately emitted from the potroom. This trend is certainly supported by Garrec and Passera's study of fugitive dust from a smelter that had deposited on vegetation surrounding the site; 80% of particulates were of an ultrafine nature ($<2\mu\text{m}$), with very few particles in the $>5\mu\text{m}$ range [11].

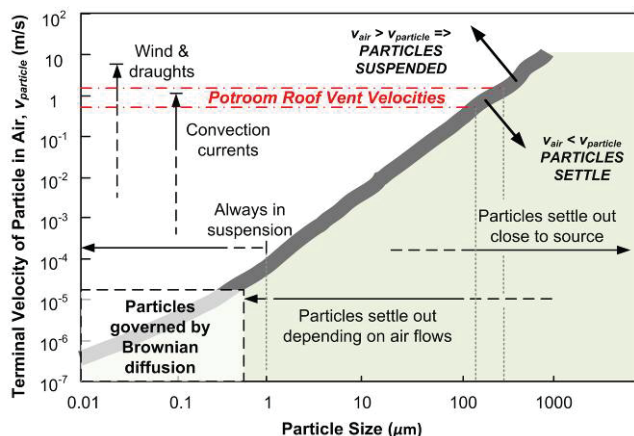


Figure 1 – Simplistic relationship between particle terminal velocity vs. particle size. Figure adapted from Chambers *et al.* [8].

In understanding the transport of dust, a further consideration is that of air flow patterns within the potroom. While the dominant airflow direction in a potroom is upwards (driven by the convective heat losses from pot superstructures, rising towards the roof), many potroom ventilation studies have shown that potroom air flow patterns vary with time and are fairly complex [12, 13], e.g. with swirls and eddies that influence the patterns of dust settling. Factors that can impact on potroom air flows include [9, 10]: external wind gusts, cyclic day- night breezes, and potroom doorways or openings. As is suggested by Figure 1, external wind gusts and air flows can act to pick up or re-suspend old, settled dust from various potroom surfaces. Furthermore, potroom operations involving open cells with exposed bath or exposure of hot, fuming materials in the potroom (e.g. cooling spent anodes, cavity cleanings) are often associated with strong, rising plumes of hot gases and therefore are also expected to impact on potroom air flow patterns.

The combination of the above factors (varying particle size, complex air flows) suggests that the air-suspension vs. settling behaviour of dust particles cannot be easily predicted or modelled. However, clues as to the fate of particles can still be obtained by looking at the particle size distribution of settled and airborne dust at multiple locations and elevations in a potroom. These are presented in the remainder of the paper.

Sampling & Particle Size Analysis Methodology

Samples of *settled dust* (dust sweepings, passively collected dust) were taken from a range of potroom locations and elevations at each smelter: from the basement, to the operating potroom floor, pot super-structure level, up to the roof or rafters level. Similarly, *airborne dust* was sampled at operating floor and potroom roof levels at each smelter, using *Tisch TE-2000P* high volume samplers (350 L/min, 110mm Whatman GF/C filters); sampling was conducted over entire cycles of operations (24-48 hours) and individual operational shifts (anode change and metal tap shifts). At one smelter, airborne dust from cooling spent anodes (immediately after anode change) was also collected in a special-purpose monitoring facility. Samples of *suspected dust sources* – feed alumina, anode cover material, crushed bath and pot fume (represented by GTC or dry scrubber inlet duct particulate and condensed particulates from the undersides of pot hoods) – were also collected at each smelter for comparison. For more details on dust sampling, refer to [5, 6].

Particle size analysis differed for samples in loose particulate form (i.e. settled dust and dust sources) vs. dust collected on the surface of filters (airborne dust). Samples of loose particulates were characterised via dry sieving for coarse particles ($>500\mu\text{m}$) and by laser particle sizing for fine particles ($<500\mu\text{m}$). Dry sieving was conducted using 500 μm , 850 μm and 1700 μm sieves. Laser sizing was conducted using a *Malvern Mastersizer 2000* with agitation, ultra-sonification and water dispersant; refractive indices used were estimated on the basis of composition for each dust sample. For airborne dust, particle size analysis was conducted by SEM analysis on small 5x10mm cut-out sections from dust filters. These provided a means to visually estimate the size distribution of particles, as well as to assess the type and morphology of particles present. Dry sieving and laser sizing were not conducted on airborne dust due to the difficulties involved in extracting samples from dust filters.

Results & Discussion

Particle Size of Settled Dust & Dust Sources – Coarse Fractions

Sieving results for settled dust and suspected dust sources are displayed in Figure 2 for Smelters A and C (please note that sieving was not done for Smelter B, whereas results for Smelter D were not shown for the sake of brevity). Particle size fractions are in terms of wt % $<500\mu\text{m}$, $500\text{--}850\mu\text{m}$, $850\text{--}1750\mu\text{m}$ and $>1750\mu\text{m}$. Also indicated are the potroom elevations from where settled dust samples were collected, from the basement up to the potroom roof level. Figure 2 provides two key observations.

Firstly, at both Smelters A and C, there is a clear trend that the particle size of settled dust *decreases* with increasing potroom elevation. At the floor and basement elevations, the level of coarser $>500\mu\text{m}$ particles can be up to 50%; however at the roof level, there are few coarse $>500\mu\text{m}$ particles ($<1\%$) in settled dust. This supports the action of a ‘natural stratification’ effect in the potroom where larger particles settle at lower elevations of the potroom and finer particles tend to reach higher elevations.

Secondly, the particle size of settled dust is clearly linked to the particle size of its material sources. At Smelter A, where cover granulometry is relatively ‘fine’ (Table I), fine $<500\mu\text{m}$ particles are the dominating component (75–93%) of settled dust at the floor level. At Smelter C where cover granulometry is ‘coarse’ (Table I) however, fines $<500\mu\text{m}$ play a considerably smaller role in settled dust at the floor level (50–59%). This link between cover and settled dust confirms previous compositional findings that cover material is a dominant contributor to settled dust at both smelters (Table I). The influence of different bath crushing technologies is also apparent, with the *autogenous mill* at Smelter A producing very fine crushed bath (87% $<500\mu\text{m}$), whereas *rotary breakers* at Smelter C produce coarser crushed bath (as low as 34% $<500\mu\text{m}$ fraction); coarser bath reduces the propensity of cover to form dust (Table I).

As for other sources, both alumina and pot fume (represented by GTC inlet duct particulate) are much finer than crushed bath and cover material, being composed of almost all particles $<500\mu\text{m}$.

Particle Size of Settled Dust & Dust Sources – Fine Fractions

Results from laser sizing of the finer ($<500\mu\text{m}$) fractions of dust sources from Smelters A, C and D are shown in Figure 3. The top graph displays size distributions for secondary alumina and cover material, whereas the bottom graph is for pot fume samples, represented by GTC inlet duct particulate and condensed material under pot hooding. Similarly, a comparison of settled dust in relation to its dust sources from Smelter A is shown in Figure 4.

Interestingly, the fractions $<500\mu\text{m}$ for cover material were very similar across the three smelters (Figure 3), despite being regarded as relatively ‘fine’ at Smelter A and ‘coarse’ at Smelters C and D (Table I). This suggests that different bath crushing technologies have more of an impact on the proportion of coarser $>500\mu\text{m}$ particles (Figure 2) than on the size distribution of smaller size particles $<500\mu\text{m}$. The particle size distributions for alumina were also very similar (Figure 3), except for the alumina at Smelter A being slightly finer. Volume-median particle diameters, $d(0.5)$, for $<500\mu\text{m}$ fractions ranged $60\text{--}70\mu\text{m}$ and $70\text{--}90\mu\text{m}$ for cover and alumina samples, respectively.

Pot fume, represented by *GTC inlet duct particulates* were relatively similar in size across the three smelters (Figure 3), apart from material at Smelter A being finer (consistent with ‘fine’ cover). This material is finer than both cover and alumina, with a $d(0.5)$ of $20\text{--}30\mu\text{m}$. Interestingly, these samples did not contain a significant level of sub-micron particles as was found by earlier researchers [1, 14]. Pot fume particulates at Smelter D, primarily consisting of *condensed particulates from underneath pot hooding*, were considerably finer than any other collected sources, with a very small median particle diameter, $d(0.5)$, of $0.2\mu\text{m}$.

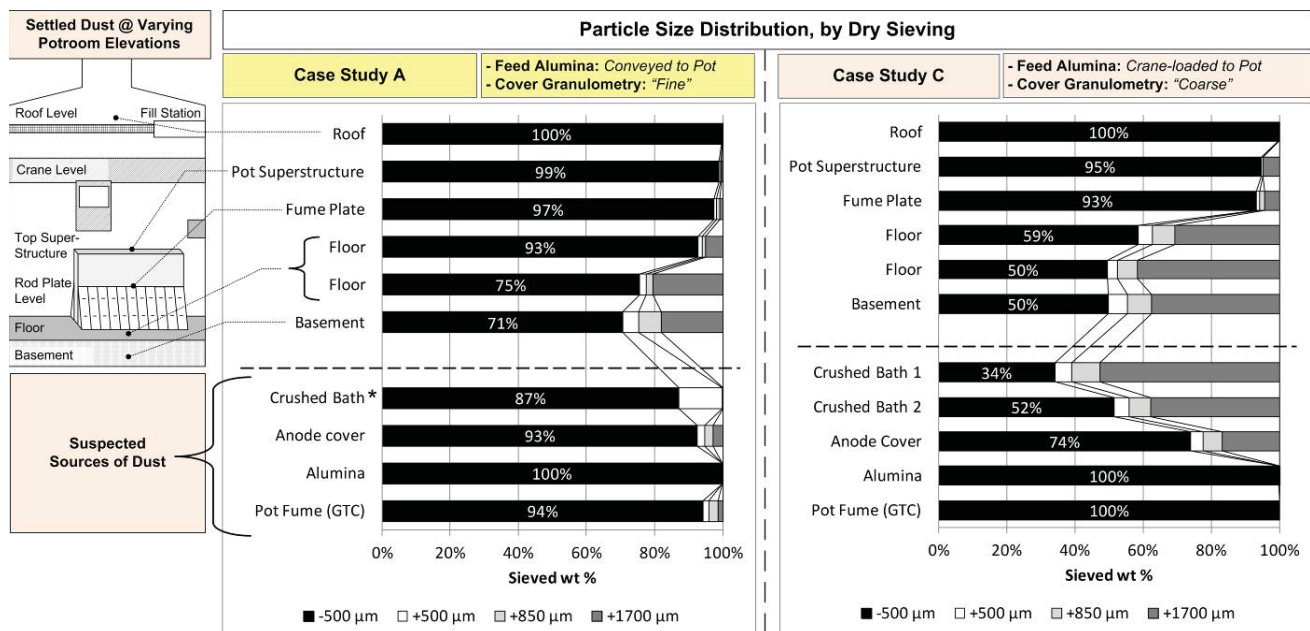


Figure 2: Particle size distribution of settled dust and dust sources (by dry sieving) for [Left] Smelter A and [Right] Smelter C, displayed as a function of potroom elevation. *Note: for the crushed bath sample in Smelter A, the $+850$ and $+1750\mu\text{m}$ fractions were not measured.

As mentioned, these particles are linked to condensed bath fume or vapour since they were high in fluorides and bath phases (confirmed with EDS elemental and XRD analysis); furthermore, a gas-to-solid process such as the condensation of bath vapour, would be expected to form particles in the $<1\mu\text{m}$ sized range [7]. Particles that result from a particle break up or other mechanical processes (e.g. crushed bath and cover) typically do not fall within the $<1\mu\text{m}$ range [7].

Particle size ‘fingerprints’ relating to each dust source were then compared to *settled dust* at Smelter A. As shown in Figure 4, the $<500\mu\text{m}$ size distribution of settled dust largely matched that of cover material and feed alumina. While settled dust also has a ‘tail’ of particles in the $1\text{-}10\mu\text{m}$ range (probably from cover or alumina fines), it does not venture into the $<1\mu\text{m}$ size range that would be characteristic of condensed bath fume. As such, the size analysis clearly distinguishes cover and feed alumina as the major sources of settled dust. Finally, the trend of decreasing particle size with increasing potroom elevation is also visible in the $<500\mu\text{m}$ size fractions of settled dust (Figure 4), again pointing to the natural stratification of dust within the potroom.

Particle Size Nature of Airborne Dust

The PSD of airborne dust is different to that of settled dust. A set of SEM images of airborne dust from Smelter C is shown in Figure 5; this is obtained from sampling over an entire cycle of potroom operations at both the operating floor and potroom roof levels. For reference, SEM photos of different dust source particles are also shown; these include alumina (regular blocky

appearance, broken shards or sharp platelets of corundum), crushed bath (irregular shaped particles), entrained bath droplets ($10\text{-}20\mu\text{m}$ spheres) and ultrafine particles and needles ($<1\mu\text{m}$) of condensed bath fume. Note that crushed bath and alumina particles vary considerably in size from several microns up to the $100\mu\text{m}$ shown.

First, it can be observed that airborne dust is comprised of a wide range of particles, including: alumina, crushed bath, bath droplets, bath fume and carbon flakes (not shown). Second, there is a distinct difference in airborne dust at the roof vs. floor level. Dust at the roof appears considerably finer with fewer coarse particles of alumina and crushed bath. In comparison, floor level dust appears to contain a greater proportion of coarser particles, i.e. alumina and bath. However, dust at both elevations contain a high level of ultrafine bath fume particles which matches with the high bath content found in the general composition of airborne dust (Table I). Since ultrafines ($<1\mu\text{m}$) do not feature significantly in the PSD of settled dust (Figure 4), this again confirms the differences between settled and airborne dust.

Finally, at Smelter C, there is an even greater incidence of ultrafine bath fume particles at the roof than at the floor level, which again highlights to the natural stratification of dust particles after the point of emission with coarser particles tending to settle closer to the floor level and finer particles tending to be aerated up to the roof level and into the air. Please note that while the same general trend was found in SEM investigations of airborne dust at all four smelters in the study, the particle size differences in roof vs. floor level dust were the most distinct at Smelter C (Figure 5).

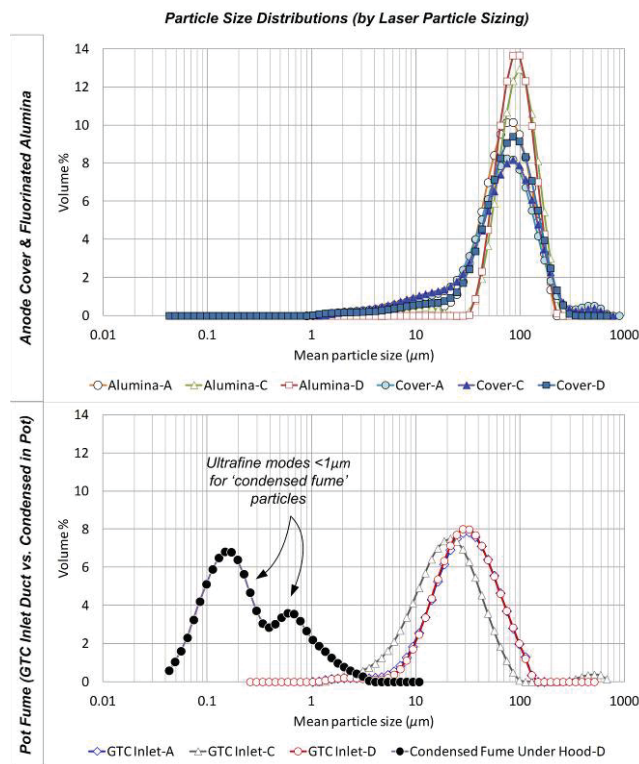


Figure 3: Particle size distributions (by laser sizing) for sieved $<500\mu\text{m}$ fractions of dust sources from Smelters A, C and D, i.e.: [Top] alumina and anode cover material and [Bottom] condensed fume from under pot hooding and GTC inlet duct particulate.

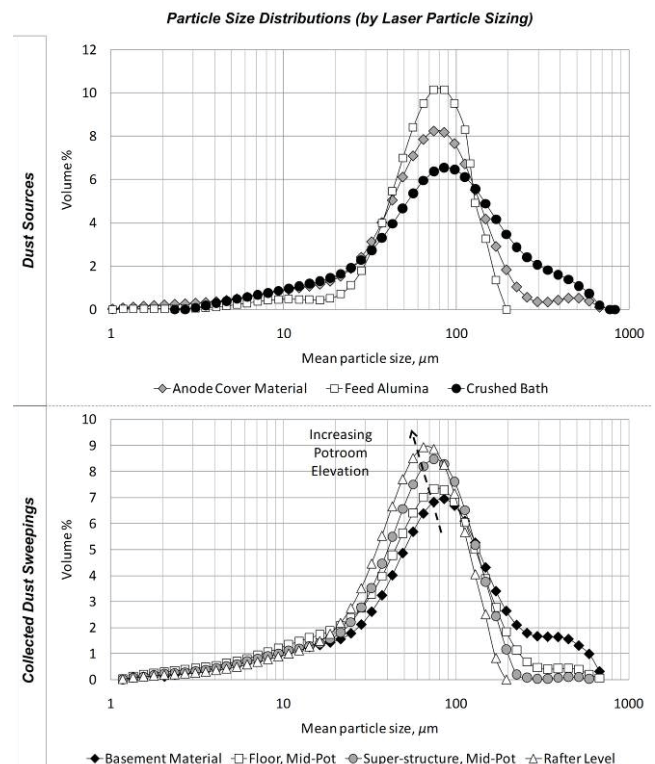


Figure 4: Particle size distributions (by laser sizing) for sieved $<500\mu\text{m}$ fractions of [Top] dust sources and [Bottom] settled dust sweepings at various potroom elevations from Smelter A.

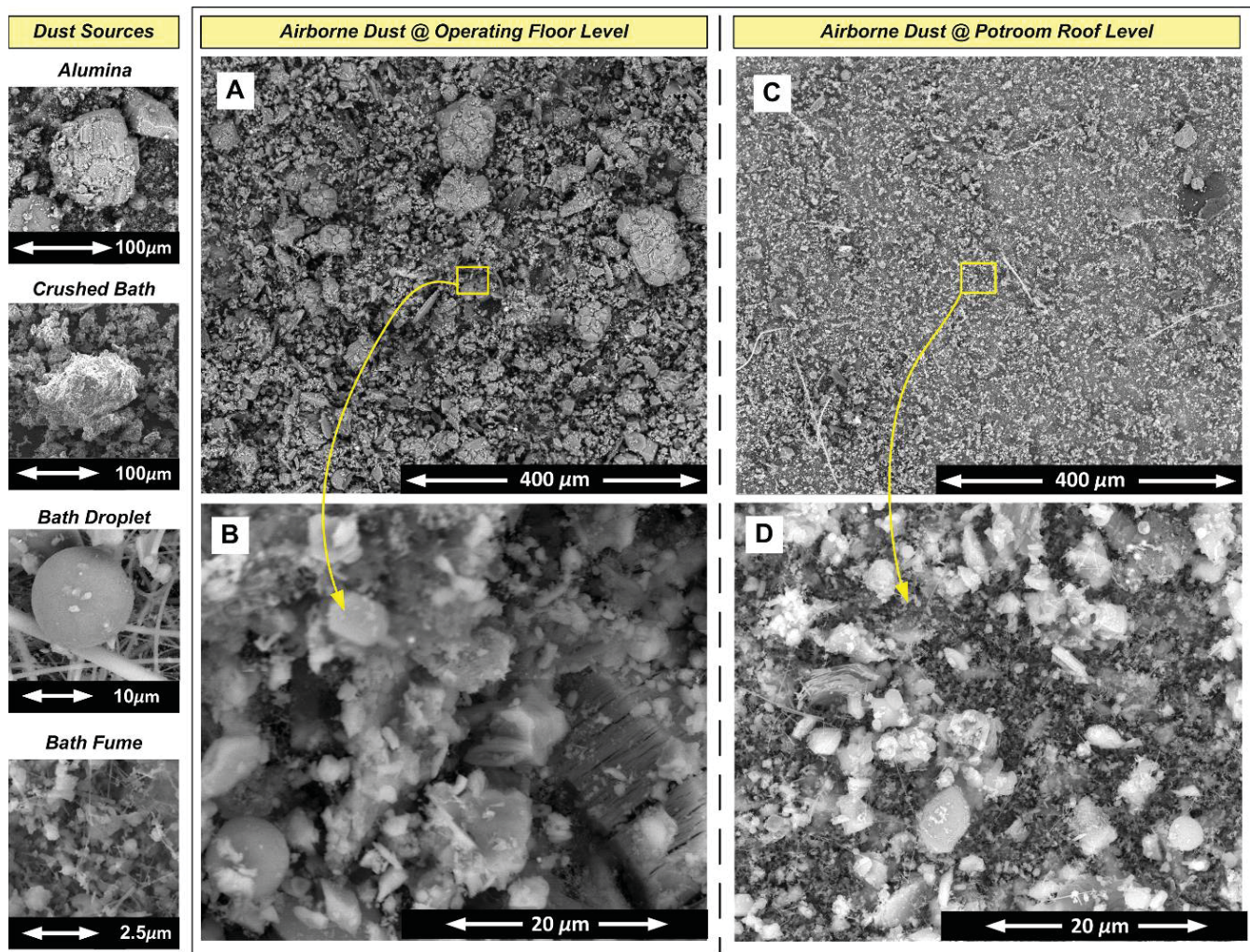


Figure 5: SEM photos of dust sources [Left] and airborne dust [Centre and Right] from Smelter C, from sampling over an entire cycle of operations at both the operating floor [A, B] and potroom roof level [C, D]. Note the differences in scale in each SEM photo.

Airborne dust particles emitted from cooling spent anodes were also investigated using SEM, the results of which are shown in Figure 6. Unlike airborne dust collected from within the potroom, airborne dust collected from above cooling anodes did not contain a wide range of particles. Rather, it comprised of almost all ultrafine ($<1\mu\text{m}$) particles and in some cases needles of condensed bath fume. This supports the hypothesis that bath fume (not cover or alumina) is the main form of dust emitted from hot, bath-related materials left in the potroom (spent anodes, cavity cleanings); this means the same type of emission can also be expected during operations involving open cells with exposed liquid bath, e.g. anode changes, metal tapping, bath transfers and so on. As these are all major events in the operational cycle of the potroom, it is not surprising to find that bath fume is a major component of airborne dust.

Discussion on the Fate of Dust Particles by Emission Source

By combining the above findings on dust composition and particle size, one can start to deduce the fate of different dust particles. Compositionally, *airborne dust* contains high levels of bath fume with contributions from cover material and alumina, particularly

at the operating floor level. Operations that involve *exposure of hot materials, liquid bath and open cells* are likely to be responsible for the bath fume component of airborne dust. These emissions are high in fluorides and contain a high level of ultrafines ($<1\mu\text{m}$) that are highly mobile and easily aerated, and therefore have a great propensity to be emitted from the potroom. As such, these particles would be of particular interest to environmental stake-holders in the industry. Furthermore, the ultrafine and chemical nature of bath fume may also be of interest to those managing occupational exposures in smelters.

Operations that involve the *loading of raw materials* (hopper loading, cover application) are likely to be initially responsible for the bath cover and alumina components of airborne dust. These emissions involve particles that are much coarser in particle size and therefore have a greater propensity to settle within the potroom, with larger particles settling closer to the floor and finer particles settling on higher potroom surfaces. These transport processes are well supported by the strong links between settled dust vs. cover and alumina, both in terms of composition and particle size. Accumulations of settled dust can then become a further source of dust emission, in the form of re-aerated or

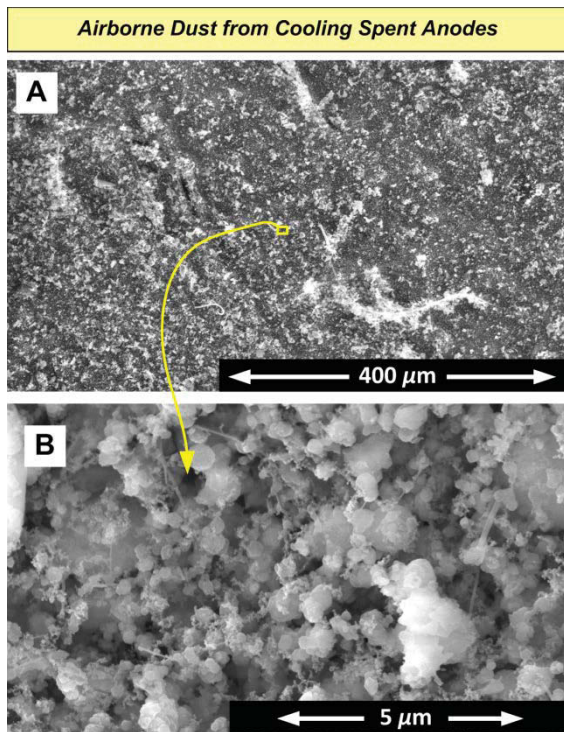


Figure 6: SEM photos of airborne dust collected above spent anodes after anode change, at low [A] and high magnification [B].

recirculating dust, through housekeeping operations, vehicle movements, or even through gusts of wind or air movements through the potroom. Recirculating dust subsequently becomes a further contributor of bath cover and alumina-based particles in airborne dust.

Conclusions

The study of the particle size distribution of potroom dust and its sources has provided many insights to understanding the fate of dust particles, following their origin and subsequent point of release into the potroom. Settled dust, being largely composed of cover and alumina, is initially released as airborne dust during materials loading or handling operations; due to their coarse particle size nature, emitted cover and alumina particles have a tendency to settle in the potroom on various surfaces. The settling of dust results in a stratification of particles by size – larger particles settle closer to their emission sources at the operating potroom floor, whereas finer particles either settle on higher potroom surfaces or are emitted from the potroom. Settled material then represents a source for re-aerated or recirculating dust. In contrast, operations involving open cells, exposure of hot, fuming materials and exposure of liquid bath, are highly related to emissions of condensed bath fume. These fluoride-rich particles have a high content of ultrafines ($<1\mu\text{m}$) and are therefore easily aerated, highly mobile and are more likely to be emitted from the potroom as fugitive dust.

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