REACTIVE EXTRUSION
CONTINUOUS POLYMER PRODUCTION/MODIFICATION USING CO-ROTATING TWIN-SCREW EXTRUDERS

Reactive extrusion is continuous, chemical polymer modification or polymer synthesis in an extruder. It enables polymer-analogous reactions to be carried out without the use of a solvent. It also allows polymers to be further processed, mixed with other polymers (blended) or implemented directly into the component in an injection molding process, directly after modification.

Advantages of reactive extrusion
- Cost savings through elimination of solvent
- Handling of higher viscosities up to $10^6$ Pa·s
- Optimal mixing and heat transfer conditions adjustable by screw and barrel design
- Cost and energy savings by decrease of processing steps
- Improved material properties, as exposure to thermal stress is minimized

Reactive extrusion: experience and applications at Fraunhofer ICT
1) Bulk polymerization from a monomer / low-molecular-weight prepolymer:
   → e.g. ring-opening polymerization of PLA, polycondensation of PGA, repolymerization of PET oligomers, step-growth polymerization of TPU
2) Functionalization and grafting reactions through linking of monomers / oligomers to polymer backbone
   → e.g. radical grafting of anhydride on polymers
3) Interchain copolymerization between two or more polymers with copolymer formation
   → e.g. modification of thermoplastic starch by copolymerization with anhydride-grafted biopolymers
4) Coupling or branching with polyfunctional coupling agent to increase the length of the homopolymer chain
   → e.g. PET chain extension with difunctional anhydride
5) Degradation reactions decreasing the molecular weight of the polymer
   → e.g. degradation of PET with ethylene glycol, devulcanization of rubber

**Online analytics**

Besides standard techniques, at Fraunhofer ICT on-line viscometry and multi-position online NIR technologies are also available for the effective characterization of reactive extrusion. Especially for reactions involving a large change in viscosity, on-line viscometry is a versatile measurement to evaluate the process efficiency. In the early stage of research, multi-position NIR analysis generates a very detailed process understanding, including information about where reactions or side reactions occur in the extruder. At a later stage, NIR can be utilized for tracking the quantity of a selected additive or for a quick and easy quality control of the produced material.

**Equipment available at Fraunhofer ICT**

- Mini-scale extruder (batch compounder):
  - twin-screw with backflow channel
  - capacity of 6-10 g.
- Lab-scale extruders (limited flexibility):
  - screw diameter of 12-16 mm
  - throughput below 2 kg/h
- Pilot-scale extruders (tailored process setup):
  - screw diameter of 18, 27, and 32 mm
  - processing length 36-60 L/D
  - throughput of 0.2-100 kg/h depending on the processed material
- Flexible dosing for granules, powders, fibers, liquids & gases (supercritical) in a wide range of throughputs
- Vacuum technology
- Downstream equipment for pelleting, shaping, foaming...

**Our offer**

- Adjustment of the reaction system and the formulation, taking account of safety precautions
- Optimization of process control
- Analysis and quantification of the reaction, and characterization of the materials
- Development of the process chain from material selection and dosing to material processing and certification