TEGO® Surten E

Process Enablers for Lithium Ion Batteries

EVONIK
Leading Beyond Chemistry

PROCESS ENABLERS

MINUTE ADDITIVES THAT YIELD LARGE IMPROVEMENTS IN PRODUCTIVITY AND PROCESSABILITY

Every small improvement counts with Lithium Ion Batteries (LIB). Evonik's process enablers help contribute to further improvements in the production of LIB's which yield better electrical performance and lower the overall costs. Each contribution facilitates the transition to a more sustainable mode of transportation.

This brochure will give you an overview about our additives with a description of how using them can help you to produce lithium ion batteries more efficiently.

Our broad surfactant technology platform enables us to offer a wide range of products to support your battery production, from wetting and dispersing agents, to defoamers and anti-cracking agents. Clustered together they are marketed under our new brand name family of TEGO® Surten E.

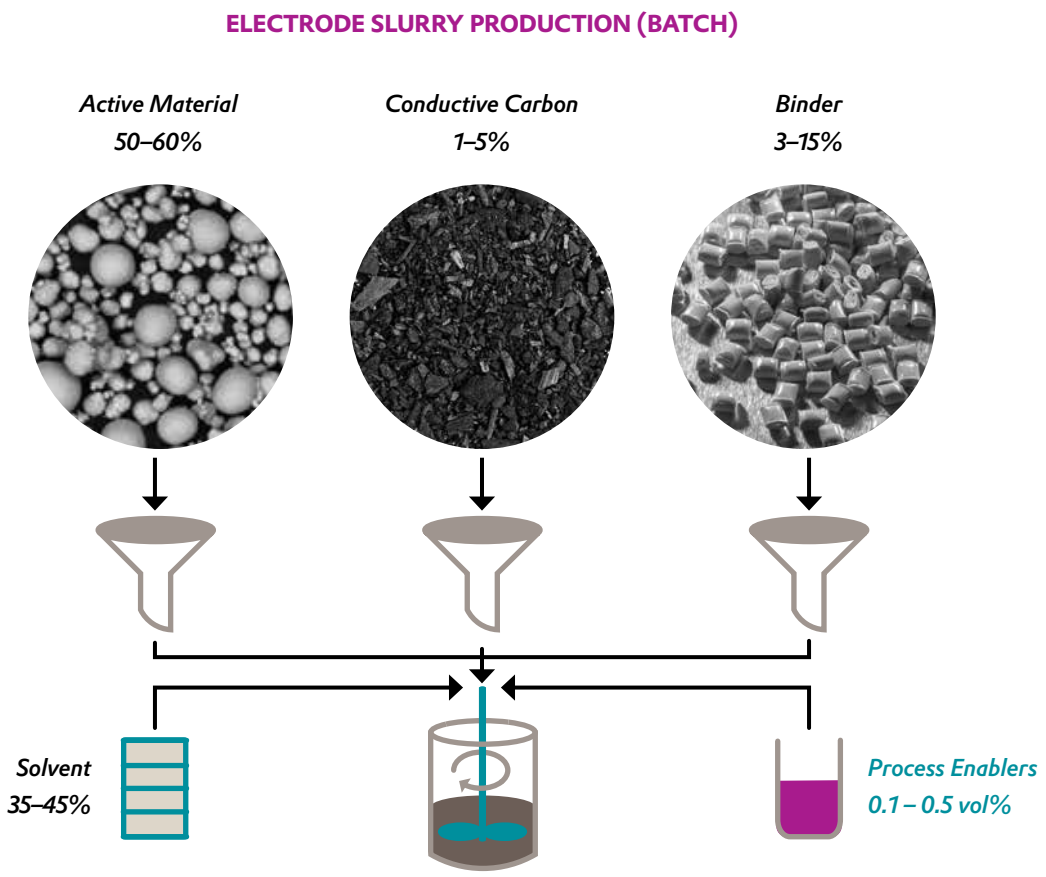
Due to the highly dynamic nature of the industry, we continue to offer customer and process specific solutions and products. Thus at this stage many experimental chemistries and products command the "XP" branding format before being fully commercialized. Our global Fluid Technologies team can assist you with any technical and developmental support, as well as help you select the best product to suit your requirements.

NEW BRAND NAME FAMILY:

"TEGO® SURTEN #XX E"

2XX= Wetting
4XX= Dispersing
6XX= Defoaming
8XX= Flexing
9XX= Others

Slurry Preparation



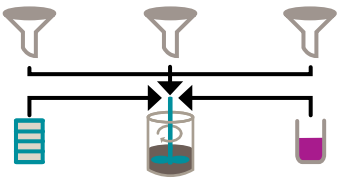
Application and key benefits

1. SEPARATOR COATING →	*Wetting agent to ensure uniform coating and adhesive promotion*
2. ANODE COATING →	*Dispersant for slurry viscosity and grinding time reduction and uniform coating*
3. CATHODE COATING →	*Plasticizer as anticrack and swelling prevention*
4. ELECTROLYTE FILLERS →	*Liquid dispersant for next-generation solid state electrolyte systems*
5. CALENDARING →	*Defoamers to help avoid foaming and air-entrapment*

SLURRY PREPARATION

INGREDIENTS IN THE SLURRY AFFECT THE ENTIRE PRODUCTION AND RESULTING BATTERY CELL

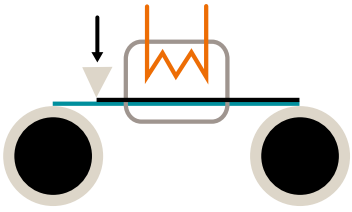
SLURRY PREPARATION



Active material and conductive agents are mixed together in a specific mass ratio

DISPERSING

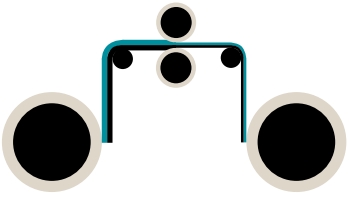
COATING & DRYING



By a tape casting procedure the electrode slurry is coated on the current collectors

WETTING

CALENDARING



During calendaring the porous electrodes are compressed by driving them through two massive rolls

FLEXING

DEFOAMING

CUTTING

The electrodes are cut or punched into strips of the desired shape

CELL ASSEMBLY

The shaped electrodes are wound or stacked together with the separator

ELECTROLYTE FILLING

Electrolyte is injected filling all void spaces and the battery cell is sealed

FILLING

PROCESS ENABLERS affecting the first three production steps of lithium ion batteries in current systems and in next-generation system also the final filling step

KEEP IN MIND: even while under a percent, our process enabling additives can improve the entire production chain

SEPARATOR COATING

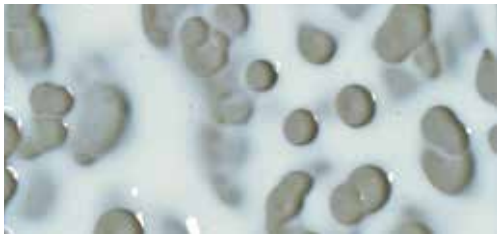
REDUCING SURFACE TENSION BY USING DIFFERENT CHEMISTRIES

Wetting agents improve the wetting behavior of dispersions on substrates and diminish the defects caused by other additives at the same time. Wetting agents are highly efficient even at very low dosage rates.

WITHOUT SURFACTANTS

- High surface tension of water
- High interfacial tension between water and hydrophobic substrate

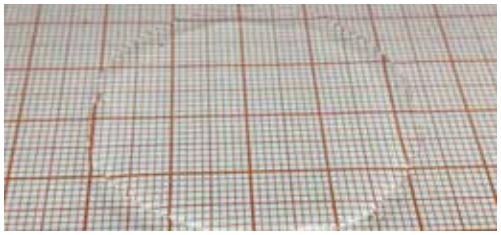
▶ Large contact angle (i.e. poor wetting)



WITH SURFACTANTS

- Lower surface tension of water
- Lower interfacial tension between water and hydrophobic substrate

▶ Smaller contact angle (i.e. better wetting)

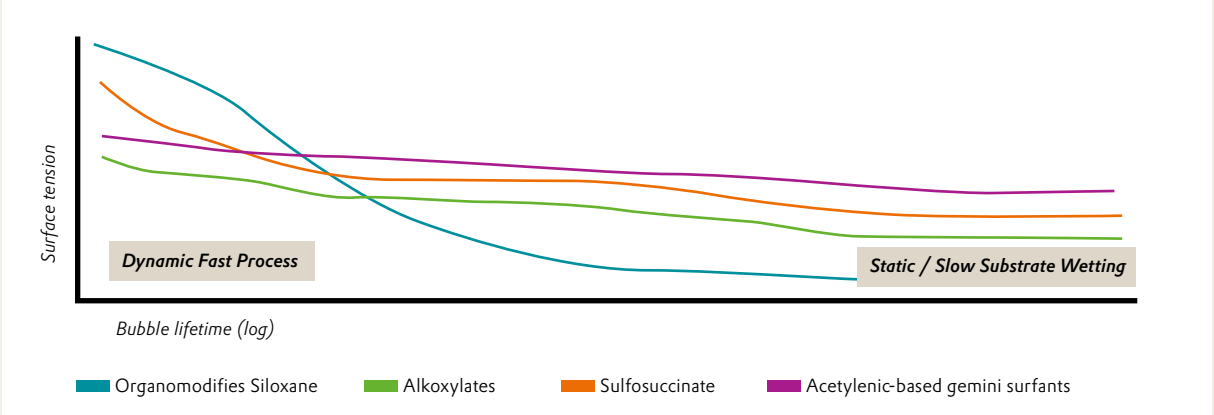


An ideal wetting agent for industrial coatings should have a low dynamic surface tension (fast range). Alcohol alkoxylates are very fast wetting agents with an additionally low foaming tendency. They are highly recommended for slot-die separator coating processes.

Most separators designed for LIB's are stretched PE / PP films coated with a ceramic slurry. These water-based slurries benefit from a wetting agent to improve the uniform coating and the general coating operation by also enabling a cleaner process.

Evonik offers wetting agents suitable for both water-miscible and solvent-based slurries. Yet the industry standard, also for academic testing, has become **TEGO® Surten 202 E**, a dynamic **alcohol alkoxylate**. More recently, **TEGO® Surten 2019 E** (a dynamic acetylenic-based gemini product), has displayed even better beneficial stabilization effects.

Dynamic surface tension



Benefits

- Uniform laminate thickness
- Adhesion improvements
- Decreases surface defects

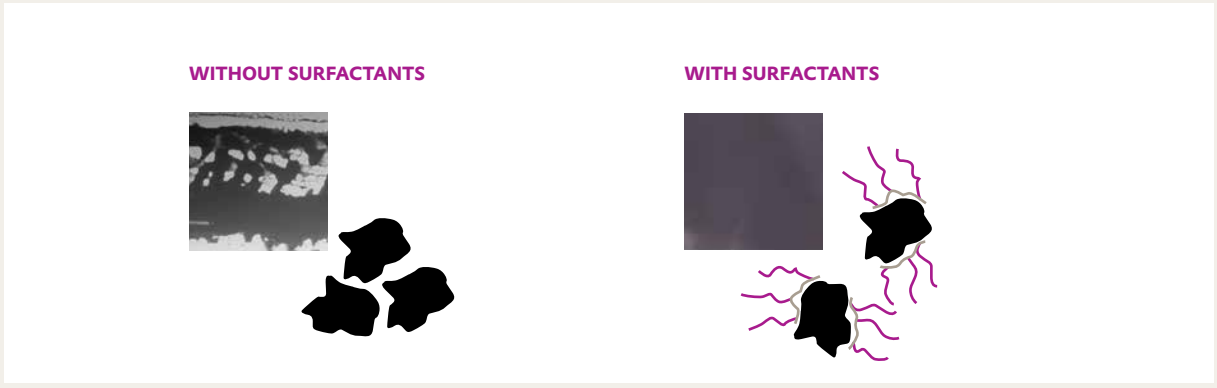
ANODE COATING

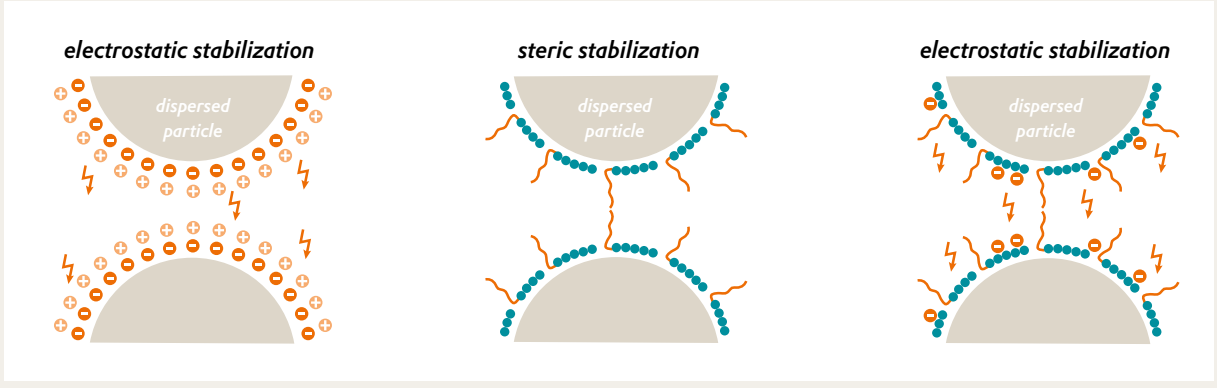
HIGHER ACTIVE LOADING AND BETTER COATING QUALITY

Dispersing agents are surface-active ingredients, which ease the incorporation of pigments and fillers into a liquid. Agglomerates are broken up by shearing to create new surfaces. They are wetted by dispersing agents which stabilize the aggregates of pigments or fillers.

Dispersing agents have amphiphilic structures to facilitate an even coating.

The images below depict conductive carbon black in water, where the dispersing agent clearly stabilizes the slurry and creates a uniform particle suspension. We also offer a range of products suitable for NMP-based cathode slurries, but our products are well suited for water-based solutions for anodes. Depending on the requirements, differing stabilization mechanisms can be pursued.



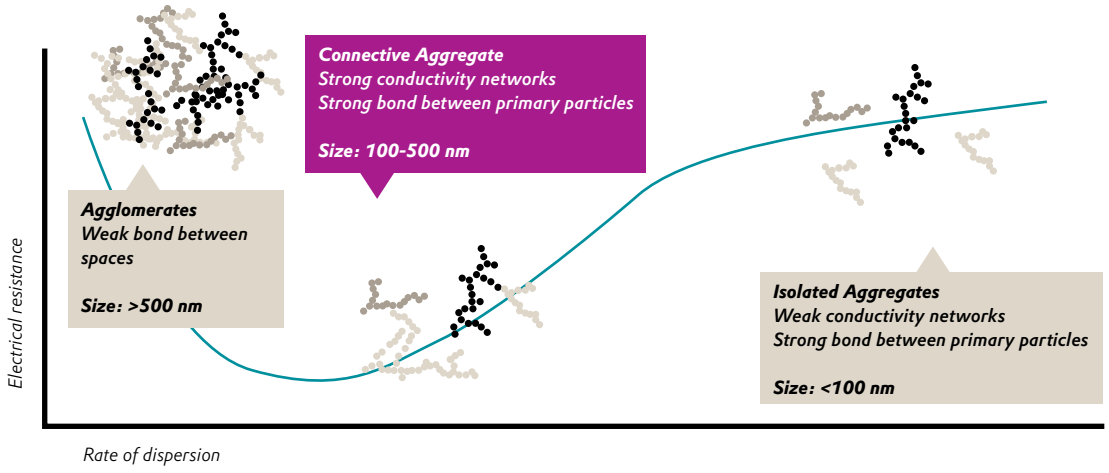


The main function is to break up the active material agglomeration and prevent flocculation during formulation (slurry mixing). The new connective aggregate enables a reduction in viscosity with improved stability and a lower electrical resistance. Additionally, the active matter (solids) loading can be increased, possibly creating thinner and lighter LIB's.

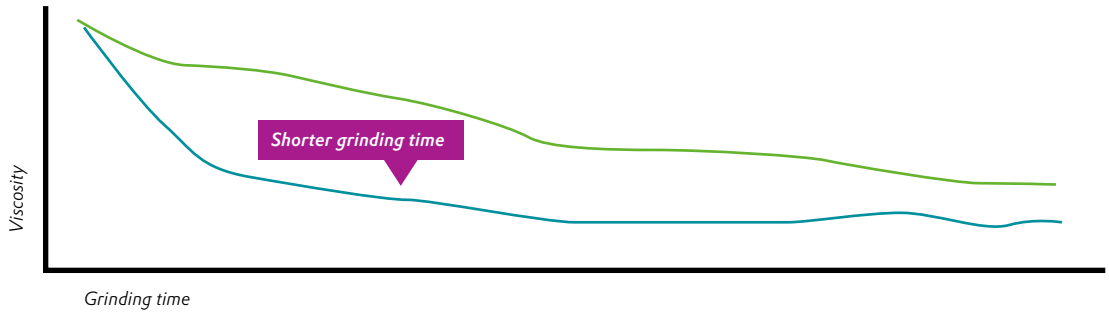
Benefits

- Improved electrical conductivity
- Reduced viscosity
- Shorter grinding time
- Less energy consumption
- Higher solids content

Electrical performance



Viscosity reduction



CATHODE COATING

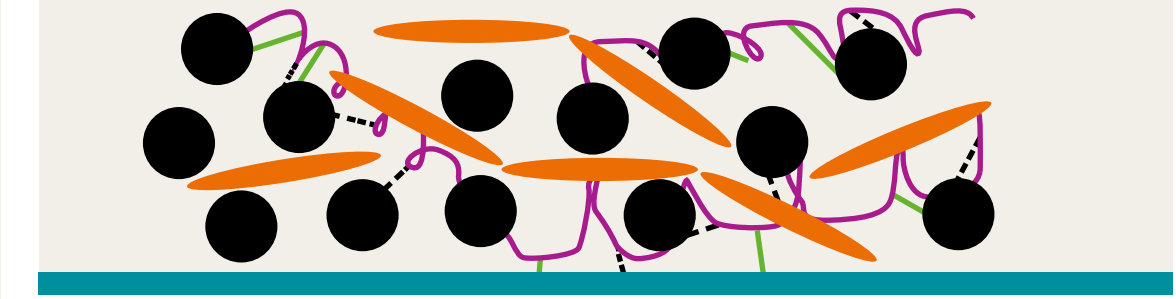
ADDING SOFTNESS WITHOUT MIGRATION

The addition of the binder (such as Polyvinylidene Fluoride = PVDF) with its rigid backbone, leads to a strong molecular interaction force which can also a lead to electrode layer cracking, especially during rolling and folding as in the newer prismatic geometries.

To reduce electrode layer cracking and the resulting process pressure during calendaring, a flexing agent should be employed. It decreases the attraction between the polymer (binder) chains through spacing or swelling to make them more flexible.

These flexing agents create covalent and hydrogen bonds with the foil substrate and active material.
Such hydrogen bonds can break and the soft backbone can stretch causing less electrode cracking and pressures during compression (calendaring).

It is tough and elastic



PVDF 25% IN NMP

Too hard and fragile

PVDF WITH PLASTICIZER IN NMP

Tough and elastic

PLASTICIZER IN NMP

Too soft and unstable

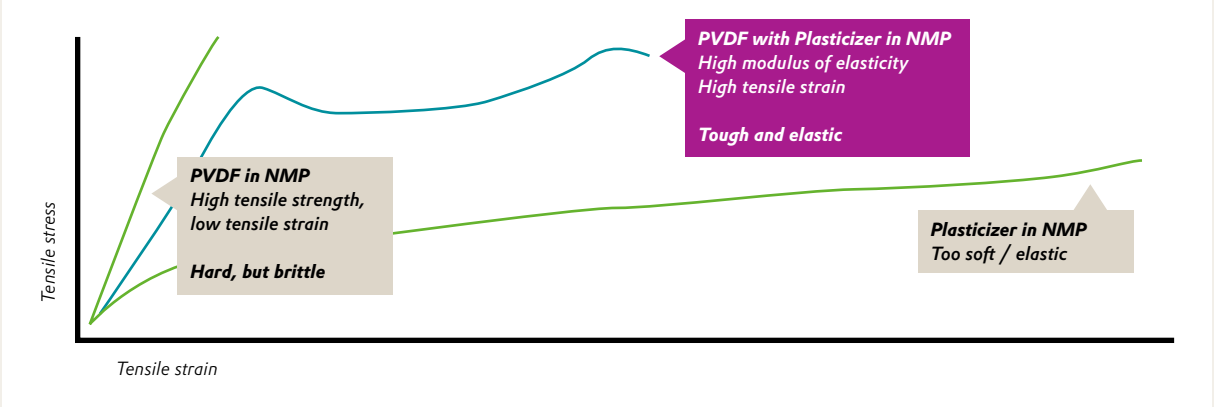
Benefits

- Reduced calendaring pressure
- Prevents electrode crack formation during rolling
- Provides toughness and elasticity
- Lower drying time and requirements
- Prevents swelling during electrical loading

The ideal balance between elasticity and toughness is effected heavily by the formulation and proprietary ingredients used in the slurry mixture. The solubility of the plasticizer can also be adjusted by relying on a different backbone structure. Even the resulting moisture content and need for electrode drying can be steered via side reactions in the plasticizer.

Evonik has a broad range of existing plasticizer and knowledge base for tailored modifications. Given the reactive nature of the plasticizers and the sensibility of the electrode it is highly recommended to develop in conjunction with a specific Evonik solution. Suitable chemistries displaying varying electrochemical stabilities can be matched for specific cathode material systems (page 15). Our solutions also include mixtures and blends of chemistries to ensure the right balance between electrochemical stability and performance.

Mechanical performance



ELETROLYTE FILLER

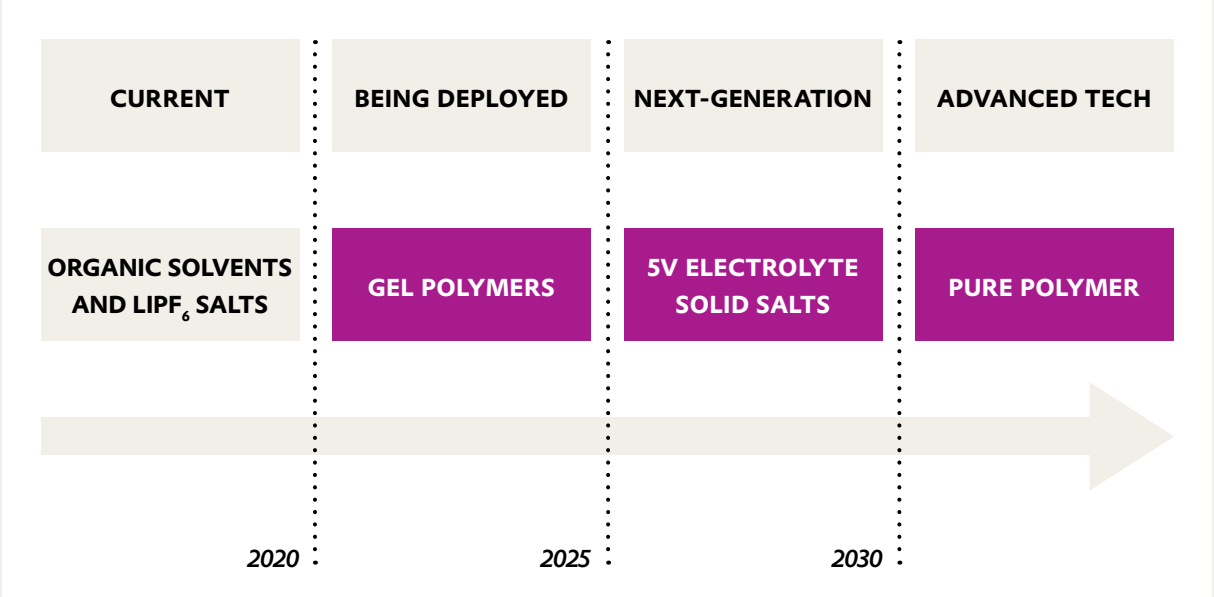
DISPERSION OF NEXT-GENERATION SOLID ELECTROLYTES USING A UNIFORM PARTICLE IN LIQUID FORM

Current electrolyte systems are liquids based on organic solvents and lithium salts. Dispersion and filling between the electrode materials occurs easily upon filling. In the coming 5–10 years there is expected to be a shift to gel and pure polymer electrolytes in a solid form.

Electrically benign polymer dispersant agents in a liquid form can help to promote and enable a good distribution, and uniform penetration of active and conductive material surface layers.

Increasing the long-term solid electrolyte interface stability is already a primary focus of solid-state battery development. The chemical backbone and tailoring abilities of Evonik will lead to suitable additives that can prevent void spaces, cracking and delamination.

Generational development of electrolyte materials



WITH LIQUID DISPERSANTS

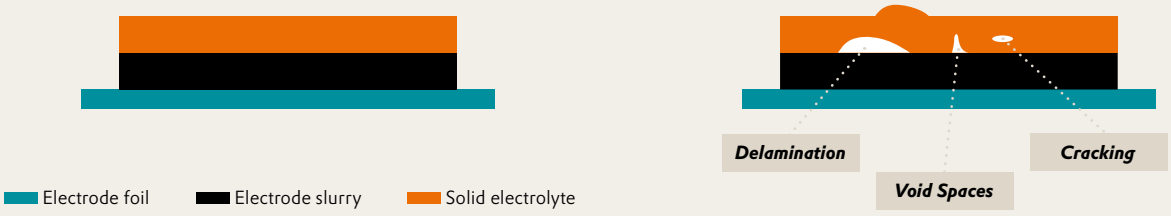
- Good adhesion
- Good flexibility

▶ Long-term Solid Electrolyte Interface (SEI) stability

WITHOUT LIQUID DISPERSANTS

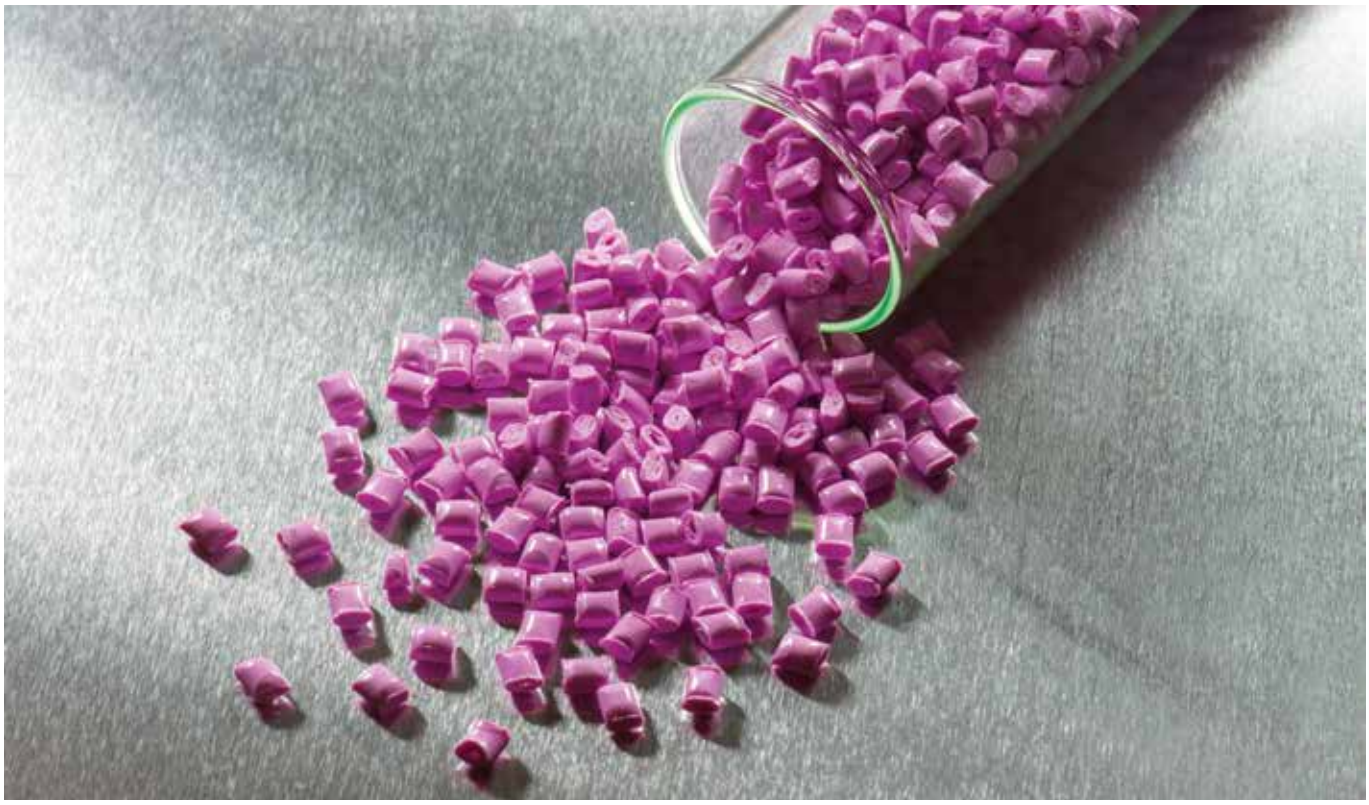
- Poor adhesion
- Rigid, causing cracks, void spaces and eventually delamination

▶ Spallation



Benefits

- Improved interfacial contact
- Spreading and wetting (liquid dispersing)
- Prevention of delamination and void space creation (cracks)

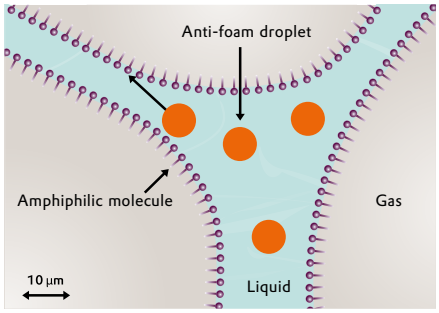


COATING AND CALENDARING

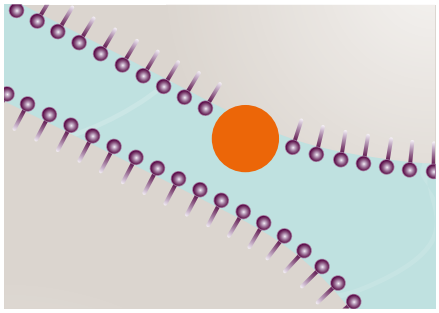
AVOIDANCE OF FOAMING AND AIR-ENTRAPMENT

There is no single defoamer theory, however, some explanations and prerequisites for effective defoamers for water-miscible and solvent-based fluids, like electrode slurries are known.
The main component of a TEGO® Antifoam formulation for aqueous systems is a hydrophobic oil which must be insoluble in the foaming medium, thus forming small droplets in the fluid that should be defoamed. This oil must have a low surface tension, ideally lower than that of the foaming medium. Under these conditions the droplet has a tendency to enter the surface of the foam lamella. If its surface tension is low enough it will start spreading within the lamella surface and exert a strong drag on the underlying layers of water, leading to a thinning and subsequent rupture of the foam lamella.
In solvent-based solutions the functional structures and chemistries are different, but the mechanism is similar.

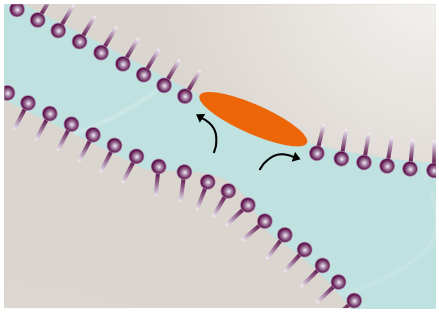
Defoaming Mechanism



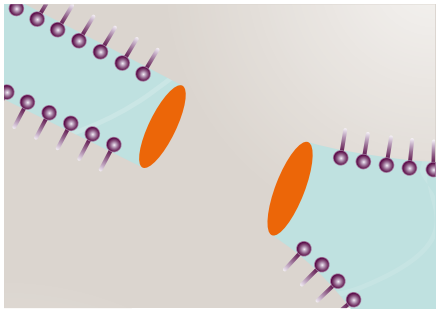
Defoamer oil droplet in foam lamella, stabilized by surfactants



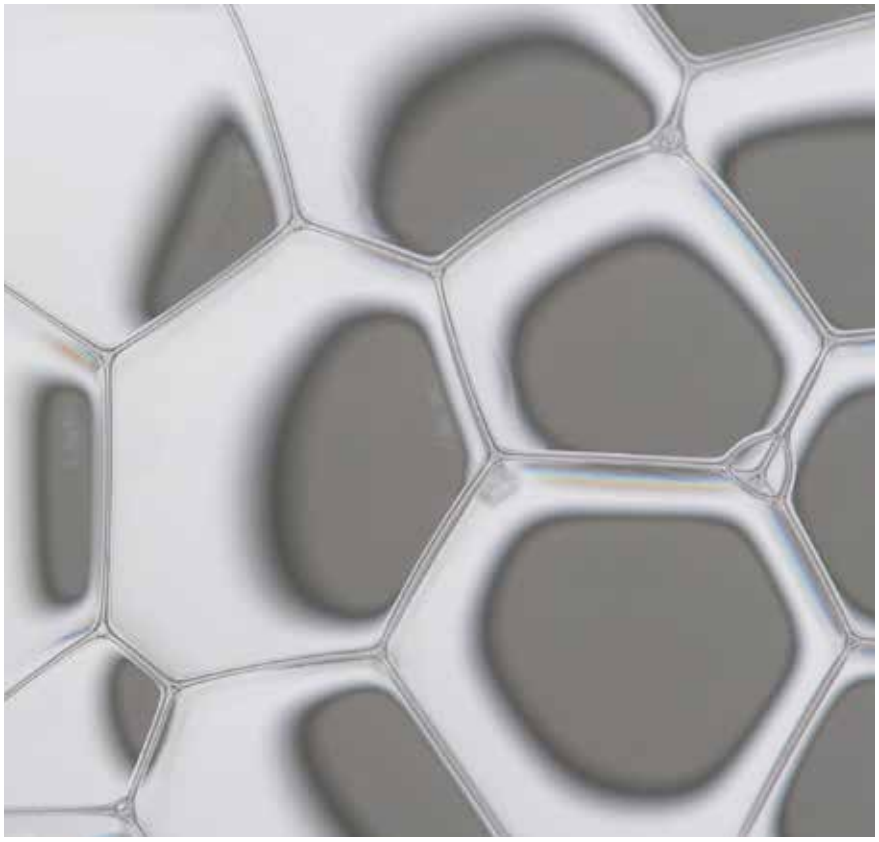
Entering of defoamer oil droplet in air/water interface



Spreading of defoamer oil droplet on air/water interface



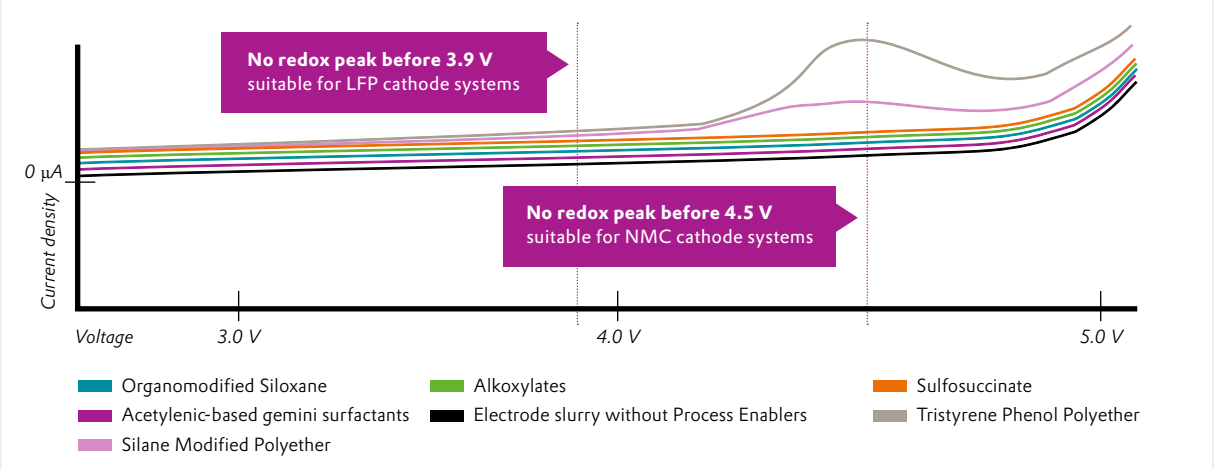
Rupture of foam lamella



Benefits

- Lower energy consumption
- Increased surface and coating quality
- Faster compaction during the calendaring process
- No negative electrical influence

Electrochemical stability



In any slurry that contains a complex array of products, whether water or solvent-based, foams are bound to be created during the high shearing forces that are generated during the stirring or mixing process. These foams interrupt, or slow down the production process and can bring negative effects to the performance of coated electrode slurries and coated ceramic separators.

Thanks to our broad product family and technology platforms, Evonik supplies all kinds of antifoams/defoamers to the market. Based on specific systems, we can offer tailored foam control solutions to enhance the slurry production efficiency and avoid flawed appearances in foil/electrode and separator coating.

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Inv.-Nr.: 48-2020

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