Size Reduction, Classification, Spheronization, and Recycling of Electrode Active Raw and Recycling Materials

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Abstract. The rapidly growing demand for lithium ion batteries increases the need for efficient and sustainable processing of battery materials along the entire value chain. Across both first life material production and battery recycling, size reduction, classification, and spheronization represent key process steps governing material performance and process efficiency.

This contribution presents three exemplary applications illustrating the relevance of these unit operations:
(i) grinding, classification, and spheronization of natural and synthetic graphite for anode active materials
(ii) fine grinding and classification of lithium carbonate as a cathode precursor, and
(iii) classification of black mass to recover anode graphite and subsequent respheronization for battery recycling applications.

Advanced NEUMAN & ESSER impact mill and classifier technologies (ICX, ICS, and DCX) are applied to address the specific process requirements of each application, enabling high energy efficiency, narrow particle size distributions, and controlled particle morphology. The presented approaches enhance material performance in first life batteries and enable the production of high quality secondary raw materials, supporting a circular "battery to battery" value chain.

1. Introduction

The accelerated transition toward renewable energy and electromobility has dramatically increased global demand for batteries. While lithium is often perceived as the key element, the graphite content in a single lithium-ion cell is typically 10–15 times higher than the lithium content, making graphite processing a central challenge in battery manufacturing. High-performance anodes require high purity, precise particle size, and particularly spherical morphology to ensure defined specified values for surface area, flake formation, and tap density as well as long cycle life.
Alongside first-life battery material production, the end-of-life treatment of batteries is becoming increasingly strategic. In addition to tightening EU recycling regulations, black mass recycling provides significant potential for recovering graphite and critical raw materials such as cobalt, enabling substantial CO_2 reductions and facilitating a closed-loop "battery-to-battery" value chain.

2. Grinding, Classification, and Spheronization of Graphite as Anode Active Material

The overall development goal for the NEUMAN & ESSER (NEA) spheronization system was to increase both yield and throughput in comparison to conventional plants, and to offer a system that can easily be adapted to different final product requirements and offers an easy scale-up. The resulting NEA system for the spheronization comprises merely two units. The size reduction, hereinafter referred to as micronization, occurs in the NEA ICX (Impact Classifier Mill eXtra) with an internal dynamic air classifier. The actual spheronization is conducted downstream of the NEA ICX in a NEA ICS (Impact Classifier Spheronization). Both machine types are available in various sizes offering a suitable plant size for any required output capacity.

Superfine comminution in the NEA ICX (Figure 1) requires increased grinding intensity. Therefore, the grinding zone geometry was designed accordingly. The size of the final product is determined by the intensity as well as the frequency of the mechanical stress during the grinding process. These factors are both strongly influenced by the fluid dynamics in the mill [1] [2] [3].

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The same applies to the development of the NEA ICS for spheronization. Grinding intensity must be adjusted carefully to ensure shaping within as few internal circulations as possible, without overstressing the product.

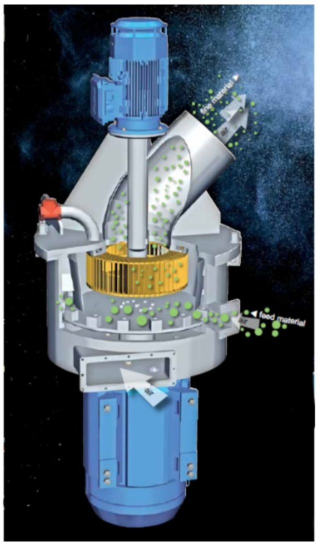

Figure 1: Impact Classifier Mill Extra (ICX)

The routing of the particles from the grinding zone towards the classifier wheel is of the same importance: It is crucial that the ground material is distributed homogenously across the classifier wheel flow cross-section.

For good classification results, both the radial and tangential velocity component of the process gas have to correspond to the desired cut condition at the outer circumference of the classifier wheel. The classification efficiency strongly depends on the inflow conditions of the dynamic classifier wheel [4] [5] [6] [7] [8]. The guide ring design takes this requirement into account. Furthermore, the classifier wheel was designed fto enable superfine cuts. The design principle of both the classifier wheel and the guide ring correspond to the design of the NEA Deflector Classifier Extra (DCX, see Figure 2) [9], and the NEA Guide Ring Classifier (GRC) [10].

Production lines include the classifier NEA DCX. With additional classification steps in the production line, both residual dust as well as final product can be separated from the particle stream to avoid overloading the comminution and spheronization apparatuses, and overstressing of the product. This leads to an increase in final product yield.

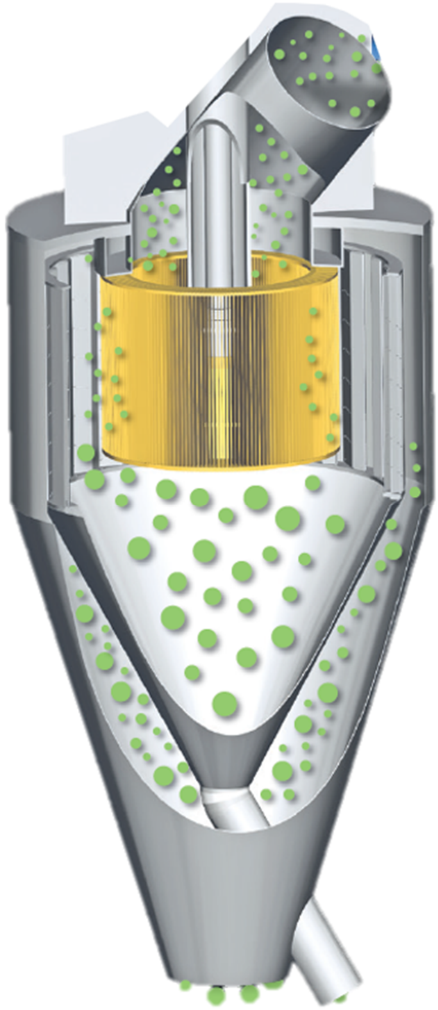

Figure 2: Deflector Classifier eXtra (DCX)

The presentation will show grinding and spheronizing results of the NEA spheronization system, which has been tested extensively in the NEA test center and successfully put into commercial operation. Key parameters determining the final product quality are particle shape (e.g., determined by flow cytometry), tap density, particle size distribution (PSD), specific surface area (SSA), combined with high yield and throughput. All of those can be adjusted by applying appropriate settings of the process parameters.
Spheronized product with a d_{50} between 5 µm and 20 µm and tap densities > 1 g/cm³ can be produced reliably at high yields.

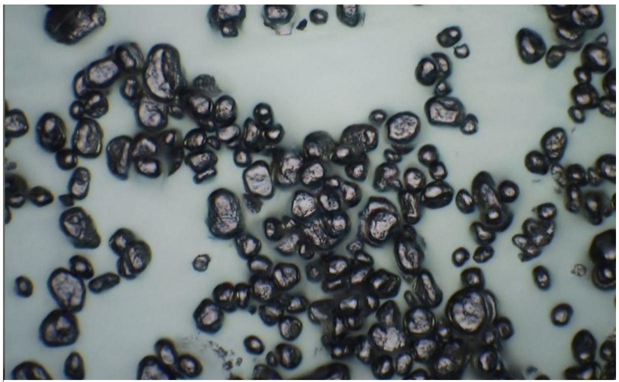

Figure 3: Shaped natural Graphite

Figure 4: Synthetic graphite precursor; green/calcined coke

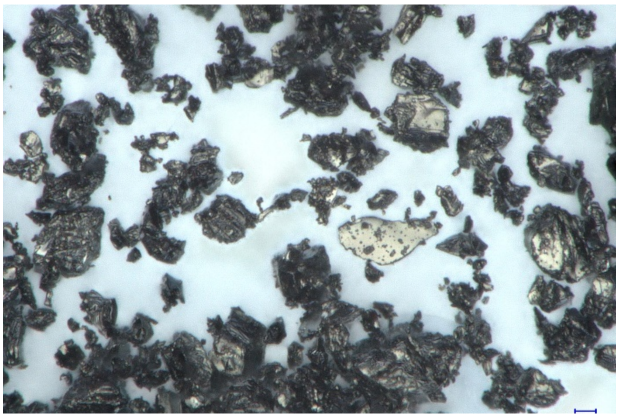

Figure 5: Hard carbons from biomass, suitable for Na-Ion battery

3. Grinding and Classification of Lithium Carbonate as Cathode Precursor

Lithium carbonate (Li_2CO_3) is a critical precursor for cathode active materials, particularly NMC, NCA, and LFP chemistries. Its fineness, PSD, and purity directly affect downstream processes such as calcination, solid-state reactions, and slurry rheology.

Lithium carbonate processing imposes several challenges:

- Agglomeration tendency: Li_2CO_3 often forms soft agglomerates, requiring controlled, low-stress grinding.
- Heat sensitivity: Excessive process temperature promotes caking and alters moisture levels.
- Ultra-fine PSD: Typical required top cuts are d_{98} < 10–20 µm, depending on cathode chemistry.
- Stable classification: Narrow PSD improves reactivity and homogeneity during cathode precursor synthesis.

The NEA ICX is also suited for lithium carbonate micronization. Its grinding zone can be configured for softer, brittle materials, minimizing excessive fines formation. Controlled rotor speed and classifier settings ensure:

- uniform breakage of soft agglomerates
- minimal generation of <1 µm dust
- stable product temperature (<70–80°C)

The NEA Classifier provides high-efficiency top cuts critical for cathode precursor performance.

The presentation will show grinding and classifying results on a small production size impact classifier mill NEA ICX at a d_{50} < 5 µm, and will provide an outlook to the processing of lithium carbonate on the largest available NEA ICX1600 with a grinding chamber diameter of 1600 mm!

4. Classifying Black Mass to Recover Graphite and Respheronization of Recovered Anode Material

Recycling black mass—generated from mechanical battery shredding—plays a central role in the sustainable battery industry. While most attention focuses on lithium, nickel, cobalt, and manganese, high-purity graphite is also recoverable and constitutes a major mass fraction.

The recycling of graphite imposes several challenges:

- contaminated with cathode particles, separators, carbon black, and metallic debris
- partially degraded and may have irregular morphology
- mixed across wide PSD ranges (d50 from 5 µm to >100 µm)

Effective and efficient separation requires a robust air-classification strategy.

The NEA Classifier provides

- fine separation between graphite (low density) and active cathode particles (higher density)
- narrowing of PSD for downstream processing
- reduction of heavy impurities (Cu, Al, Fe)

Through controlled air-classification, a refined graphite fraction can be isolated with higher purity, enabling reuse. Recovered graphite typically exhibits flake-like or crushed morphology. To reinstate its usability in battery anodes, the particles are rounded via the ICS spheronizer. This process yields recycled spherical graphite with:

- improved tap density
- reduced specific surface area
- restored electrochemical performance comparable to primary graphite

The presentation will show results from successful tests of classifying and respheronizations test of recovered black mass from recycled batteries.

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