Workshop: Lifecycle of Plastics

Introduction to Polymer Processing

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C-PlaNeT
CIRCULAR PLASTICS NETWORK
FOR TRAINING

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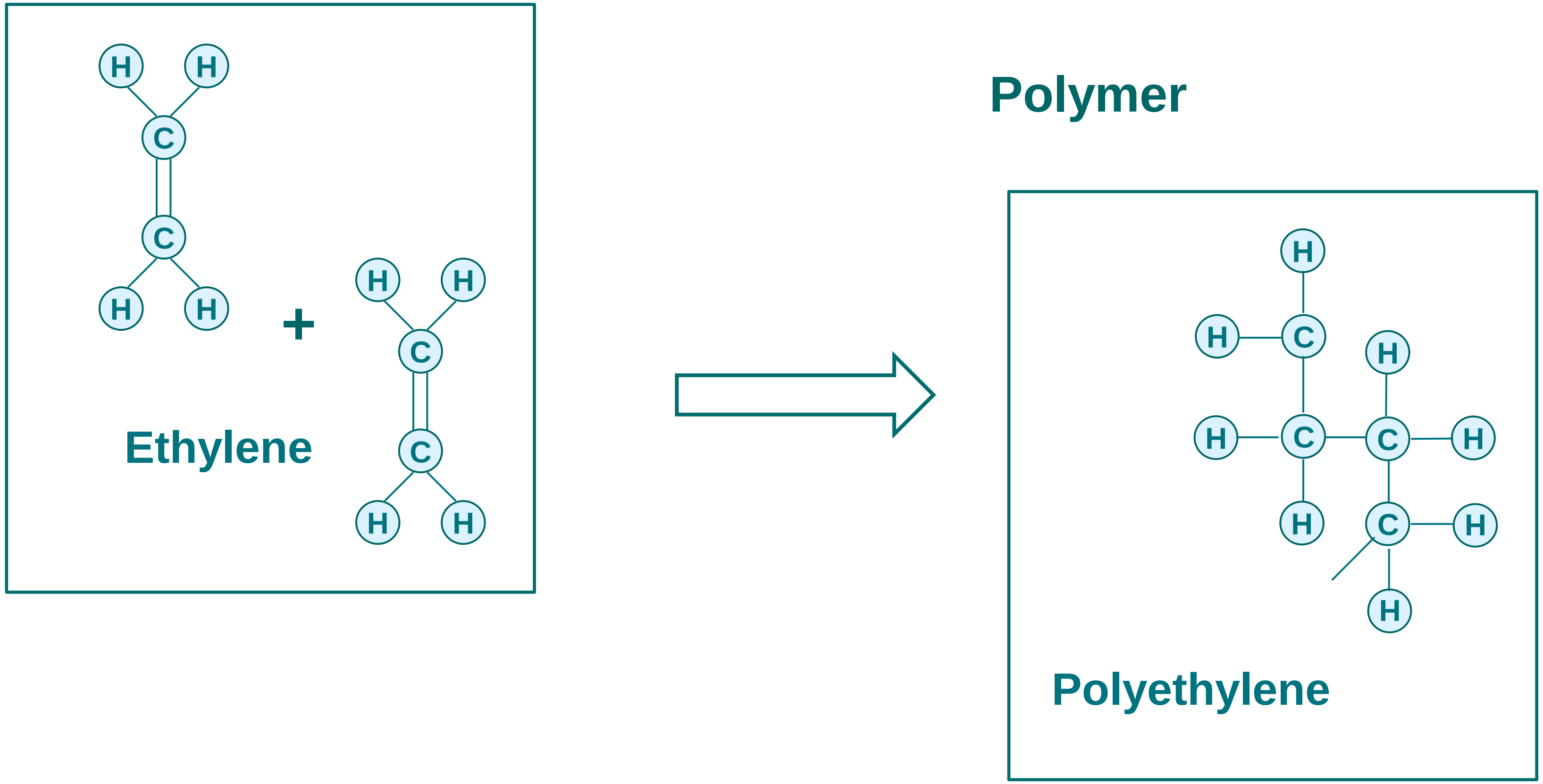
- Introduction
- Basics of polymer rheology
- Principles of polymer processing
  - Extrusion (pipe, film)
  - Blow molding
  - Thermoforming
  - Injection molding
  - Additive manufacturing
- Summary

Introduction

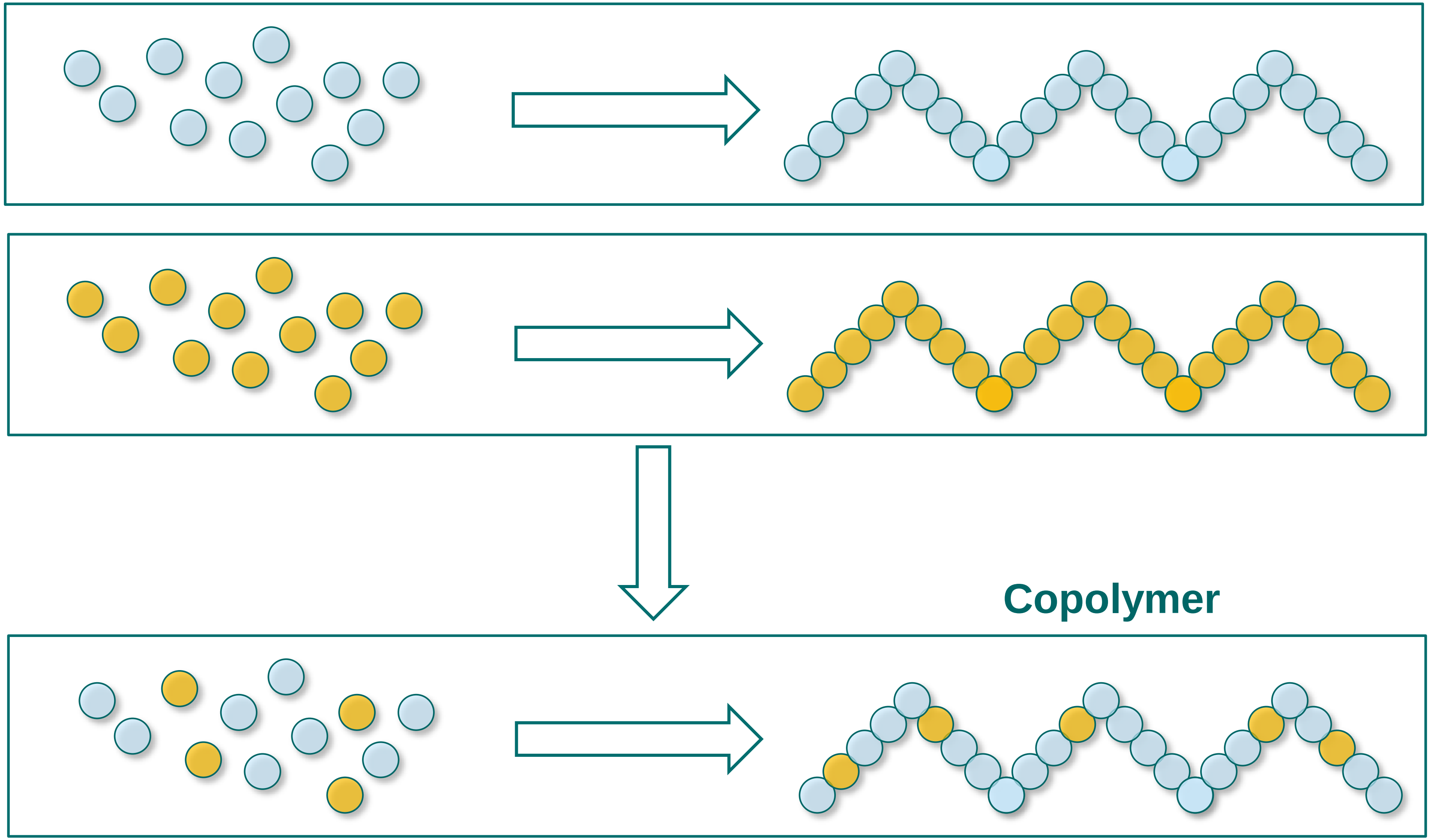
Polymers consist of macromolecules

Monomer

Polymer



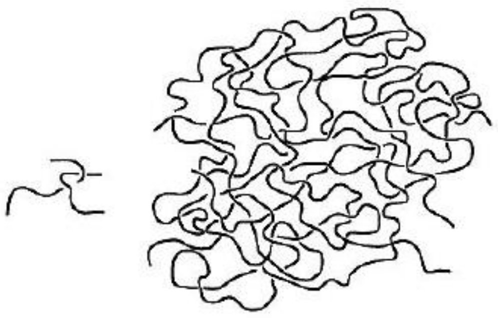
Composition of polymers



Morphology of polymers

Thermoplastics

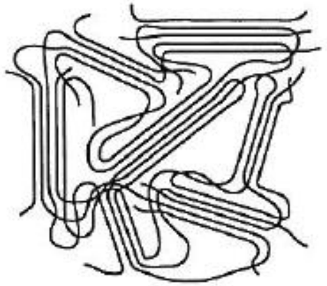
amorphous



e.g. acrylic glass

By User Leonard G. on en.wikipedia [CC SA 1.0 (http://creativecommons.org/licenses/sa/1.0/)], via Wikimedia Commons

semi-crystalline

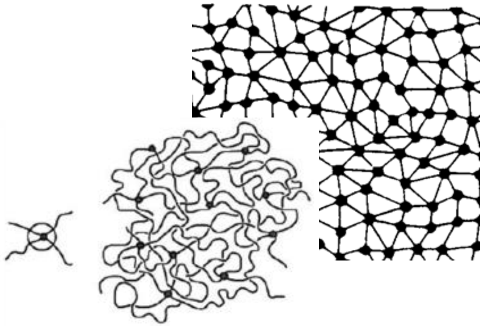


e.g. front bumber

von Jason Eade from Kambalda, Western Australia, Australia (Clubfront) [CC BY 2.0 (http://creativecommons.org/licenses/by/2.0)], via Wikimedia Commons

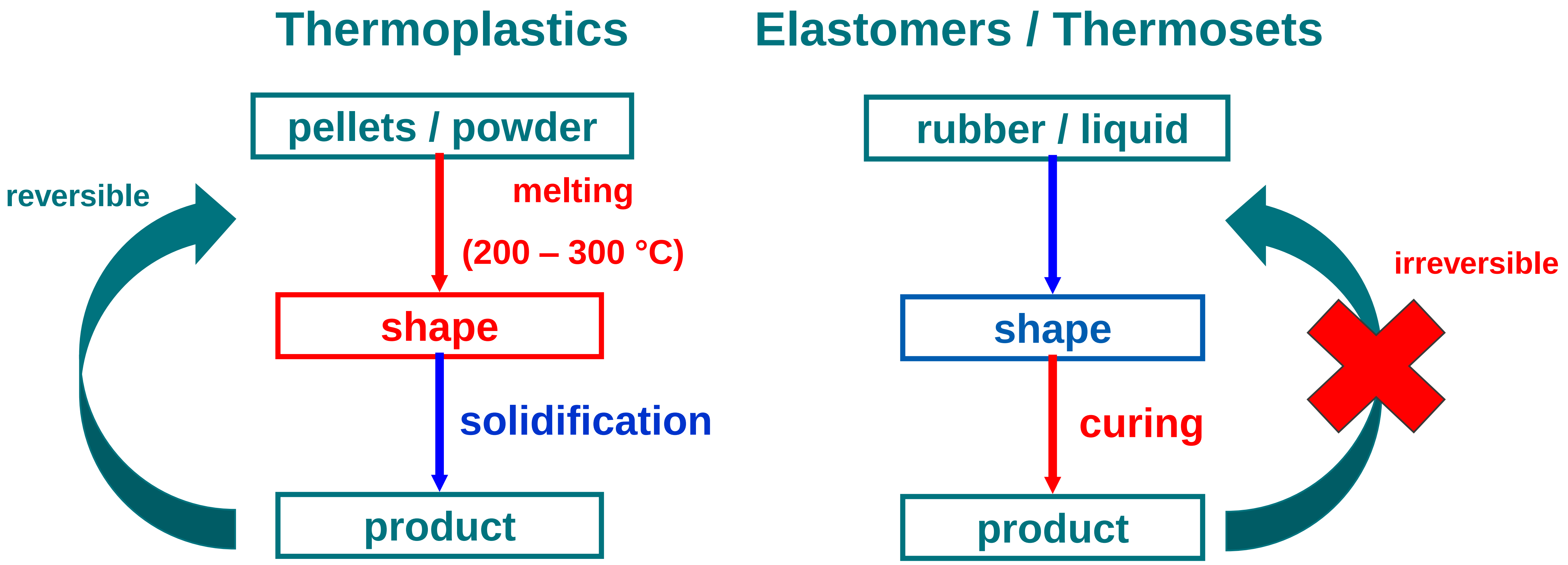
Elastomers/duromers (thermosets)

cross-linked

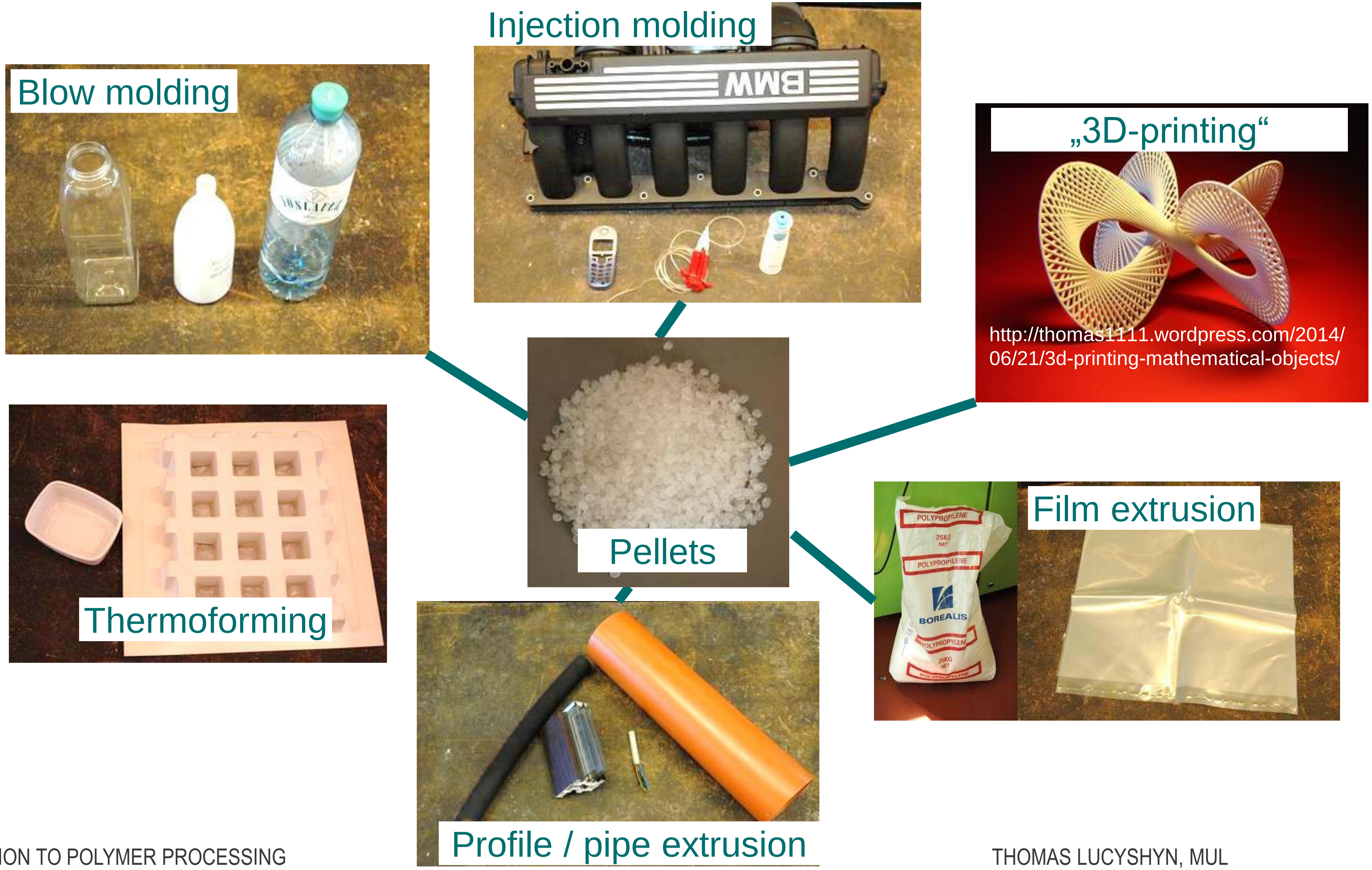


e.g. rubber glove

Processing differences thermoplastics - thermosets



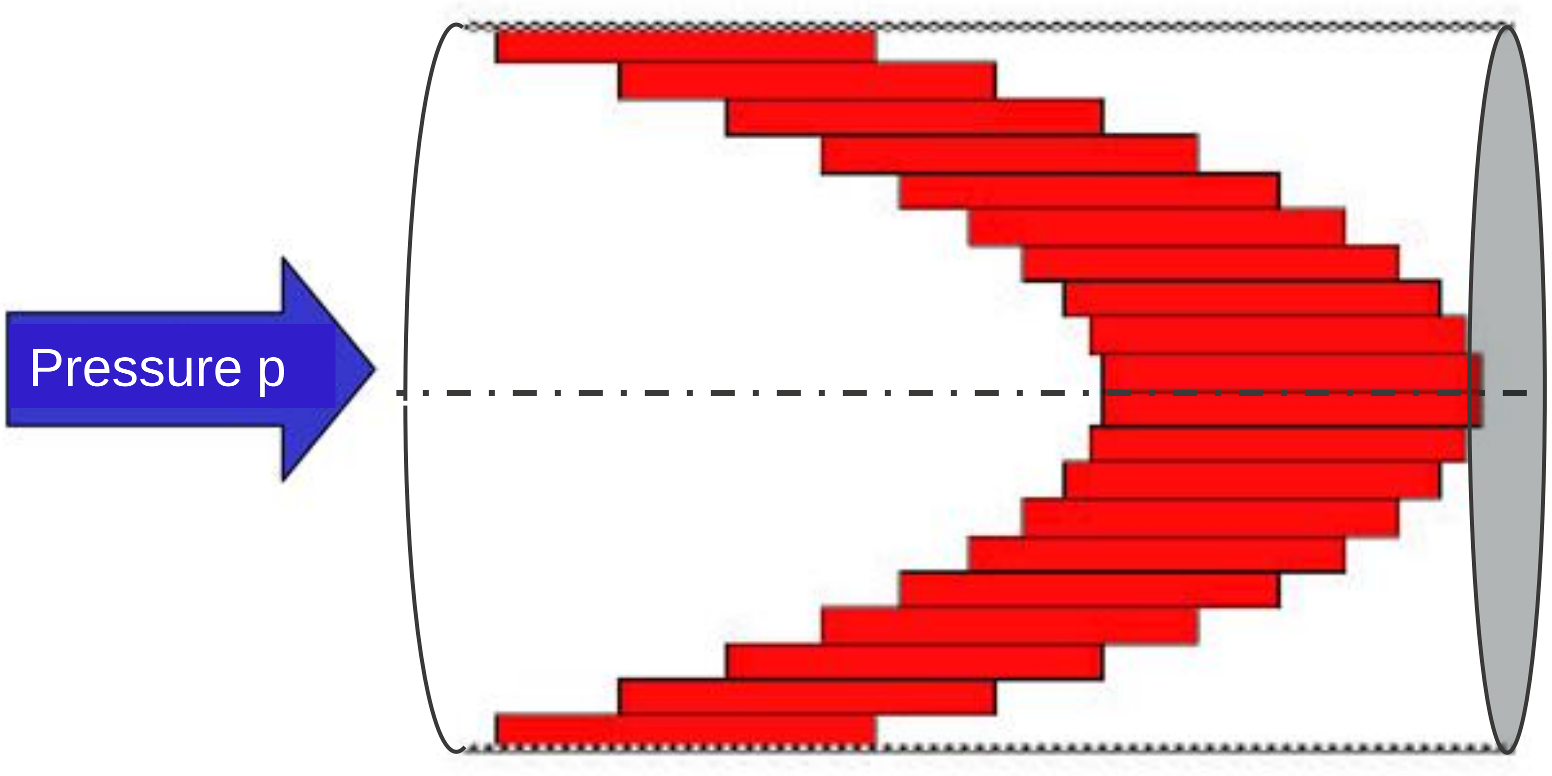
Processing methods for thermoplastic products



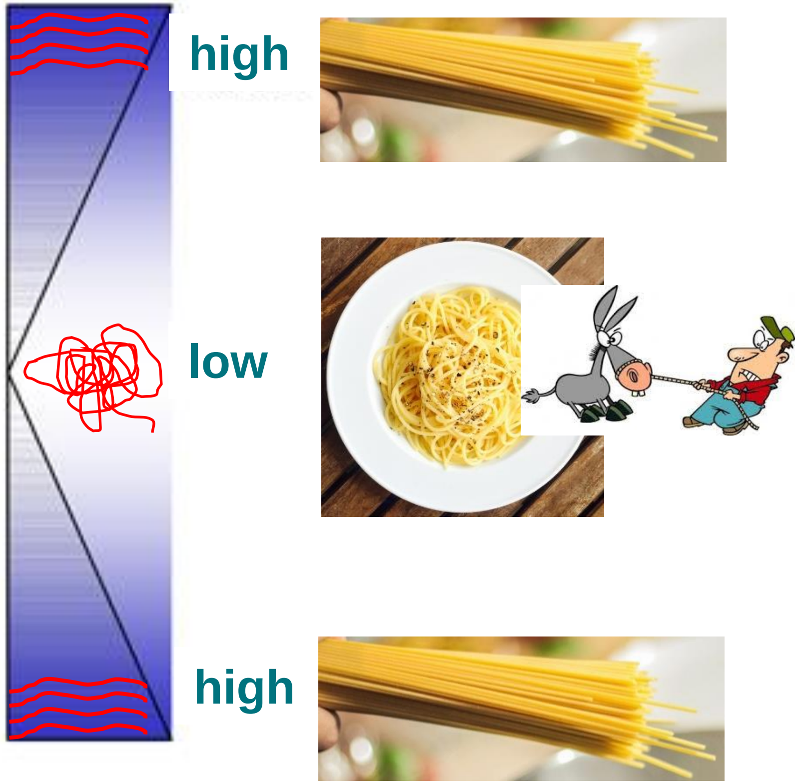
Basics of polymer rheology

Flow in a round die – shear deformation

Material adheres to the die walls (v = 0)



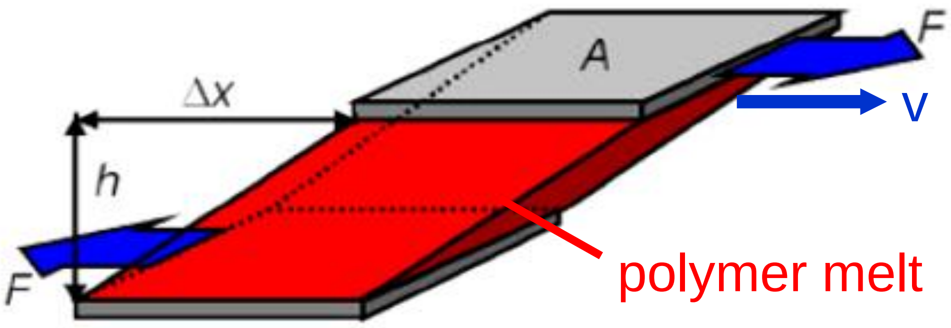
Shear rate



Source: Waßner, E.: Rheologische Grundlagen für die Auslegung von Extrusionswerkzeugen,, VDI-Praktikum: Werkzeugauslegung mit Excel, Paderborn, 2003.

Definitions for shear and elongational flow

Shear flow



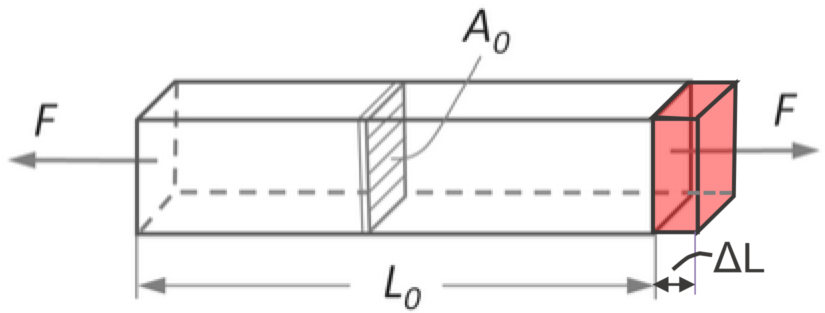
Shear stress $\tau = \frac{F}{A}$ (N/m² = Pa)

Shear deformation $\gamma = \frac{\Delta x}{h}$ (-)

Shear rate $\dot{\gamma} = \frac{1}{h} \cdot \frac{\Delta x}{\Delta t} = \frac{v}{h}$ (s^{-1})

Shear viscosity $\eta = \frac{\tau}{\dot{\gamma}}$ (Pa·s)

Elongational flow



Normal stress $\sigma = \frac{F}{A_0}$ (N/m² = Pa)

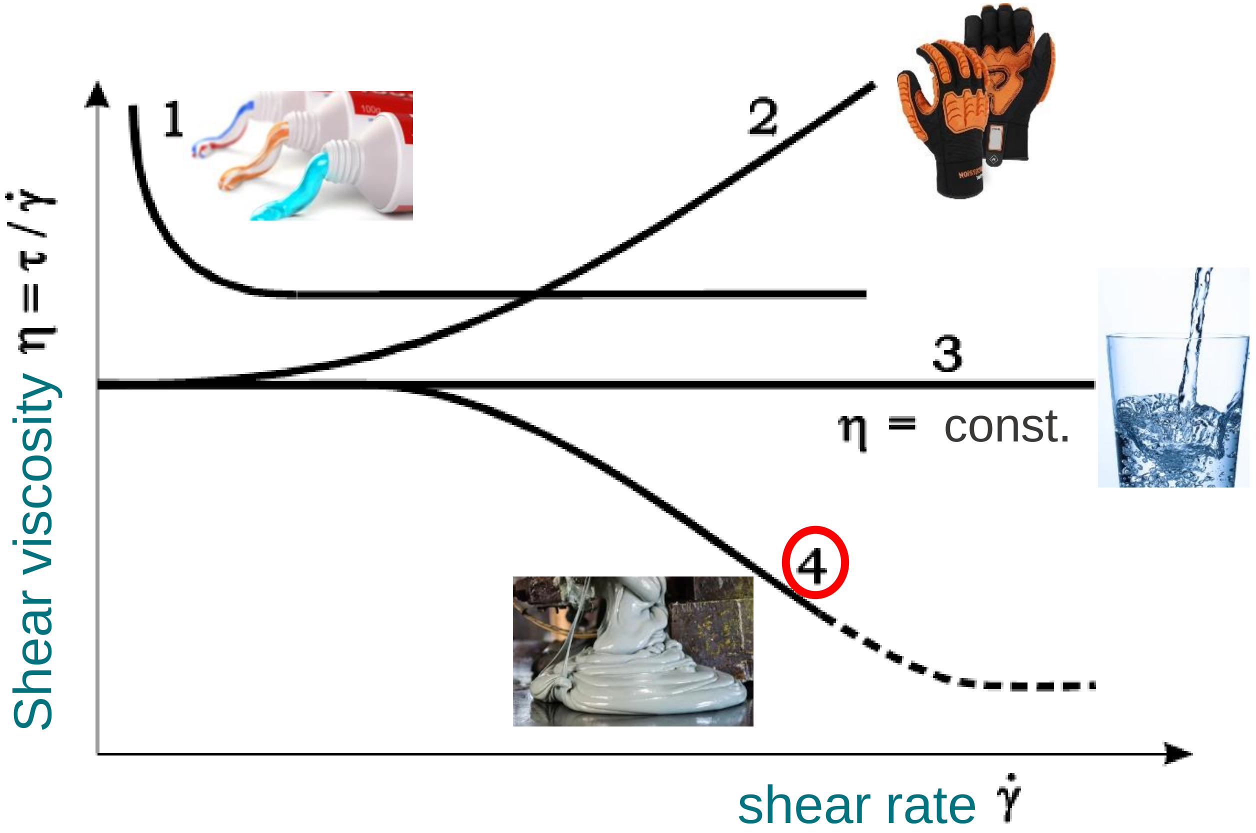
Elongation $\varepsilon = \frac{\Delta L}{L_0}$ (-)

Elongation rate $\dot{\varepsilon} = \frac{1}{L_0} \cdot \frac{\Delta L}{\Delta t} = \frac{v}{L_0}$ (s^{-1})

Elongational viscosity $\lambda = \frac{\sigma}{\dot{\varepsilon}}$ (Pa·s)

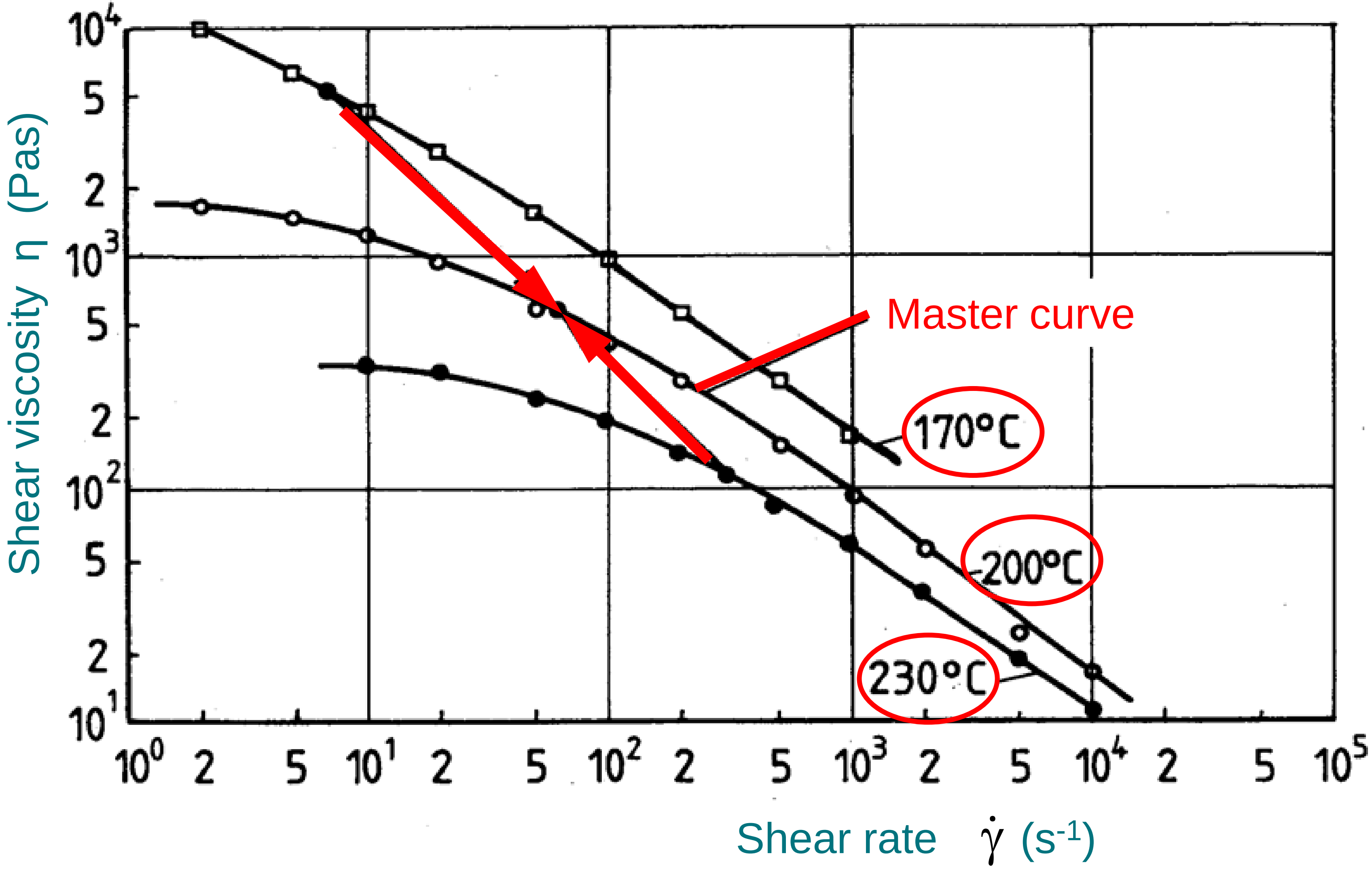
Viscosity = measure of flow resistance

Different flow characteristics in viscosity curve

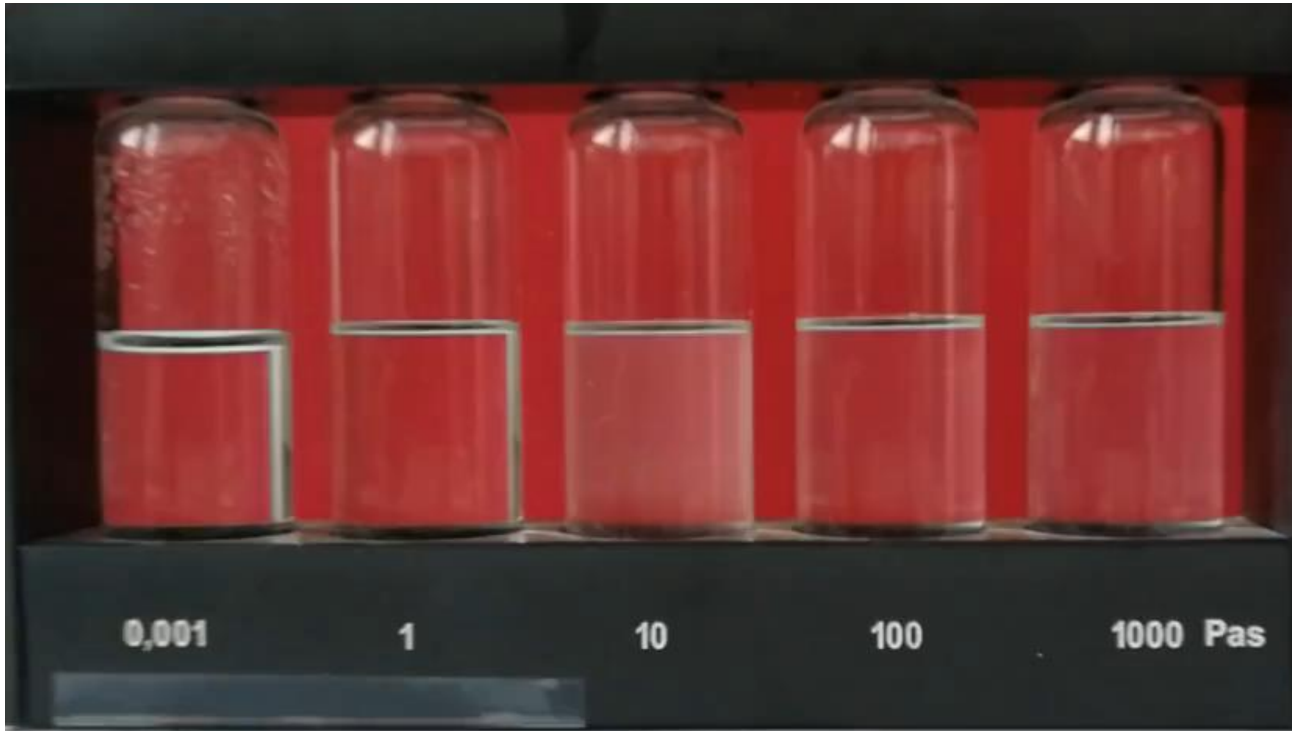


1 … Bingham (e.g. tooth paste)
2 … Dilatant (e.g. protection gels in clothings)
3 … Newtonian (e.g. water)
4 … Shear thinning → typical of polymer melts

Temperature dependence of viscosity



Comparison of fluids with different viscosity



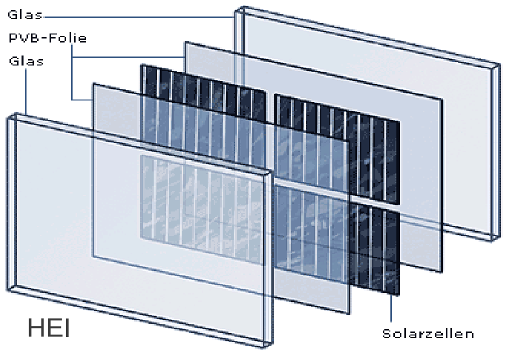
0.001 1 10 100 1000 Pas

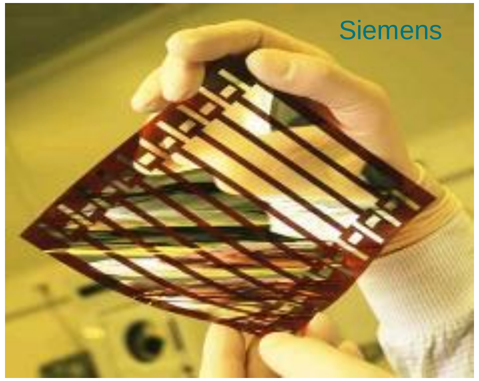
water

thermoplastic polymer melts

Principles of polymer processing – Extrusion

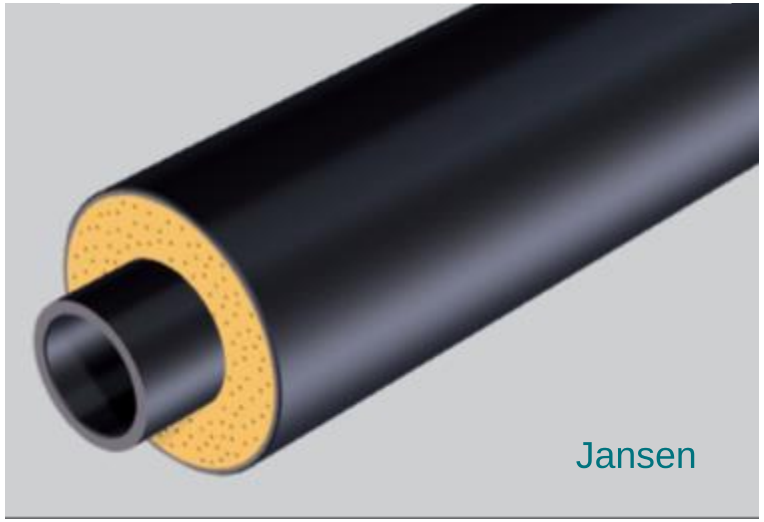
Extruded products for solar applications





Extruded pipe applications

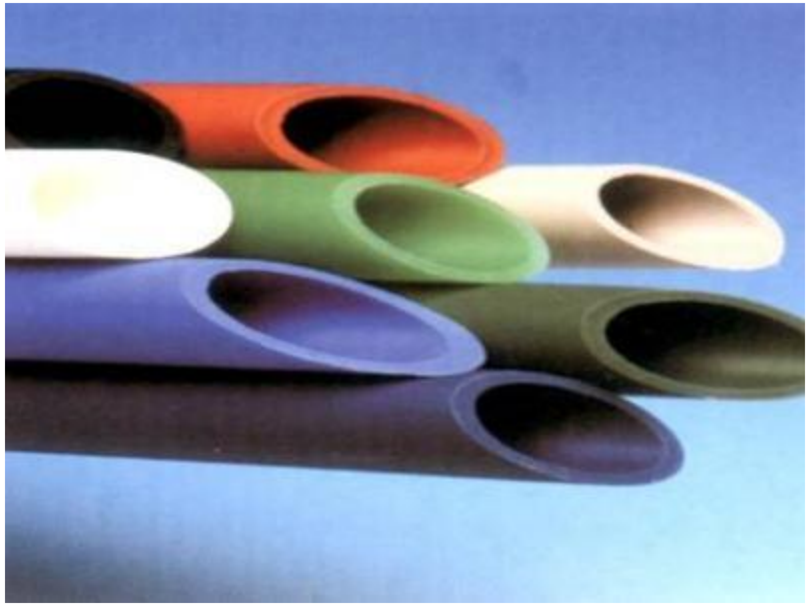
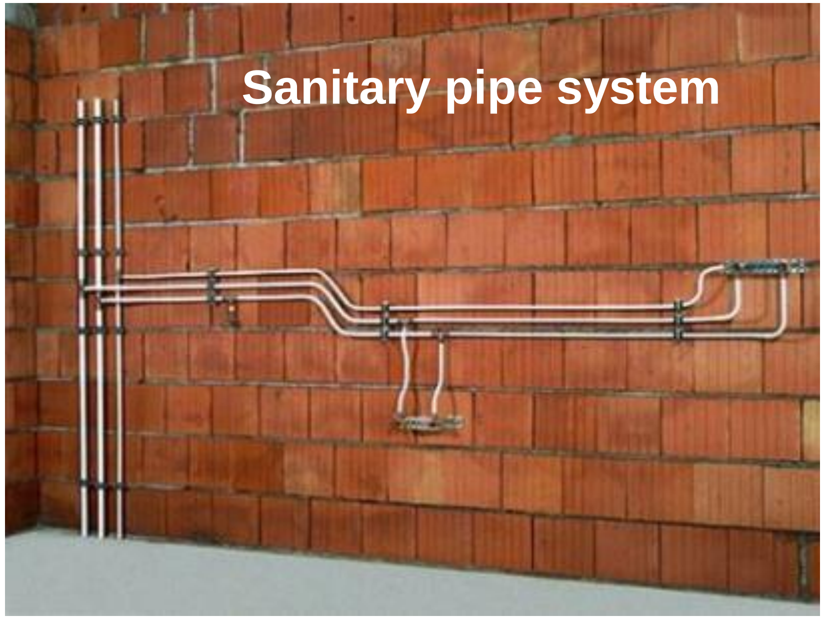
Dusche

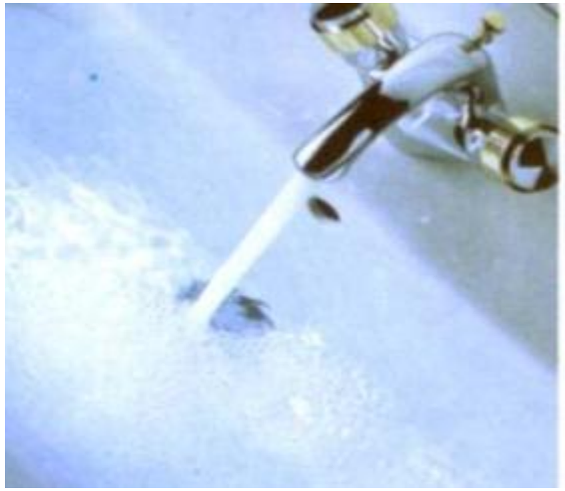
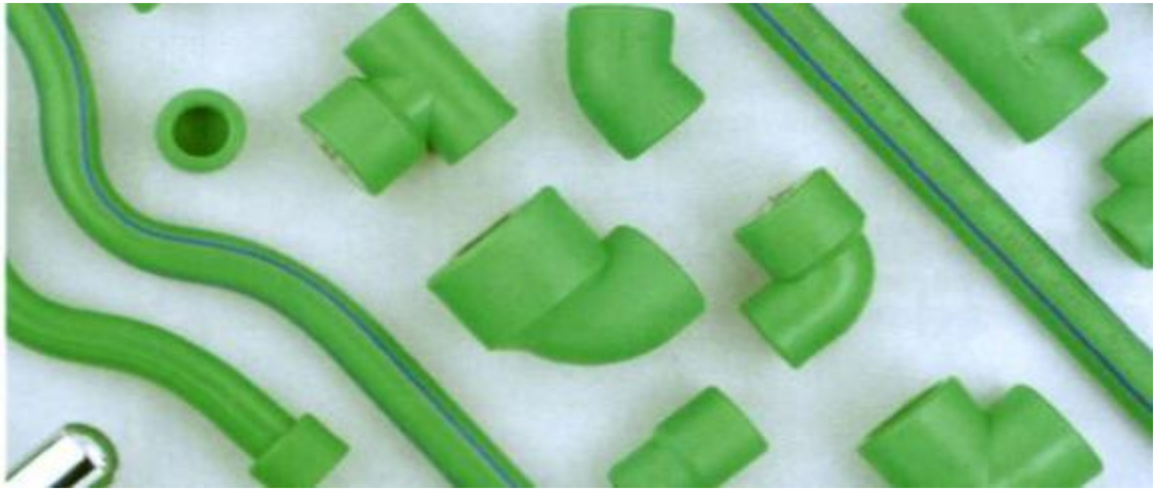


Jansen

Gasokol

Hot and cold water pipes

Continuously extruded PE pipes into the sea

From Pipelife Norge AS, Stathelle, Norway

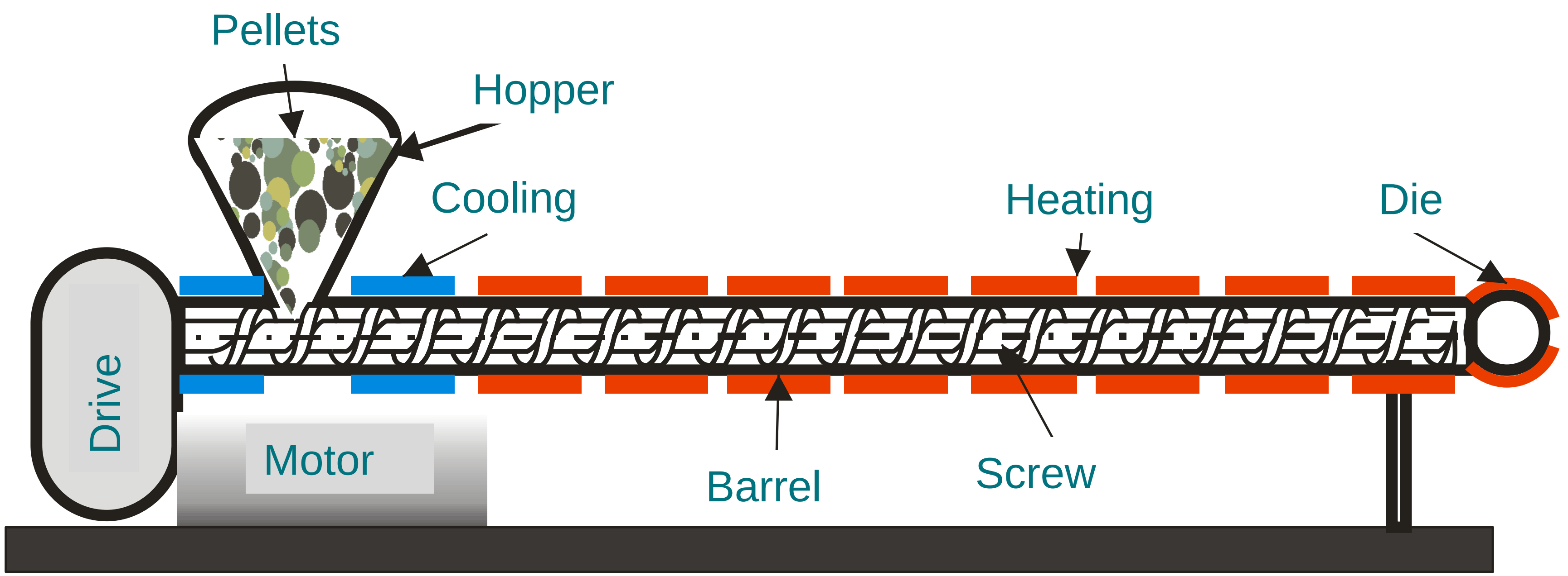
Protected location in a narrow fjord

Continuous extrusion into the fjord

Transport by tugboat to the marine destination

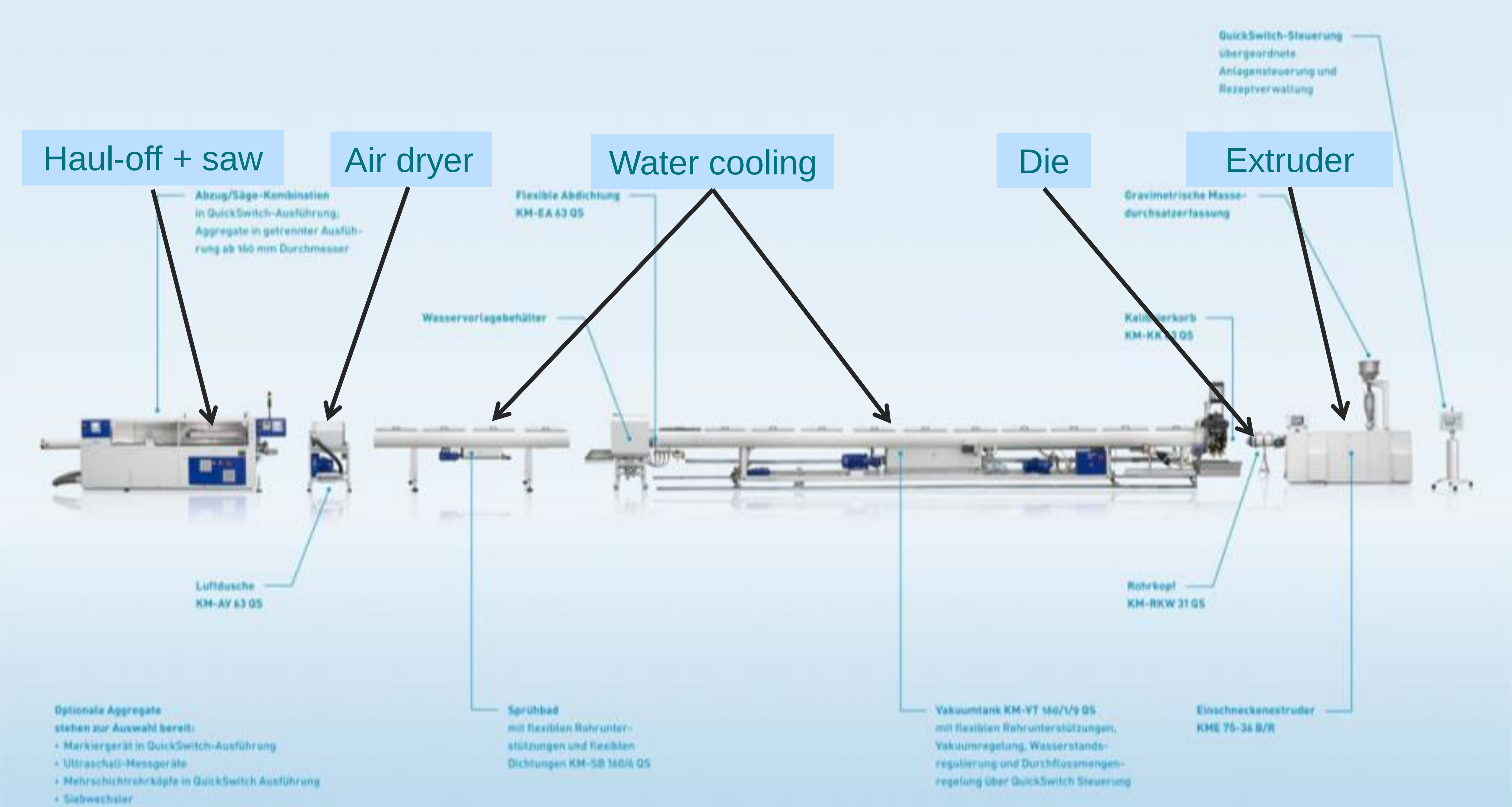
PIPELIFE

Components and working principle of an extruder



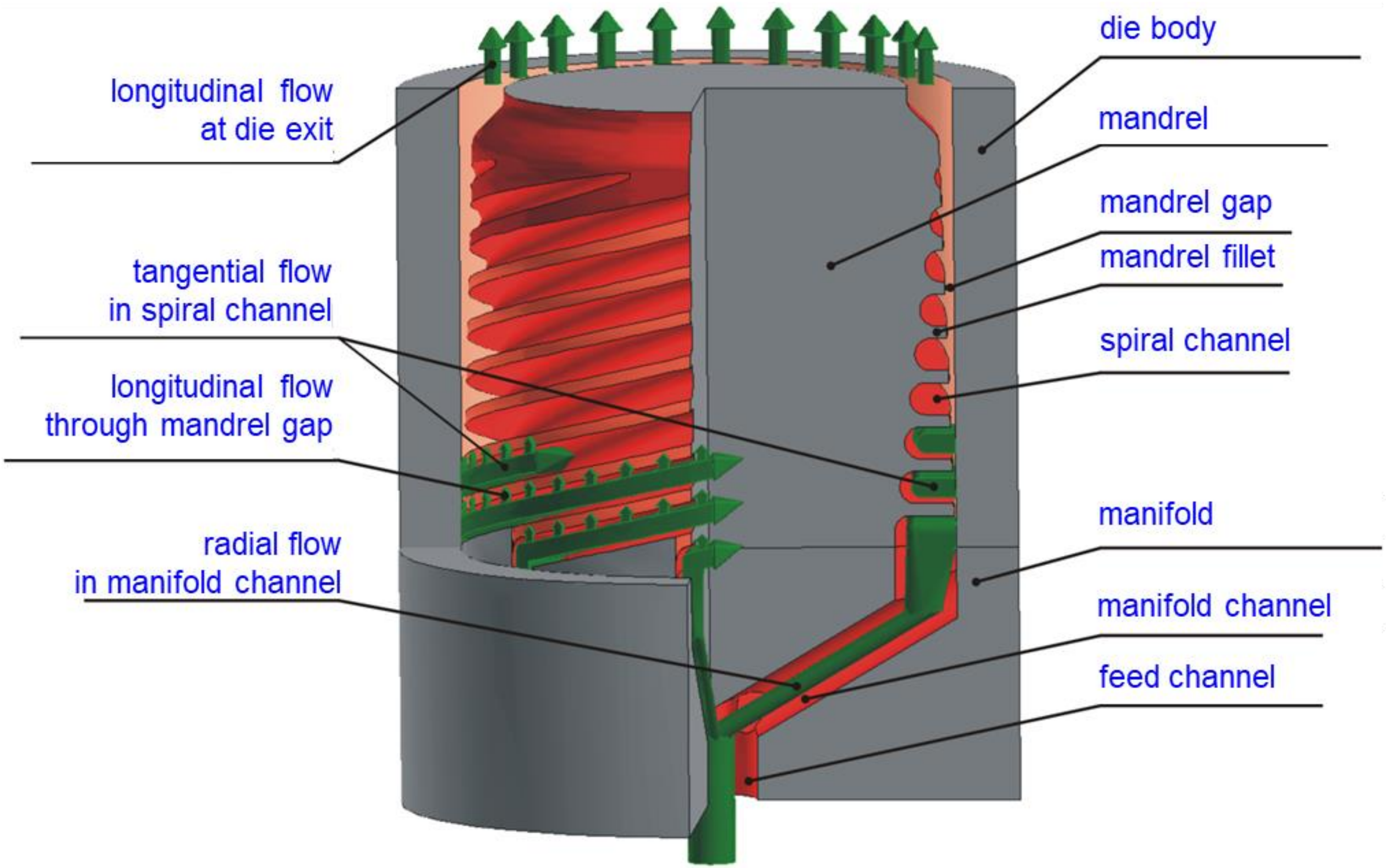
- Feeding of pellets into the hopper
- Compression of pellets
- Melting of polymer
- Homogenization of the melt
- Pumping the melt through the extrusion die (shaping of film, profile, pipe, …)

Pipe extrusion line

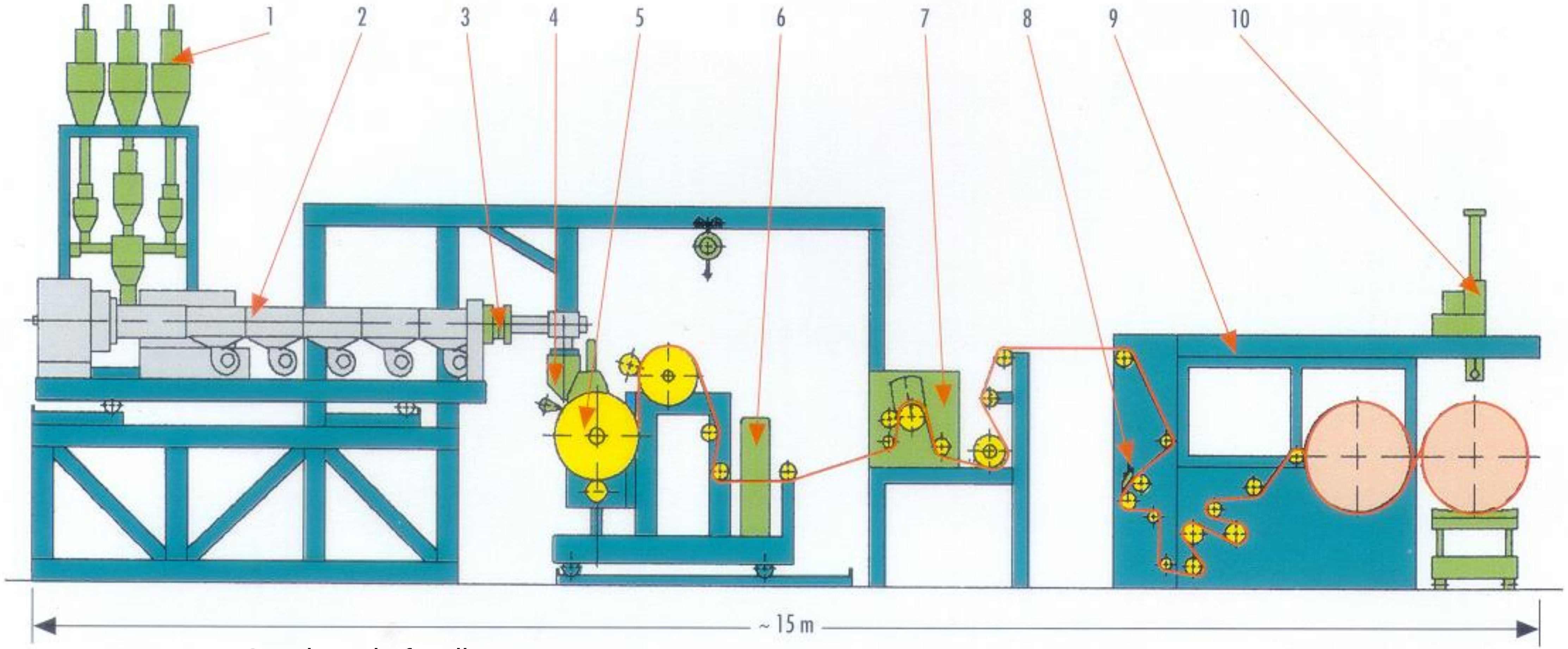


KraussMaffei Berstorff

Pipe extrusion die (spiral mandrel die)

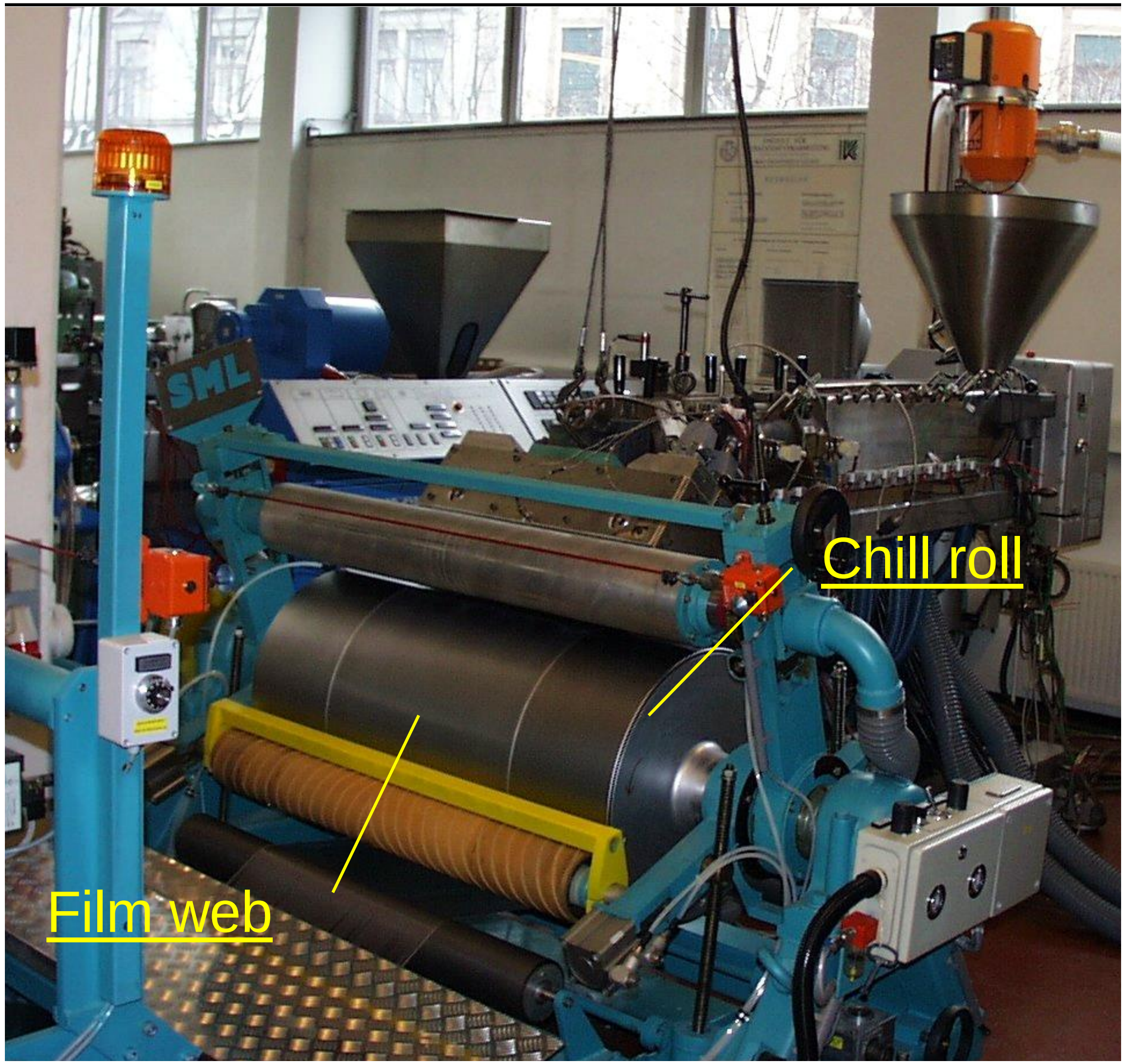


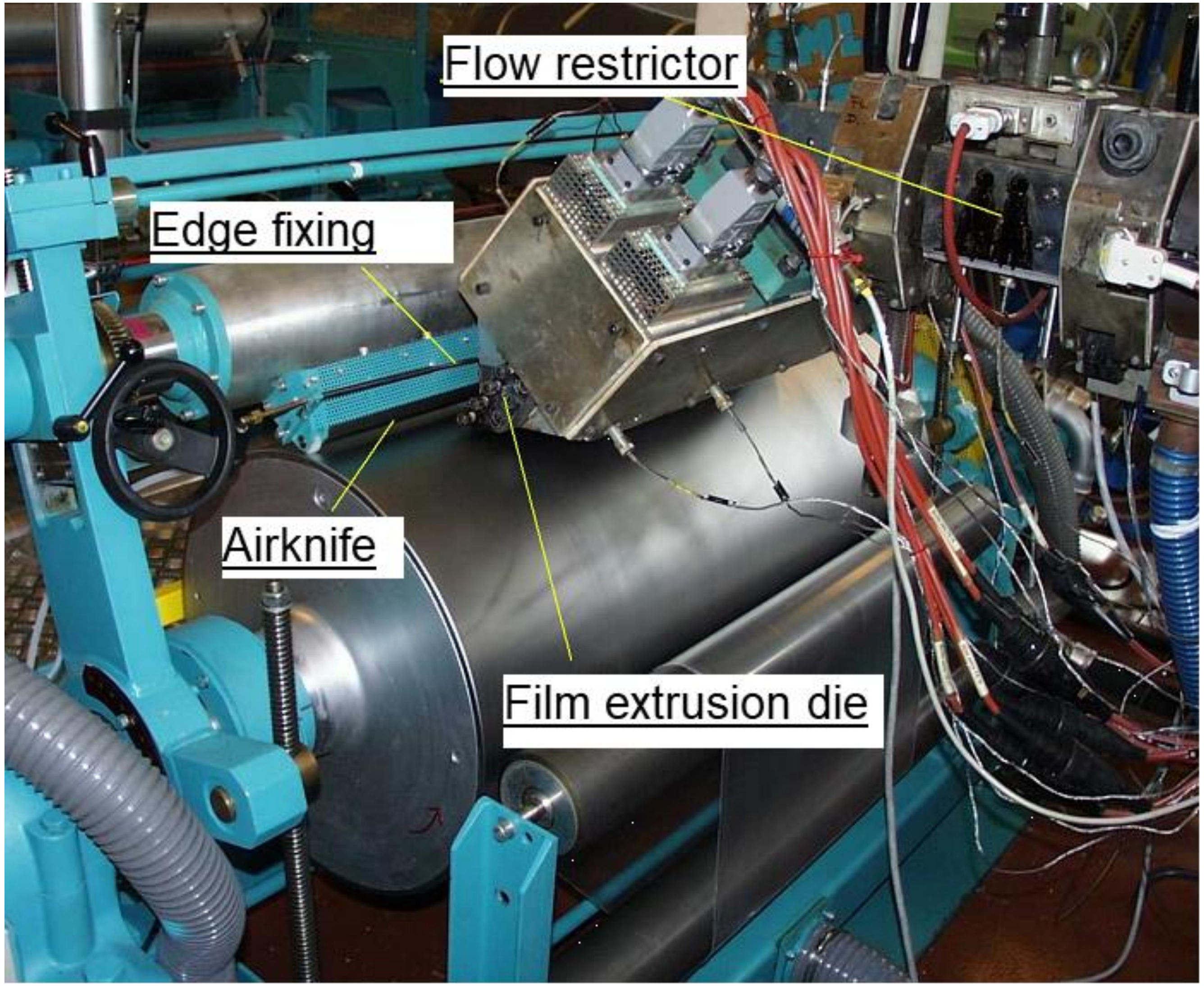
Cast film extrusion line (Chill roll)



1. Gravimetric feeding
2. Extruder
3. Melt filter
4. Automatic die, airknife and vacuum box
5. Chill roll unit
6. Thickness measuring device
7. Post-cooling roll
8. Edge trimming unit
9. Winder
10. Winding shaft handling system

Cast film extrusion line (Chill roll)



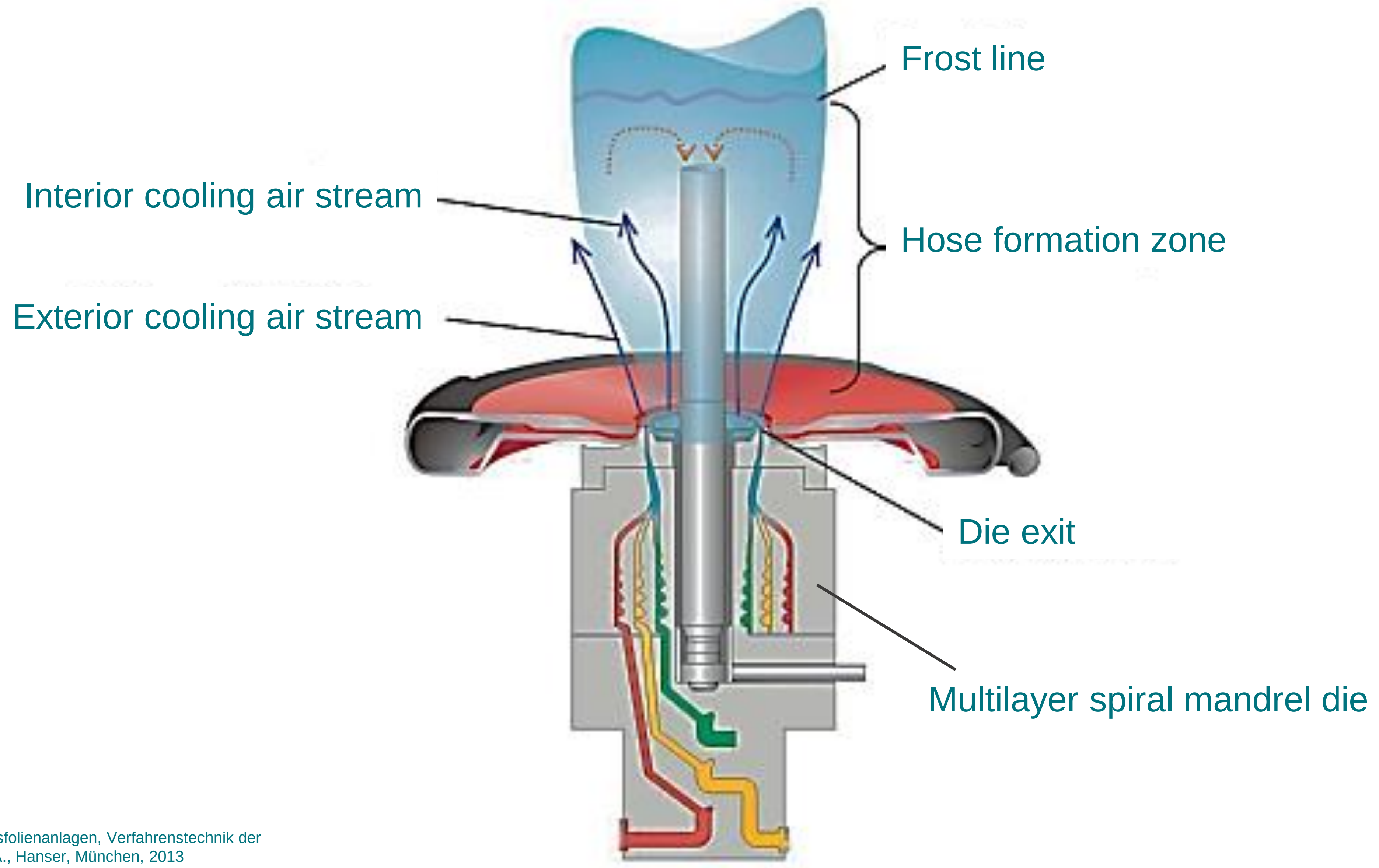


Blown film extrusion line

1. Material feed
2. Material metering
3. Extruder
4. Screen changer
5. Blowing head
6. Exterior cooling
7. Profile control
8. Interior cooling
9. Calibration screen
10. Profile gauge
11. Film take-off
12. Web center guide
13. Pre-treatment
14. Pre-take-off
15. Winder
16. Shaft extraction system
17. Process visualization

Hosokawa Alpine Blasfolientechnolgien in Perfektion, Folienblasanlagen 09.13/05/DE

Blown film extrusion head



Backmann M., Rübbelke I.: Blasfolienanlagen, Verfahrenstechnik der Thermoplastextrusion, Limper A., Hanser, München, 2013

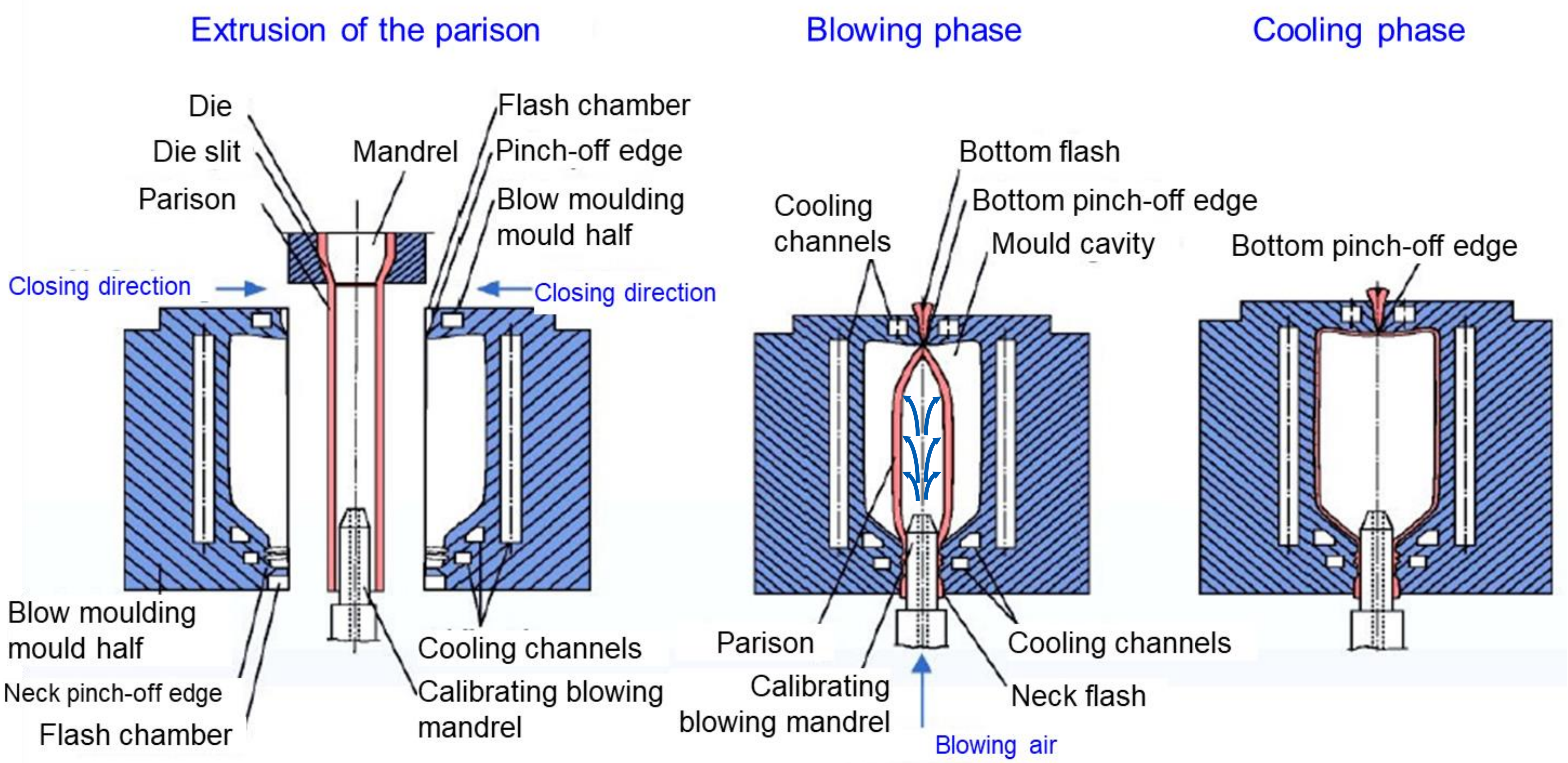
Blown film extrusion line with 9 extruders

Principles of polymer processing – Blow molding

Extrusion blow molding – introduction

- For the production of hollow articles
- Two fundamental phases
  - Extrusion of a parison (preform)
  - Fast blowing of the hot, elastic parison

Extrusion blow molding process steps



Extrusion blow molding process

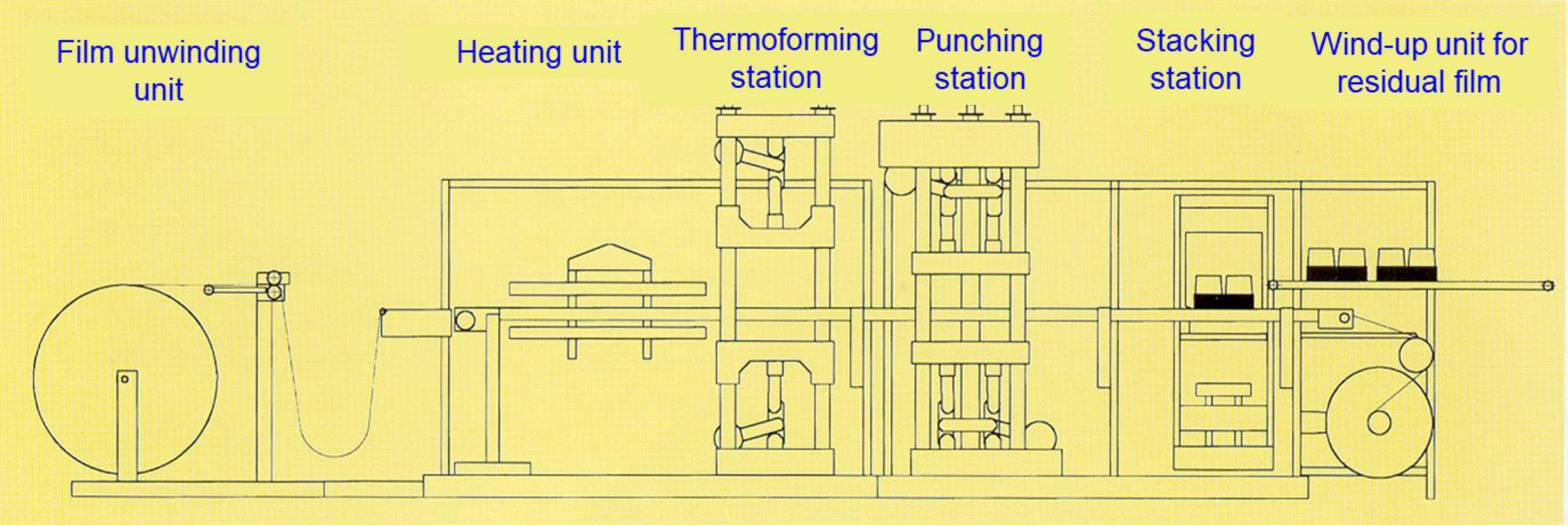
Principles of polymer processing – Thermoforming

Thermoforming – products

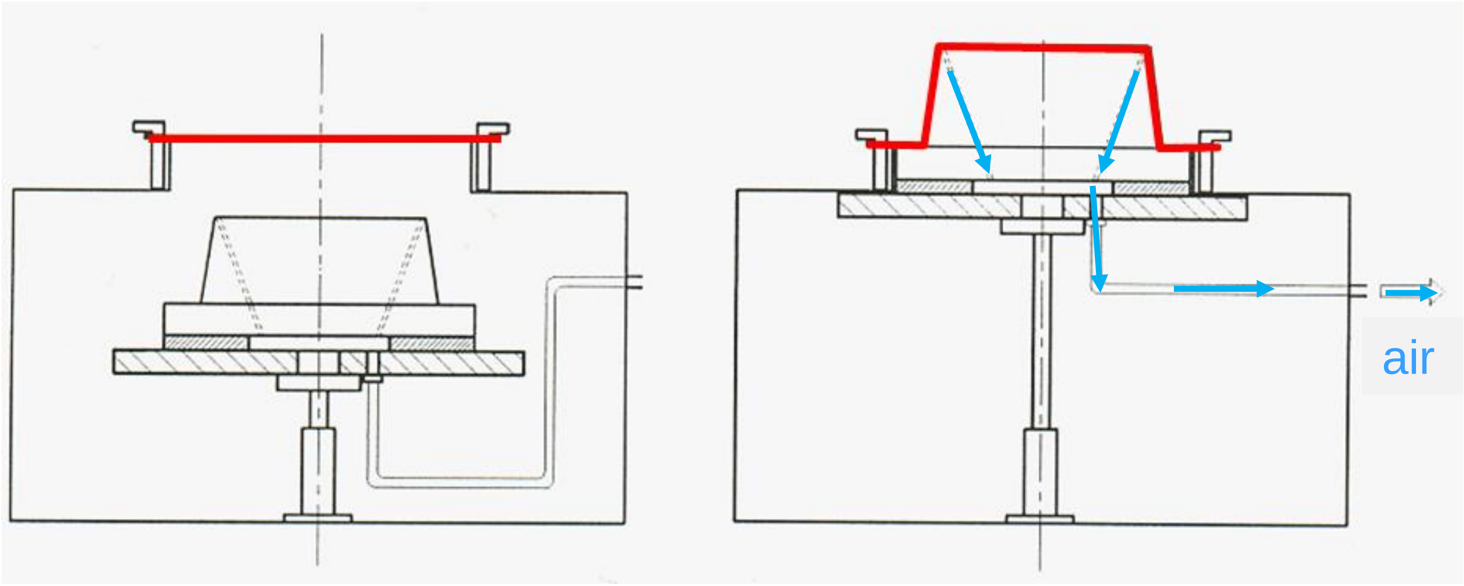




Thermoforming process principle

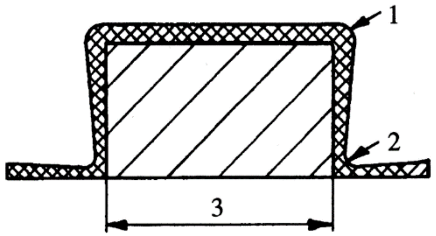


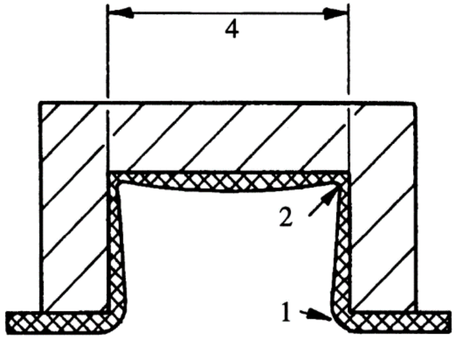
Positive and negative thermoforming



Positive forming

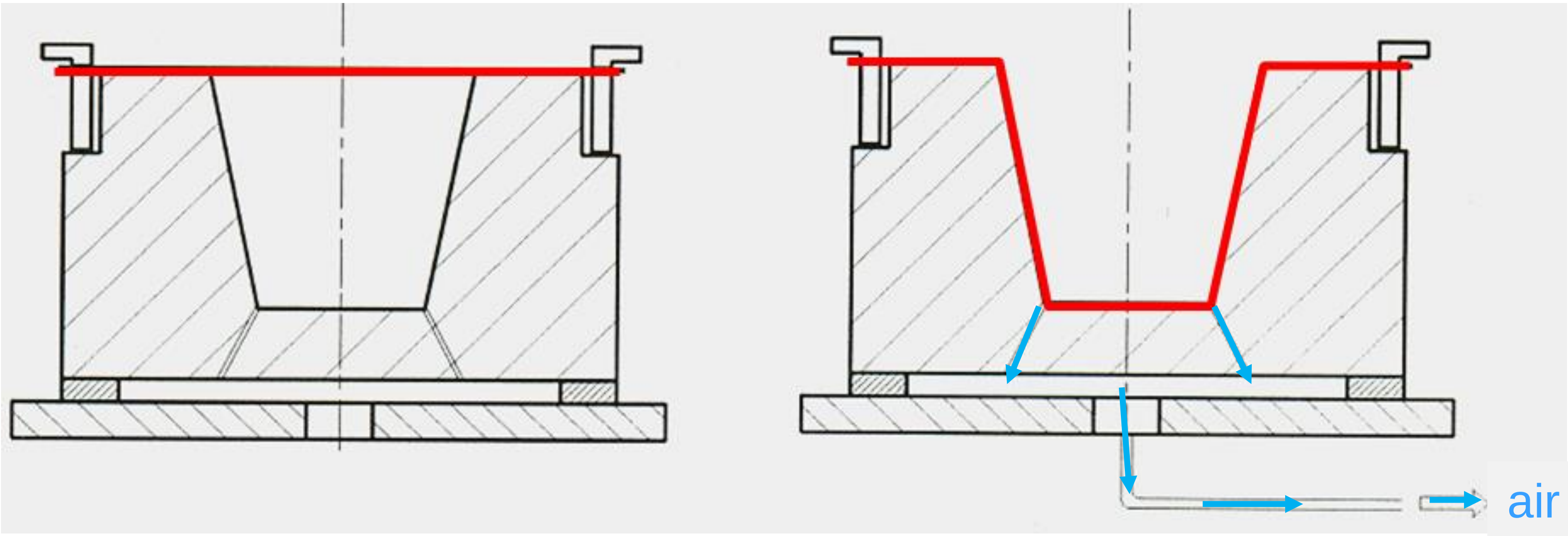
- Inside of part in contact with mold
- Exact shape only on inside contour





Negative Forming

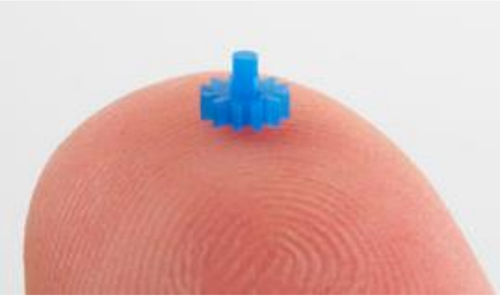
- Outside of part in contact with mold
- Exact shape only on outside contour



Principles of polymer processing – Injection molding

Injection molding - introduction

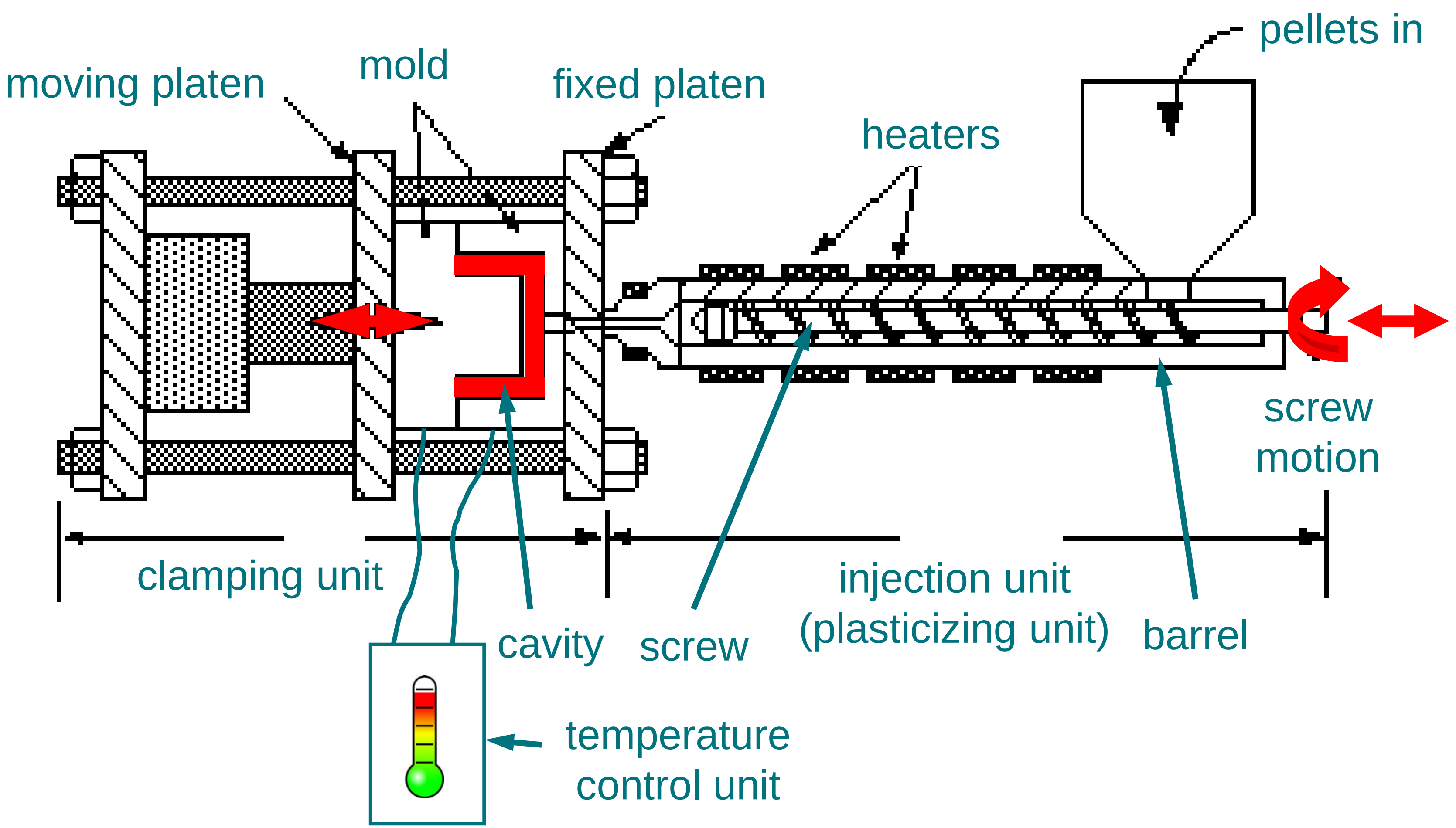
- One of the most important polymer processing methods
- Advantages:
  - Direct path from raw material to final part
  - Little or even no further treatment of the parts
  - Fully automated process possible
  - High reproducibility of the process at large numbers (> 1 mio.)
- Part range:
  - From tiny gears (1 mg) to huge containers (up to 150 kg)



Source: www.directindustry.com

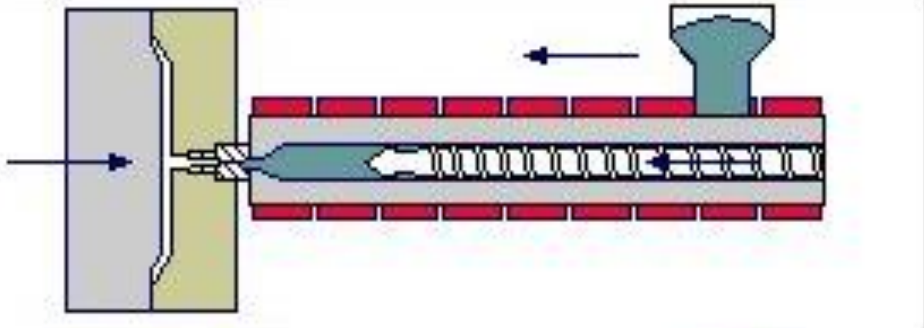
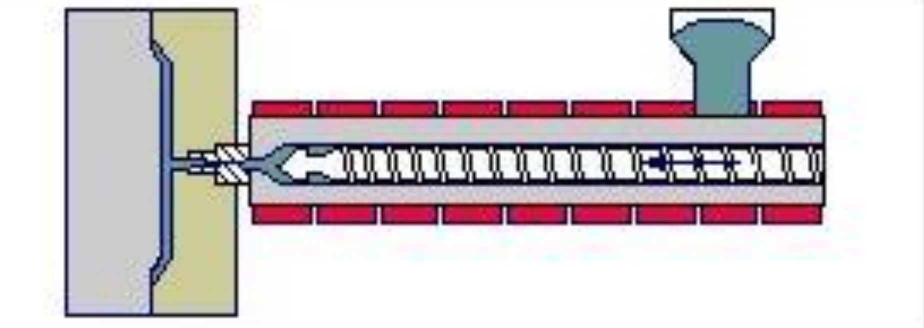
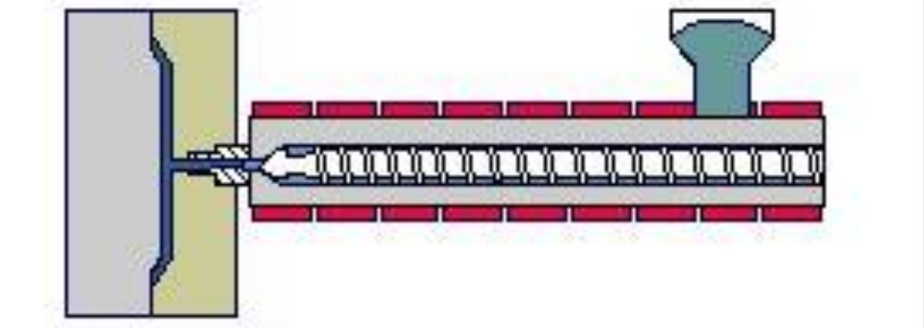
Source: www.delker-werkzeuge.de

Injection molding machine

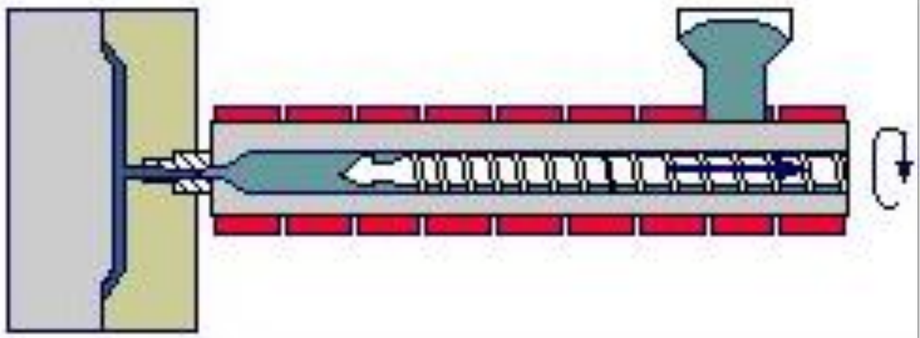
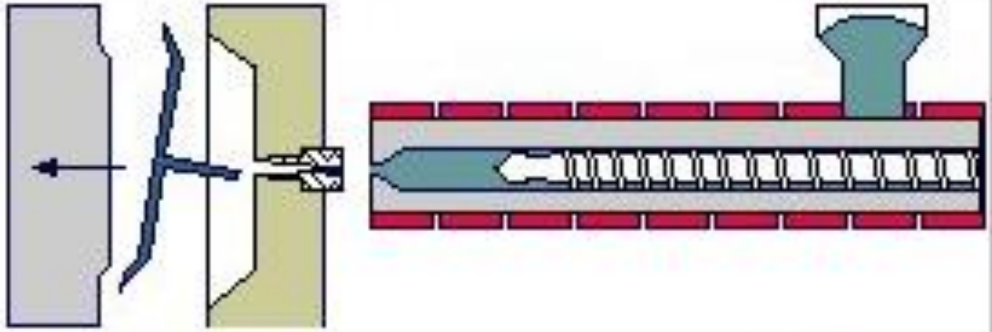
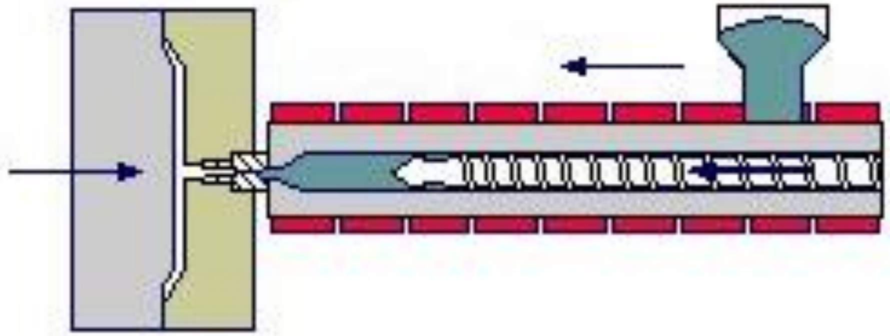


Injection molding machine

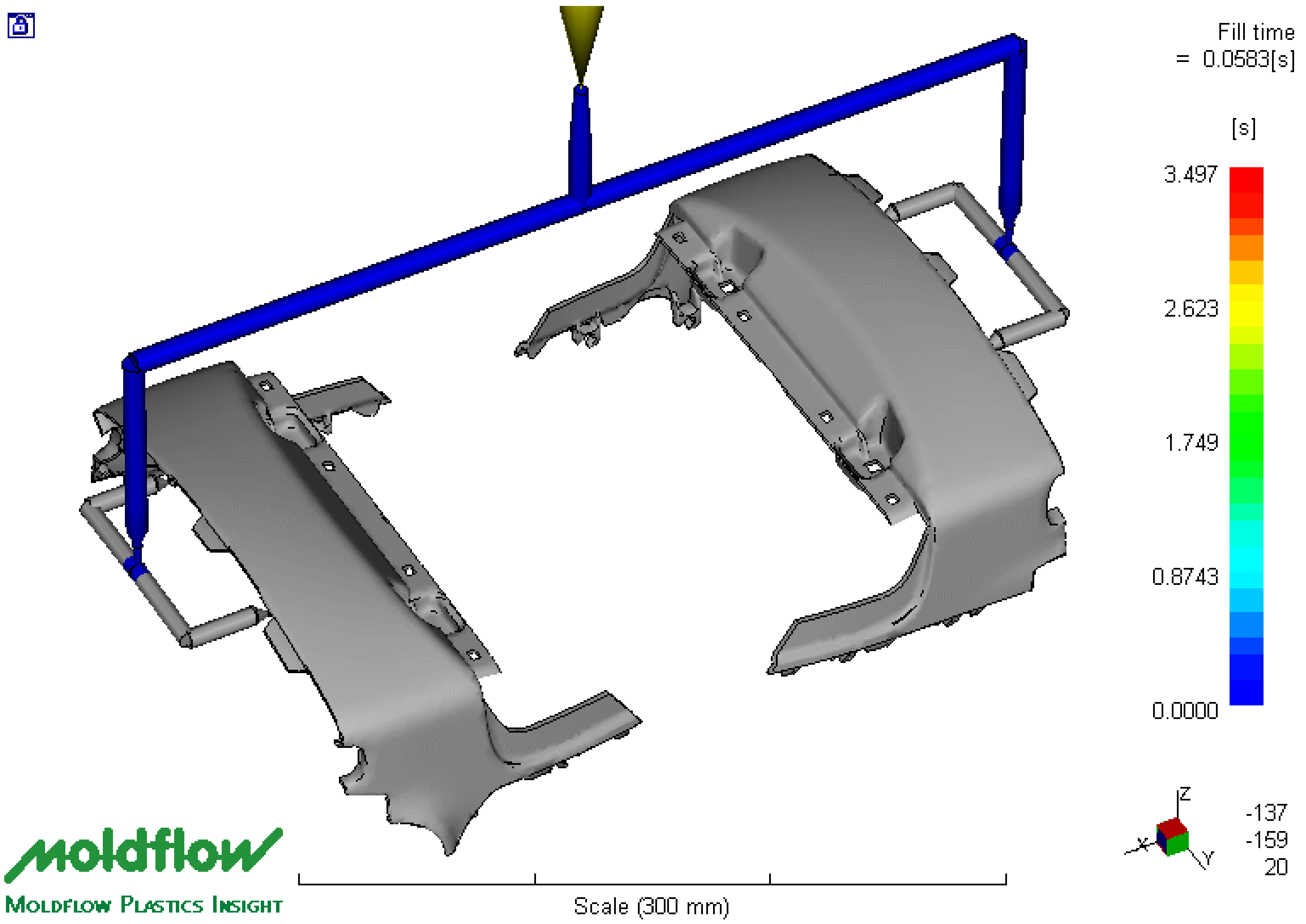
Injection molding cycle (1)

1	The mold is closed; the plasticizing unit is moving to the mold and the injection phase can start.	
2	Injection phase: the cavity is filled by forward movement of the screw (like a piston). Starting of the cooling time.	
3	The material is compressed within the mold: packing (or holding) phase to compensate shrinkage of the polymer.	

Injection molding cycle (2)

4	Gate frozen → new melt is plasticized by simultaneous rotation and backward move-ment of screw. After feeding, the plasticizing unit is moving back.	
5	After sufficient cooling time, the mold opens to eject the part.	
6	The mold closes again, the plasticizing unit moves forward – the cycle starts again.	

Simulation of filling pattern of complex part

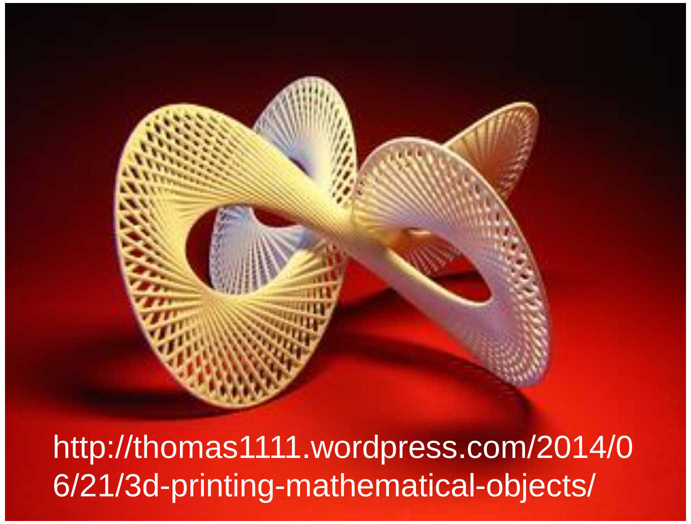


Principles of polymer processing – Additive manufacturing („3D-printing“)

Additive manufacturing - introduction

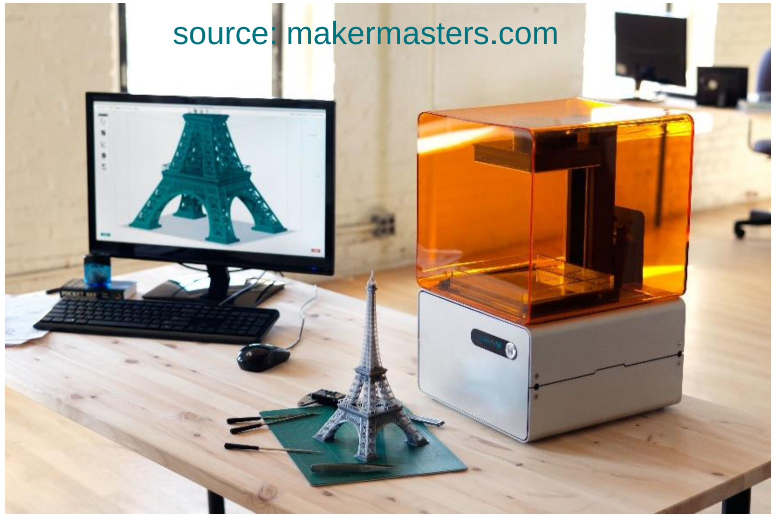
- For complex shapes
- Individualization of single products
- Fast realization from project idea to physical part

- Slow process (not for mass production)
- Limited number of materials
- Quality not comparable with conventional processing



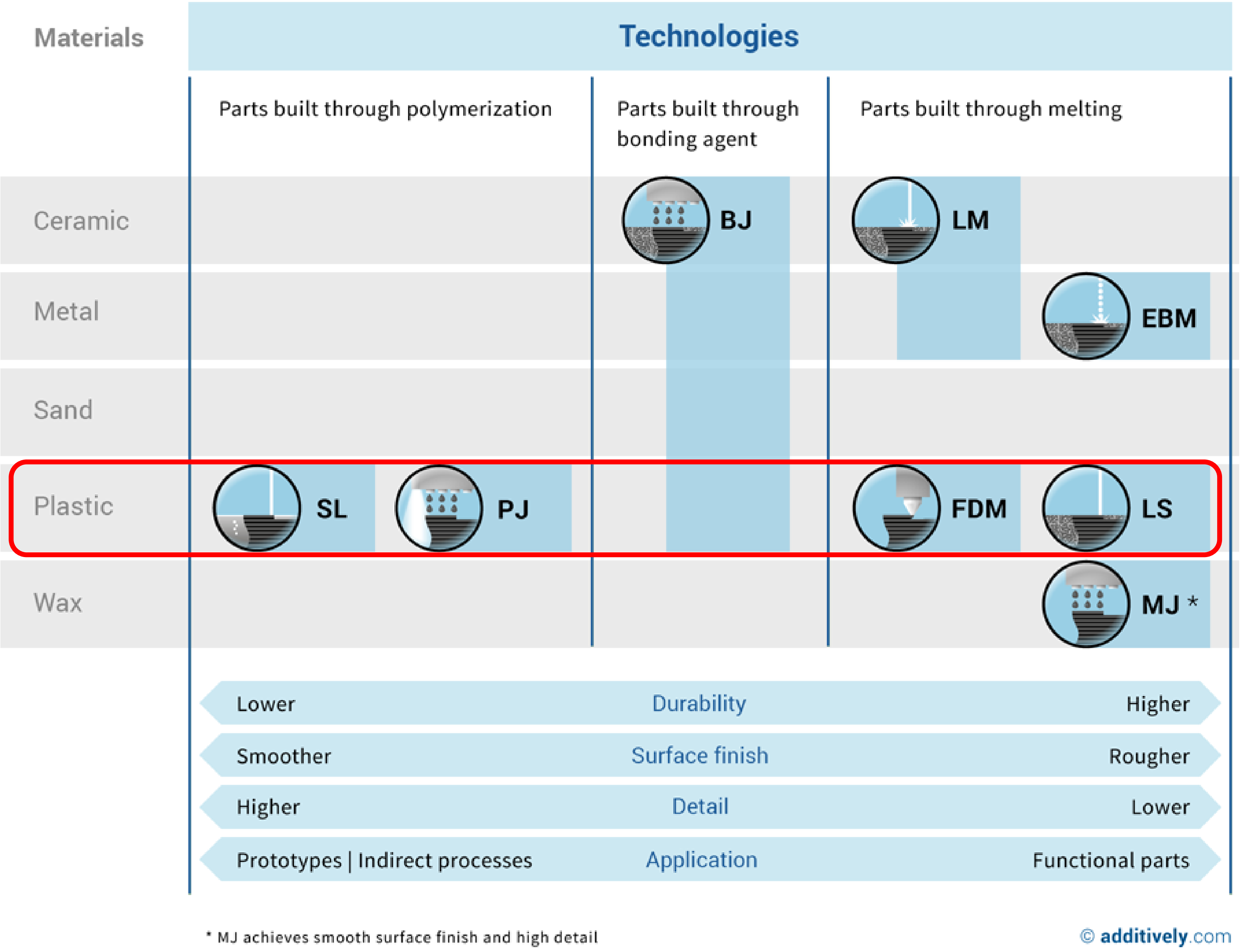
http://thomas1111.wordpress.com/2014/06/21/3d-printing-mathematical-objects/

source: stratasys.com



source: makermasters.com

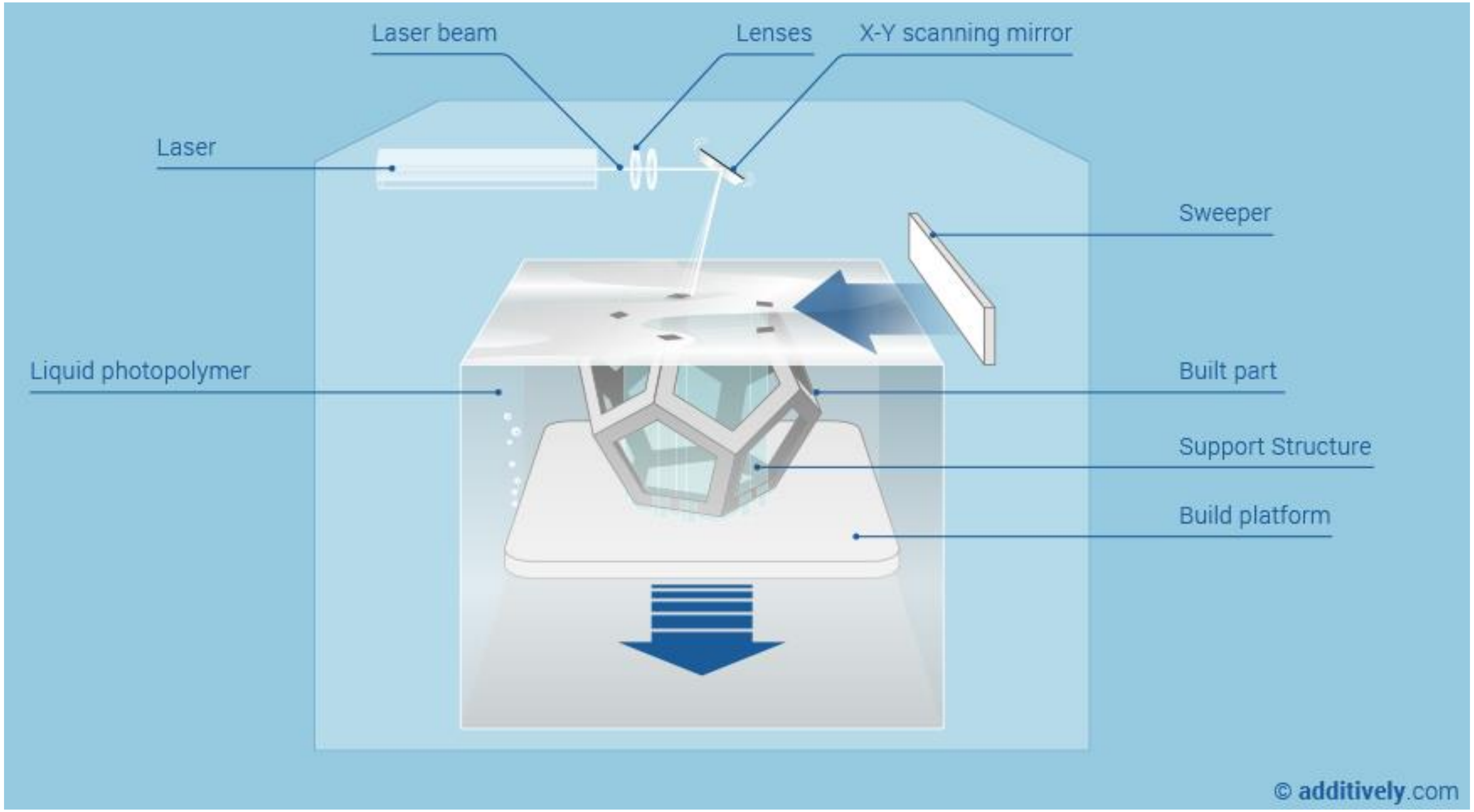
„3D-printing“ – one term for many processes



Binder Jetting (BJ)
Electron Beam Melting (EBM)
Fused Deposition Modeling (FDM)
Hybrid Processes (HP)
Laser Melting (LM)
Laser Sintering (LS)
Material Jetting (MJ)
Photopolymer Jetting (PJ)
Stereolithography (SL)

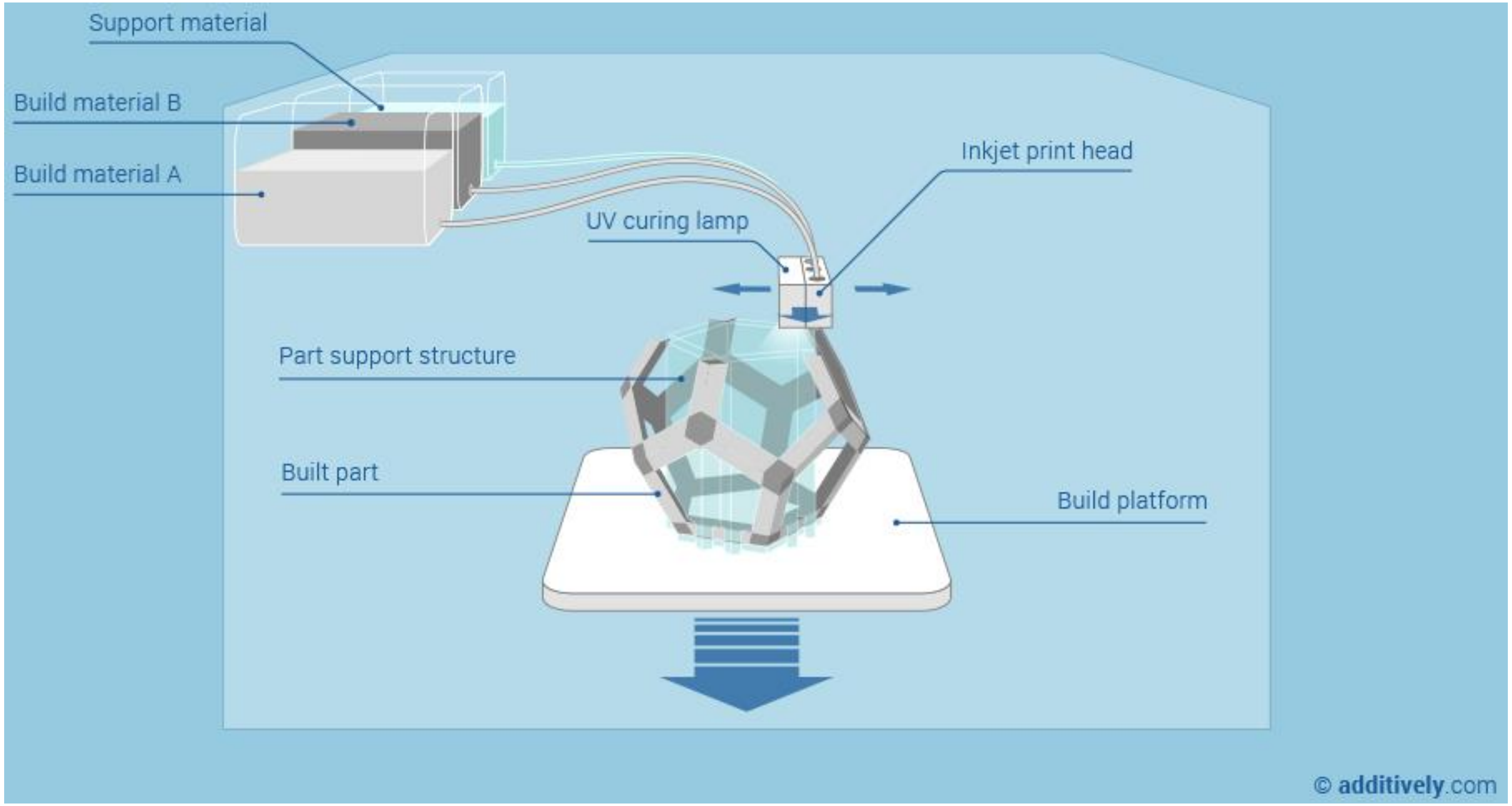
Stereolithography (SL) - principle

- UV-Laser cures liquid photopolymer on surface of a fluid
- Part is created by lowering the platform



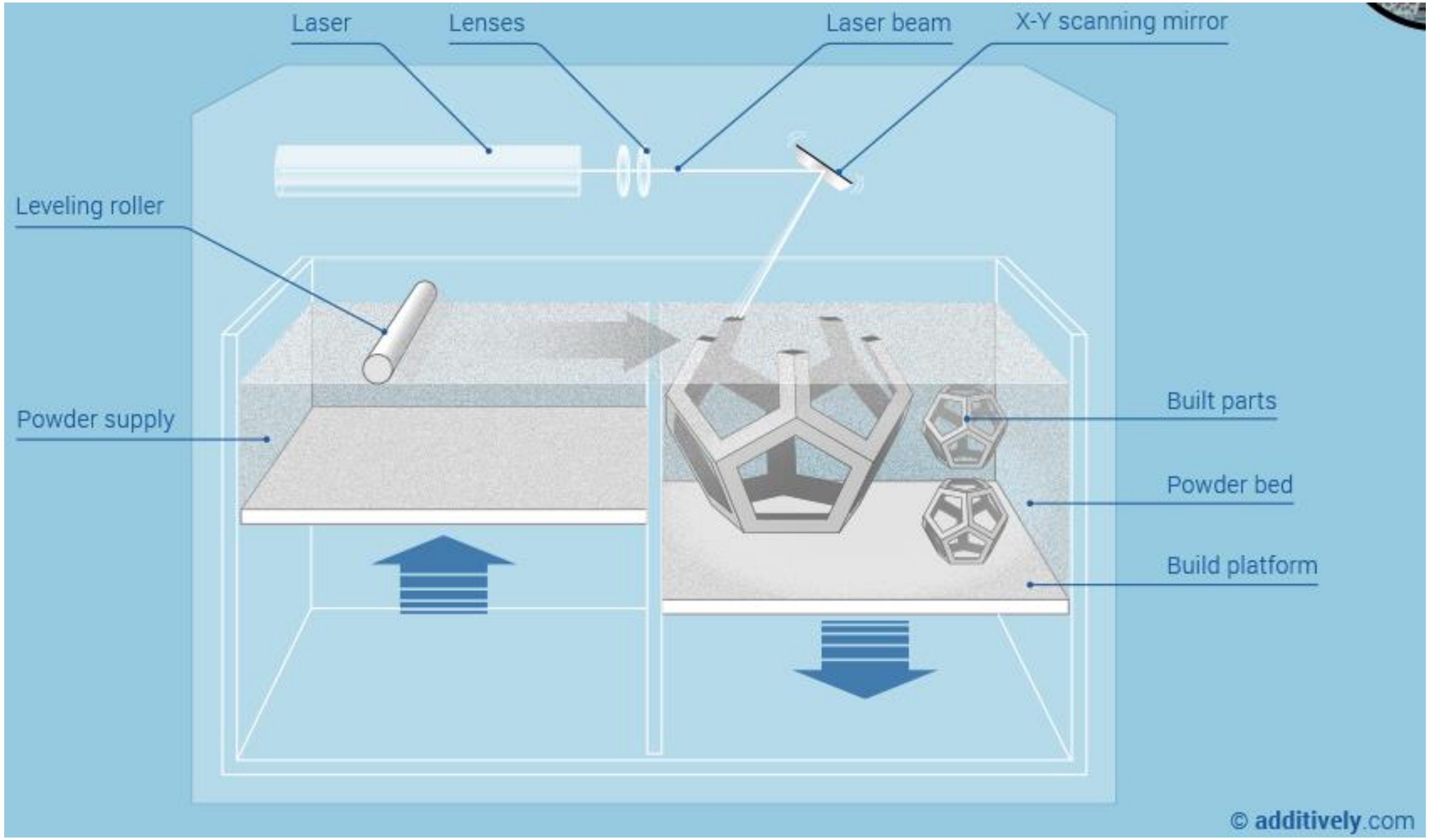
Photopolymer jetting (PJ) - principle

- Printer heads spray liquid photopolymers onto a platform
- Curing with UV-lamps → parts are created layer by layer



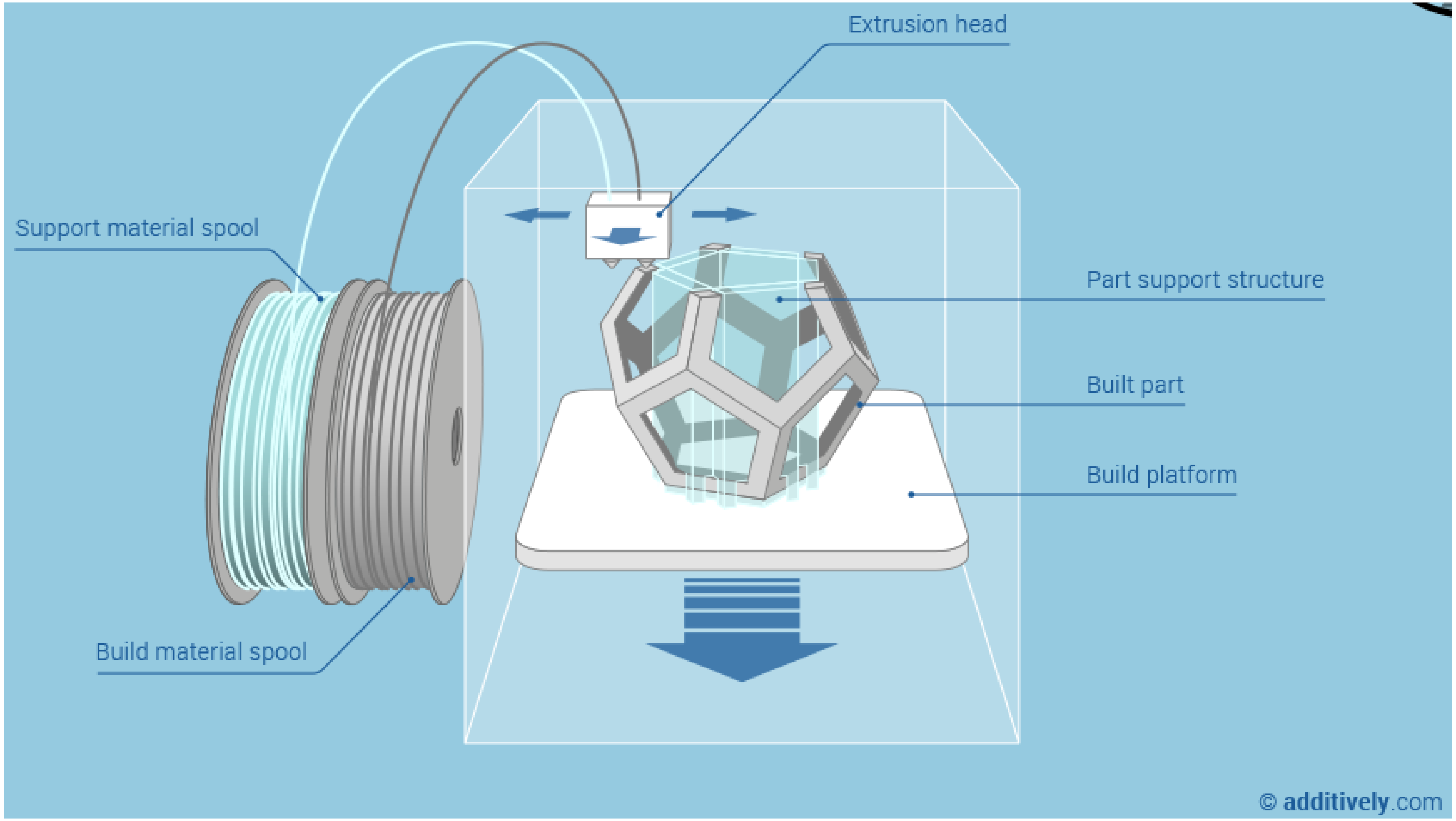
Laser Sintering (LS) or Selective Laser Sintering (SLS) – principle

- Thin layer of polymer powder is selectively melted by laser
- Creation of part layer by layer in powder bed



Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) - principle

- Polymer filament is melted and extruded through a heated die
- Creation of part by deposition of the filament in layers



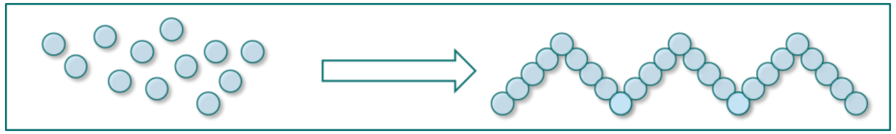
Research project iPrint: implants from 3D-printer

- Cooperation with Medical University Graz and Hage Sondermaschinenbau
- Polymer implants are printed during surgery
- Second surgery can be avoided
- Tailor-made for each patient
- Winner of Fast Forward Award 2016 in Austria


Summary

Summary

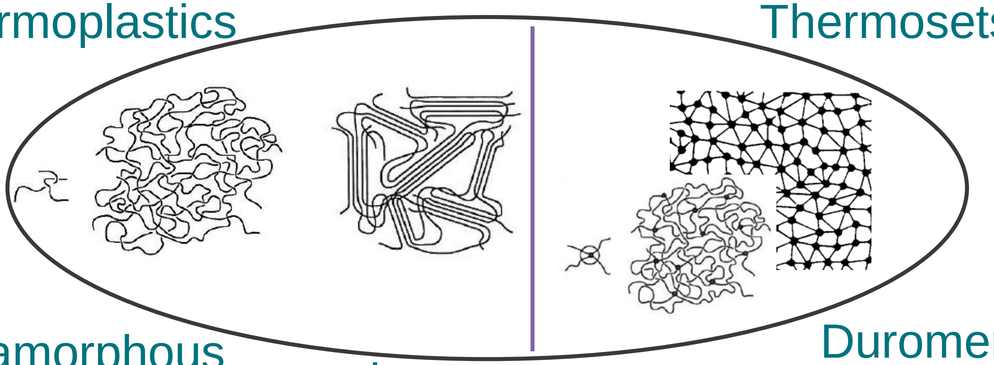
Monomer



Polymer

Thermoplastics

Thermosets

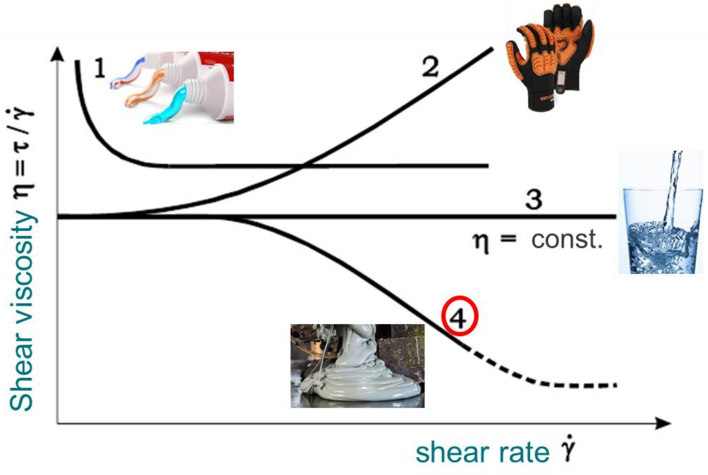


amorphous

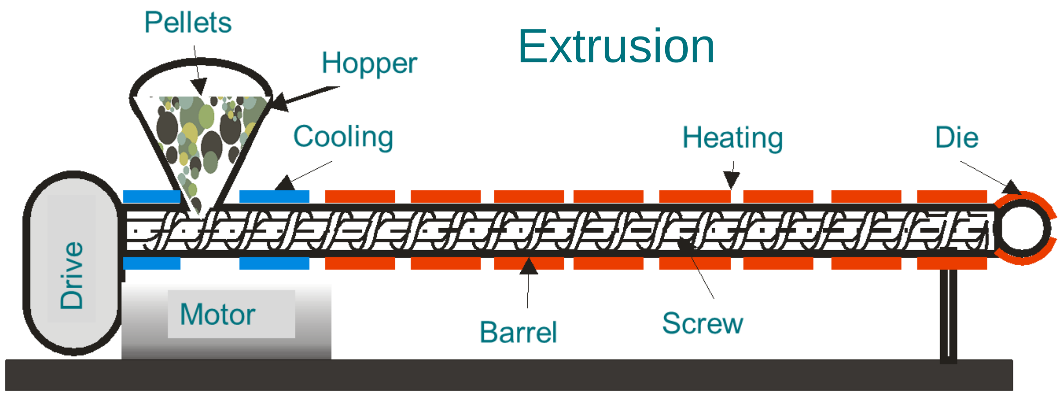
semi-crystalline

Duromer

Rubber



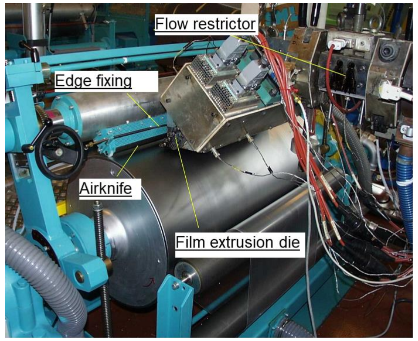
Shear viscosity



Extrusion

Pipe

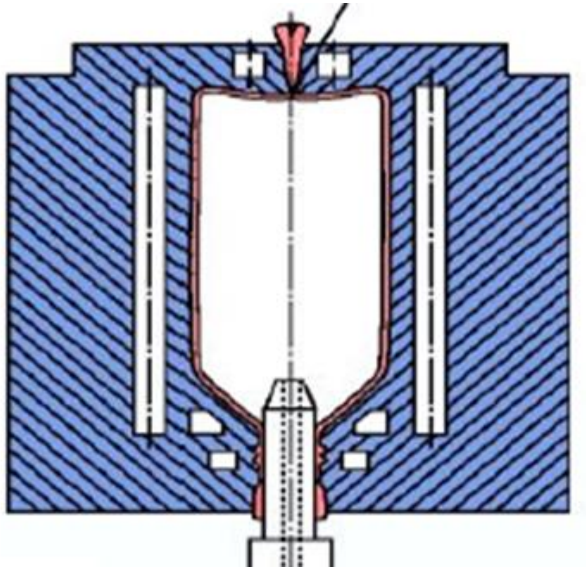
Flat film

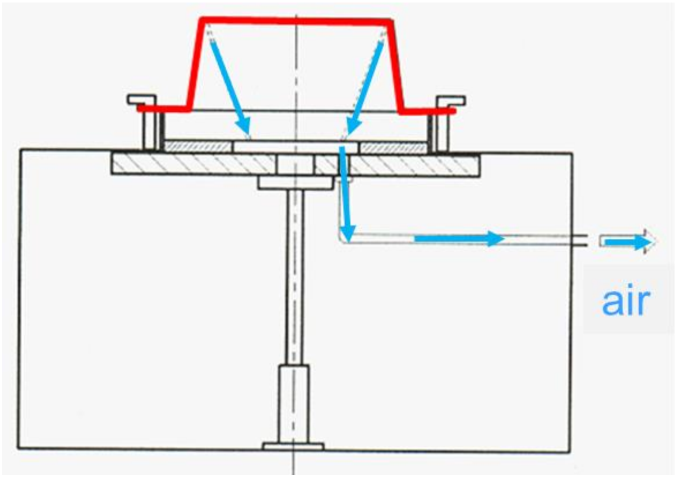


Blown film

Summary

Blow molding

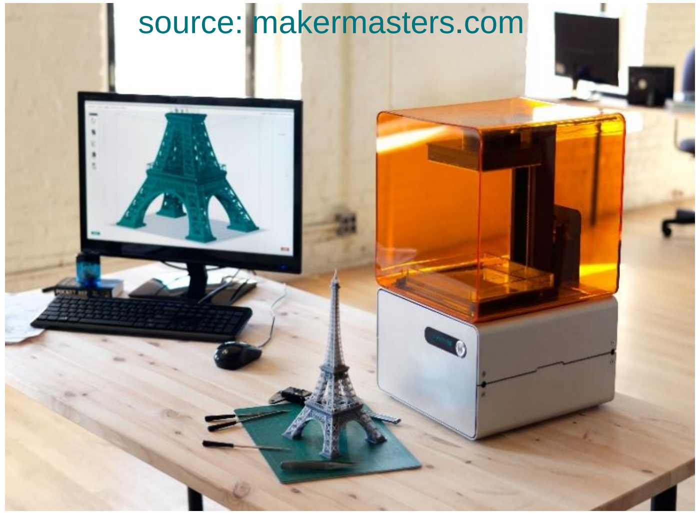




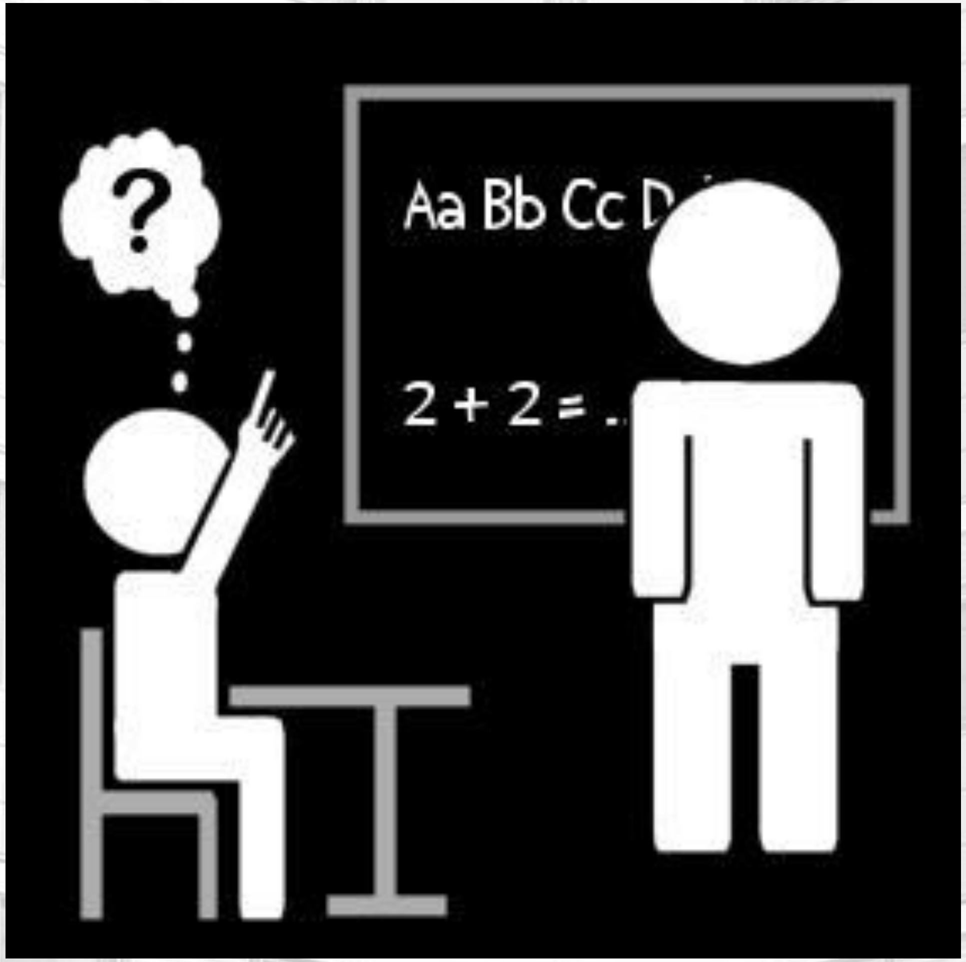
Thermoforming

Injection molding

source: makermasters.com



Additive manufacturing



Questions?

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