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Polymer processing techniques

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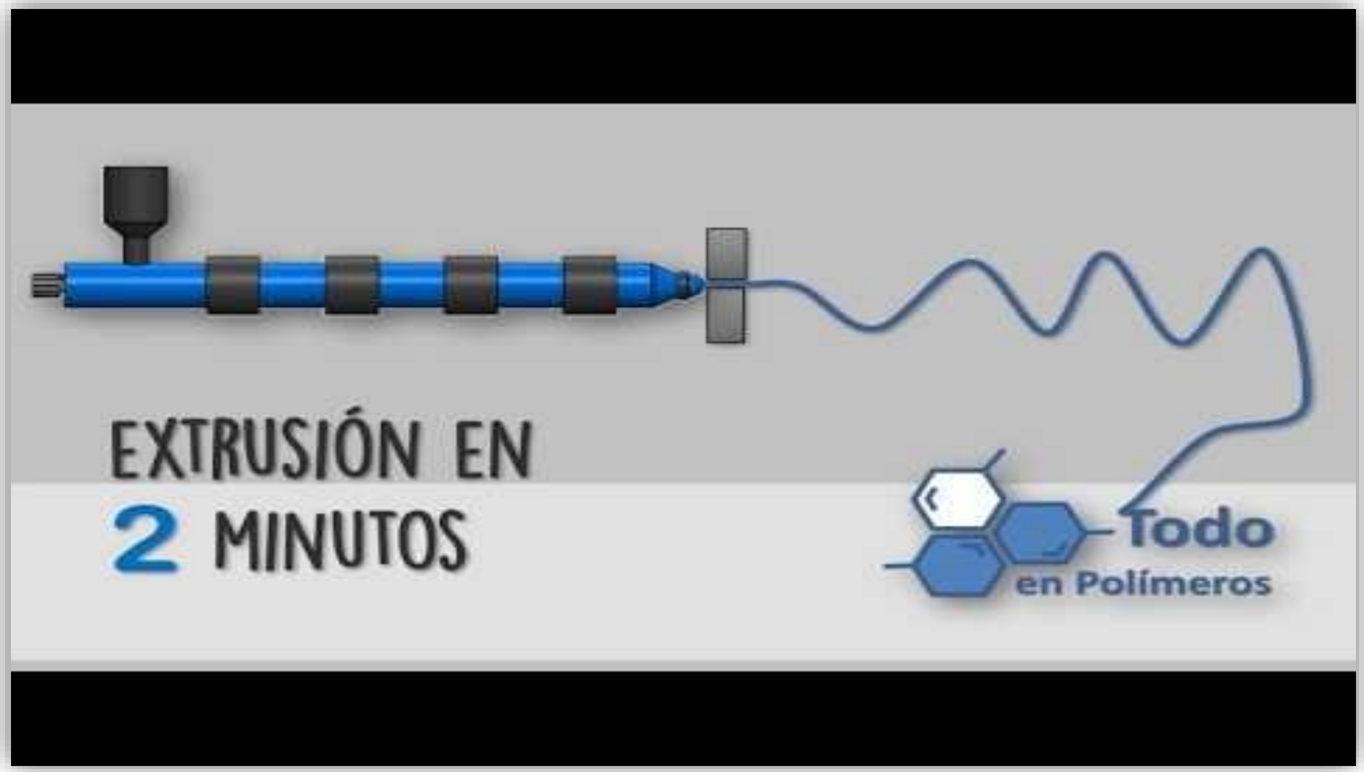
Extrusion

Author: Belén Montero / Anja Schmidt

01. Objectives

- The thermoplastics extrusion pursues usually two objectives:

    - The molding of the material into the final shape of the part (pipes, fibers, film, sheets, profiles, etc).
    - The homogeneous mixing of the different components of the material formulation (polymers, fillers, additives ....) (COMPOUNDING).



https://www.youtube.com/watch?v=AWCzmIEfHnY&t=13s

02. Extrusion-Description

- In extruders, the polymers (pellets or powder) are melted and homogenized inside the cylinder (plasticization).
- The mixture comes out of the nozzle with the desired profile shape due to the pressure exerted by the rotating screw.

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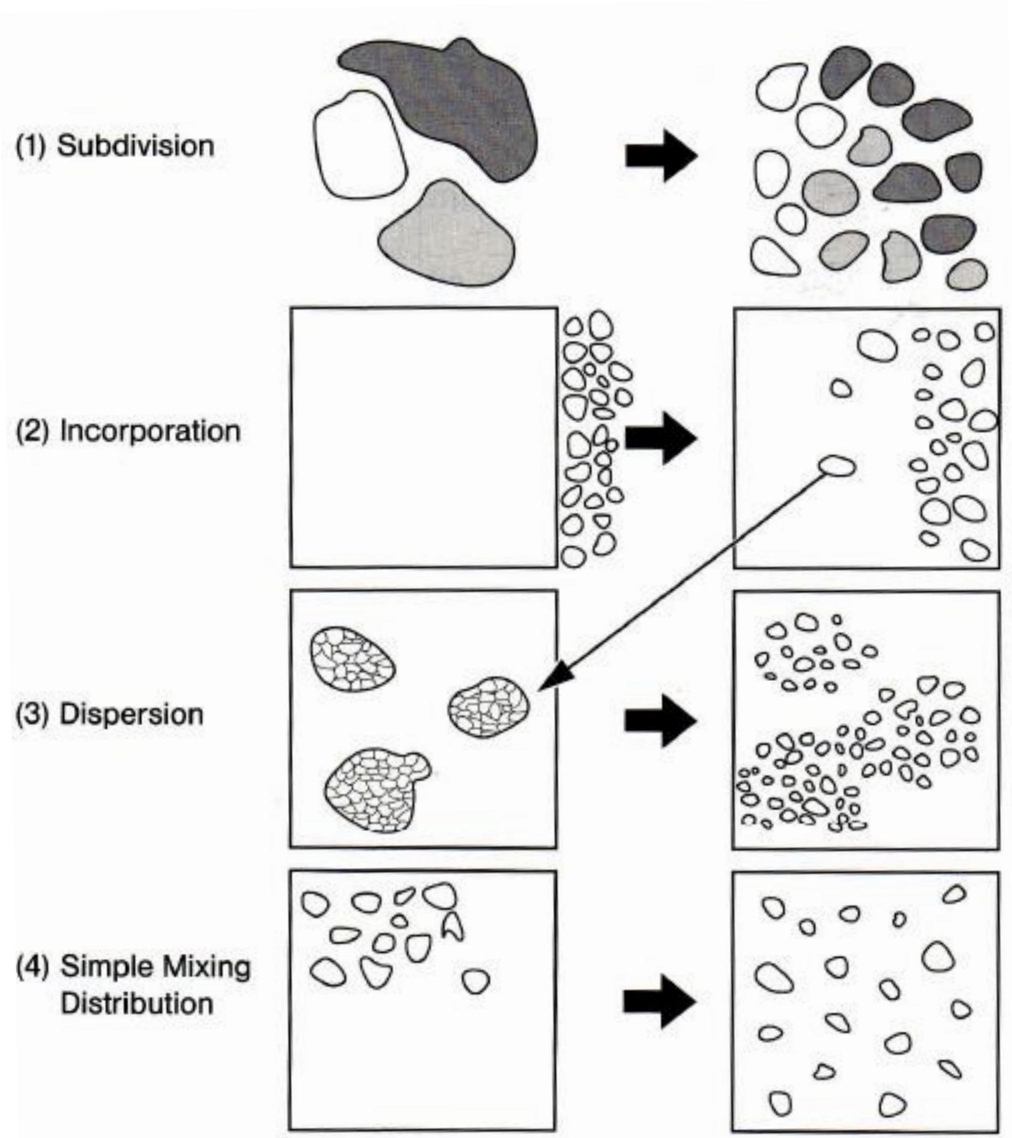
02. Extrusion-Considerations

- Aspects to take into account:
- -Extruder type
- -Screw design
- -Working parameters

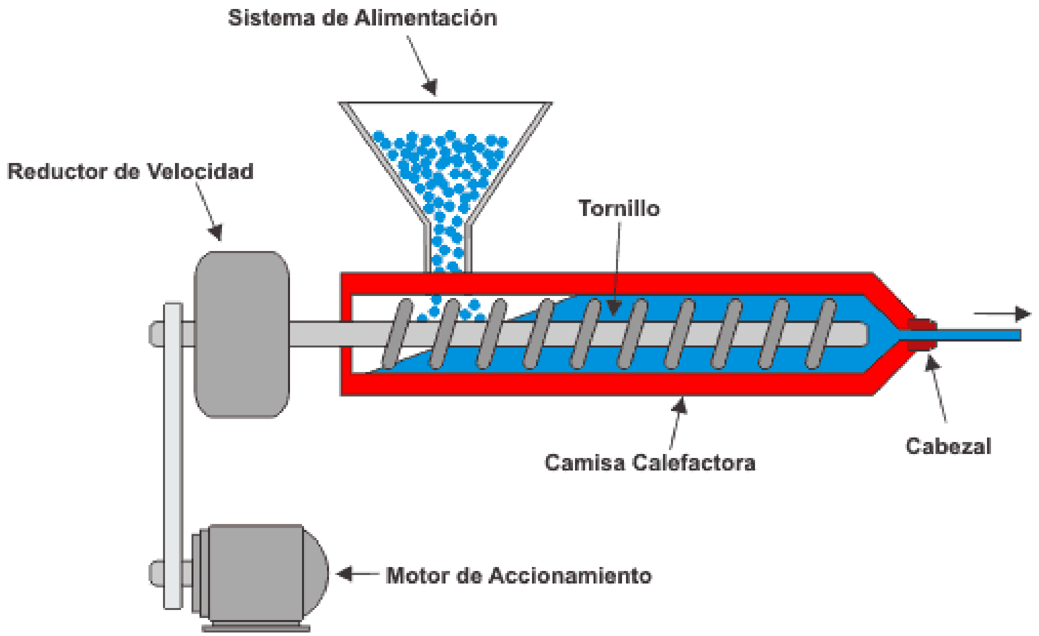
- -Dispersive/distributive mixing type
- -Mixing intensity



02. Extruder types

EXTRUDER CLASSIFICATION:

- Single-screw / twin-screw
- L/D Ratio



MAIN ELEMENTS

motor

sleeve or barrel

screw

screw

hoppers (feeders)

cooling system

degassing systems

accessories (coolers, calibrators, etc)

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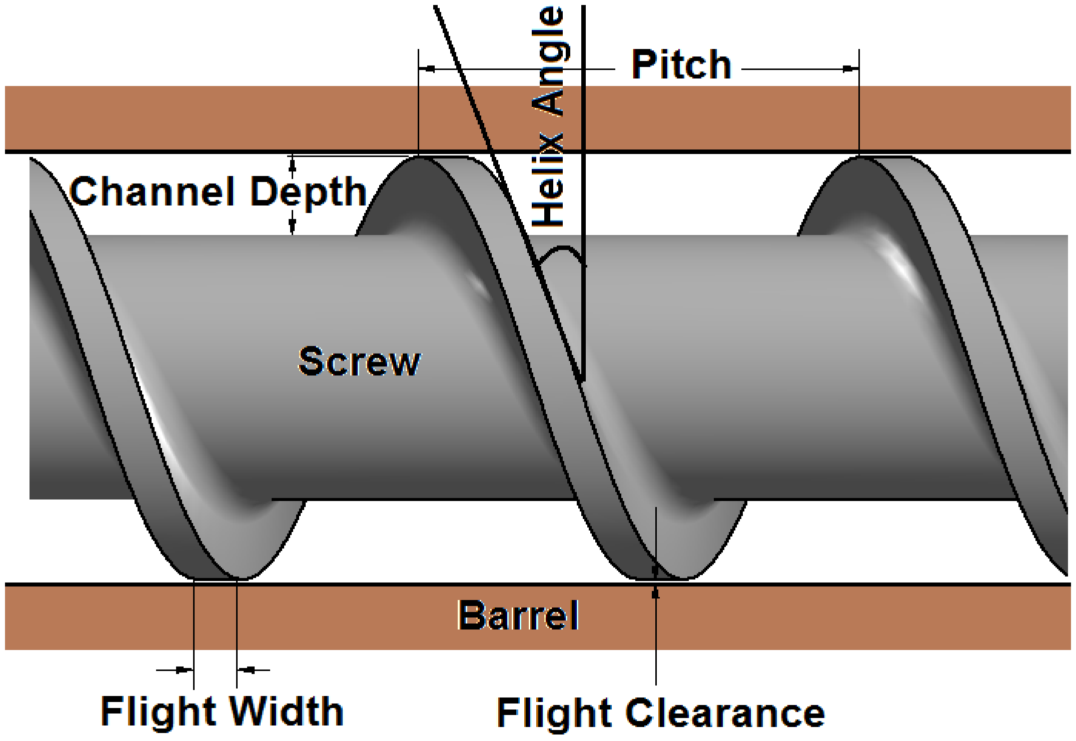
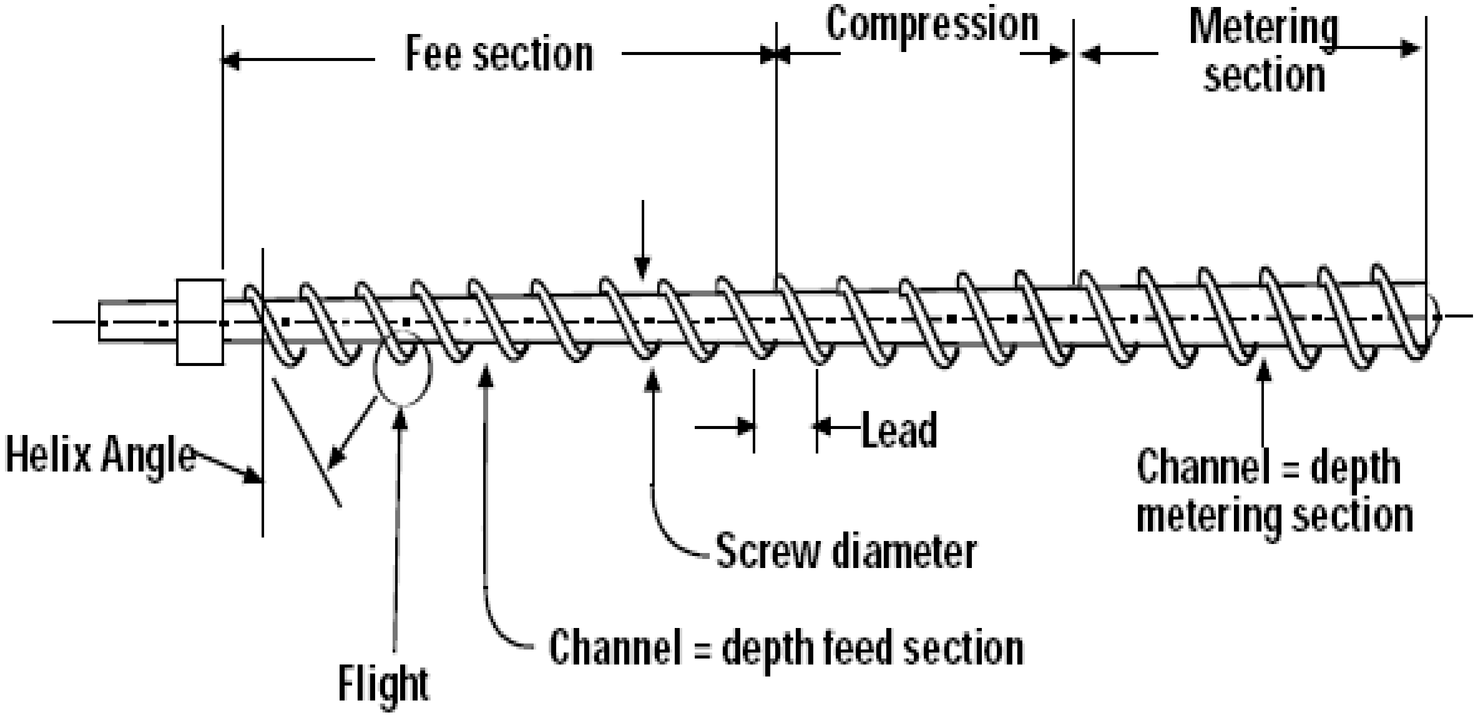
02. Screw-Screw Extruders:

- They have a single screw or spindle (the fundamental part of the machine).
- **Plasticizing capacity:** defines the interaction that the material will have between the screw surface and the liner containing it (ideally low friction with the screw and high friction with the liner walls).
- **L/D ratio:** determines the surface area of the barrel and its plasticizing capacity.
- Commercially D:20 to 600 mm diameter and L/D:20-25.
- The central axis of the screw is cylindrical or conical.



02. Syngle-Screw Extruders:

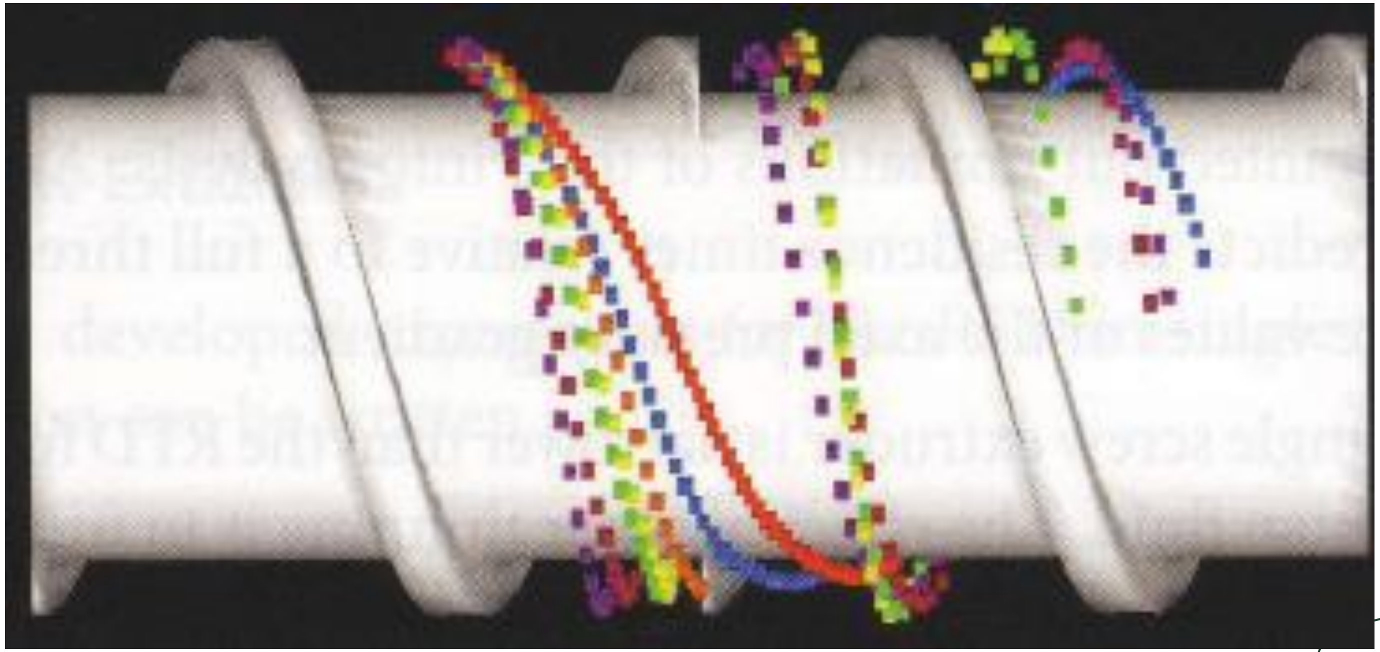
- Syngle-Screw design:



$$Compresion\ ratio: \frac{Chanel\ depth\ in\ feed\ section}{Chnale\ depth\ in\ metering\ section}$$

02. Syngle-Screw Extruders:

- Screw helical shape
- Distance between threads is equal to diameter and angle of inclination 17.7º (to the left or right)



02. Syngle-Screw Extruders:

Optimization of working parameters: **PROCESSING WINDOW**

- Temperature profile
- Spindle speed (residence time)
- Importance of material viscosity

✓They obtain very high spindle pressures
✓They are more economical
✓Inefficient mixing of poorly miscible polymers or complex formulations.

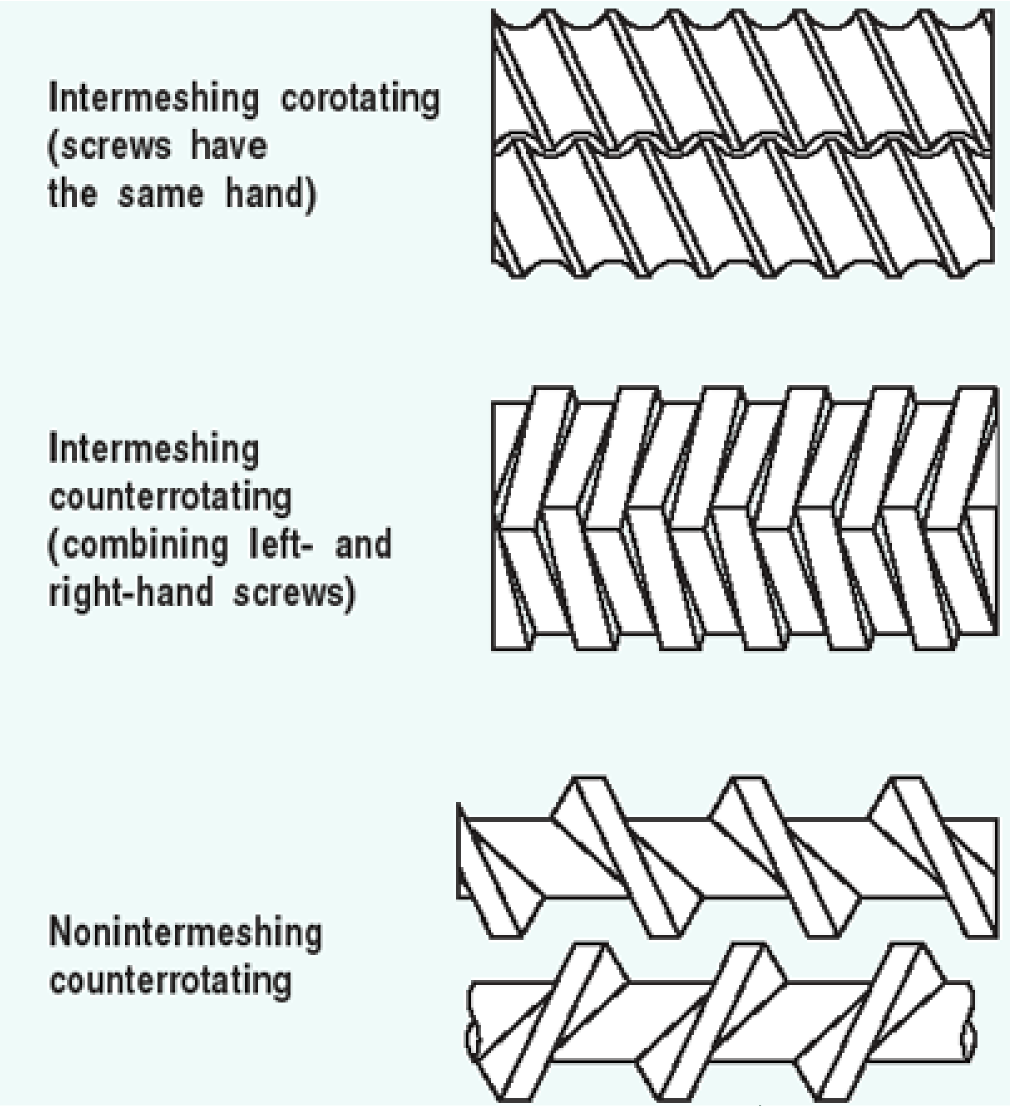
03. Twin-Screw Extruders:

TYPES:

COROTATING / COUNTER-ROTATING.

Depending on the distance between the screws:

- **Tangentially intermeshing** (Tangentially Intermeshing or non intermeshing)
- **Partly intermeshing** (Partly intermeshing)
- **Fully intermeshing** (self-cleaning)



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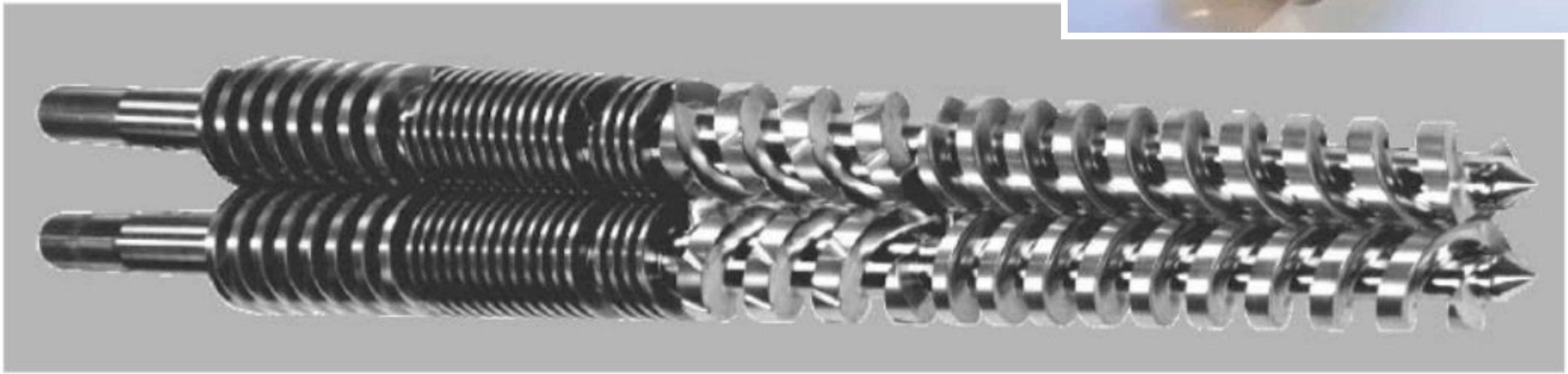
03. Twin-Screw Extruders:

Parallel spindles

Conical spindles



03. Twin-Screw Extruders:

Screws of twin-screw extruders are modular and composed of different elements.

The configuration of the screws is designed according to the application required.

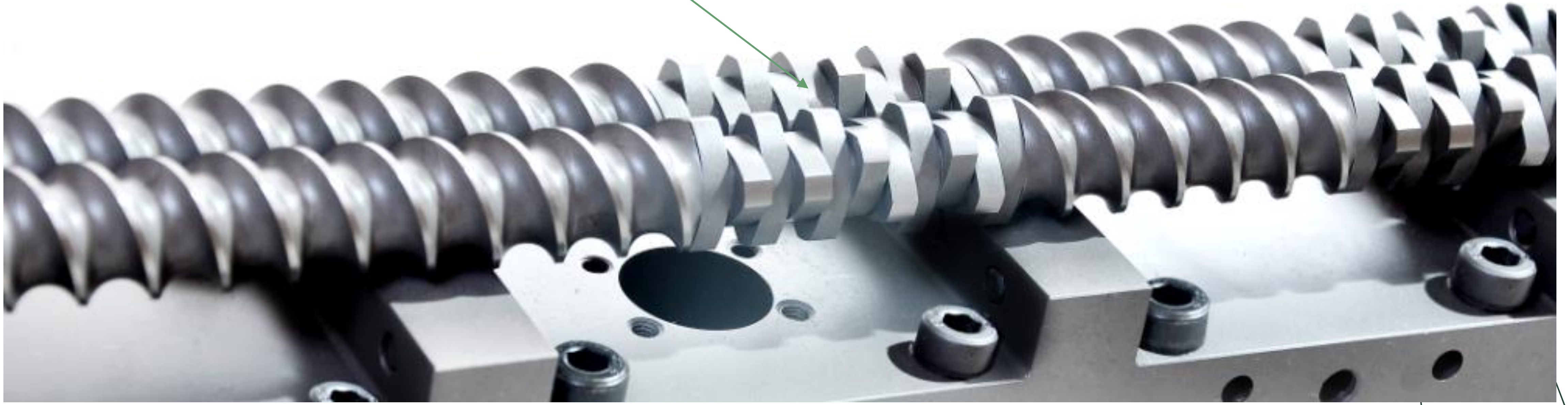
The main elements are:

- Elements with inclined right-hand thread
- Elements with inclined left-hand thread
- Kneading blocks

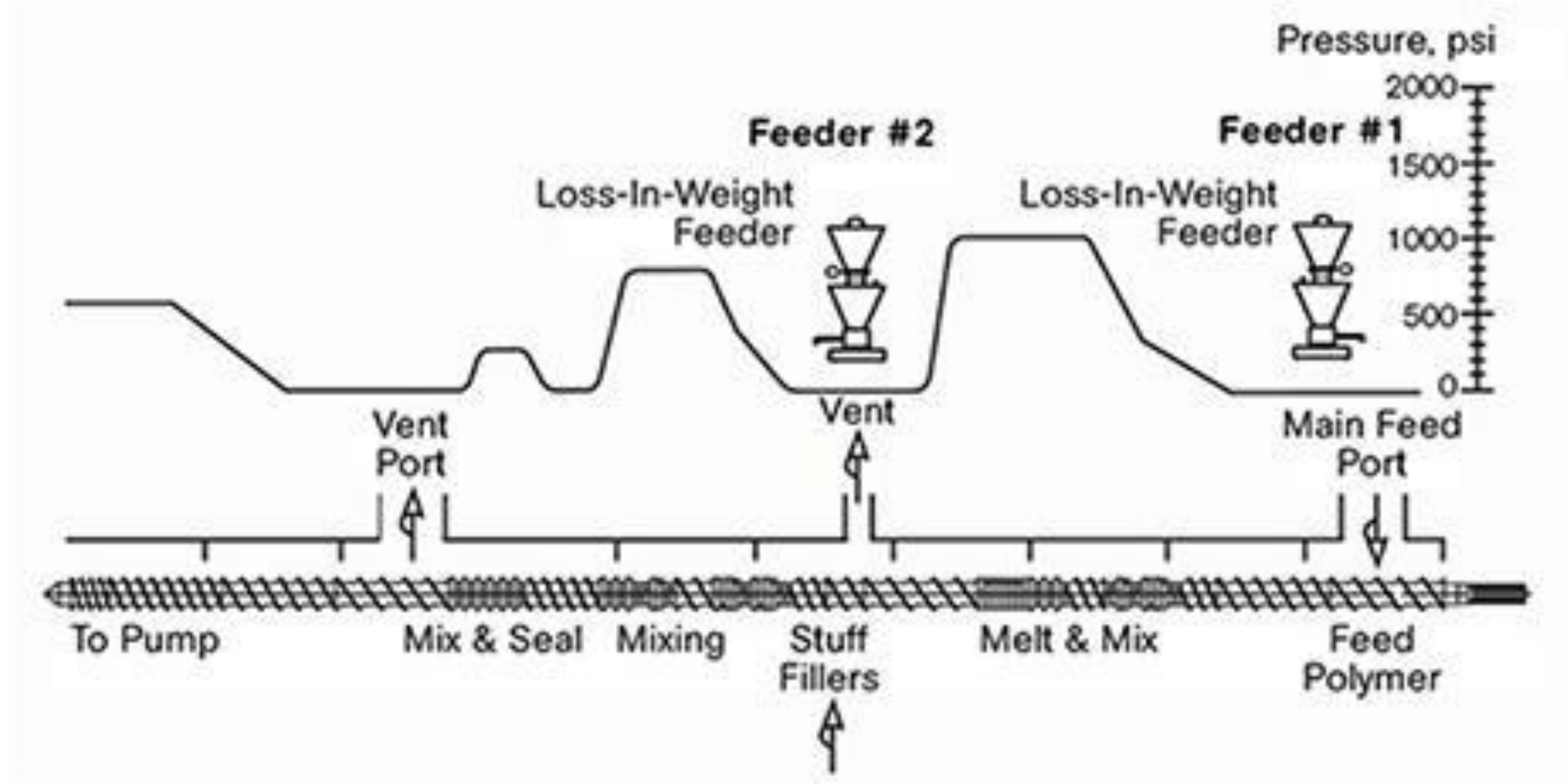
03. Twin-Screw Extruders:

Kneading blocks

produce both dispersive and distributive mixing (allow the polymer to melt much earlier due to the frictional heat input)



03. Double-Screw Extruders:



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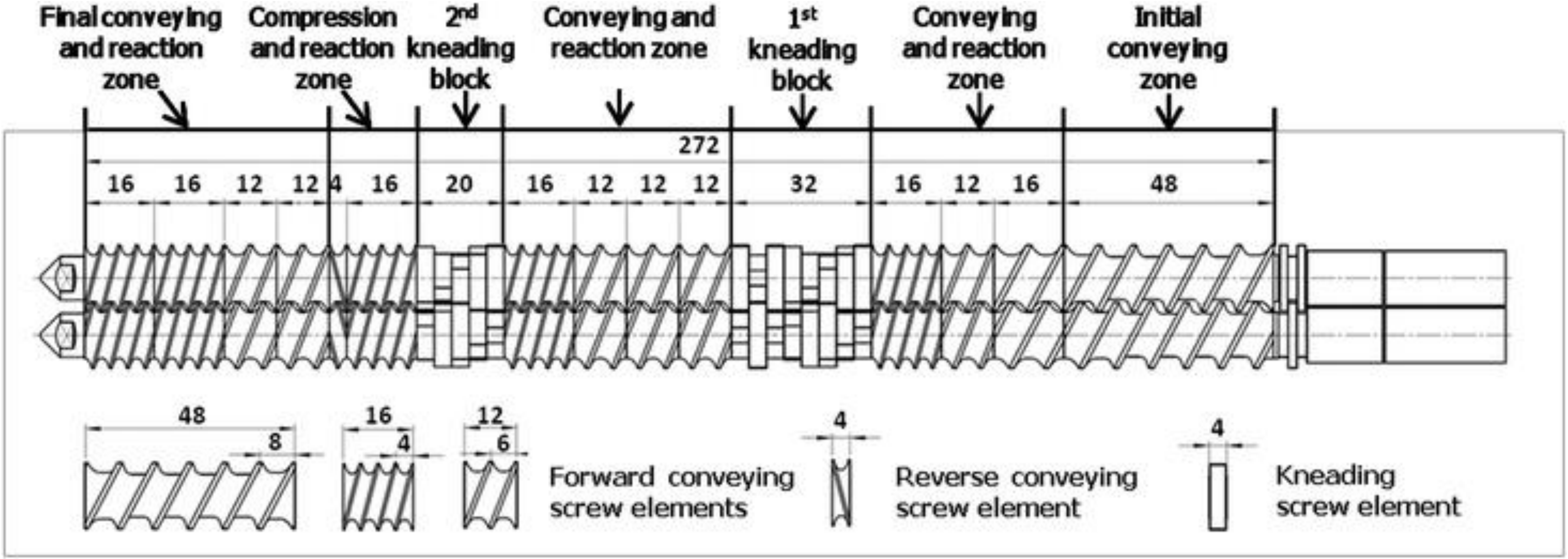
03. Double-Screw Extruders:

- Spingle Design:



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04. Twin vs Single Screw

- Improved dispersive and distributive mixing over single-screw with lower L/D ratios
- Higher conveying capacity at lower speeds
- Better control of material temperature during processing and short residence times
- Allows processing of high viscosity materials
- In general they have several dosing zones where additives can be added, reactive mixtures can be made.
- High pressures and vacuum can be used.

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04. Twin vs Single Screw

- They are self-cleaning (especially the fully geared ones), maintenance costs are lower.
- They allow to mix the material and mold it to the final shape in the same cycle, saving time and costs.
- They allow to extract volatiles from the melt and reactive extrusions: for copolymerization of materials or grafting reactions.
- They are more versatile than single-screw extruders, allow complex mixtures and increase productivity and product quality.
- On the other hand, they are still more expensive than single-screw machines.

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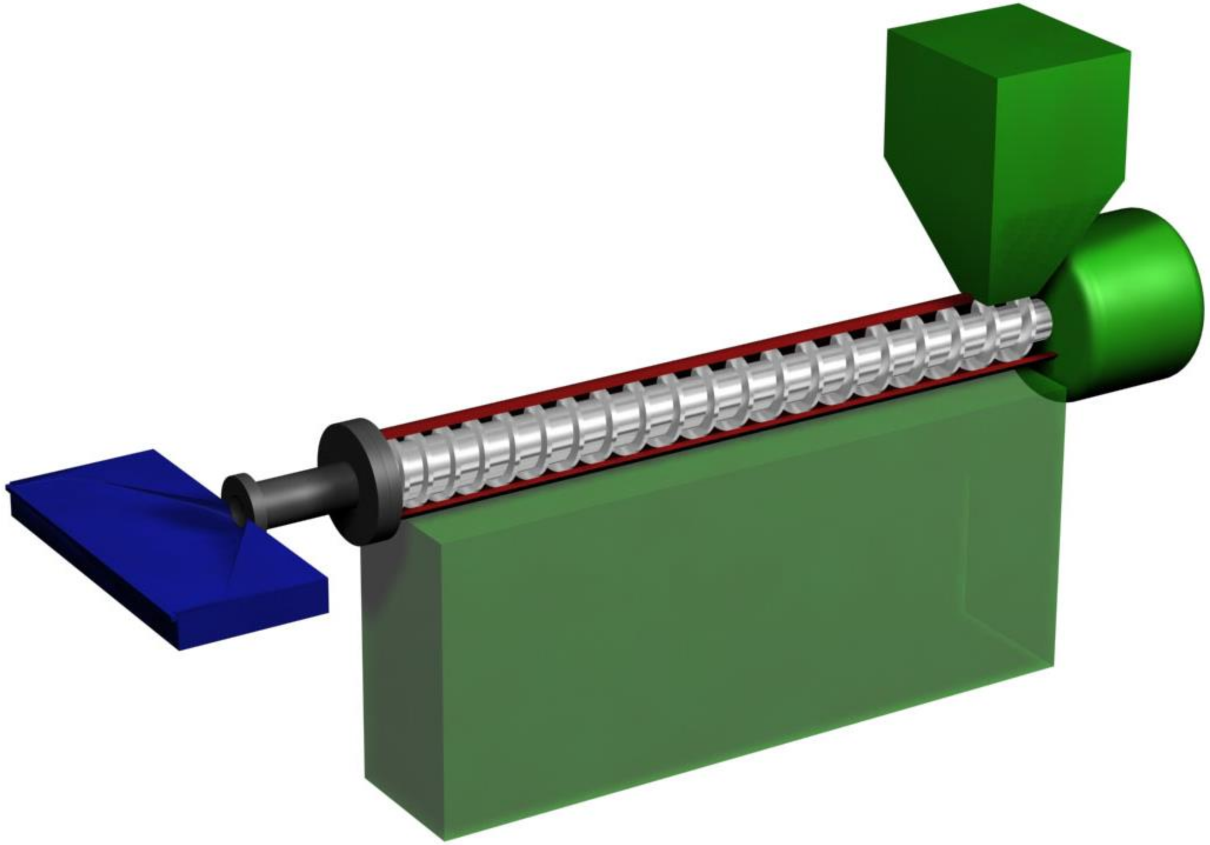
05. Film processing by extrusion



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05. Film processing by extrusion

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06. Parameters optimization

The extrusion parameters to be optimized in the process are:

- temperature profile
- screw speed
- feeding speed.

Previously, the type of extruder and the shape of the screw or screws are selected, taking into account:

- The characteristics of the thermoplastic to be used
- Shape of the product to be extruded
- Required production speed (in general production costs)

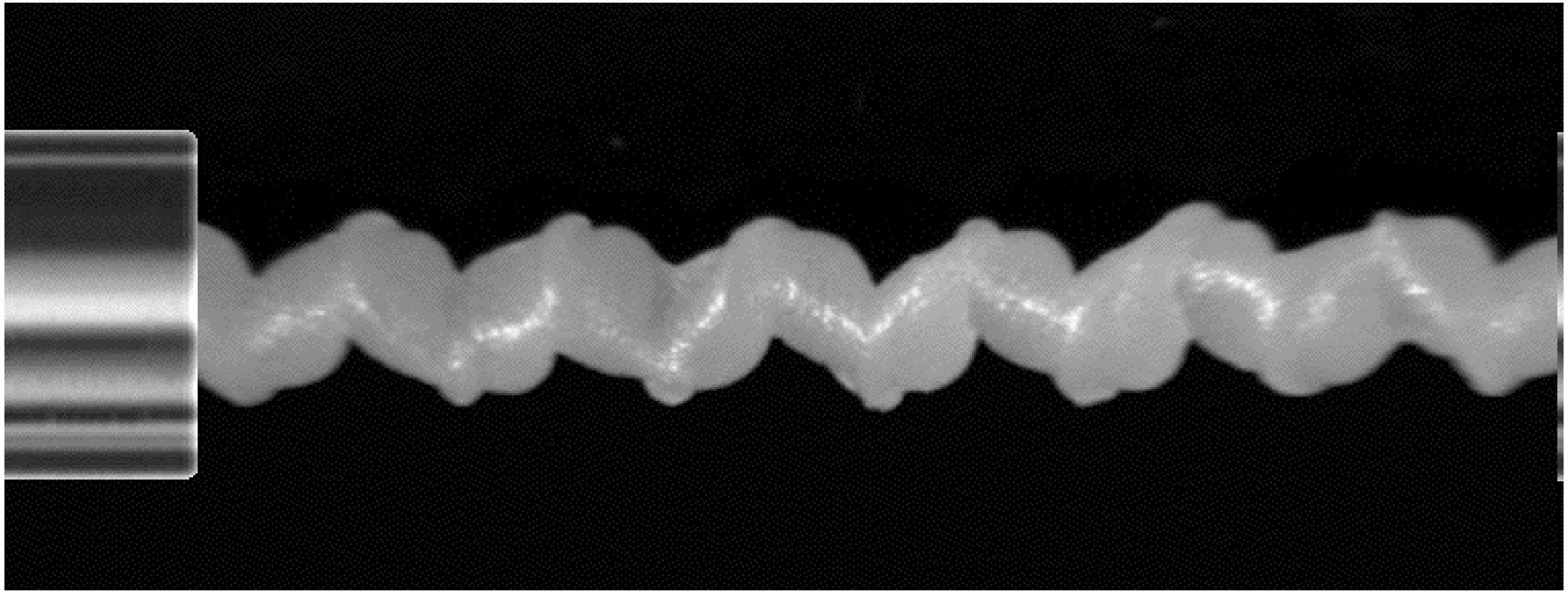
TEMPERATURE PROFILE

Good temperature control of the material is important due to:

Maintaining proper viscosity

Avoiding instabilities in the flow at the outlet of the header

Avoid thermal degradation of the material



SPINDLE SPEED (FLOW VELOCITY)

The speed is limited by flow instabilities.

- Swelling in the nozzle (die swell)
- Fracture of the melt
- Stretch resonance
- Slip-stick effect

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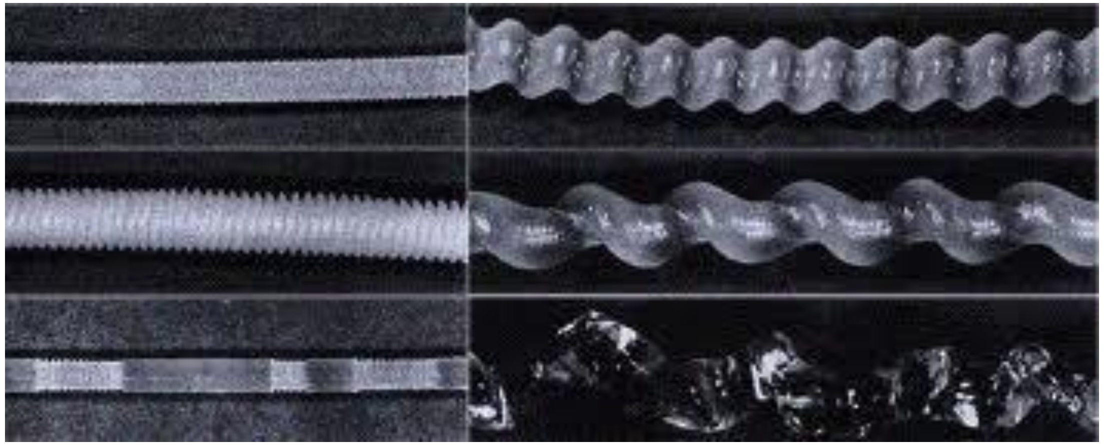

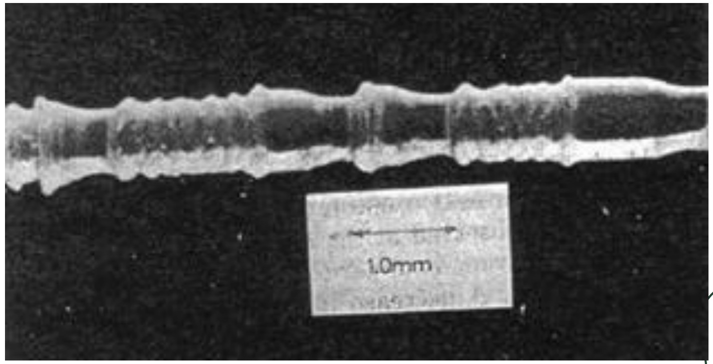

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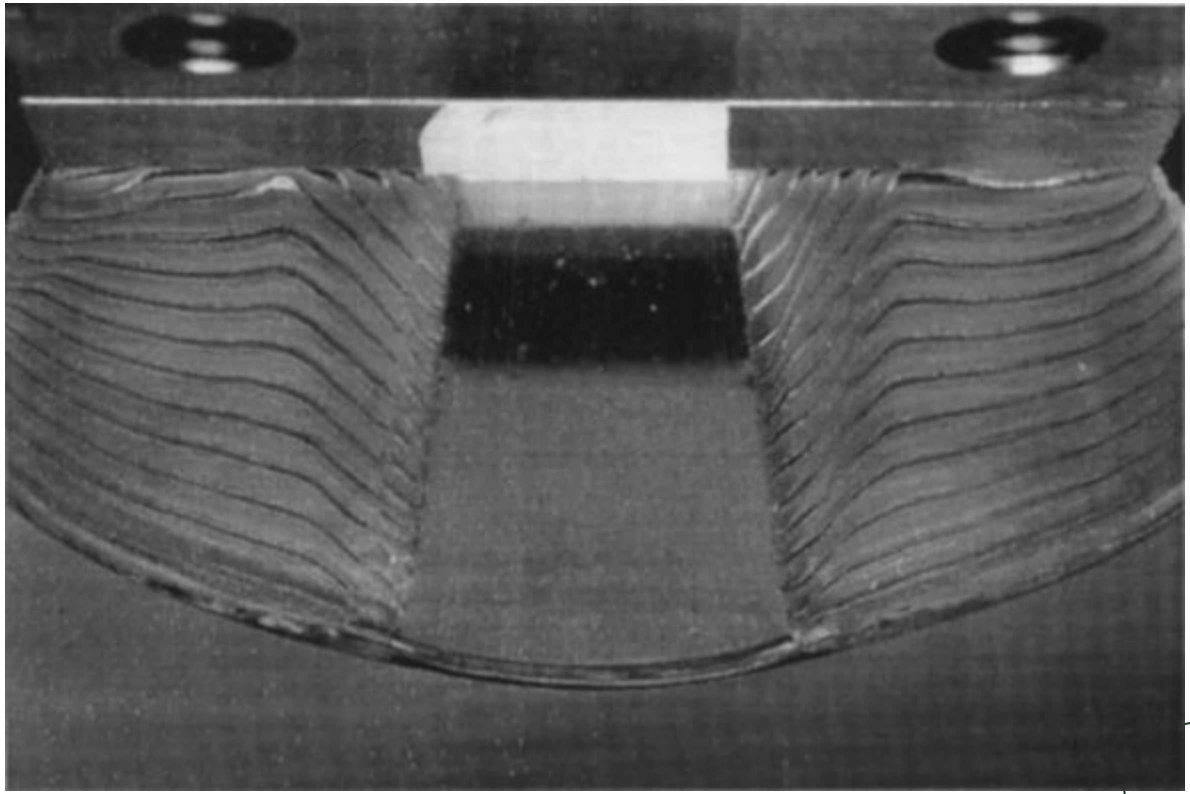
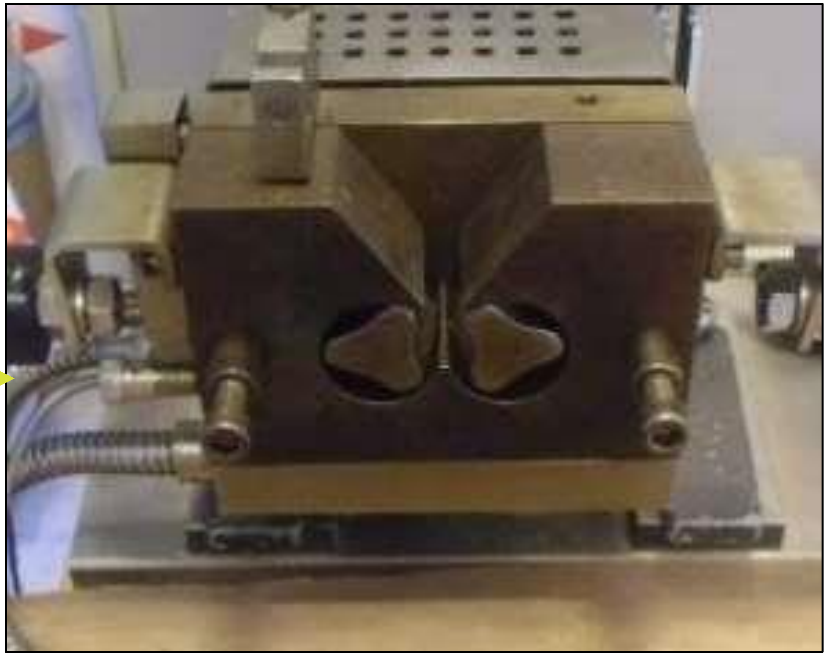


07. Lab-scale processing

INTERNAL MIXERS:

Polymers and additives are added in an enclosed, heated chamber with parallel rotors.

Internal mixer Brabender W50-E 3 zones PL-type 2000-3



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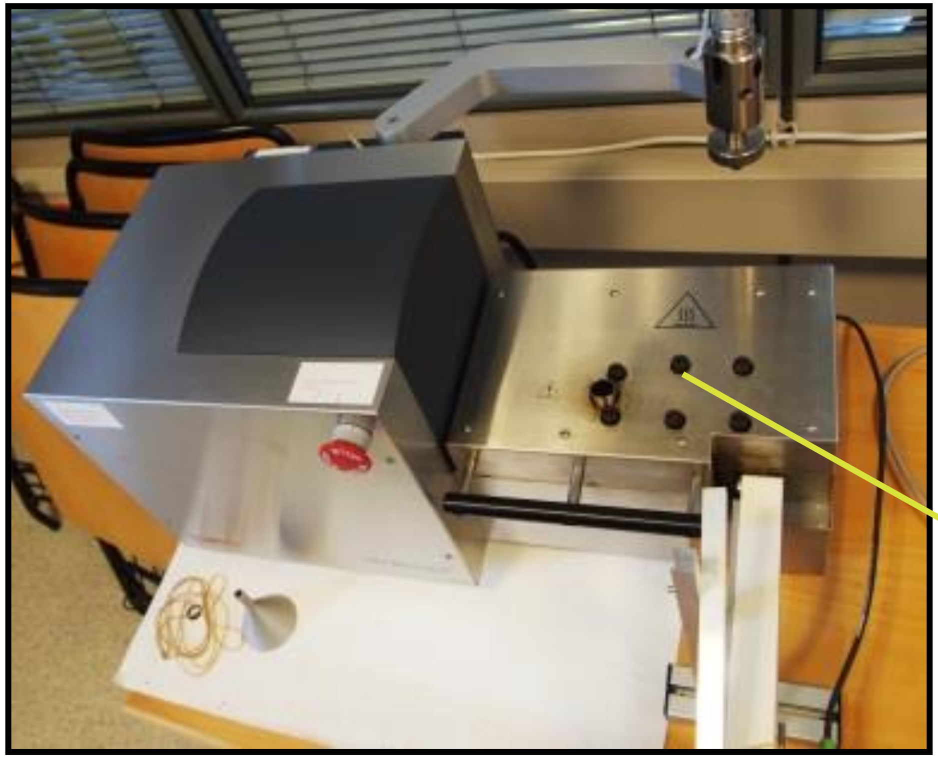
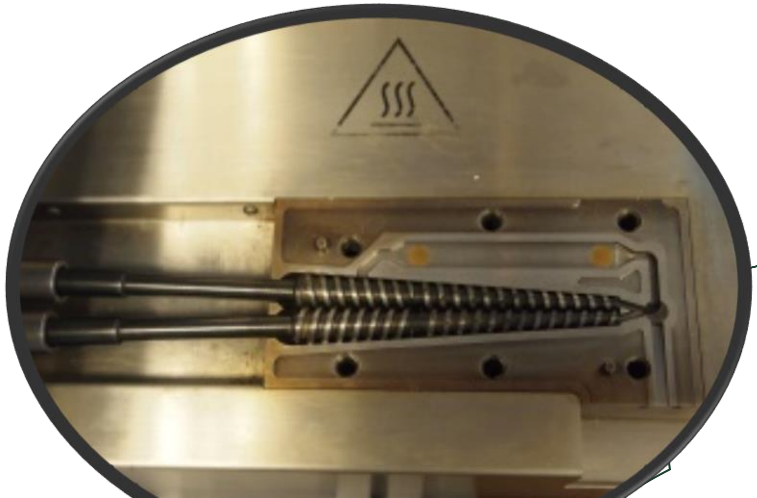
07. Lab-scale processing

Microextruder MiniLabII HAAKE™ Rheomex CTW5



- Co- and counter-rotating twin screws
- Integrated viscosity measurement
- Automatic bypass operation for circulation/extrusion
- Pneumatic feeding
- Split barrel exit for easy cleaning
- Compact enough to fit into laboratory fume hood



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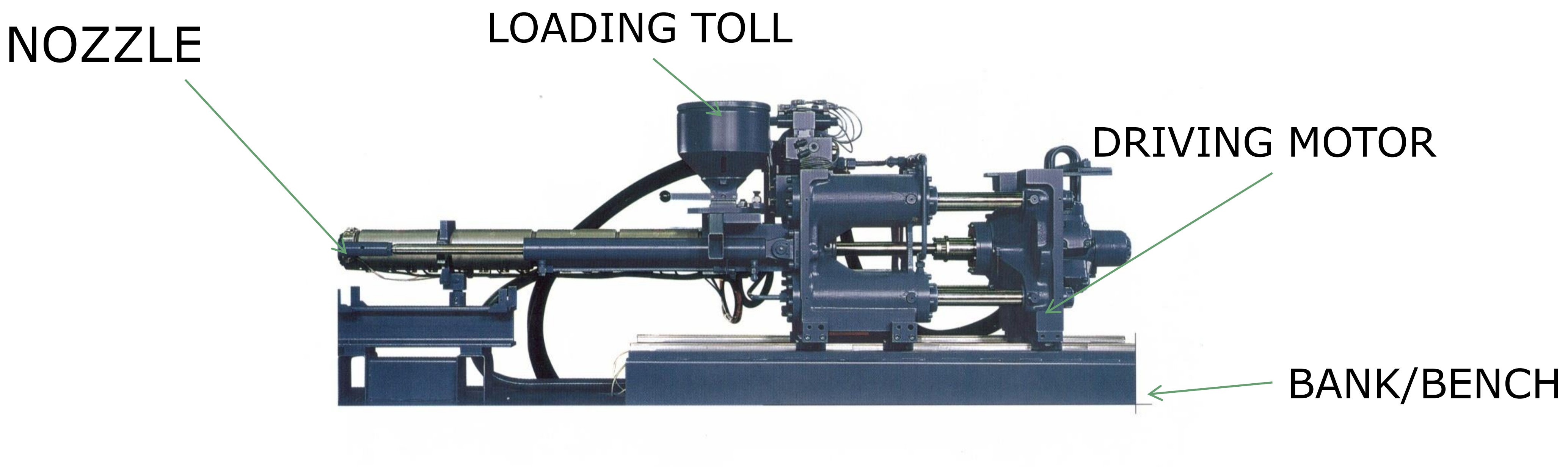
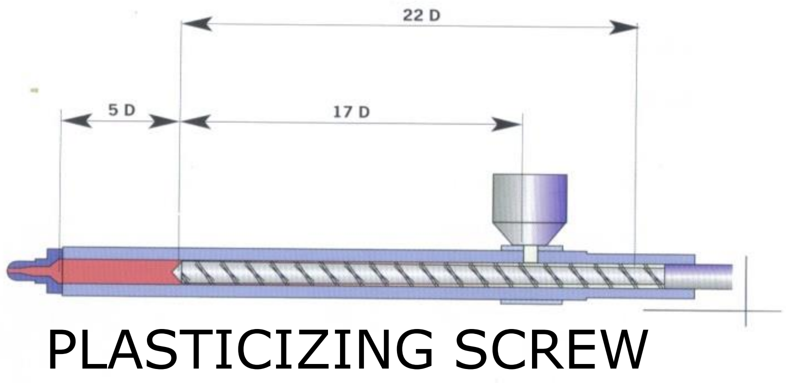
Injection

Author: Belén Montero / Anja Schmidt

01. Injection-Description



PLASTICIZING CHAMBER



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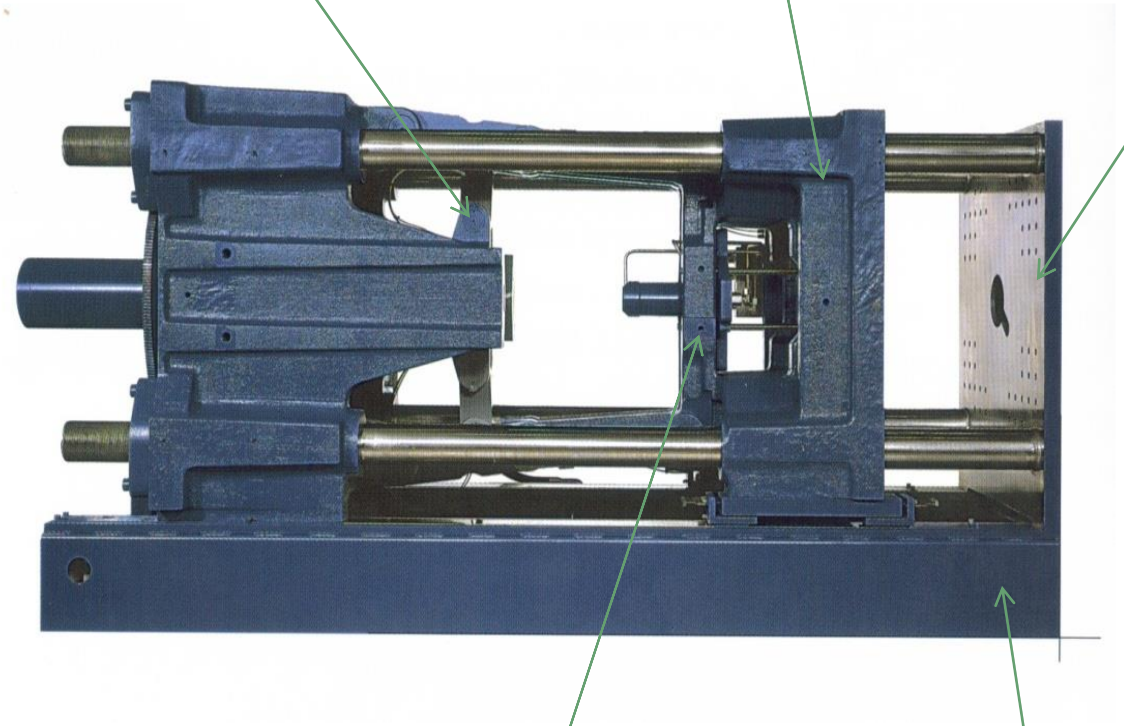
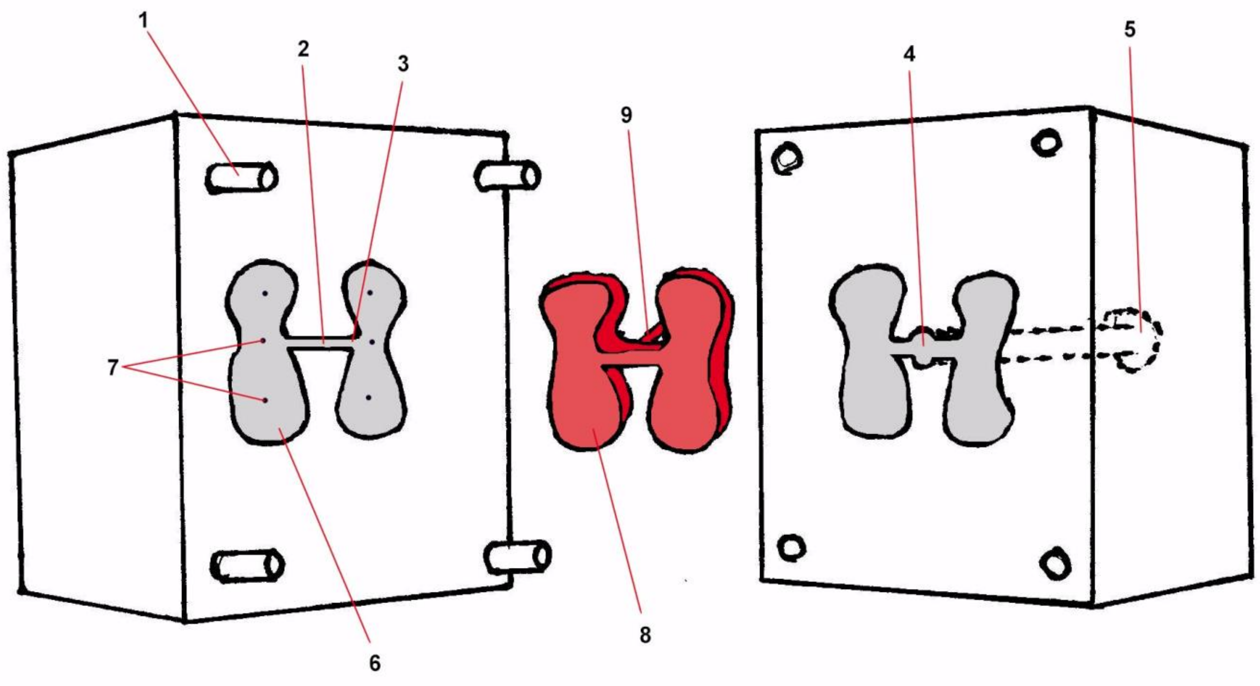


01. Injection-Description

In most of the molds we can distinguish the following parts:

1. Guide pins
2. Flow distributor (sprues)
3. Cavity inlet
4. Pouring channel
5. Mold inlet
6. Mold cavities
7. Ejectors
8. Molded mass
9. Casting (sprue)



01. Injection-Description

INJECTION UNIT:

Screw diameter (14-240 mm).

Injection pressure max (1200-2500 bar)

Max injection volume (25 cm^3-50000 cm^3)

Plasticizing capacity (2-410 g/s)

CLAMPING UNIT:

Max. clamping force (25-4000 Tn).

Distance between bars (27-250 cm)

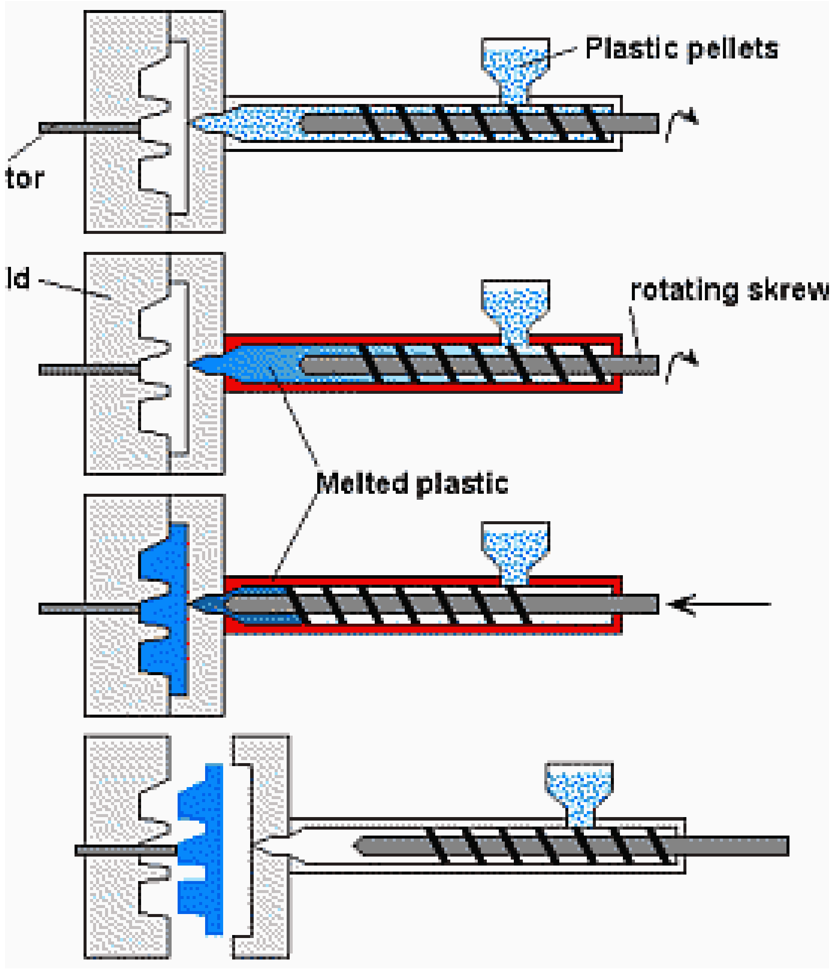
Plate sizes (47x28 - 360x334 cm)

01. Injection-Description

Injection volume(cm^3)	Close force (Tn)
25-50	25/35
150-350	80/100/130/150/180/200
400-1000	210/270
1000	350
1500-2000	450/550/650
10000	1300/1600/2000/2400
50000	4000

02. Injection-Process

02. Injection-Process



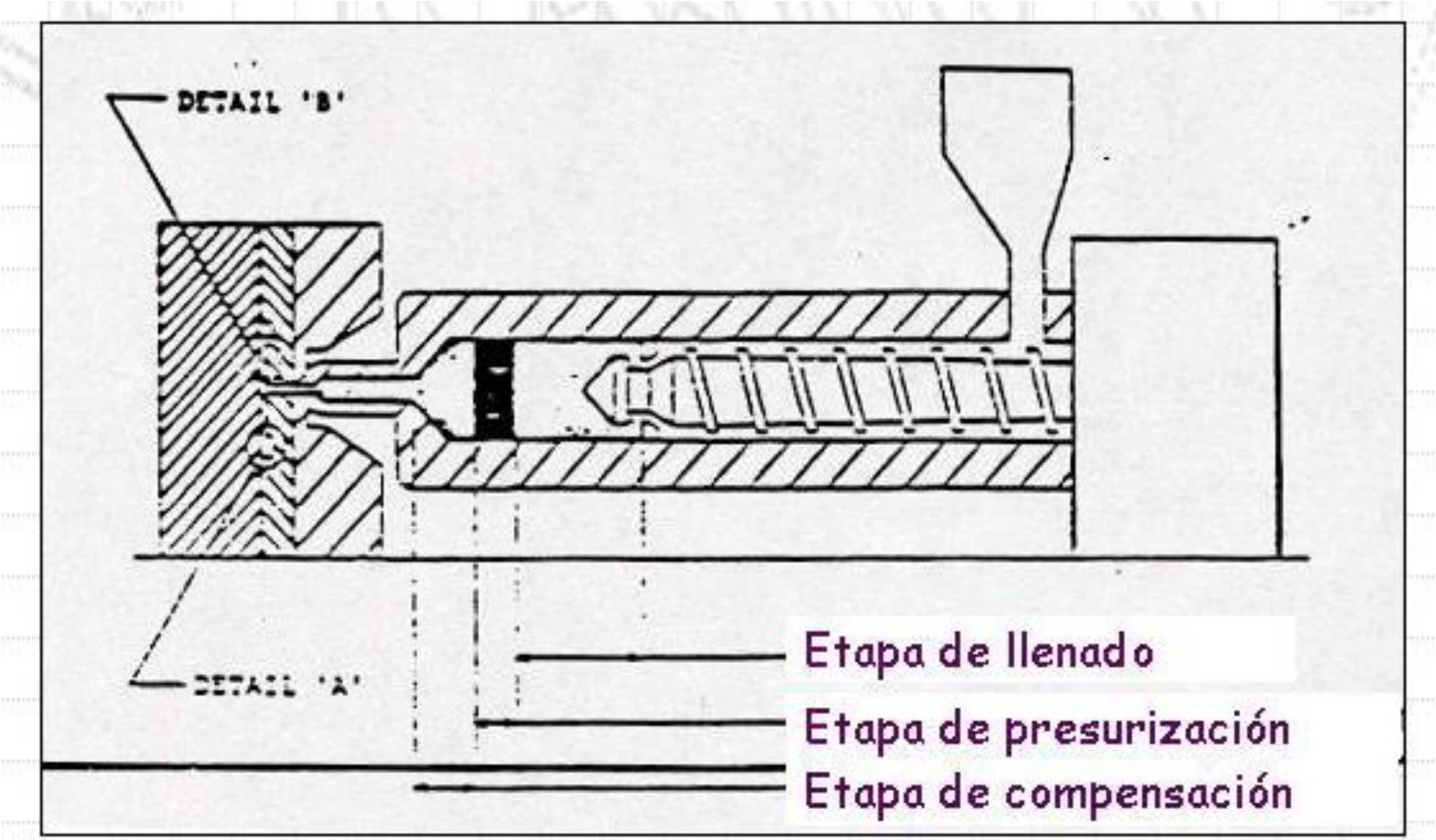
The injection process is divided into three phases:

1. PLASTICIZING PHASE
2. INJECTION PHASE
3. DEMOLDING PHASE

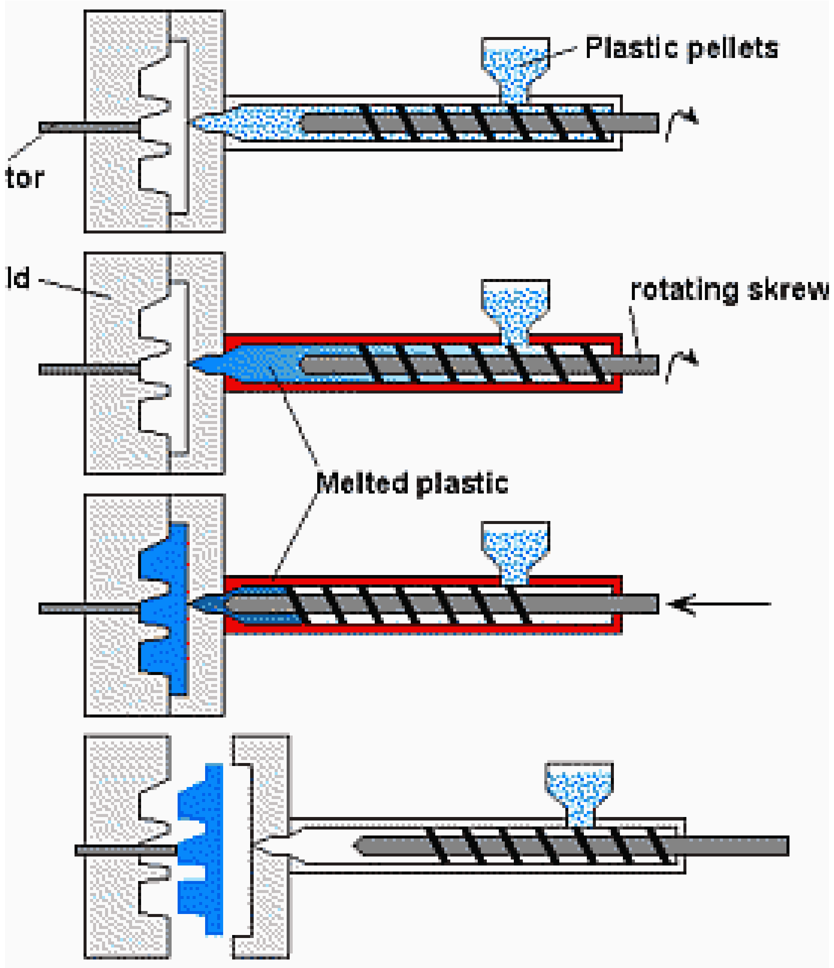
02. Injection-Process

INJECTION PHASE

The fluid is injected into the closed mold.
It has three stages: filling, pressurization and compensation.



02. Injection-Process



DEMOLDING PHASE

In general, cycle times are very short so that production is high once the injection parameters have been optimized.

03. Injection Process-optimization

The most important injection parameters are:

- Screw temperature
- Injection speed
- Injection pressure
- Compaction pressure
- Mold temperature
- Cooling time

03. Injection Process-optimization

SCREW TEMPERATURE

Affects the plasticization of the material and the homogenization of the melt.

INJECTION SPEED

Maximum speed at which the melt enters the mold.

High speeds, short cycles, but material may degrade.

Too low speeds, incomplete filling of the mold.

INJECTION PRESSURE

Maximum pressure at which the mold is filled (pressurization stage).

Depends on temperature and injection speed.

Excessive pressure, parts with internal stresses.

Low pressure, incomplete filling of the mold or parts with shrinkage.

03. Injection Process-optimization

COMPACTION PRESSURE (2nd pressure)
Pressure maintained by the screw on the polymer already injected into the mold. Depends on the material, mold geometry and part size.
Excessive pressure, internal stresses in the part.
Insufficient value, leads to dimensional variations and shrinkage.

MOLD TEMPERATURE
It depends on the type of polymer used and the part thickness.
In semi-crystalline TP it determines its degree of crystallinity.
Low T influences the correct filling of the mold, it can produce layers, internal tensions, etc.
Excessive T greatly lengthens the cooling time and can cause deformations in the part during demolding.

COOLING TIME
Time the part remains in the mold before it is ejected. It depends directly on the T of the mold.
It should be sufficient for the part to reach dimensional stability but should be kept to a minimum so as not to lengthen the cycle time.
A very important element is the quality of the mold.

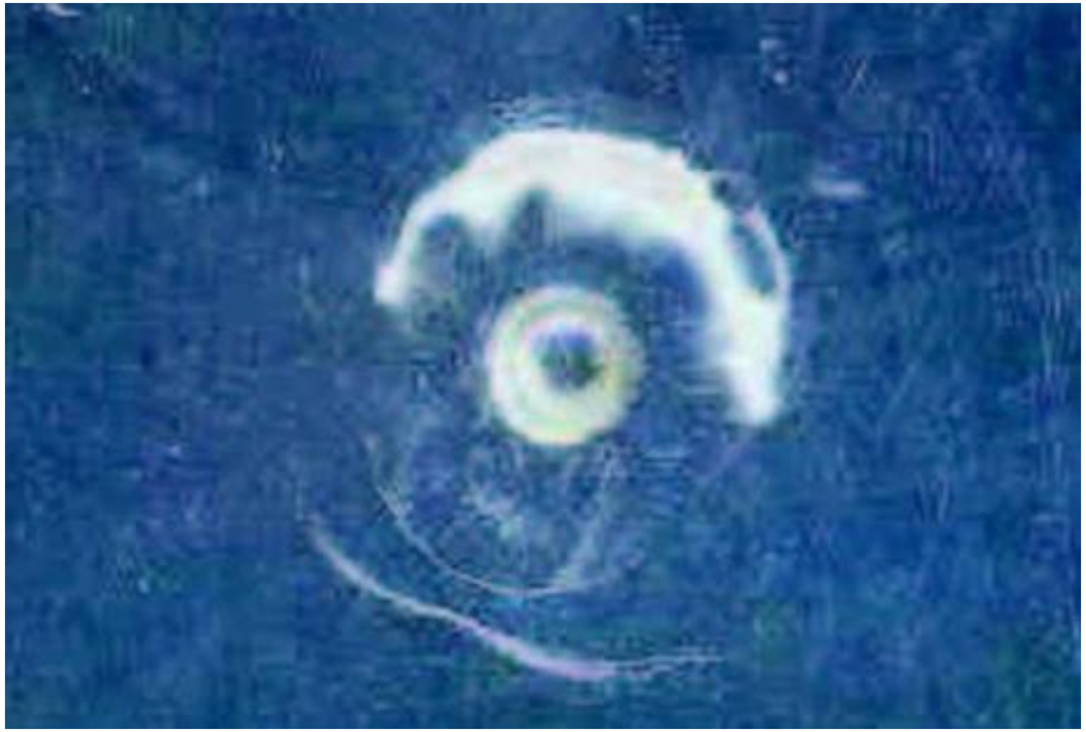
04. Injection Defects

1- Discolorations/cloudy surfaces
2- Brittle parts
3- Burn marks
4- Delamination
5- Dimensional stability
6- Ejector marks
7- Burrs
8- Non-uniform gloss
9- Parts warp or twist
10- Dieseling effect
11- Gas entrapment
12- Melt lines

04. Injection Defects

1. **Discolorations or cloudy surfaces near cavity entrances:**

Problem: Discolorations, turbidity, differences in brightness near the entrance to the cavities and in the direction of flow. These are due to expansion and contraction of the material as it passes through a small inlet and subsequent cooling.



Solutions:

- Reduce injection speed
- Increase material temperature, especially in the nozzle.
- Increase mold temperature
- Increase the size of the inlets

04. Injection Defects

2. Brittle parts:

Problem: decrease of mechanical properties in part of the part or heterogeneity in its mechanical properties.

Solutions:

- To dry the material well (if it is hygroscopic)
- To reduce the amount of recycled material
- To avoid thermal degradation (decrease temperatures and/or residence time in the spindle, decrease spindle speed, etc).

Design: increase wall thickness, include reinforcements, avoid abrupt corners, increase radii...

04. Injection Defects

3. Burn marks

<u>Problem:</u> generally dark spots appear on the part.

<u>Solutions</u>:

Discard contaminated material (clean machine).

Discard thermal degradation (decrease material temperature, injection speed, screw speed, check heating elements and thermocouples.

Avoid accumulated gases inside the mold by reducing the filling speed, increasing the number of air outlets in the mold, etc.

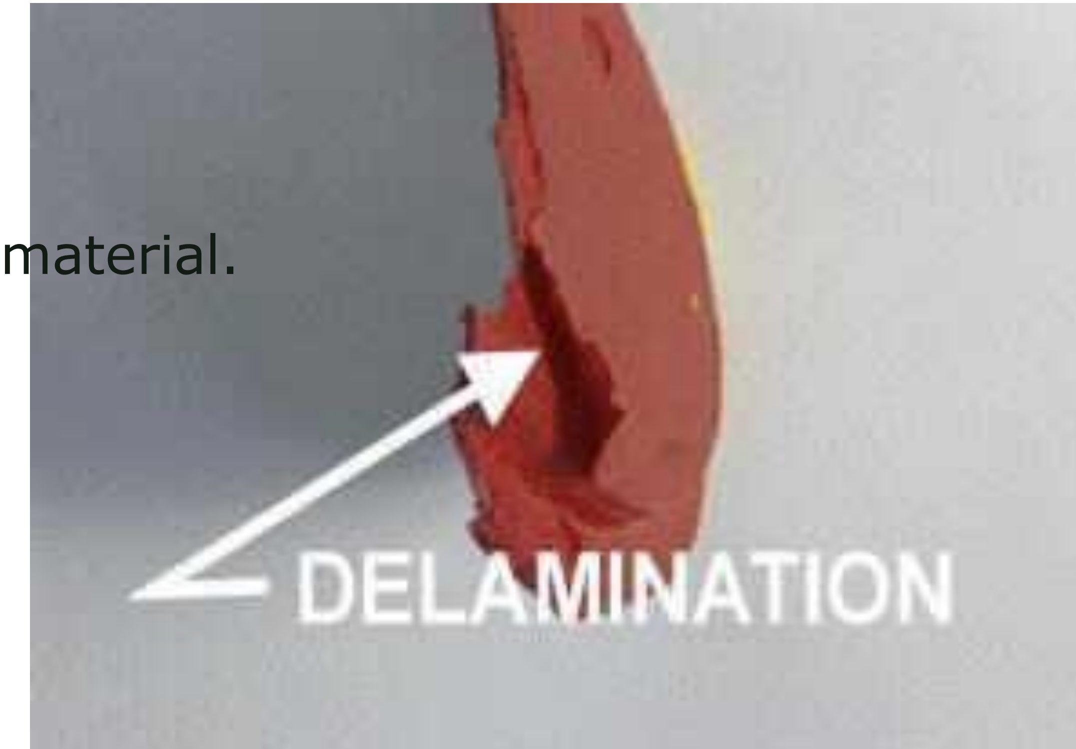
<u>Design</u>: increase the cavity inlet diameter, avoid roughness at the inlet (polishing).

04. Injection Defects

4. Delamination

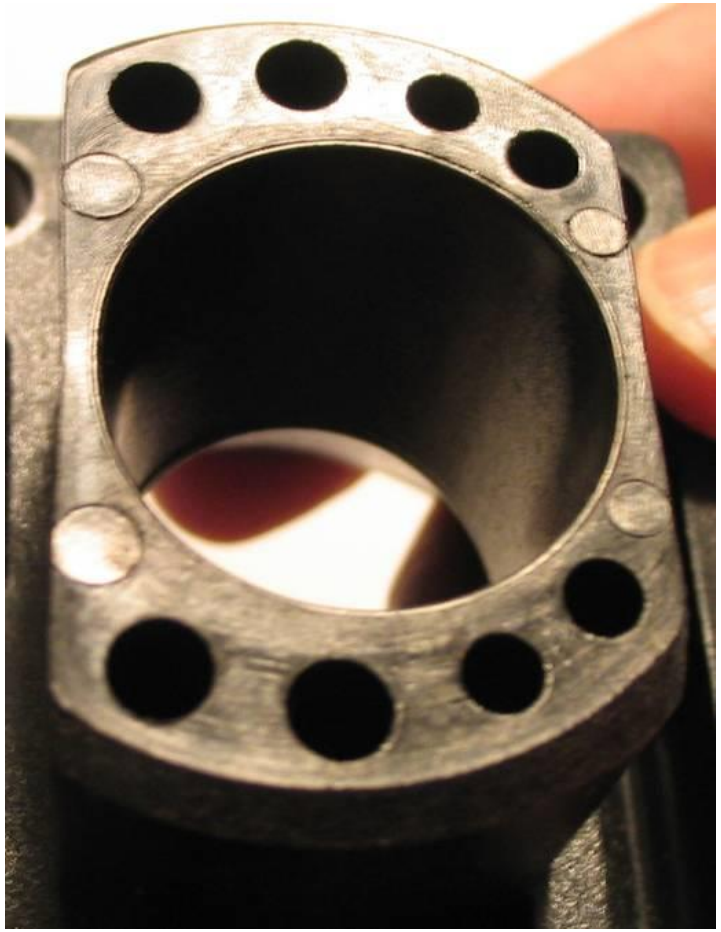
Problem:
The surface skin or surface layer separates from the rest of the part (pickling or peeling).

Solutions:
- Eliminate contaminations in the raw material
- Dry material properly
- Improve the melting and mixing process of the material.



04. Injection Defects

5. Dimensional stability

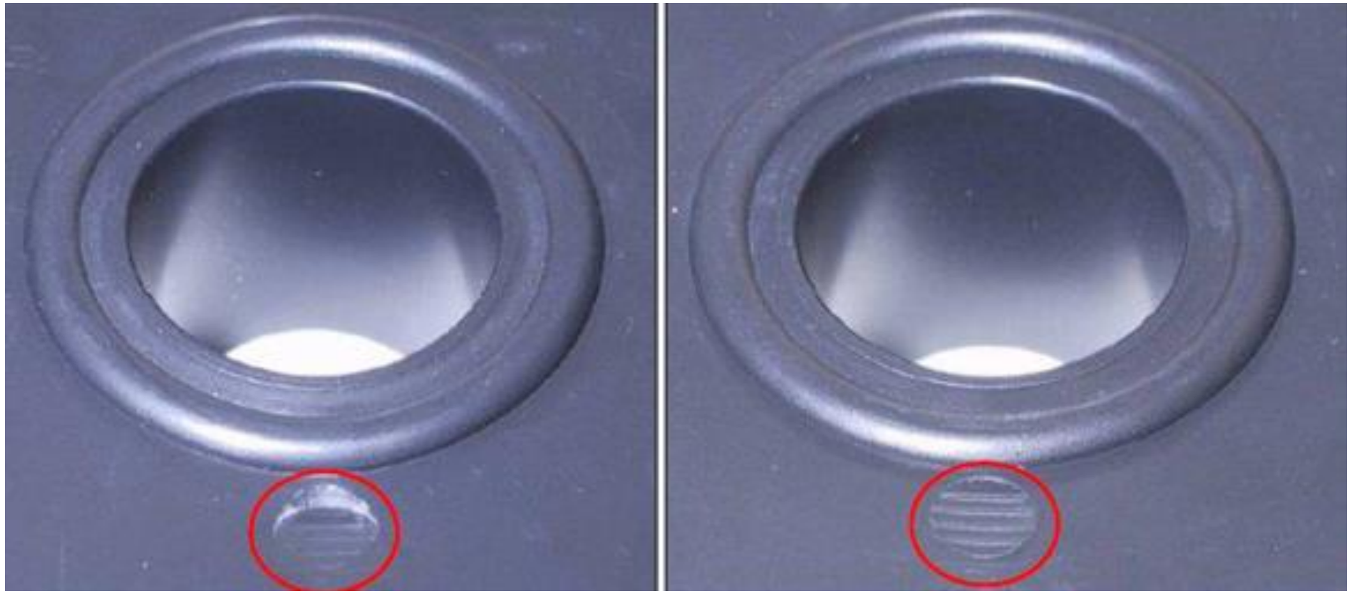


Problem:
The dimensions or weight of the part vary from cycle to cycle.
Irregular contractions.

Solutions:
- Check the wear of the injection molding machine.
- Optimize value and time of compaction pressure application.
- Increase nozzle diameter
- Control cooling speed on semi-crystalline TP to avoid unwanted shrinkage on excessively large parts.

04. Injection Defects

6. Ejector marks



Problem:
The ejectors deform the part and/or leave marks on the surface

Solutions:
Distribute the ejectors properly
Check that their length is identical
Allow the part to cool sufficiently before ejecting it (optimize cooling time and mold temperature)

04. Injection Defects

7. Burrs

Problem:

Excess of material coming out of the edges of the part because the mold does not have sufficient clamping force.

Solutions:

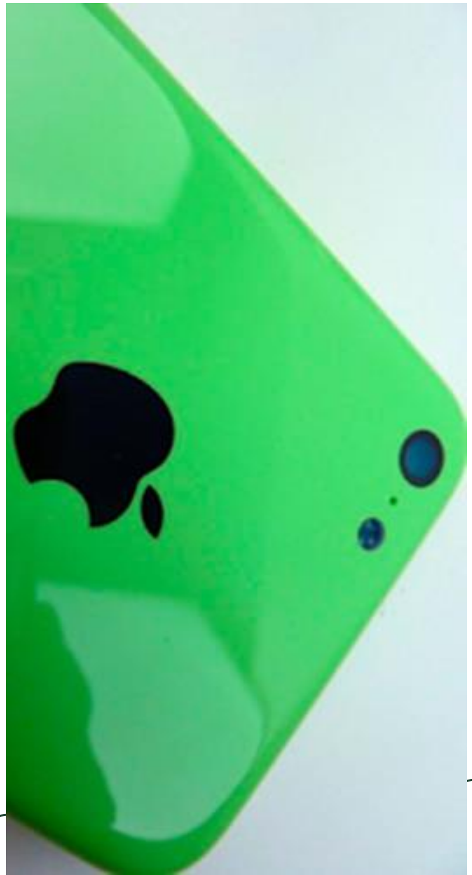
- Verify that the machine is suitable for the mold
- Reduce the mold ventilation zones
- Reduce dosage
- Increase material viscosity (lower temperatures)
- Increase diameter of inlets or polish appropriately

04. Injection Defects

8. Non-uniform gloss

Problem:

The surface of the part does not have the required brightness or is not uniform.
Brightness: amount of light that is reflected without scattering.



Solutions:

- Improve mold finish (polishing)
- Increase melt temperature
- Increase mold temperature
- Increase compaction pressure

04. Injection Defects

9. Rechupes

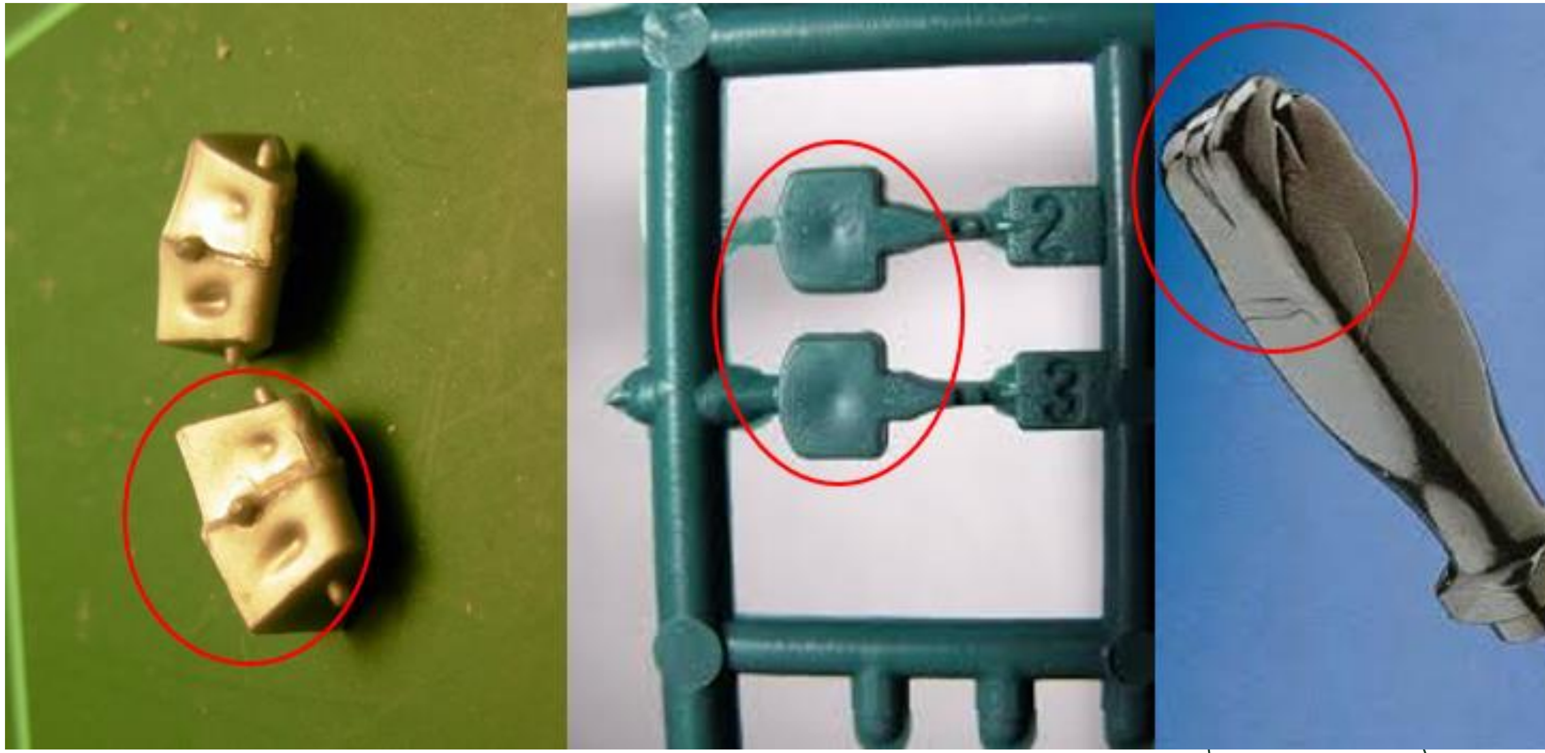
Problem:

Depressions or sinks in parts of the part caused by the inside of the part contracting more than the surface due to insufficient compaction and cooling time.

Solutions:

- Increase compaction pressure
- Decrease melt temperature
- Increase cooling time
- Increase injection speed
- Increase mold temperature

Design: To fill the thickest areas first and then the thinnest areas.



04. Injection Defects

9. Parts warp or twist

<u>Problem</u>:

Straight surfaces warp or the part twists once it is ejected from the machine or during its service life (overcompaction)

<u>Solutions</u>:

- Avoid over-compaction (adjust compaction pressure)
- Cool the part uniformly (redesign the mold cooling channels and increase the cooling time).
- Optimize the ejector phase (increase the number of ejectors and decrease the ejector pressure)

Design: uniform wall thickness

04. Injection Defects

10. Dieseling effect

The gas is compressed and its temperature is greatly increased, producing defects in the parts.

11. Gas entrapment

The air from the mold does not evacuate fast enough and is trapped inside the part.

Solution:

- Increase injection pressure and/or decrease injection speed.
- Increase mold vent outlets or reposition the cavity inlet.

12. Melt lines:

They occur when two material flow fronts are too cold and do not adhere properly.

Solution:

They can be reduced by increasing temperatures and injection speed and/or by conveniently positioning the inlets to the cavities