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3M Separation and Purification Sciences Division
Customer Application Brief

Filtration of Electrode Slurries in Lithium-ion Battery Cell Plants

Introduction

A Lithium-ion (Li-ion) battery cell is composed of anode, cathode, electrolyte, separator, and other components. Inside the battery, lithium ions move between anode and cathode, carrying electronics and storing them during charging and discharging. The major battery cell manufacturing steps are:

- **Mixing:** at this processing step, the active ingredient of the anode and cathode solid materials in the form of powder are mixed separately in a liquid carrier to produce a homogeneous mixture also known as cathode and anode slurries.
- **Coating:** The slurries made during the mixing need to be coated on a metallic foil substrate as a thin uniform layer. Non-uniform coating would result in high points on the coating that could result in non-uniform electron flow density which could cause short battery life and power storage capacity. The coating process involves pumping the slurry to the slot coaters that lay down a thin layer on the moving substrate. The coating must be cured to form a solid layer by evaporating the carrier or the solvent. The electrodes are layered with a separator in between and wound to be a big roll or stacked sheets depending on the architecture of the battery design. This assembly will be cured in an oven to ensure that all of the solvents are removed from the battery assembly.

In the whole manufacturing process, electrode slurries filtration in the coating step is the most critical filtration application. Cathode/anode slurries should be coated on to the metal poles (current collectors) after filtration. Cathode slurry is coated on to the aluminum foil, and the anode is coated on the copper foil. The coating layers on to metal poles should be smooth, otherwise, the electrical shorts and power performance of the battery will be affected. The coating defects on the electrode reduce the battery production yield and increase the defects. To provide high assurances that the large particles on the coating layer do not cause short circuits or low battery life, a screening filter is needed to allow only active materials smaller than the specified particle size to pass through while the large particles are held back. No filtration or inadequate filtration causes defects on the electrode surface. Usually, a charge coupled device (CCD) is installed after the coating head to detect the quality of electrode. Some defects related to the inadequate filtration and coating are: craters, gel agglomeration, bright scratch, blisters, coating pit, etc.

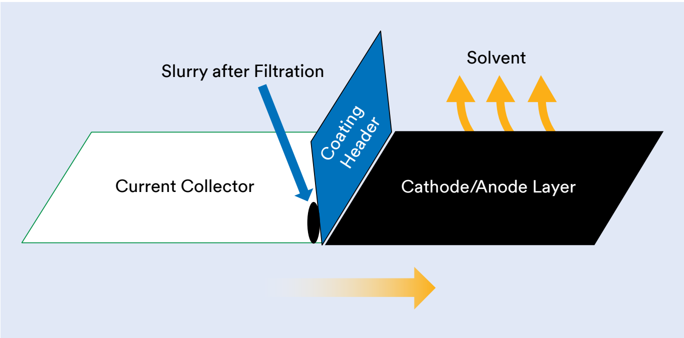

Figure 1: Coating Process

Figure 2: 3M™ CTG-Klean Encapsulated Filter System GPJ Series

This application brief reviews the proper filtration methods that can be employed during the coating of electrode slurries to reduce large particles and deformable contaminants. Proper filtration ensures a consistent material supply to the coating dies which can result in increased throughput, increased revenues, and overall equipment effectiveness.

The Slurry Composition

The cathode slurry contains ternary material ($Li(NiCoMn)O_2$) or $LiFePO_4$ as the active ingredient; Poly Vinylidene Fluoride (PVDF) as the adhesive; N-Methyl pyrrolidone (NMP) as the solvent; and some other chemicals as additives. The anode slurry is consisting of: graphite as the active ingredient; Styrene-butadiene rubber (SBR) as the adhesive; DI water as the solvent; and some other chemicals as the additives, such as Carboxymethylcellulose (CMC) as the thickening agent.

The Role Of The Filtration Process

The process of making slurries is time consuming and good mixing can be achieved if given long time and energy input. However, the last 0.1% of particles may need hours of mixing to achieve a 100% homogenous slurry. It is more economical to reduce the mixing cycle time and remove the 0.1% unmixed particles by filtration. The filtration could be optimized with one filter with one micron rating, a filter with gradient pore size structure, or several filters with decreasing pore size from upstream to downstream of the coating die. The optimization of the filtration system depends on the particle size and size distribution of active battery particles. Providing high quality slurry to the coating die requires monitoring the pressure drop of the system as well as the pressure drop across each filter. This ensures that enough slurry is provided to the die and filters are changed out on timely basis which prevents low flow due to high pressure drop across the filters. Slurry coating processes are designed differently however, with the majority of the systems using a two or three stage filtration. Most customer designs utilize a metal mesh as the first stage of filtration. These metal mesh filters can be cleaned and reused to reduce the operation cost. The second and the third stages of filtration employ non-woven depth filters. Capsules offer a good operational choice for the second and the third stages since they can reduce cleaning time and provide quick-change outs, thereby reducing the chance for interruption of the continuous coating process.

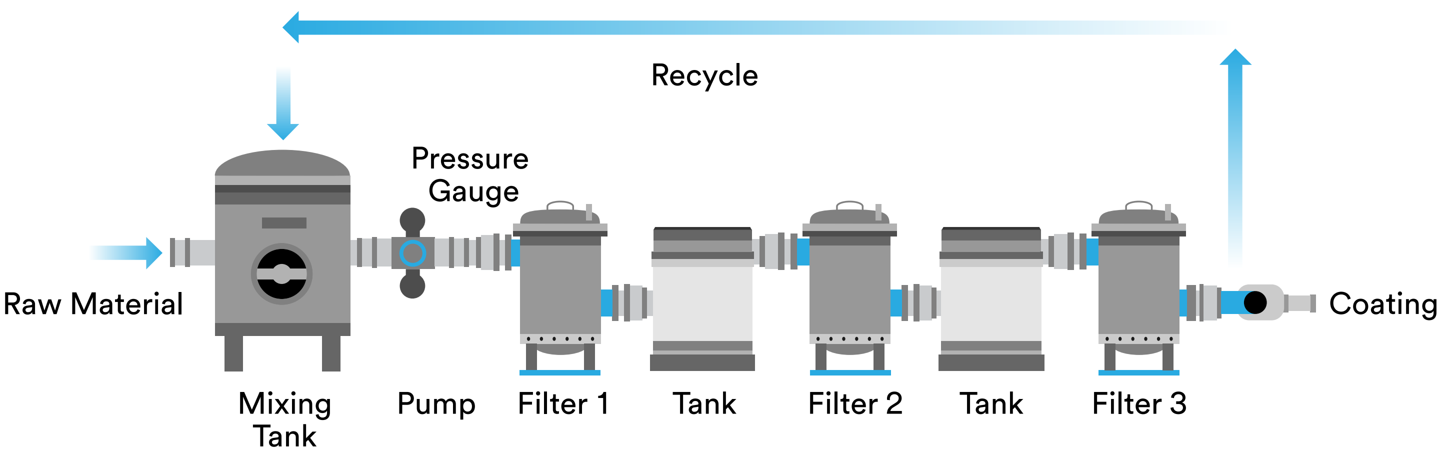

Figure 3: Typical Cathode/Anode Slurries Filtration Process

High Defect Rate

Both cathode and anode slurries have very high viscosities of about 10K cP (usually, cathode slurry is stickier than anode slurry). So, a rigid filter cartridge is preferred for this application to avoid cartridge deformation and collapse resulting from high pressure drop associated with the flow of viscous fluids.

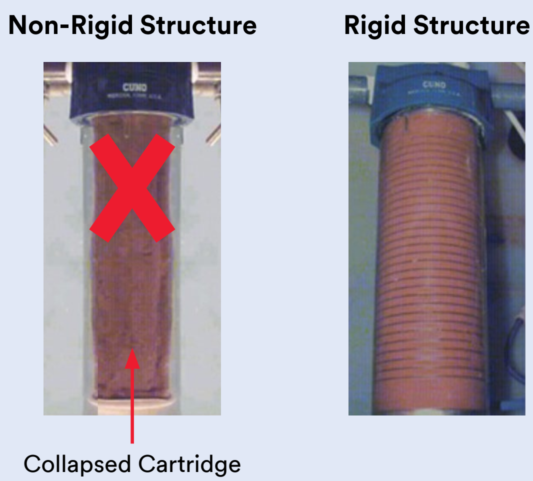

Figure 4: Comparison of Rigid Structure Media and Non-Rigid Media

The slurry also contains gel-like contaminants in the cathode/anode slurries. The gels are produced from premature curing or drying of the binders in the slurry. The best approach for removing gel-like impurities is to use a rigid depth filter. If the gel-like contaminants are not removed or extruded through the surface filters, they will deposit on to the cathode or anode electrodes leading to diminished battery performance.

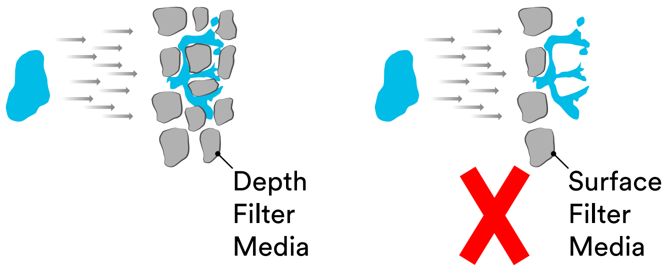

Figure 5: Comparison of Depth Media and Surface Media

In the slurry filtration process, a filter with a sharp (classifying) cut-off will be required to stop the oversize particles and let the small size active ingredients pass through. The classifying filtration helps the slurry remove large particles while maintaining solid content. Usually, the classifying filter is made of the media with uniform density porosity.

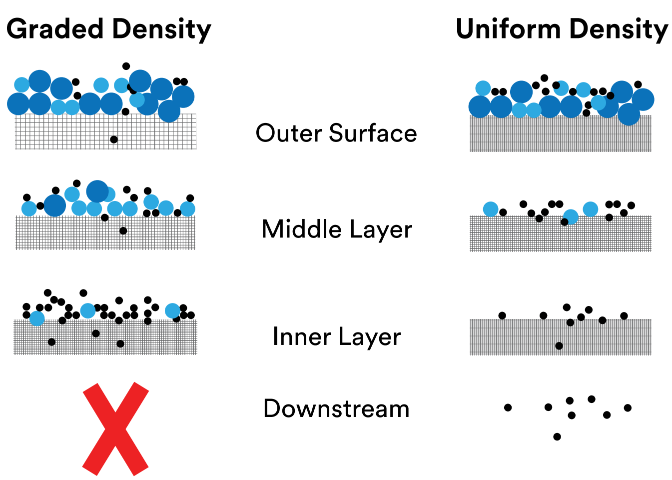

Figure 6: Comparison of Classifying Media and Clarifying Media

In addition, a depth filter cartridge with classifying rigid structure media is needed for slurry filtration to provide a multitude of filtration layers and resist pore size change due to applied pressure.

Preventing Slurry Waste

The electrode slurry is expensive, especially cathode slurry due to the high cost of the active raw materials. Therefore, slurry waste should be avoided as much as possible. A capsule design offers several advantages if it could provide low to no spillage, easily recoverable slurry material, minimize cleaning and the use of solvent and added waste. In contrast, if a cartridge filter is used in the coating process, the used filter housing should be cleaned with chemical or DI water, which would result in additional operational costs during the manufacturing of the Li-ion battery.

The Solution

The battery defects can be significantly reduced by proper filtration of slurries and by removing large particles and deformable contaminants. Therefore, producing a consistent slurry quality that enables stability of the cathode/anode battery and the coating process. 3M™ Betapure AU Series cartridge filters have a rigid self-supporting structure that is suitable for the high viscosity slurry filtration. 3M™ Betapure Series cartridge filters exhibit excellent filtration capability during their service life. From start to finish, the filter performance is stable. The rigid 3M™ Betapure AU Series filter structure resists deformation, particle unloading or filter by-pass, while providing consistent high particle removal efficiency. Compared with surface filters, 3M Betapure AU depth media could retain more deformable gel-like contaminants at the same pressure drop. Moreover, 3M™ Betapure AU filter cartridge has uniform porosity, which has good classification performance by stopping the oversize particles and allowing the small size active ingredients pass through.

Furthermore, the 3M™ CTG-Klean Encapsulated Filter System GPJ Series is a soft capsule design that encapsulates the filter cartridge with a thin film providing a physical barrier between the filter and the metallic housing. All the pressure load is transferred to the metal housing thereby not needing a heavy plastic body. The material use is minimized and at the same time material waste is optimized. This soft and thin sheet can be easily cut to recover any residual slurry left in the capsule after the conclusion of the filtration process. These design advantages help reduce customers' total cost of filtration. According to the calculation, a piece of 20" 3M™ CTG-Klean Encapsulated Filter System GPJ Series capsule could recover about 0.5 L slurry. If the cost of the cathode slurry is $100 USD/L, it could provide $50 USD of savings per filter change out. The 3M™ CTG-Klean Encapsulated Filter System GPJ Series capsules could include 3M™ Betapure™ AU, 3M™ Betapure™ NT-T, and 3M™ Micro-Klean™ RT filters cartridges. Each of these filters offer unique features and benefits that could be used for the optimization of the cathode or anode filtration train. In most cases, a two- or three- stage filtration train provides optimized filtration operation in terms of filter life extension, reduced filter change-out, and total cost of operation.

Conclusion

1. The slurry coating process contains several filtration points after slurry blending. 3M offers filtration solutions to ensure that the slurry is produced at the highest quality, meeting the slurry specifications at the point delivery to the coatings dies. Utilizing high performance of filter cartridges and capsules noted in the "solution" section above will reduce the potential for scratch defect on the electrode surface. It's a good way to reduce customer total operation cost.

2. The 3M™ Betapure™ AU filter cartridge has rigid, depth media with uniform porosity, which can remove oversize particles and gel-like deformable contaminants and keep small-size active particles in the slurries. It is a suitable choice for cathode/anode slurries filtration.

The 3M™ CTG-Klean Encapsulated Filter System GPJ Series capsule with the suitable cartridge inside not only has all the advantages of the cartridge, but also can save slurries based on its "soft capsule" design. More advantages of 3M™ CTG-Klean Encapsulated Filter System GPJ Series capsule include, being environmentally friendly, having no need to clean the filter housing, and having no contact with the slurry by operator, etc.

Reference Material And Related Product Information

3M™ Betapure™ AU Series Filter Cartridges – 3M™ Betapure™ AU filter cartridges utilize state-of-the-art technology to produce a clean, rigid filter structure with consistent and reproducible filtration characteristics for slurry filtration application. The filter matrix is constructed using long bi-component fibres, each fibre having an inner core and an outer sheath (See product data sheet). 3M™ Betapure™ AU filter cartridges are available in two bi-component fibre structures, polypropylene/polyethylene, or polyester/co-polyester, to provide the greatest range of chemical compatibility.

The bi-component fibres of the filter matrix are thermally bonded by utilizing the difference in melt temperatures of the two fibre components. Heating the matrix to the melt temperature of the polyethylene sheath, but below that of polypropylene core causes the fibre-to-fibre bond at every contact point. The high degree of fibre-to-fibre bonding provides a rigid structure, that reduces the need for a core support and any possibility of media migration. Dynamic applications where the filtration system is pulsed, cycled, or exposed to high differential pressures can cause non-rigid filters to unload contaminants back into the process fluid. The rigid structure of 3M™ Betapure™ AU filter cartridges resist deformation, particle unloading, and by-pass to deliver consistent particle reduction efficiency even under adverse operating conditions.

3M™ CTG-Klean Encapsulated Filter System GPJ Series capsules – 3M™ CTG-Klean Encapsulated Filter System GPJ Series capsules are designed for industrial filtration applications. Various 3M series filter cartridges could be installed into the capsule, including 3M™ Betapure™ AU, 3M™ Betapure™ NT-T, 3M™ Micro-Klean™ RT filter cartridges. Benefits of the capsule design include: being environmentally friendly, no need to clean the filter housing, and no operator contact with the slurry. The easy-to-cut-open "soft" design brings us the important advantage of recovering residue during the filtration process.

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