New benchmarks in CO2-efficient battery production

Dry electrode production

Dr. Stefan Gerl

The demand for lithium-ion batteries is growing continuously. In Europe alone, production capacities are expected to grow tenfold by 2030/35, even if the hype and exaggerated expectations of recent years are currently being followed by the trough of disillusionment. The prerequisite is that the manufacturers of energy storage systems succeed in working together with their technology partners to make the production process as efficient as possible. On the one hand, European battery manufacturers can only be competitive on the global market if they can at least compensate for the higher European electricity costs of on average 20 ct/kWh compared to industrial electricity prices of around 8.5 ct/kWh in other nations such as China, the USA or South Korea. Secondly, the European Union's demand must be implemented: The current 27 member states of the EU are to become climate-neutral by 2050.

The first step is to achieve a 55% reduction in greenhouse gas emissions by 2030 compared to 1990. It is therefore not only manufacturers of lithium-ion battery cells for electromobility and stationary energy storage systems that need to take swift action if they want to achieve this ambitious target. The newly introduced EU Battery Regulation obliges manufacturers to declare the carbon footprint of their products from February 18, 2025, so that truly green batteries can be identified and efficiency gains in production technology become visible.

Important levers for greater energy efficiency in gigafactories lie in electrode production, particularly in the first production step - mixing. Planetary mixers are used as standard for wet electrode production. However, alternative mixing processes such as the Eirich mixer perform significantly better in a comparison of energy consumption, CO2 emissions, space requirements and costs and are therefore increasingly finding their way into global gigafactories. With Eirich mixers a company who have played an active role in the development of industrial mixing technology for more than 100 years, in the MixSolver® version, energy cost and CO2 savings of 90% and more are possible in wet processing alone [1].

Experts and cell manufacturers also see potential for an even more efficient electrode production process overall in innovative dry electrodes. Further significant savings in the mid double-digit range are expected. Today, coating and drying, including solvent recovery, account for a good 20% of manufacturing costs and a good 45% of energy consumption and by this CO2 emissions [2]. At best, these can be almost completely eliminated.

Optimization potential through dry electrodes

In view of the challenges facing this industry it is important not only to further develop electrode production in an evolutionary way, but also to have the courage to break new ground. Tesla provided a major impetus for groundbreaking technological changes at its Battery Day 2020 with the presentation of the dry electrode process. It goes back to developments by Maxwell for supercaps in 2014 [3]. While all cell manufacturers were essentially working on classic wet processing before 2020, global university and non-university research work for dry electrode increased dramatically due to the cost reduction potential promised by Musk. In addition, there is even more intensive industrial development work, such as by Tesla, AM Batteries, Sakuu and Licap or as recently published by LG, Samsung SDI, PowerCo and other European OEMs.

Dry electrodes save space

The dry electrode process eliminates the coating and drying step as well as the vacuum post-drying of the coils. The powder mixtures are usually processed into electrodes in modified heated multi-roll calenders. In addition to the complete elimination of all liquids used, these do not have to be evaporated, condensed or, in the case of solvents, reprocessed. The 50 to 100 m long drying sections between the coater heads, which currently determine the building dimensions, are no longer required. This also applies to the hot air generation and filter/condensation systems for supplying/disposing the dryers with drying air, the cold-water generators for the condensers and the distillation systems for reprocessing the NMP separated from the exhaust air.

The building structure of the Gigafactory can therefore be significantly reduced in size, resulting in corresponding savings in construction and operation [4].

Segregation free structured dry mixes as a basis

Two conceptually different production processes with different TRL levels are currently in competition.

- Production of a powder mixture with subsequent powder application by spraying, brushing, printing, with or without the aid of electrostatics, onto the current collector foil with subsequent hot calendering [5]

- Production of a powder mixture with superimposed fibrillation of PTFE to produce a moldable, elastically plastic mix, which is processed into a free-standing film in a calender gap and then directly or separately laminated onto the current collector foil [4].

In both cases, segregation-free structured electrode dry mixes are required. One possibility to achieve this is to coat conductive carbon black onto the particle surfaces of active materials in order to produce a segregation-free compound that does not separate again on the further processing route into the electrode and leads to non-uniform electrode properties. High shear forces such as those present in the Eirich mixer are a prerequisite for realizing carbon coating.

The polymer binder must be mixed in irreversibly homogeneously and, when using PTFE, must also be broken down into fine micro- and nanometer-thick fibers, so-called fibrils, by means of targeted temperature control and high shear. The fibrils link together to form a spider web-like structure, which makes the mixture moldable or rollable into a stable film. The highly plastic, fibrillated mixture, which is difficult to handle and difficult to dose, can be converted into a granulate or powder structure that is easy to convey and dose by means of targeted temperature control in the Eirich mixer. This structured dry mixture is then easy to store and can be fed uniformly into calender gaps, where it can be rolled into a thin film in several stages.

Special challenges

The processing of a completely dry powder mixture into an electrode presents a number of new challenges.

- Achievement of flexible, free standing and stable thin films with 50 – 80 µm thickness (thick stable films are relatively easy to produce). The films become increasingly brittle with each additional rolling step if the mixture is not soft and malleable enough.
- Production of absolutely uniformly films across the width with sharp edges on the collector foil
- Production of wide electrode films up to e.g. 1.2 m width like today in wet coating or alternatively several parallel electrode tracks on one collector foil
- Control of wear/abrasion of machine parts in contact with CAM like NCM or SiOx containing Anode material – High wear is causing iron intake, reduces lifetimes of machine parts, increases scrap and produce finally high costs for maintenance and downtime

- Binder content vs. amount of ultrafine particles < 1 µm (e.g. conductive carbon, LFP fines). More fines need typically more binder to compensate the higher particle surface, which is counterproductive in view of electrochemistry
- Capacity loss and stability problems on Anode by use of PTFE
- Handling, storage and high accurate, small amount dosing of easy to fibril pristine PTFE
- Transfer and storage of structured dry mix between mixing plant and electrode production without (negative) change of product properties, followed by
- a precise and uniform dosing of an elastic, plastic fibrillated mix over large feed gap widths on the calender
- Recycling of the cut-off electrode film edges – The handling of thin edge trimmings and the 100% return to the manufacturing process is essential for the economic efficiency of the overall process.

Innovative mixing technology

Planetary mixers are completely unsuitable for this technology due to the low tool speeds and energy density. New mixing technology is therefore necessary. As an alternative for the production of dry electrode mixes, combinations of simple mixing systems such as low shear tumble/V-mixers with intensifier bar with downstream air jet mills are often proposed. However, it should be borne in mind that the energy consumption of air jet mills is extremely high, and the safe discharge and material handling of the resulting elastic plastic masses represents a major challenge.

Eirich mixers, on the other hand, are a convincing solution. The entire process can be carried out in a one pot process without any problems and can be excellently controlled. It makes no significant difference whether segregation-free powder mixtures are produced for powder application or well-formable structured mixtures for free-standing film formation. The process control and addition sequence are decisive for success. For such demanding processes, the Eirich mixer with double jacket cooling offers maximum flexibility and almost unlimited possibilities.

While wet electrode production has been continuously optimized over decades, dry electrode production is still in its infancy. The reproducible production of finely structured dry mixes whose particle structure and size distribution can be controlled is therefore the key to the efficient production of dry electrodes with good electrochemical properties. In addition to dozens of laboratory mixers currently in use, the first pilot plants with Eirich mixers on a MWh and GWh scale are already being successfully commissioned for fine optimization of the manufacturing process. Eirich has taken on the vast majority of the challenges listed above and has developed technical solutions beyond the mixer for its customers in recent years, which have been implemented in pilot plants or will be in the near future.

Conclusion

Batteries must become "greener" and more cost-effective. Saving electricity, reducing CO2 emissions and minimizing space requirements are the main goals that manufacturers of energy storage systems are currently pursuing. Important levers lie in electrode production, particularly in mixing technology. Eirich solutions in particular offer advantages in terms of cost, flexibility and efficiency either for wet or dry electrode production.

They enable significant savings in CAPEX and OPEX costs and are also a crucial piece of the puzzle in the production of low-cost, green batteries with a small, verifiable CO2 footprint.

References

[1] Gerl, S.; A dry (r)evolution for LIB electrodes; Green Efficient Technology, pp. 6-9, 1/2024,

[2] Liu Y.; Zhang, R.; Wang, J.; Wang, Y.; Current and future lithium-ion battery manufacturing, iScience, Volume 24, Issue 4, 2021, https://doi.org/10.1016/j.isci.2021.102332.

[3] Tesla, 2020 Annual Meeting of Stockholders and Battery Day;

[4] Yang, L.; Chen-Zi, Z.; Hong, Y.; Jiang-Kui, H.; Jia-Qi, H.; Qiang, Z; Dry electrode technology, the rising star in solid-state battery industrialization; Matter 5, 876–898, March 2, 2022

[5] Ludwig, B., Zheng, Z., Shou, W. et al. Solvent-Free Manufacturing of Electrodes for Lithium-ion Batteries. Sci Rep 6, 23150 (2016).

Dr. Stefan Gerl,
Project Director LIB & Head of Process Technology
Eirich