Inline-Monitoring in der Kunststoffverarbeitung: Vom Compoundieren bis zum Spritzguß

Ingo Alig, Bernd Steinhoff, Dirk Lellinger

Deutsches Kunststoff-Institut
Schlossgartenstr. 6
D-64289 Darmstadt

ialig@dki.tu-darmstadt.de

In-line Methods for Polymer Processing at DKI

Classical Methods	Spectroscopic Methods	Scattering Methods	Imaging Methods
Pressure	***NIR, IR, UV/VIS***	***Light scattering***	*Optical microscopy*
Temperature	***Raman***	*X-ray scattering*	*X-rays*
Viscosity	***Fluorescence***	***Sound scattering***	*NMR*
Conductivity	***Dielectrics***		*Terahertz waves*
	Microwaves		*Ultrasound*
	Terahertz waves		
	NMR		
	Vibration analysis		
	Acoustics		
	Ultrasound		
State of process Material properties	Composition Conversion Material properties	Structure, Morphology, Defects	

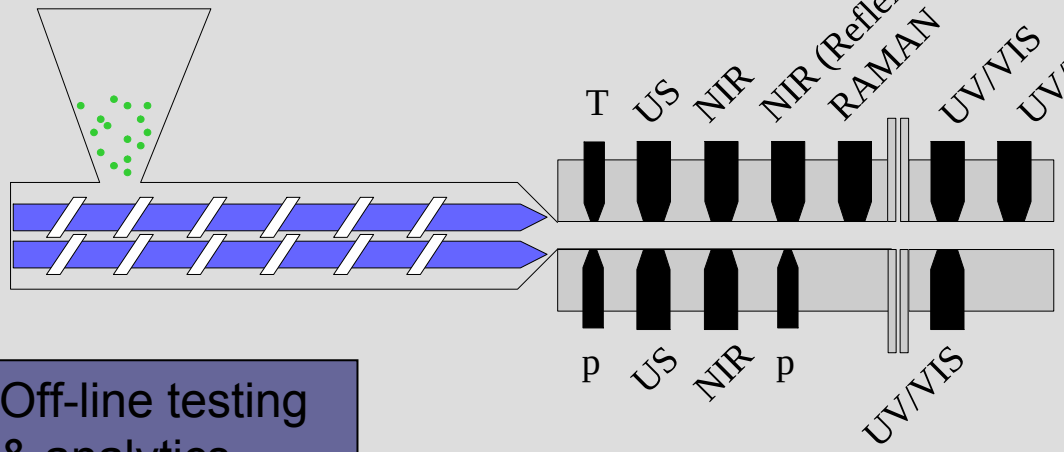
Concept for Process Control

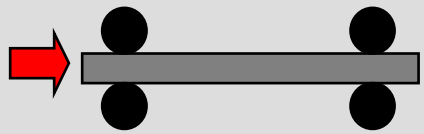
Design of experiment (DoE)

Melt monitoring (in-line)

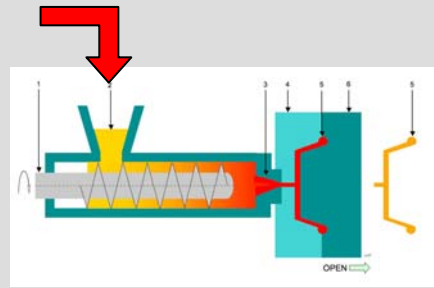
Monitoring of solid state

Polymers, additives, fillers ...





flat film extrusion



Injection moulding

\+ Off-line testing & analytics

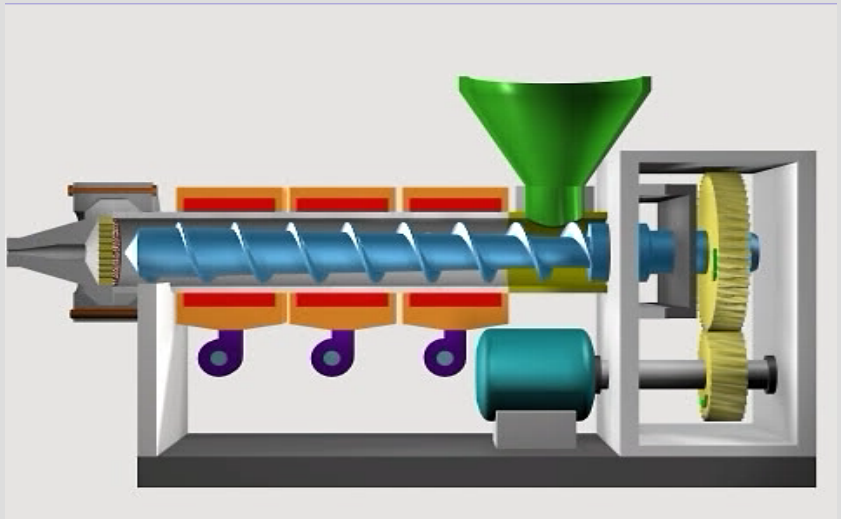
\+ Data mining 'chemometrics'

available (1995 – now)

I. Alig, D. Fischer, D. Lellinger, B. Steinhoff, Macromol. Symp. 230 (2005) 51

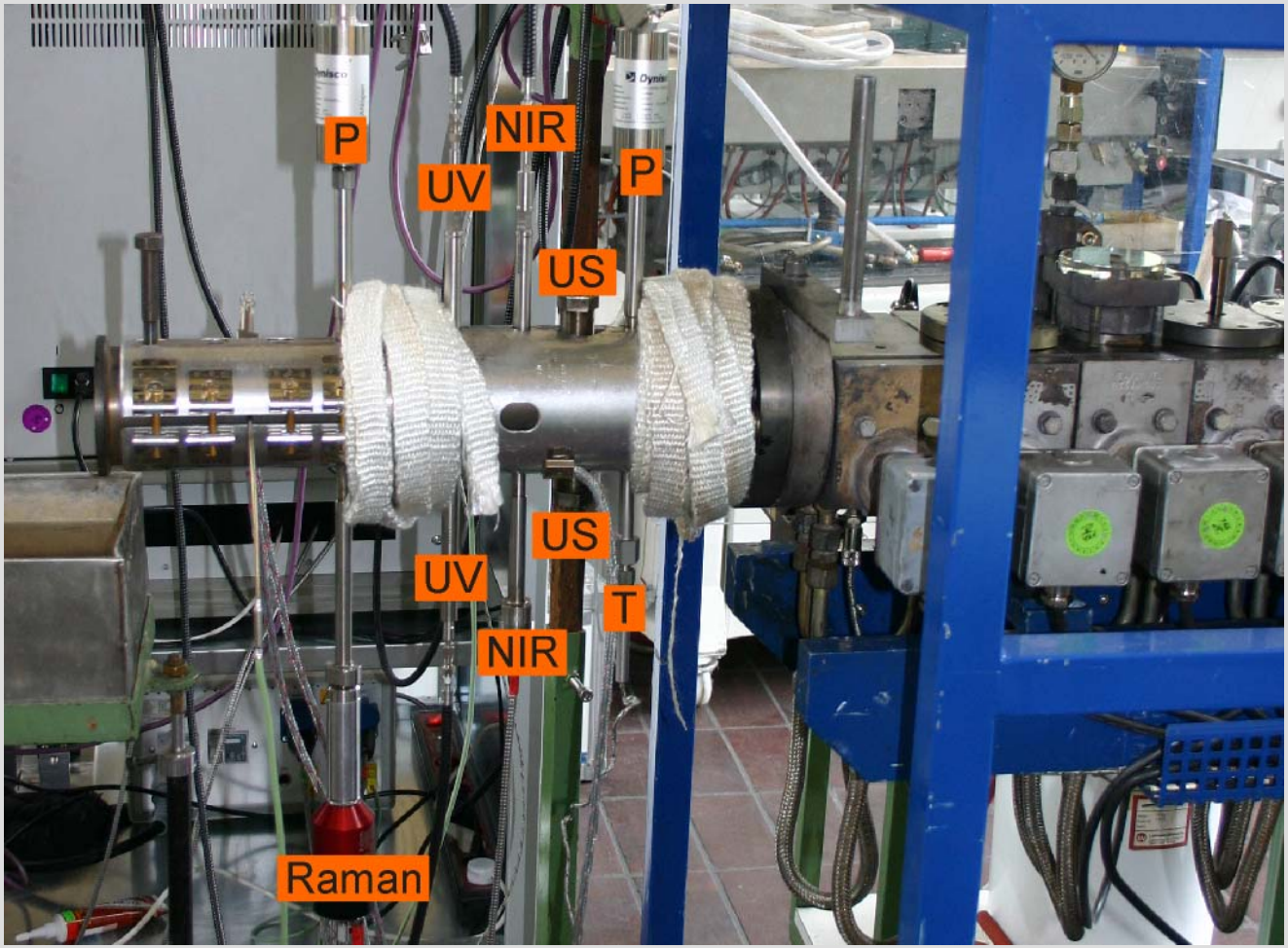
In-line monitoring along the process chain

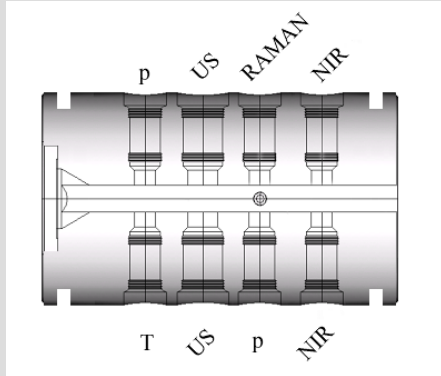
- Compounding
- Injection molding
- Flat film extrusion



Prozessmesstechnik in der Kunststoffaufbereitung
ISBN: 978-3-8343-3117-5
Vogel Buchverlag
Hochrein, Th. / Alig, I. (Hrsg)

Experimental Setup
(pilot plant scale)



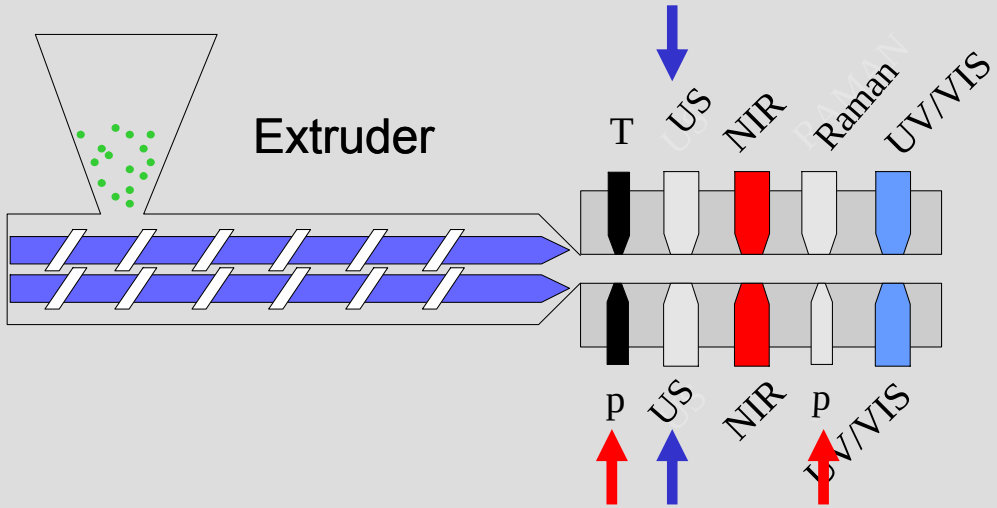


In Cooperation
with D. Fischer (IPF)

Twin screw extruder: ZSK-30

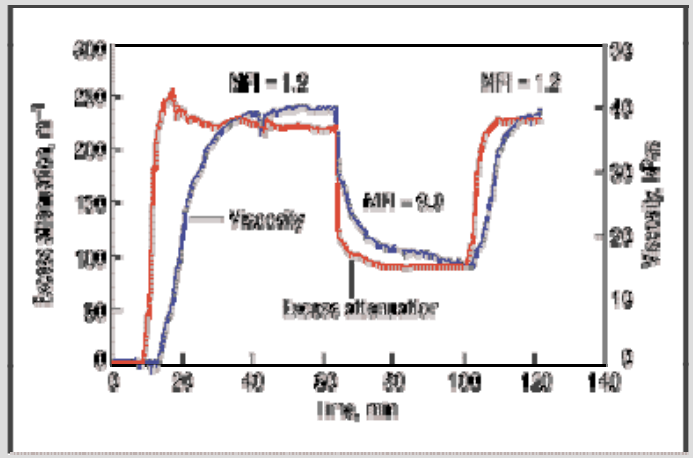
I. Alig, D. Fischer, D. Lellinger, B. Steinhoff, Macromol. Symp. 230 (2005) 51

Information from Melt Monitoring

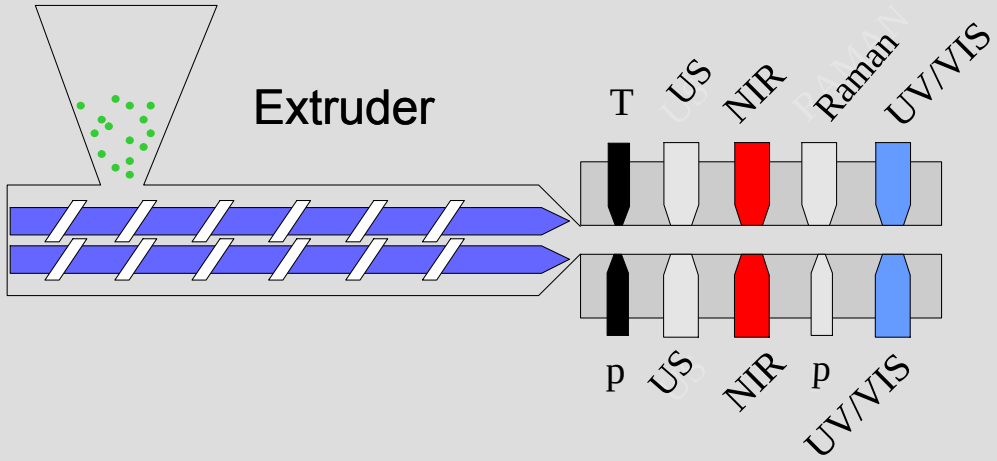


Information on:

- viscoelastic properties
- chemical composition
- additive/filler content
- degree of dispersion / agglomeration
- blend morphology
- degradation of (bio)polymers

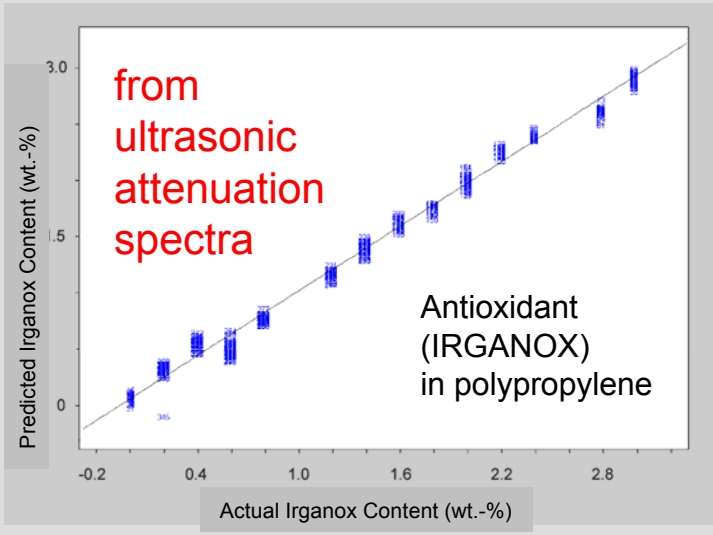


Information from Melt Monitoring

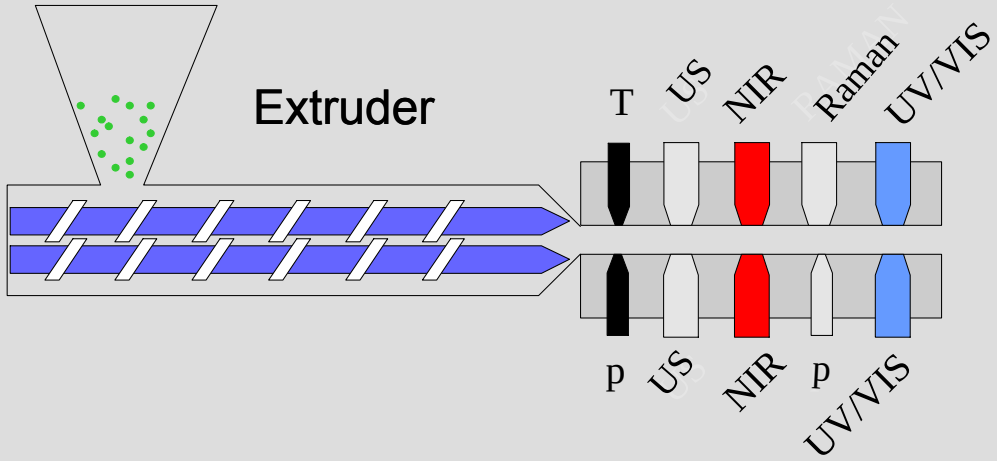


Information on:

- viscoelastic properties
- chemical composition
- additive/filler content
- degree of dispersion / agglomeration
- blend morphology
- degradation of (bio)polymers

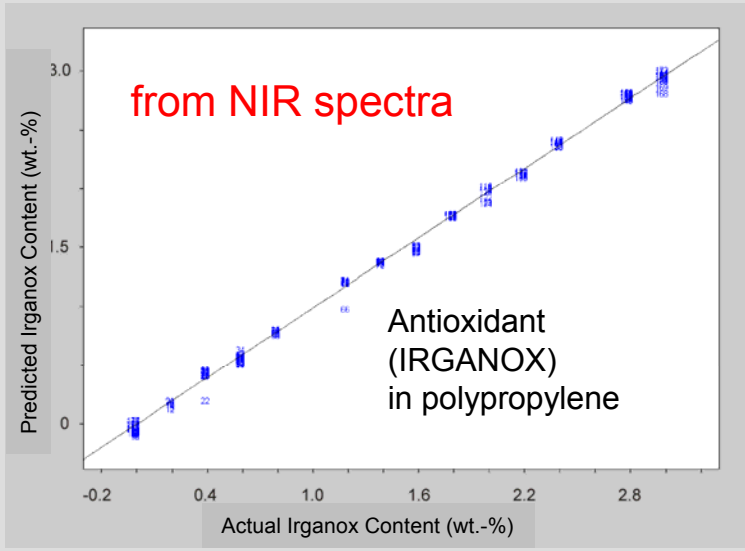


Information from Melt Monitoring



Information on:

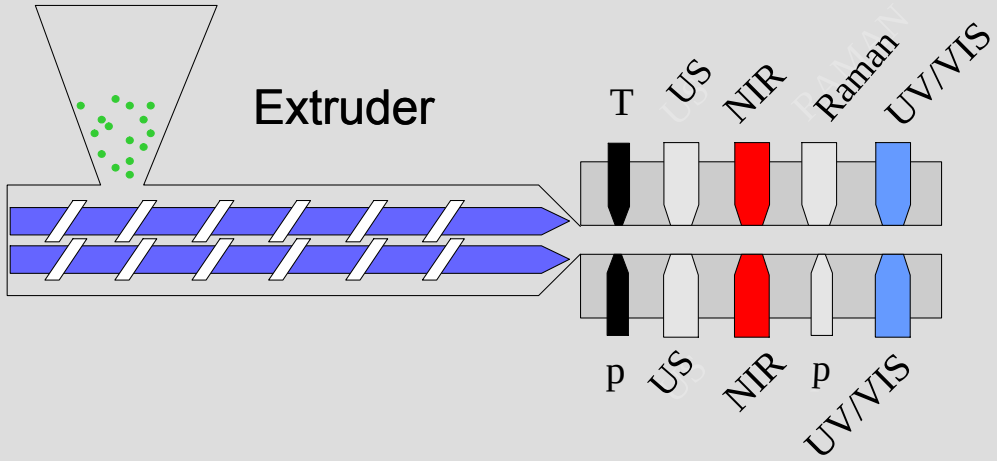
- viscoelastic properties
- chemical composition
- additive/filler content
- degree of dispersion / agglomeration
- blend morphology
- degradation of (bio)polymers



Deutsches Kunststoff-Institut

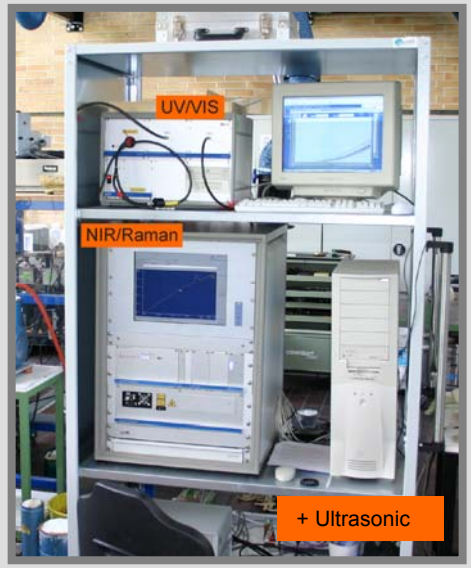
Information from Extrusion Monitoring

TECHNISCHE UNIVERSITÄT DARMSTADT



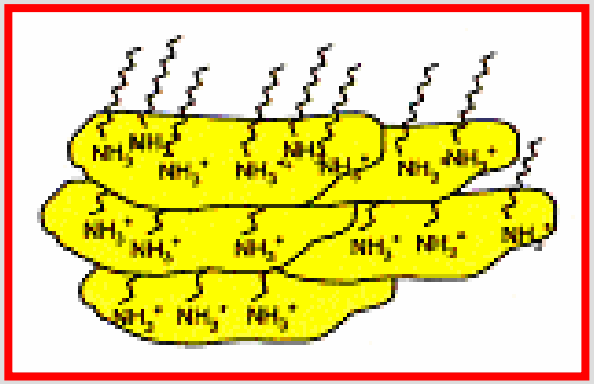
Information on:

- viscoelastic properties
- chemical composition
- additive/filler content
- degree of dispersion / agglomeration
- degradation of (bio)polymers
- blend morphology



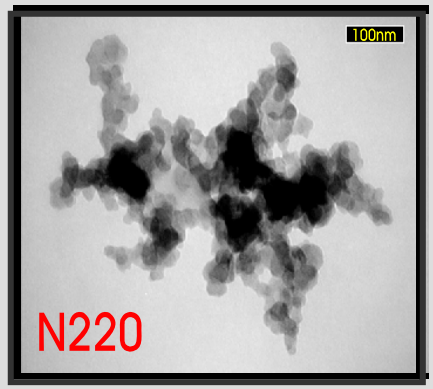
Micro- and Nanoparticle

Non-conductive

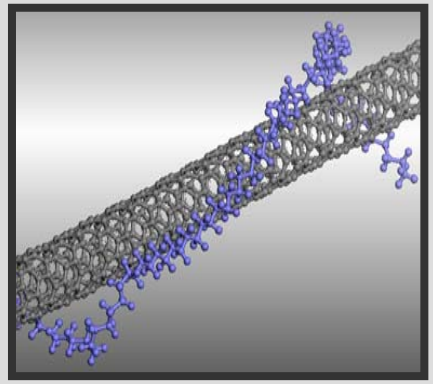


Clay

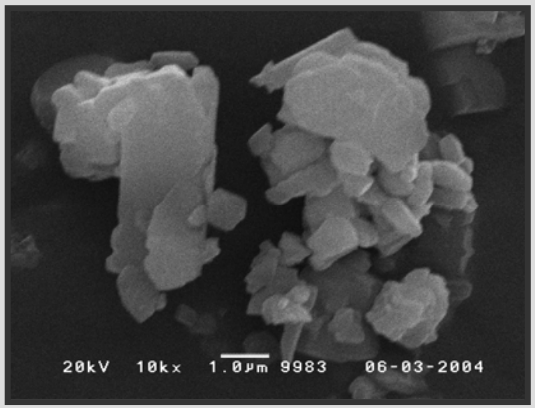
Conductive



Carbon Black



Carbon Nanotubes

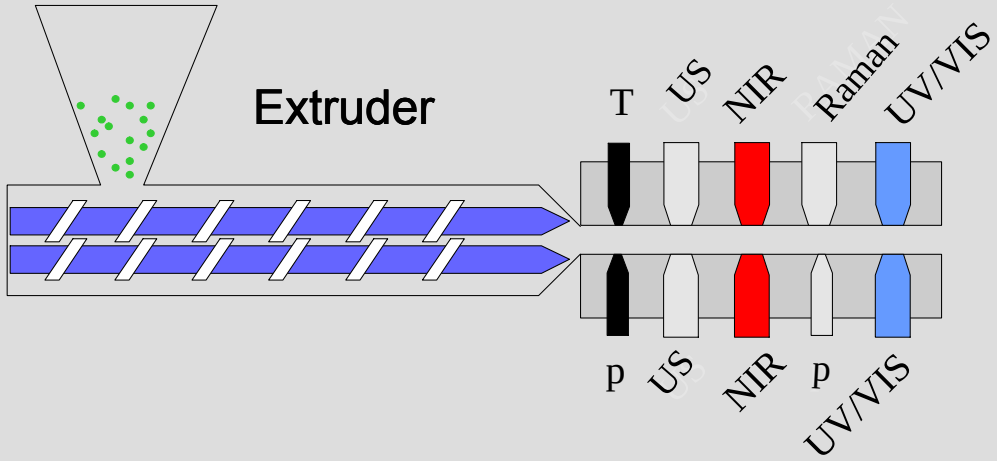


Chalk

Alig, Lellinger, Dudkin, Pötschke
Polymer 48 (2007) 1020
Alig, Lellinger, Engel, Skipa, Pötschke
Polymer 49 (2008) 1902

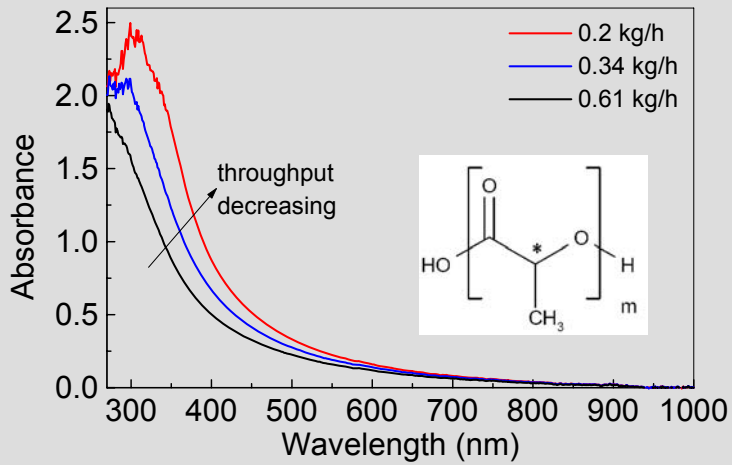
Alig, Lellinger, Steinhoff, Fischer
Kunststoffe (plast europe) 96, 5 (2006) 68

Information from Extrusion Monitoring



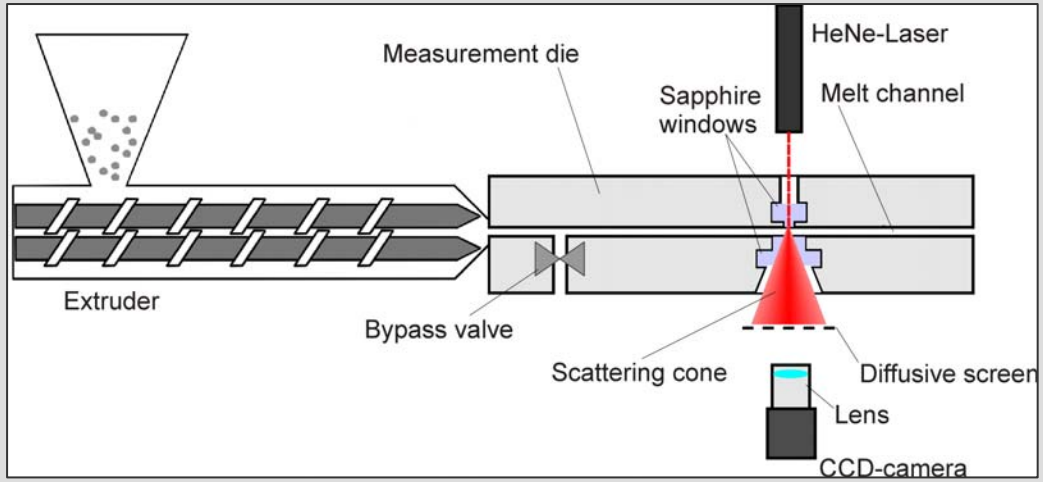
Information on:

- viscoelastic properties
- chemical composition
- additive/filler content
- degree of dispersion / agglomeration
- degradation of (bio)polymers
- blend morphology



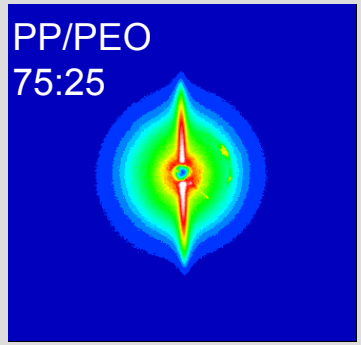
Y. Wang, B. Steinhoff, Ch. Brinkmann, I. Alig, *Polymer* 49 (2008) 1257-1265

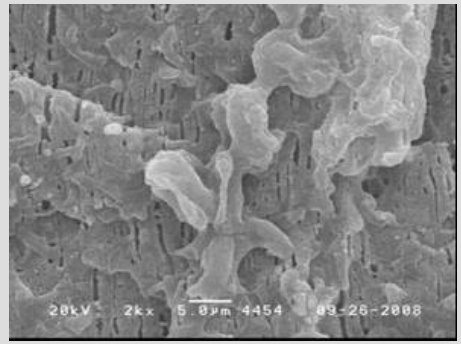
Information from Extrusion Monitoring



Information on:

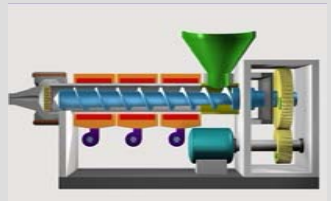
- viscoelastic properties
- chemical composition
- additive/filler content
- degree of dispersion / agglomeration
- degradation of (bio)polymers
- blend morphology

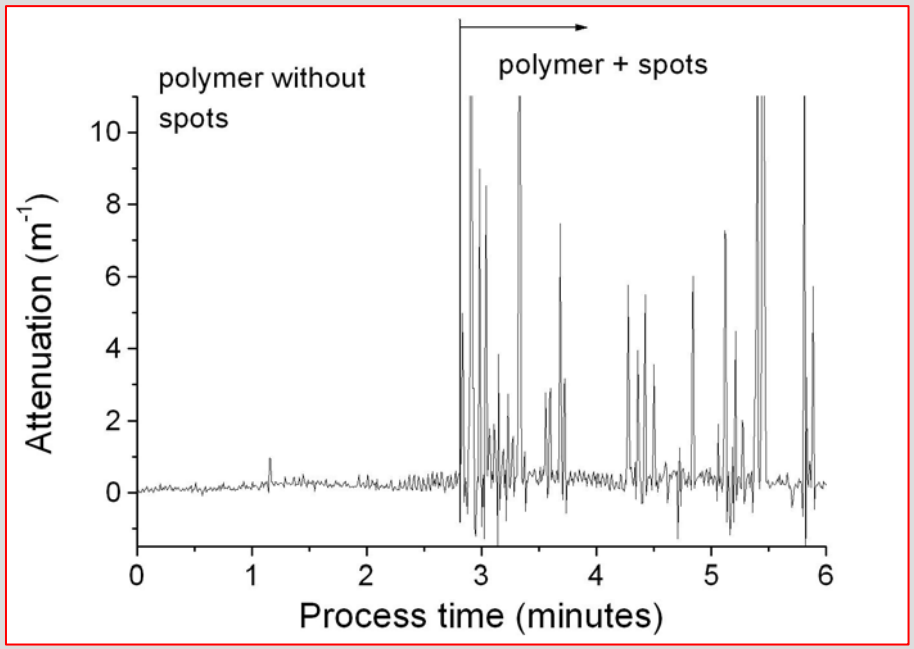


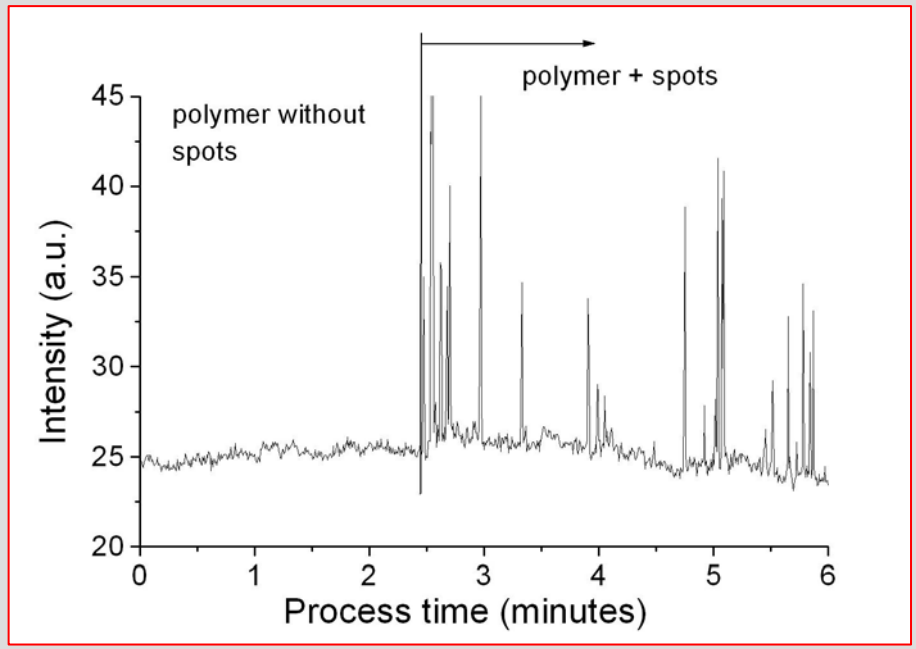


I. Alig, B. Steinhoff, D. Lellinger, Meas. Sci. Technol. **21** (2010) 062001-20

Adding of material containing spots (diameter about 0.7 mm) to a thermoplastic elastomer at process time zero

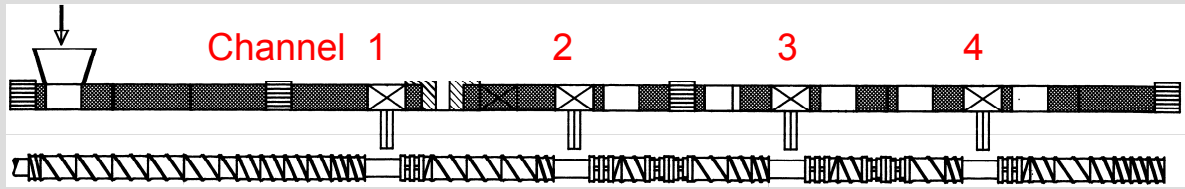


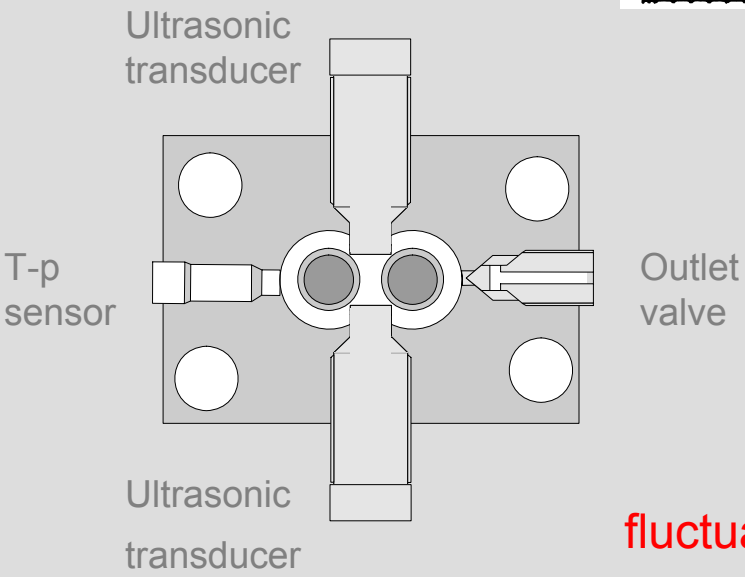




Fluctuations of **ultrasonic attenuation** (left) and **scattered light intensity** (right)

Process Control along the Processing Unit
- Extrusion -



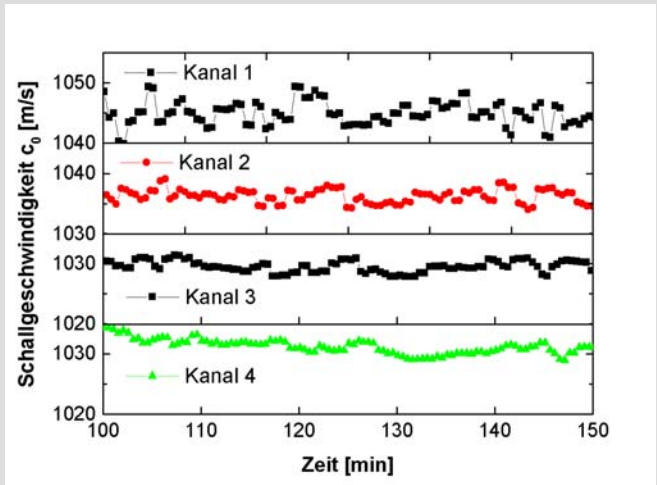


auto- and cross-correlation:

$$A_{ij}(\tau) = \langle c_i(t) c_j(t+\tau) \rangle = \int_0^\infty c_i(t) c_j(t+\tau) d\tau$$

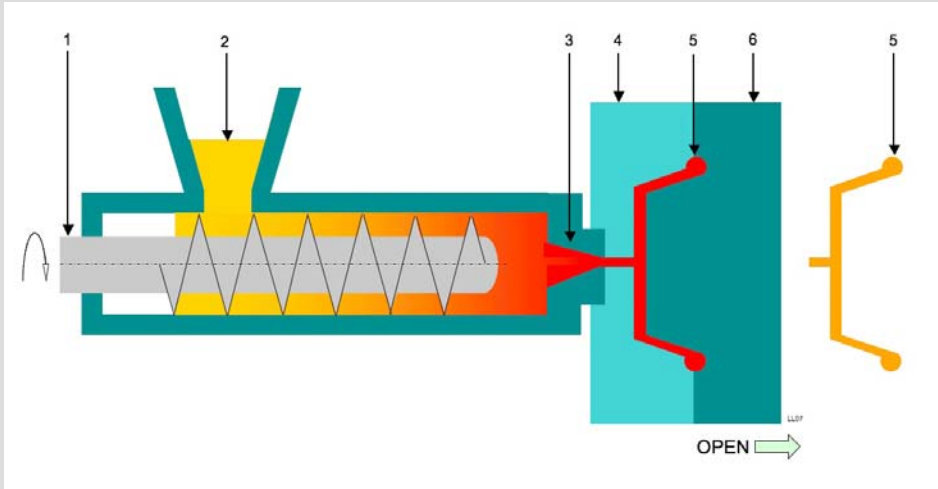
fluctuations of sound velocity

→ quality of mixing

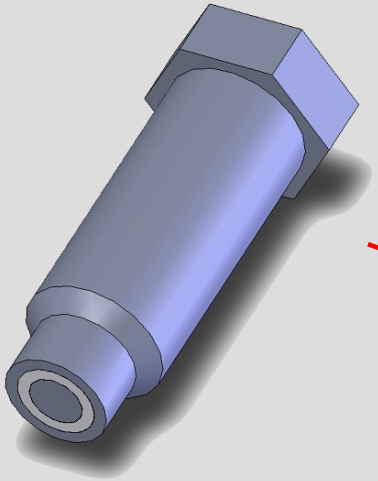


In-line monitoring along the process chain

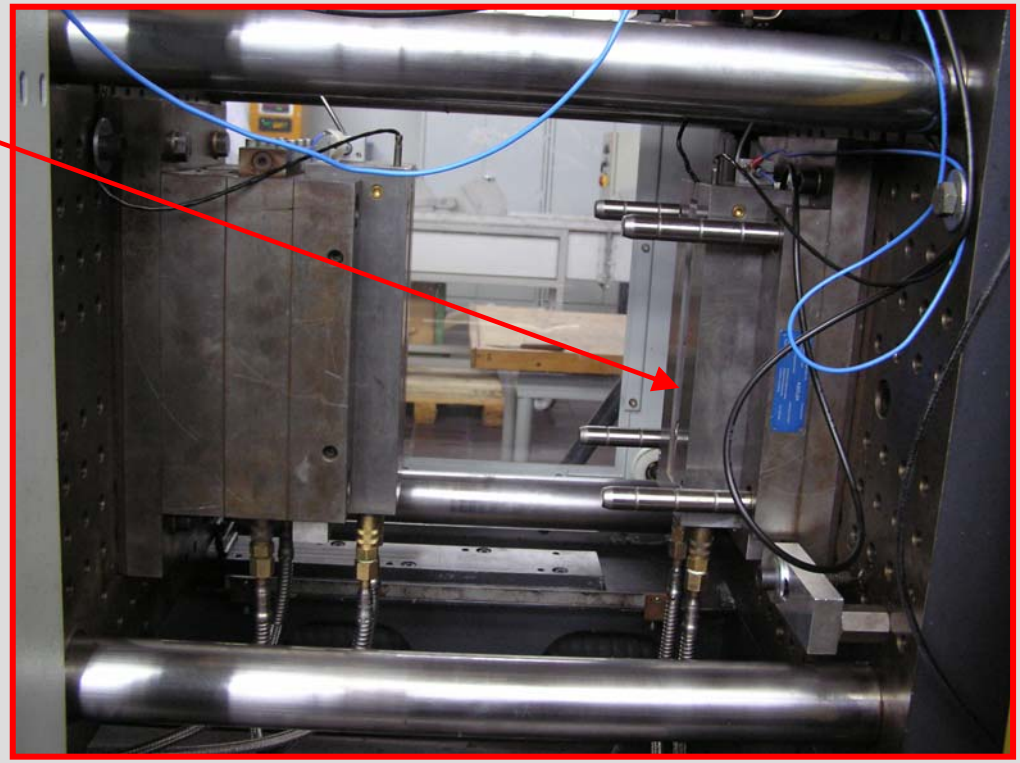
- Compounding
- Injection molding
- Flat film extrusion



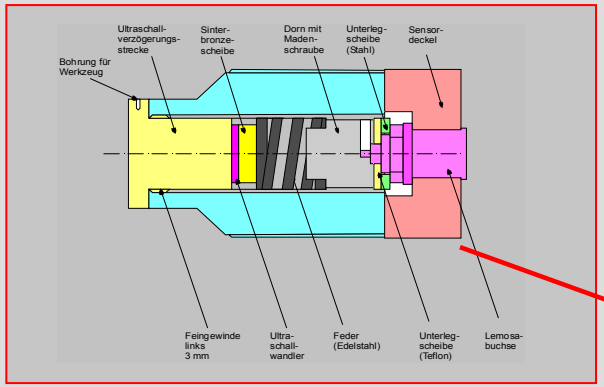
Conductivity sensor



MWNT in PC

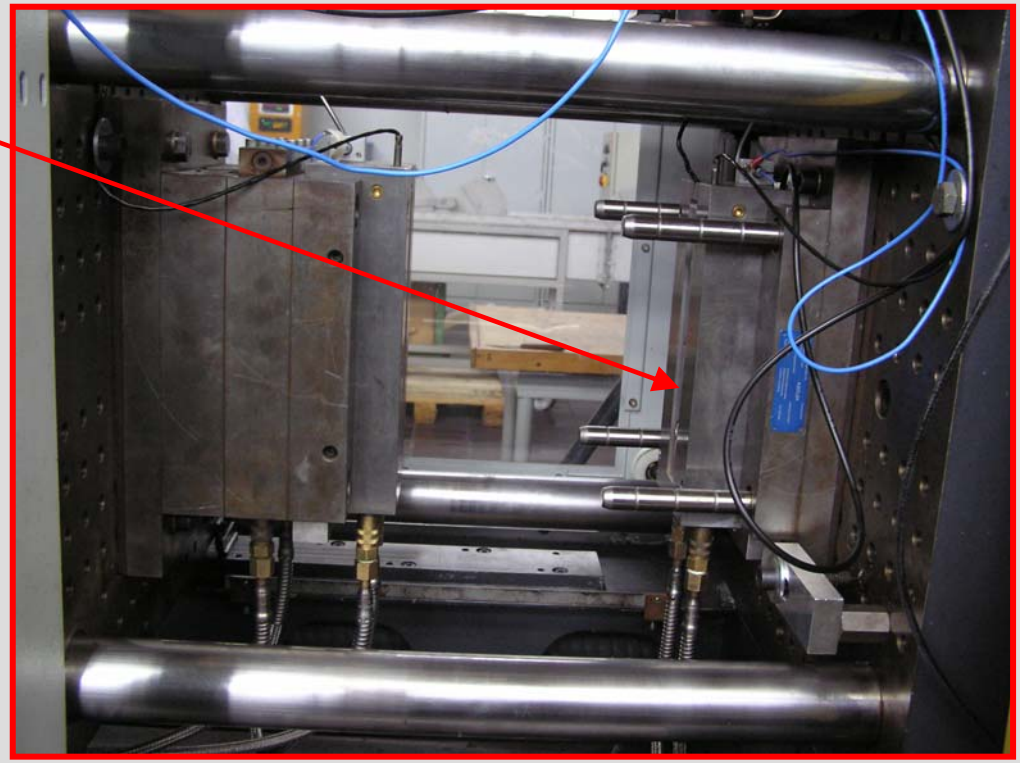


Injection molding machine



Ultrasonic sensor

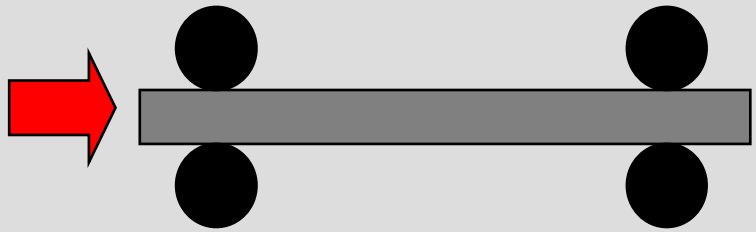
- Injection molding of semi-crystalline polymers
- Monitoring of growth of crystalline boundary layer
- Comparison to FEM simulation



Injection molding machine

In-line monitoring along the process chain

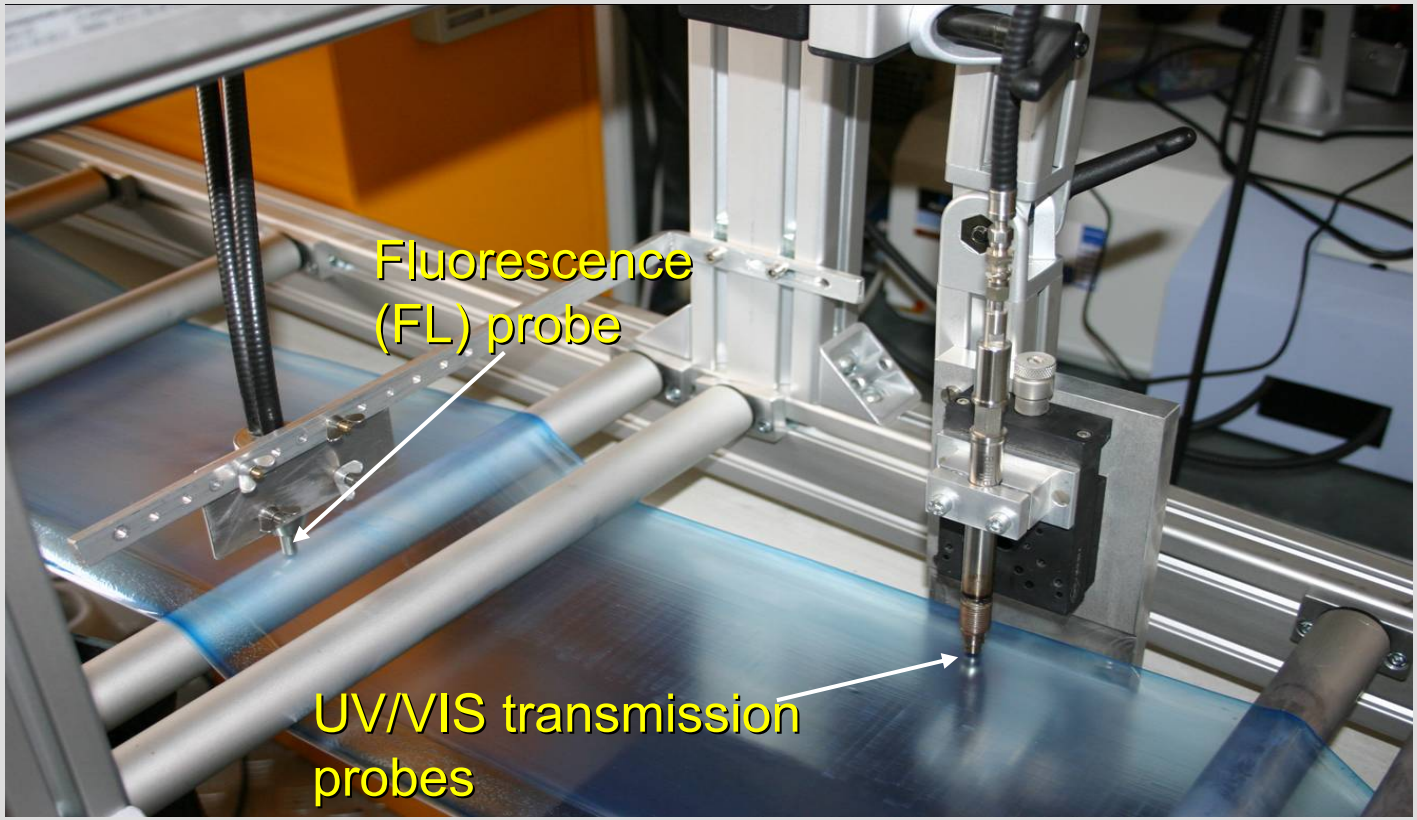
- Compounding
- Injection molding
- Flat film extrusion



Deutsches Kunststoff-Institut

Monitoring a flat film line

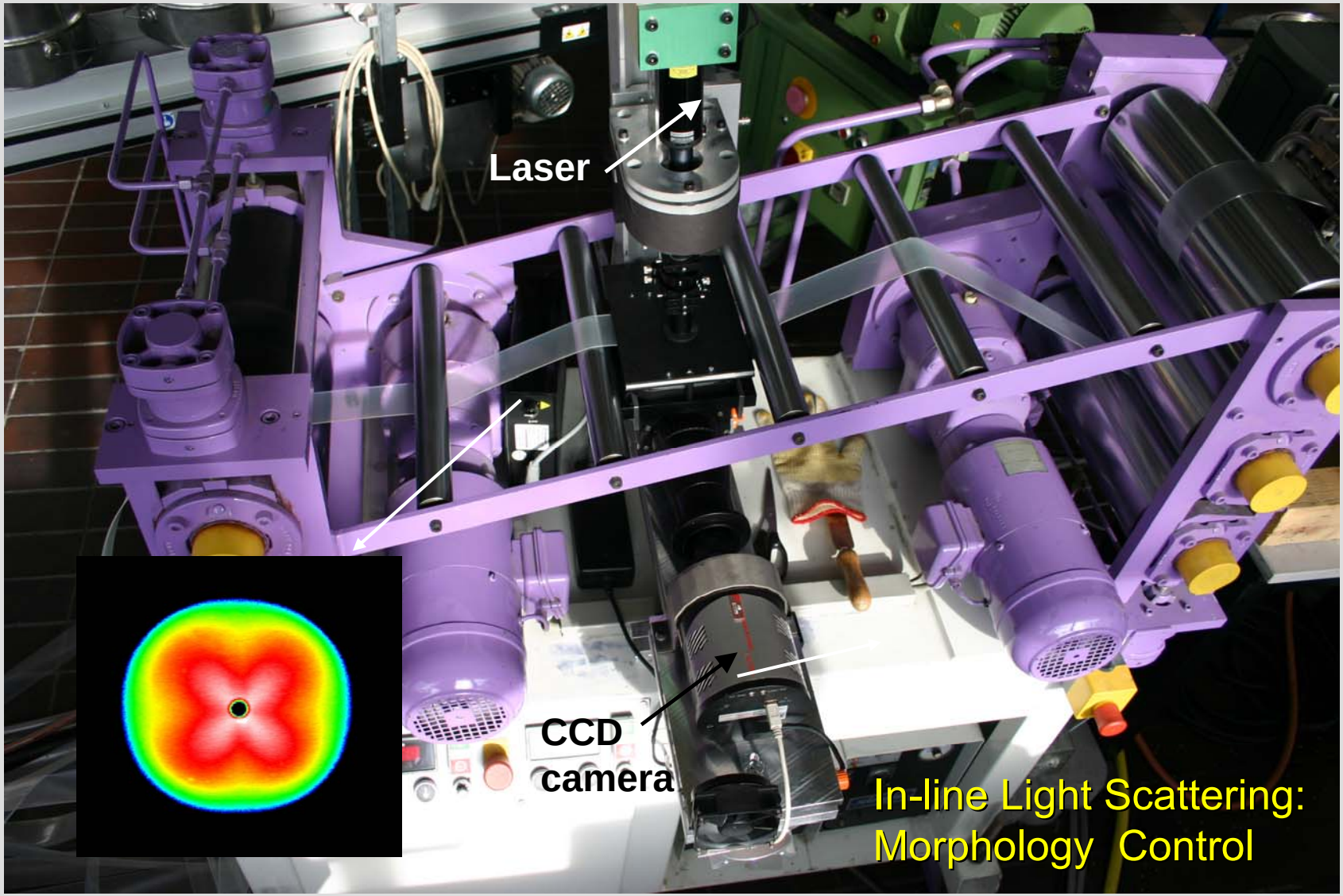
TECHNISCHE UNIVERSITÄT DARMSTADT



Deutsches Kunststoff-Institut

Monitoring a flat film line

TECHNISCHE UNIVERSITÄT DARMSTADT



Summary

Optical and ultrasonic spectroscopy:
composition, filler content and dispersion, degradation etc.

In-line light scattering and optical spectroscopy:
Morphology control

Electrical conductivity and permittivity measurements:
Monitoring of conductive (nano) composites and blends

Process control along the processing unit:
residences time and material fluctuations

Extension of in-line methods to solid state:
Injection molding and flat film extrusion