

BEYOND CONVENTIONAL WISDOM: RETHINKING MICRONIZATION TECHNIQUES FOR BATTERY PRODUCTION

A case study on a comparison between spiral
and opposed jet mill on Lithium Carbonate

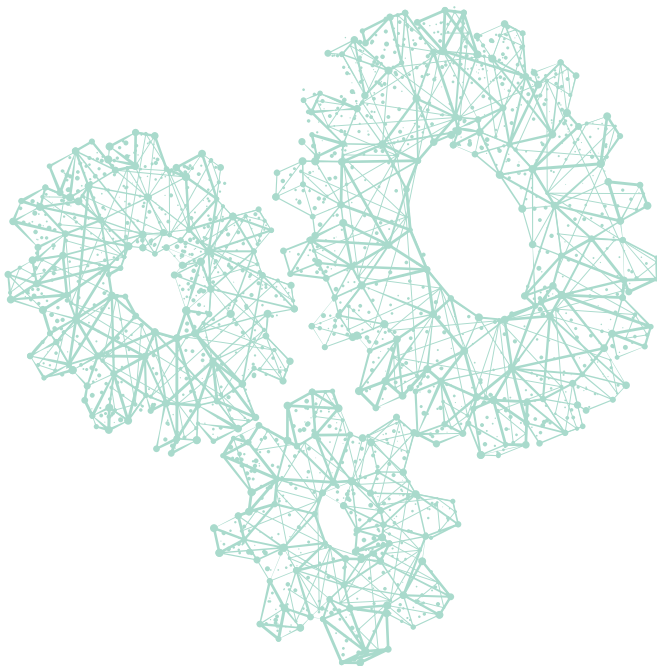
INTRODUCTION

EVOLUTION AND ROLE OF LITHIUM IN MODERN BATTERY TECHNOLOGY

The lithium industry's growth over the decades mirrors the advancement of modern technology, particularly in the realm of batteries. Once known for its applications in ceramics and lubricants, lithium's most transformative role today lies in powering rechargeable batteries. As portable electronics proliferated in the late 20th century, and the 21st century ushered in a focus on sustainability and electric vehicles (EVs), the demand for lithium-ion batteries took center stage.

Historically, battery development evolved from the lead-acid cells of the 19th century to the nickel-based batteries of the late 20th century. The arrival of lithium-ion technology in the 1990s marked a significant leap, offering unparalleled energy density and longevity. These batteries not only catered to the portable electronics market, but also drove the electrification of the automotive sector. As global emphasis shifted towards renewable energy, lithium-ion cells became central to grid-scale storage solutions, bridging the intermittency gaps of sources like wind and solar.

In refining the performance of these batteries, the micronization of lithium compounds emerged as a pivotal process. Achieving the right particle size and consistency in lithium (in all its variants) is crucial for optimizing battery efficacy. As the industry strives to meet global energy demands and continuous innovation, techniques such as micronization remain at the heart of these efforts, intertwining the growth of the lithium industry with the evolution of battery technology.



MICRONIZATION IN THE LITHIUM INDUSTRY: A DEEPER DIVE

As the utility of lithium-ion batteries expanded across diverse sectors, from handheld devices to vast power grids, so did the need for perfection in every aspect of battery design and manufacture. An important detail was the size and consistency of lithium particles used in the battery's components. This is where micronization came into play.

Micronization refers to the process of reducing the size of particles to the micron level, mostly using specialized equipment. In the context of lithium carbonate and lithium hydroxide, the two primary compounds used in lithium-ion batteries, this process optimizes the surface area and ensures uniformity in particle size.

Why is this important? A consistent and optimized particle size can:

- Enhance Electrochemical Performance¹
- Increase Energy Density²
- Improve Battery Lifespan³

The most common tools used for this precision-driven process in the lithium industry are the spiral and opposed jet mills. While the opposed jet mill has been a preferred choice for many manufacturers, the spiral jet mill offers potential advantages under certain circumstances. This white paper discusses the intricacies of these milling techniques, assessing their contributions and weighing their advantages and limitations.

1. Uniformly micronized particles can facilitate better ion flow between the battery's anode and cathode, leading to improved charge and discharge rates.
2. A finer and more uniform particle size, thanks to micronization, allows for more efficient packing of particles in the battery cell. This can lead to higher energy storage capacities.
3. Consistent particle sizes ensure even wear and tear during charge and discharge cycles, potentially extending the battery's overall life.

IMPACTS ON BATTERY EFFICACY

The efficacy of a battery, often measured in terms of its energy density, discharge rate, and overall lifespan, can be significantly influenced by a myriad of factors. One factor is the particle size and consistency of the active materials used within the battery. This made micronization become a vital process to ensure these parameters are optimized.

Particle Size and Energy Density:

The energy density of a battery, essentially the amount of energy stored in a given unit of space, can be directly impacted by the particle size of the lithium compounds. Smaller, uniformly sized particles offer a greater surface area for electrochemical reactions. This can allow more lithium ions to participate more efficiently in the charge and discharge processes, leading to batteries that can store more energy within the same footprint.

Discharge Rate and Particle Consistency:

A battery's discharge rate (its ability to deliver power efficiently), can be improved with consistent particle sizes. Inconsistent or overly large particles can impede the flow of lithium ions between the anode and cathode, causing inefficiencies in the battery's performance. Micronized particles, with their uniformity, can facilitate smoother ion flow, allowing for faster and more efficient discharge rates.

Battery Lifespan and Material Uniformity:

The overall lifespan of a battery, or the number of charge-discharge cycles it can undergo before significant capacity loss, is also influenced by the particle size and consistency of its active materials. Uneven particle sizes and inefficient packing can result in localized stress points during cycling, leading to faster degradation of the battery materials. Consistent, micronized particles ensure even ion distribution and flow, potentially extending the overall life of the battery.

Safety Considerations:

While not often the first consideration, safety is paramount in battery design and operation. Micronization (producing consistent particle sizes), can reduce the risk of internal short circuits caused by uneven material distribution. Furthermore, finer particles allow for better thermal management within the battery, reducing the risk of overheating and potential thermal runaway.

In conclusion, the micronization of lithium compounds is not just a technical detail but a fundamental process that impacts every aspect of a battery's performance. As the demand for high-performing batteries grows, especially in sectors like EVs and renewable energy storage, the role of micronization in determining battery efficacy becomes increasingly important.



SSM 300 Spiral Jet Mill

MICRONIZATION

The most common technologies for particle size reduction and determination with lithium carbonate are the spiral jet mill and the opposed jet mill. In the rapidly evolving landscape of the lithium industry, micronization has emerged as a pivotal process, dictating the efficacy and performance of lithium-based products, particularly in battery applications. As companies strive to achieve optimal particle sizes for better reactivity and conductivity, the choice of the right micronization technique becomes crucial.

Predominantly, the industry leans towards the use of opposed (or opposite) jet mills for the micronization of lithium. The choice is rooted in both tradition and the tangible benefits its technique offers. Opposed jet mills have consistently demonstrated their ability to achieve the desired fine particle sizes, coupled with a reduction in contamination risks. Their high grinding efficiency, adjustability, and reduced wear and tear have made them the industry standard. With scalability being a key concern, especially as the demand for lithium-ion batteries continues to grow, the ability of opposed jet mills to cater to large-scale production without compromising on quality has been a significant advantage.

With innovation being at the heart of industry growth, the spiral jet mill, often overshadowed by its opposed counterpart, presents a set of unique advantages that make it a worthy contender in specific scenarios. Although less common in the battery field (contrarily to pharmaceutical applications where it is generally preferred), this method has shown potential into generating consistent size distributions and sometimes preserving particles shape. The operational simplicity of spiral jet mills can be an attractive feature for certain applications or settings.

This white paper takes a deeper look into the comparative study of these two prominent techniques. While the industry's current inclination towards opposed jet mills is acknowledged, the paper aims to shed light on the circumstances where the spiral jet mill might not only be a viable alternative, but also offer distinctive advantages. By doing so, it hopes to provide stakeholders with a broader perspective, enabling informed decisions that can potentially reshape micronization norms in the battery industry.



Lab Pilot Spiral Jet Mill SSM 150

SPIRAL JET MILL : AN OVERVIEW

PRINCIPLE AND MECHANISM

A spiral jet mill utilizes a combination of fluid energy and a spiral flow pattern to achieve micronization.

Here's a breakdown of its functioning:

- ❏ **Feed Introduction:** The feed material (coming from a feeder) is introduced into the milling chamber through a venturi injector.
- ❏ **Acceleration and Grinding:** Within the chamber, high-speed pressurized gas (often air or inert gas) is introduced tangentially. This generates a vortex or spiral flow pattern which accelerates particles.
- ❏ **Particle Collision:** The accelerated particles follow the spiral flow, and due to their high kinetic energy, they collide with each other, leading to particle size reduction.
- ❏ **Separation and Collection:** The finer particles are carried with the spiral airflow towards the center of the chamber from where they exit the mill. Coarser particles, due to their higher inertia, remain at the periphery of the chamber and are subjected to further milling.
- ❏ **Output:** The fine particles are then generally collected below a filtration system while the gas is vented out. Certain jet mill manufacturers allow to collect the milled product directly below the milling chamber itself (bottom discharge configuration).

BENEFITS IN LITHIUM MICRONIZATION

There are multiple benefits of using the spiral jet mill for lithium micronization, and they strongly vary on the design of the manufacturer of the machine.

Advantages are:

Increased fineness of the micronized product: spiral jet mill, normally used in pharmaceuticals to produce inhalation compounds, are highly effective when it comes to reduce the particle size toward the limit of micronization, in ranges that can vary between 0.5 to 10 micrometers or more, depending on the required specifications.

Depending on the manufacturer's design, there are increased possibilities of personalizing the particle size distribution further, compared with an opposed jet mill (see also Schedio Personalized Micronization™). Certain manufacturers allow adjustments to multiple configurations of the spiral jet mill, like product contact materials, nozzles angles, milling chamber geometry, classification geometries, collection points etc., to push the particle size engineering even further.

Compact Design: Spiral Jet Mills generally occupy less space compared to opposed jet mill technologies, making them more suitable for facilities with space constraints.

No moving parts: The spiral jet mill does not have mechanical moving parts (e.g. rotating classifiers, rotators, etc.). This allows for easier maintenance and higher process reliability due to its robustness.

Moreover, with certain designs, it is also possible to have a double collection from the spiral jet mill, one at the bottom and one at the top. With most particles (up to 99%) being collected from the bottom of the mill, it is possible to use the cyclonic effect of the spiral jet mill inside the milling chamber in order to increase collection below the mill, and at the same time get rid of the finest fraction (the remaining 1%), which instead is collected into the bag/cartridge filter afterwards.

Removing ultra-fine particles is sometimes very beneficial for the process steps that follow micronization, and without using the cyclonic effect of the chamber of the spiral jet mill, it would otherwise be more difficult (e.g. with the use of sieves) or with much lower yields (in the case of use of cyclonic separators).

POTENTIAL CHALLENGES AND LIMITATIONS

The Spiral Jet Mill, while offering numerous advantages for the micronization of various compounds, is not without its challenges and limitations, especially when processing lithium carbonate. Here are some of the significant concerns, constraints and stereotypes normally associated with its use and how they should be addressed:

Wear and Tear on Equipment:

Lithium carbonate, like other hard minerals, can lead to increased wear and tear on milling equipment.

The erosive nature of the jet milling process, combined with the hardness of lithium carbonate, may result in shorter equipment lifespans or the need for frequent maintenance.

Such constraints can be easily addressed by adopting a milling chamber made of a more wear resistant material (e.g. ceramics) or with a metal compatible with the final product, which would not affect the final performances even in case a certain amount of PPM is found due to abrasion.

Narrow Optimal Operating Conditions:

Achieving the desired particle size and distribution can be sensitive to slight changes in operating conditions such as feed rate, grinding pressure, or gas type. This sensitivity might require close monitoring and precise control, which may result in the spiral jet mill being more expensive than an opposed jet mill.

Energy Consumption:

While Spiral Jet Mills are efficient in their design, they can still demand significant amounts of compressed air or gas. For large-scale operations, this could lead to considerable energy costs, especially when compared to alternative milling techniques. Nitrogen or Argon recirculation system could be useful to reduce the overall energy consumption and operational costs of the machine. A valid alternative is to use the spiral jet mill combined with a co-axial configuration (see Schedio white paper "Reducing gas consumption by 20% during the micronization process with the coaxial jet mill" Aug. 2022).

Increased amount of ultrafines:

The Spiral Jet Mill, while capable of producing very fine particles, also generates small percentages of submicron particles, which may be undesirable for certain applications. This characteristic of the spiral jet mill can be easily addressed by either using a collection below the jet mill (thus using the mill itself as classifier), to remove the finest portion, or through an in-line dynamic classifier, as described in the following chapters.

In conclusion, while the Spiral Jet Mill offers specific benefits, it's crucial for industries to be aware of its potential challenges and limitations. A comprehensive understanding of these aspects is vital to properly design it according to the specific requirements of battery industry standards.



Spiral Jet Mill SSM 100

OPPOSED JET MILL: THE INDUSTRY STANDARD

WORKING PRINCIPLE

An opposed jet mill uses the principle of counter jets and a fluidized bed to achieve micronization. Here's how it works:

Feed Introduction: The feed material enters the milling chamber centrally or laterally.

Jet Streams: High-pressure gas or steam is introduced through nozzles placed oppositely around the periphery of the chamber. This creates jets of gas that move directly towards each other.

Particle Acceleration and Collision: Particles get entrained in these jet streams. The opposing jets cause the particles to collide with each other with great force. This is the inter-particle collision, not the impact against the mill walls, which causes size reduction.

Separation and Collection: a fluidized bed created by the micronization gas stream conveys the particles toward a classification area on top of the milling chamber, where a rotating classifier separates fine particles from coarser ones depending on its rotation speed. Coarse particles fall again into the micronization area until they have reached the target particle size distribution.



Production Scale Opposed Jet Mill SOM 400 (PED)

ADVANTAGES IN LITHIUM CARBONATE PROCESSING

The Opposed Jet Mill stands as an industry-standard for various reasons, particularly in the realm of lithium carbonate processing. Here are the specific advantages for this application:

High Degree of Purity: The Opposed Jet Mill operates without any mechanical grinding media. This ensures there's virtually no risk of contamination, which is crucial for the high-purity requirements of battery applications.

Optimal Particle Size Distribution: The design of the Opposed Jet Mill, which involves particle-to-particle collision, is particularly efficient in achieving a narrow particle size distribution, enhancing the performance consistency of the final battery product.

High Efficiency and Throughput: These mills are designed to handle large volumes effectively. This makes them apt for industrial-scale operations where consistent high throughput is vital.

Irrelevant inlet particle size distribution: A big advantage of the opposed jet mill is that (thanks to its active classification system) the outlet particle size distribution isn't affected by the inlet particle size distribution, contrary of the spiral jet mill, which instead requires a constant control of the raw material.

Less dependency on constant feeding: Unlike the Spiral Jet Mill, which demands a consistent and precise feed rate, the Opposed Jet Mill is more forgiving in this regard. Its productivity primarily hinges on the classifier and gas speed, thereby reducing the necessity for an exact feeding rate.

Minimal Heat Generation: The grinding action in an Opposed Jet Mill same as a spiral jet mill is relatively cool, ensuring the thermo-sensitive properties of products remain unaltered during the process.

In essence, the Opposed Jet Mill's suitability for lithium carbonate processing stems from its ability to provide high purity, consistency, and efficiency, making it a staple in many industrial micronization setups.

CONSIDERATIONS FOR OPTIMAL USAGE

Using the Opposed Jet Mill efficiently for lithium carbonate processing, necessitates an understanding of its operational intricacies and the specific requirements of the material being processed. The following considerations are imperative to ensure the mill functions optimally:

Calibration and Control of Dosing System:

Unlike other mills where the productivity might be directly influenced by the dosing rate, the productivity of the Opposed Jet Mill is largely contingent on the classifier and gas speed. While a meticulously calibrated dosing system can help in achieving desired outcomes, a more advanced, precise and easy-to-operate approach is to assemble the jet mill body on load cells. These load cells can autonomously regulate the dosing, ensuring a consistent feed rate and thereby optimizing the milling process.

Machine Sizing:

An essential factor in ensuring consistent product quality and operational efficiency is to size the machine appropriately. This entails choosing an Opposed Jet Mill that corresponds with the volume of lithium carbonate that needs processing. Over-sizing or under-sizing can lead to inefficiencies, increased wear, and subpar product quality.

Pressure Resistance for Safety:

While the intrinsic design of the Spiral Jet Mill offers inherent pressure resistance, this is not automatically the case with the Opposed Jet Mill. When processing flammable compounds, it's vital to ensure that the Opposed Jet Mill is pressure-resistant (PED) to mitigate the risks of explosions or fires. This feature ensures a safe operating environment and safeguards against potential damages.

Maintenance and Inspection régimes:

Regularly scheduled maintenance and inspection are crucial. Given the high speed rotating classifier, components like bearings or the classifier itself may need periodic replacements. Being proactive, in this regard, ensures consistent performance and prevents unexpected downtimes.

In summary, for the Opposed Jet Mill to function at its peak potential, it's essential to integrate advanced control systems, ensure proper machine sizing, and take requisite safety precautions. Adhering to these considerations can significantly improve product quality, safety, and operational efficiency.



Lab Pilot Opposed Jet Mill
SOM 100

DYNAMIC CLASSIFIER: ENSURING PRECISION

WORKING PRINCIPLE

A dynamic classifier is used to separate particles based on size, ensuring the desired particle size distribution is achieved. It can be positioned in between a spiral or opposed jet mill and its cyclone filter to separate fine or coarse fractions depending on the needs. Its functioning can be described as follows:

Particle Feed: The feed, which contains a mixture of particle sizes, is introduced into the classifier from the outcome gas stream of the jet mill.

Fluidized bed: A nozzle at the bottom creates a fluidized bed, which suspends the particles and conveys the particles toward the classification area.

Rotating Classification Mechanism: The classifier consists of a rotating wheel, with different geometries and materials, that by rotating at high speeds allows a particle separation according to particles mass and dimension. Due to centrifugal forces, larger, coarser particles move both outwards and in the direction of a bottom outlet. Simultaneously, the airstream created by the rotor moves the finer particles to the center towards the upper outlet.

Output Streams: The coarse particles descend and are discharged from the bottom as rejects. Meanwhile, the finer particles, carried by the airstream, exit from the top of the classifier.

Adjustability: By adjusting the speed of the rotor, the cut-off size for fine and coarse particles can be controlled, ensuring the desired particle size distribution in the output.



ROLE AND IMPORTANCE

Dynamic classifiers play a pivotal role in powder micronization processes and particle size control, particularly for battery powders. These components are essential for optimizing the performance and uniformity of micronization processes. In the context of battery material production, where precise PSDs are fundamental for achieving consistent battery performance, dynamic classifiers contribute significantly. They enable real-time adjustments to the milling process, ensuring that the desired particle size specifications for battery grade lithium carbonate and other materials are consistently met; ultimately leading to improved battery performance, storage capabilities and longer life cycles. Their importance lies in their ability to meet the stringent quality standards, required in the rapidly advancing field of battery technology.

INTEGRATION WITH JET MILLS

The integration of a dynamic classifier with a spiral jet mill (and/or with an opposed jet mill) is well described in the Schedio White Paper titled "Obtaining Unique Particle Size Distributions, Through Dynamic Classification Applied To Spiral Jet Mills" (Feb. 2023)

Overall, the integration of a dynamic classifier with a spiral jet mill represents a significant advancement in powder processing. This combined system offers precise control over particle size distribution, streamlining the process and improving product quality. One of the core advantages of this integrated approach is its capability to selectively remove either the fines or the coarse particles from the product. This ensures that products meet the desired specifications without the inclusion of undesired particle sizes.

Furthermore, a notable benefit of this union is the obviation of traditional sieve processes. Sieving can be labor-intensive, time-consuming, and often less efficient in achieving the desired particle size distribution. The dynamic classifier, when paired with the spiral jet mill, not only streamlines the process, but also enhances the consistency and reliability of the output. This ensures that only particles of the desired size reach the final product, optimizing quality and minimizing waste. As a result, industries can achieve better yield and higher product standards, while reducing production steps and associated costs.

COMPARATIVE ANALYSIS: SPIRAL VS. OPPOSED JET MILLS

PARTICLE SIZE ENGINEERING

Both technologies are capable of precise PSD engineering, but they have slightly different strengths. Spiral Jet Mills are known for producing sharp and narrow PSDs, making them suitable for applications requiring fine and uniform particle size. Additionally, Spiral jet Mills can be equipped with dynamic classifiers, which further enhance their ability to control and optimize PSDs.

In contrast, opposed jet mills offer excellent control over PSD regardless on raw materials particle size and are versatile in achieving a broader range of PSDs, making them suitable for a wider array of applications, including those demanding ultrafine powders.

PARTICLE SIZE ENGINEERING

Since the spiral jet mill does not have a dynamic classification which forces large particles to remain inside the milling chamber, it requires a slightly higher gas consumption to ensure the final particle size is reached, whereas the opposed jet mill can use a lower gas pressure to obtain the same final particle size distribution, thanks to its rotating classifier which controls the time spent inside the milling chamber by the particles.

However, this may vary depending on product properties, inlet raw material fineness and scale of the plant and does not take into consideration the electric consumption of the classifier of the opposed jet mill.

SCALABILITY AND INDUSTRIAL APPLICATION

Both spiral jet mills and opposed jet mills can be seamlessly scaled from laboratory and pilot-scale setups to large scale production.

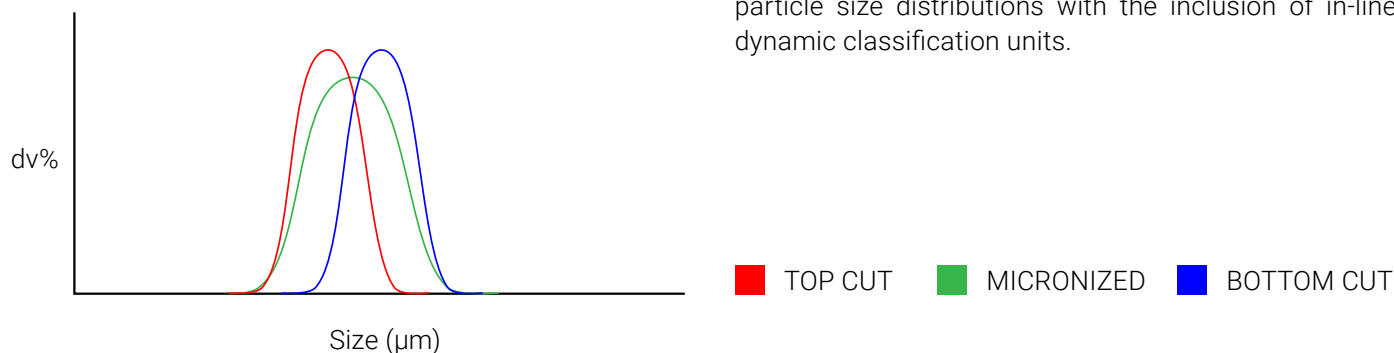
COSTS AND ECONOMIC CONSIDERATIONS

Spiral Jet Mills may have lower initial capital costs compared to Opposed Jet Mills thanks to their relative simplicity. With regards to operating costs, while the opposed jet mill consumes less gas and still requires energy for the classifier, and certain spiral jet mills, it offers the possibility to use different configurations to help save energy (e.g. Co-Axial see Schedio white paper "Reducing gas consumption by 20% during the micronization process with the coaxial jet mill" Aug. 2022).

Opposed jet mills, having several mechanical moving parts, require a more frequent maintenance, which results in machine down-time, further enhanced during product changes, as it is also more complex to clean, disassemble and re-assemble.

In summary, the choice between Spiral Jet Mills and Opposed Jet Mills depends on the specific product and needs of the manufacturing process. Both milling technologies excel in particle size control and offer efficiency and scalability.

The decision should be made based on the unique requirements of the application, and it is worth mentioning that spiral jet mills can further optimize particle size distributions with the inclusion of in-line dynamic classification units.



CONCLUSIONS

One comparative test was conducted on Lithium Carbonate processed with both a Spiral Jet Mill and an Opposed Jet Mill, with the aim of showcasing the micronization capabilities of these two different types of milling systems.

The results of comparative test provide valuable insights into the advantages and limitations of each milling technology. This information will assist industries in making informed decisions when selecting the most suitable micronization equipment for their specific application.

COMPARATIVE TEST RUNS: SPIRAL VS. OPPOSED JET MILLS

Tests were conducted on the R&D Multimill, which incorporates both the Spiral Jet Mill and the Opposed Jet Mill, and using average process parameters respectively for both technologies.

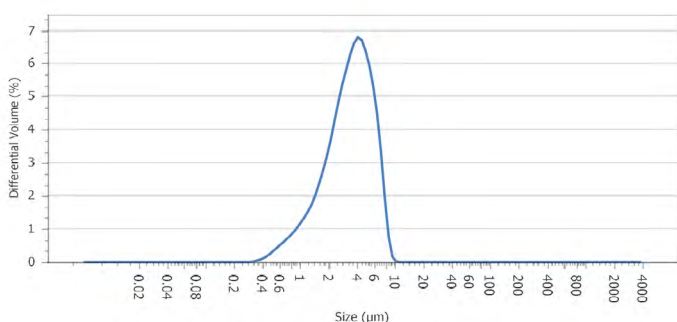
Battery Grade Lithium Carbonate ($d_{100} \leq 60\mu\text{m}$) was chosen as reference material for the battery industry, since using a well-defined reference material is crucial in such experiments as it allows for a consistent and meaningful comparison between the Spiral Jet Mill and the Opposed Jet Mill. By utilizing this specific reference material, the tests aimed to assess how effectively both milling technologies could micronize battery grade lithium carbonate to meet the stringent PSD requirements of the battery industry.

It is important to note that these results were obtained using generic process parameters, and there is ample margin for adjusting the particle size as needed. In the context of battery applications, both mills can be valuable depending on specific requirements. The spiral jet mill produced slightly finer results in terms of D10, D50 and D90, but the Opposed jet mill still achieved PSDs suitable for many battery applications. In addition to this, the Spiral Jet Mill would require an inline Dynamic Classification Unit in order to provide the same versatility of the opposed jet mill, if we consider particular PSD necessities.

Further optimization of process parameters can help fine-tune particle size to meet specific needs.

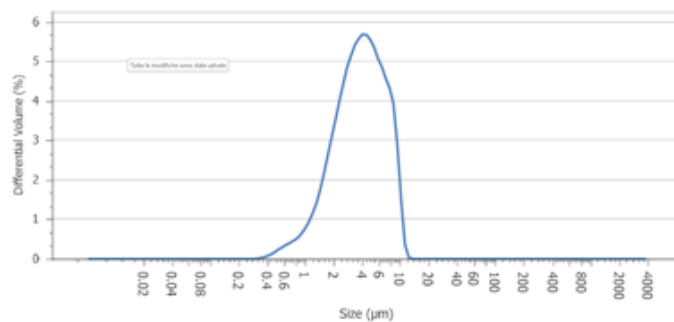
Additionally, from our experience and systems developed in past projects, when compared to the Opposed jet Mill, the spiral jet mill may offer increased tools to influence particle morphology during micronization, depending on product's properties. This capability, which strongly depends also on product's properties, may enable the preservation or deliberate creation of specific particle forms, a crucial aspect in battery material production where morphology influences the final product's performance and its attributes. The enhanced versatility of the spiral jet makes the spiral jet mill a standout choice, where particle shape control is required, with the opposed jet mill typically focusing primarily on PSD control.

Test on spiral jet mill SSM100



D10	D50	D90
1.32	3.43	6.24

Test on opposed jet mill SOM100



D10	D50	D90
1.57	3.85	7.94

Both technologies underscore the ability to maintain stringent purity controls, vital in battery production. The adaptability in achieving desired particle size distributions augments their applicability across various materials and needs. Moreover, the scalability of these methods, transitioning seamlessly from research scales to large-scale production, affirms their place in future manufacturing setups.

Contrary to prevalent industry beliefs that predominantly favor the Opposed Jet Mill for lithium carbonate processing, both Spiral Jet Mill and Opposed Jet Mill technologies present valid and compelling options. In fact, there are scenarios where the Spiral Jet Mill or its variants (see Schedio Personalized Micronization™) may even outperform its counterpart, particularly due to its enhanced flexibility and its overall robustness. Choosing the appropriate technology is not a one-size-fits-all decision.

Each case warrants individual examination, as the optimal choice hinges on the unique properties and requirements of the product in question. By acknowledging the potential of both mills and not prematurely leaning towards one, industries can harness the fullest extent of what jet milling has to offer.

Understanding the nuances and capabilities of these milling technologies has profound implications. It not only optimizes production quality, efficiency, and cost, but also paves the way for future advancements in battery technologies by refining the micronization process.

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