

How to Uniformly Disperse Nanoparticles in Battery Cathode Coatings

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Advances in nanotechnology enable precise and repeatable dispersion of nanoparticles.

The materials in anodes and cathodes within a lithium-ion battery affect voltage, capacity, and battery life. When a battery is discharging, the lithium ions move from the anode into the cathode. During the charging process, that movement is reversed. Electrolytes conduct the lithium ions and serve as a carrier between the cathode and the anode when electric currents pass through an external circuit. (Fig. 1).

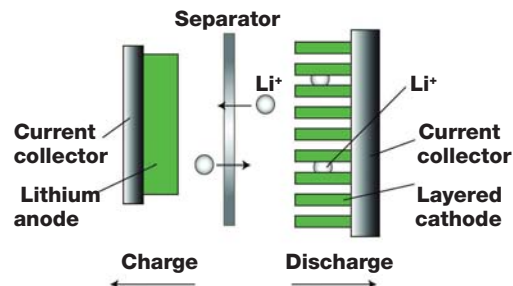


Fig. 1 – Lithium-ion battery diagram.

For anodes, graphite is the primary material for lithium-ion batteries. The carbon anode is prepared and applied as a “slurry” coating layer.

For cathodes, slurries of manganese, cobalt, and iron phosphate particles are frequent choices. In addition, lithium-cobalt oxide and lithium-manganese oxide are common cathode coatings. However, lithium-iron phosphate (LFP) particles provide improved safety, longer cycles, and longer operating life. Iron and phosphate are also less expensive than other materials, and their high charge capacities make them a good match for plug-in hybrid applications.

LFP battery cells do contain lower voltage and energy density levels than other Li-ion materials, but their slower rate of capacity loss helps maintain a higher energy density level after one year of service. Fortunately, the challenges associated with limited charge and discharge rates have been alleviated by improved manufacturing techniques. These techniques involve a precise and repeatable manufacturing approach that relies on advances in nanotechnology.

Nanotechnology Processes

Finely ground particles of lithium-iron phosphate and graphite in electrode coatings are more easily penetrated by lithium ions, and this improves the battery conductivity. Uniformly dispersed coatings comprised of nanosize particles can also help a battery hold its charge longer and re-charge at a faster rate.

Two main methods are available for producing nanosize particles for a coating mixture: The condensation or bottom-up process; and the comminution or top-down method.

- In the condensation process, particles are derived from the precipitation of molecules from solids dissolved in liquids or gases. This process makes it possible to produce very pure and almost mono-dispersed spherical particle systems, but it typically results in low production levels with limited scalability. Another challenge is that it can result in a product that is agglomerated or aggregated, which takes more energy to later turn into a coating.

- In the comminution process, larger particles are milled to nanosize. This is a more effective method, but getting larger particles down to submicron particle size requires high energy density, achieved through wet comminution with a media mill.

Nanogrinding

Media milling – or grinding – is the most well-established manufacturing method for nanoparticle production. Stirred media mills are used in many different industries to reduce particle size, and lithium ion battery manufacturers are joining the ranks of those who are able to develop higher-quality products because of this equipment. Preparing particles in stirred media mills reduces the energy needed to mix a consis-

tent coating dispersion in the next phase of the process, because of the smaller resulting particles.

Nanogrinding with a stirred media mill offers key benefits, including:

- Excellent particle size control
- Comparative cost effectiveness
- Equipment scalability, from benchtop to production
- Repeatability of process

Stirred media mill designs continue to advance, and agitator design is also an important consideration. **Figure 2** shows an agitator and chamber design of a modern media mill for grinding lithium ion phosphate and graphite. The system creates grinding and dispersion by agitating the beads with the pins or pegs on the agitator shaft. Uniform compression throughout the chamber's length is key to this process. This concept results in total utilization of the media charge and mill capacity for greater efficiency in particle size reduction.

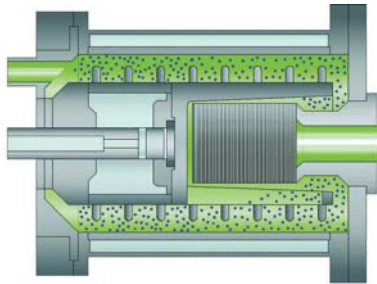


Fig. 2 — Stirred media mill system

Another key consideration is to keep particles free from contamination during the milling process. Metal grinding equipment can slough off metal particles, leading to accidental contamination, affecting the final quality of the coatings. Ceramic mills, free of metal grinding shafts and chambers, can prevent this contamination.

Improving Consistency

Coating dispersions of anodes and cathodes can also be improved with proper equipment to mix and de-aerate the solid lithium-iron phosphate and graphite particles into liquids, typically an alcohol or acetone solvent.

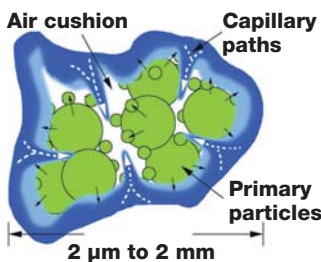


Fig. 3 — Air trapped in a wet agglomerate.

Immersing a dry agglomerate that contains air into a liquid creates small bubbles. **(Figure 3)** This can directly affect the consistency and performance of an electrode's coating. Therefore, it

is critical that coatings be free of any agglomerates or micronized air bubbles.

Some mixing equipment is able to automatically de-aerate while wetting powders into a liquid solution. Macro-cavitation and pressure wetting break down agglomerates, and a vacuum removes any micronized air **(Figure 4)** This helps ensure a repeatable, optimal dispersion that maximizes coating properties.

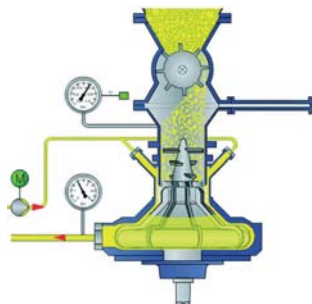


Fig. 4 — Dispersion process with Netzsch's PSI-Mix inline disperser.

By pairing stirred media mills and in-line liquid dispersion



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equipment for preparing anode and cathode coatings, manufacturers can develop repeatable and scalable processes for consistently well-dispersed coatings.

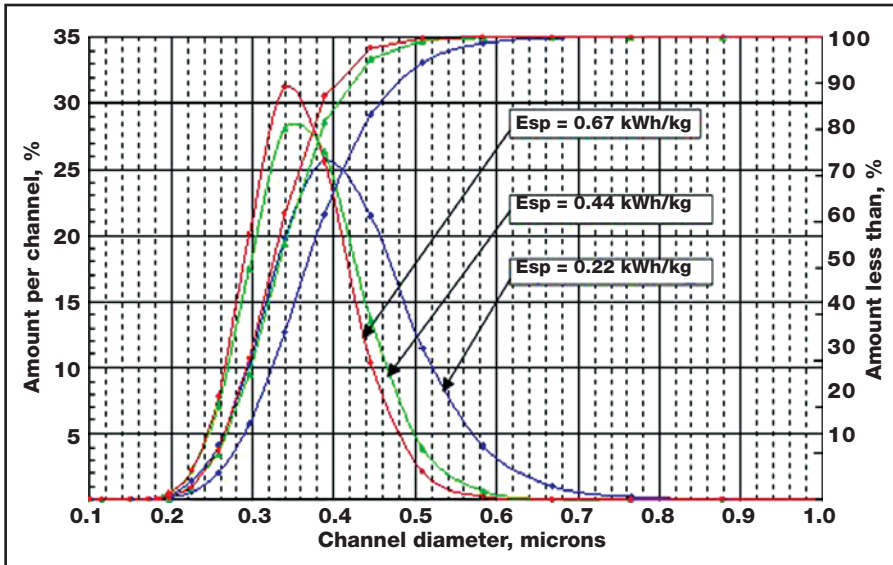


Fig. 5 — Particle size distribution of lithium iron phosphate (LiFePO₄) using a stirred media mill for grinding.

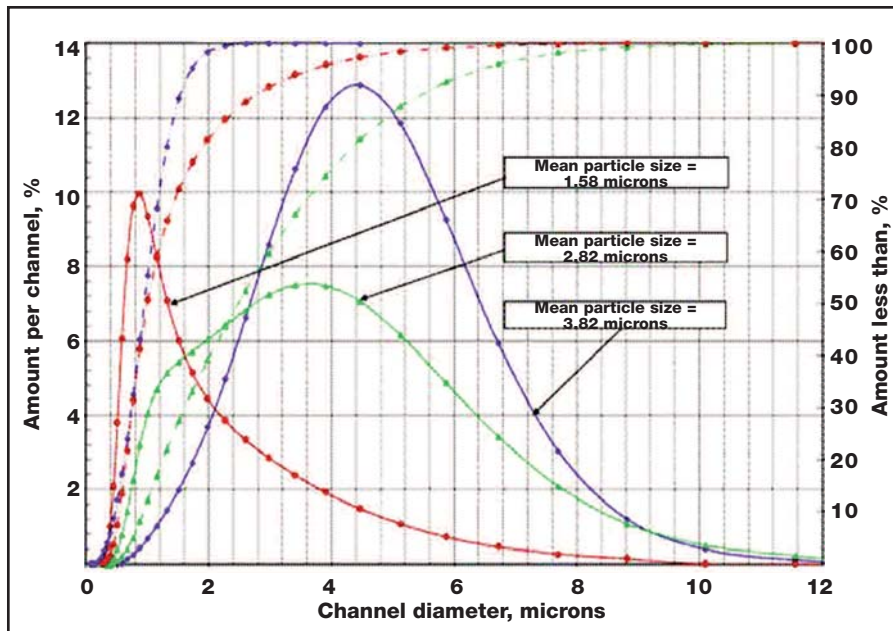


Fig. 6 — Particle size distributions of graphite in a graphite slurry after grinding.

Particle Size Distribution

The particle size distribution (PSD) of the lithium iron phosphate affects the charge and discharge cycle time of the battery. Figure 5 shows some typical PSDs possible when grinding LFP in a stirred media mill. A smaller particle size results in faster discharge capability, but to produce these submicron sizes, more grinding energy from the media mill is needed. To achieve the narrow particle size (red curve), nearly three times the grinding energy is required versus the broader, larger blue size distribution. The amount of grinding and the final particle size distribution required is dependent on the intended application of the battery.

The particle size of the graphite anode is also important. The smaller size of this component reduces the distance that the lithium ions must migrate. This improves the charge capacity and reduces the temperature during charging and discharging. Figure 6 demonstrates different particle size distributions measured while grinding graphite in a small stirred media mill. The advantages of the smaller PSD for the anode are the ability to hold more lithium ions, and the improved intercalation of these ions into the graphite matrix.

While Li-ion battery manufacturers have the opportunity to deploy these grinding and mixing techniques to improve the quality of their batteries, a considerable amount of research is taking place to explore additional nanostructured materials as alternatives to traditional carbon-based anodes. These materials have the potential to offer higher charge capacities by enabling higher lithium ion concentrations than graphite. Some examples include Li₄Ti₅O₁₂ (lithium titanium oxide), silicon, silicon nanowires, and carbon nanotubes.

As Li-ion technologies continue to evolve, nanotechnology presents the opportunity to deliver more efficient batteries regardless of the materials at hand. ○

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About the Author

With more than 24 years of chemical engineering experience, John Hill serves as Netzsch's application and process advisor. He works closely with customers in a variety of industries to solve their most difficult challenges in implementing nanotechnology.