PACKALL

PackAlliance:
European alliance for innovation training & collaboration towards future packaging

Linking Academy to Industry.

Training program: modules

- New materials and biomaterials
- **Eco-design & novel manufacturing processing**
- Citizen and Consumer Engagement
- Residue management and valorisation

Co-funded by the Erasmus+ Programme of the European Union

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Course 1-Novel Manufacturing Processing for Packaging Systems (3 ECTS)

1. **PRODUCTION PROCESSES FOR FLEXIBLE PLASTIC PACKAGING (0.6 ETCS)**

1.1. Basis of extrusion processes

1.1.1 Extrusion process: description and equipment

1.1.2 Single screw extrusion process analysis

1.2. Industrial processes for the production of flexible packaging

1.2.2. Cast film extrusion

Description of the process
Different types of cast film heads and dies
The coat hanger die
Processing parameters: Draw ratio, Chill roll temperature, Die to chill roll distance

1.2.1. Film blowing

Processing parameters for the film blowing process
Draw ratio and blow up ratio
Frost line height

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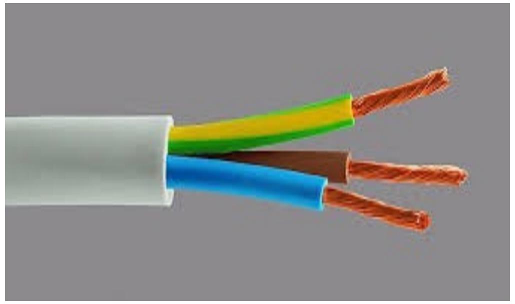
EXTRUSION PROCESS

Extrusion process represents the **most important polymer processing operation**. It is a **continuous process** that allows to obtain objects of constant section, possibly even of complex geometry, and of great length, such as tubes, films, rods, fiber, etc.



It consists in the continuous **conversion of a solid granular polymer into a highly viscous fluid,** which is subsequently pressurized in order to determine its passage through a die which has the function of **forming the molten material**.

This process is performed by an **EXTRUDER** which is the basic apparatus in the processing industry of polymeric thermoplastic materials.

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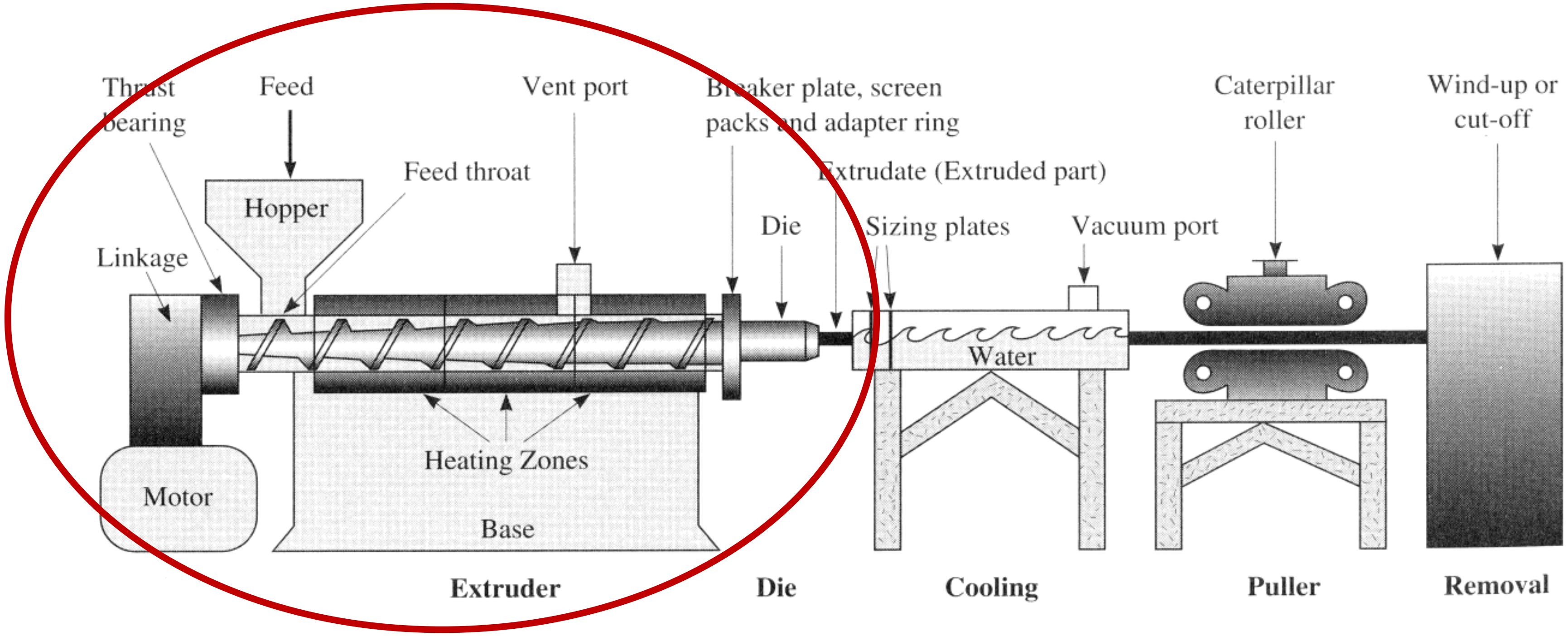
SCHEME OF AN EXTRUSION LINE WITH COOLING AND PULLER SYSTEMS

The extrusion of polymeric materials to produce finished products for industrial or consumer applications is an integrated process, with the **EXTRUDER** representing the fundamental component of the entire line.



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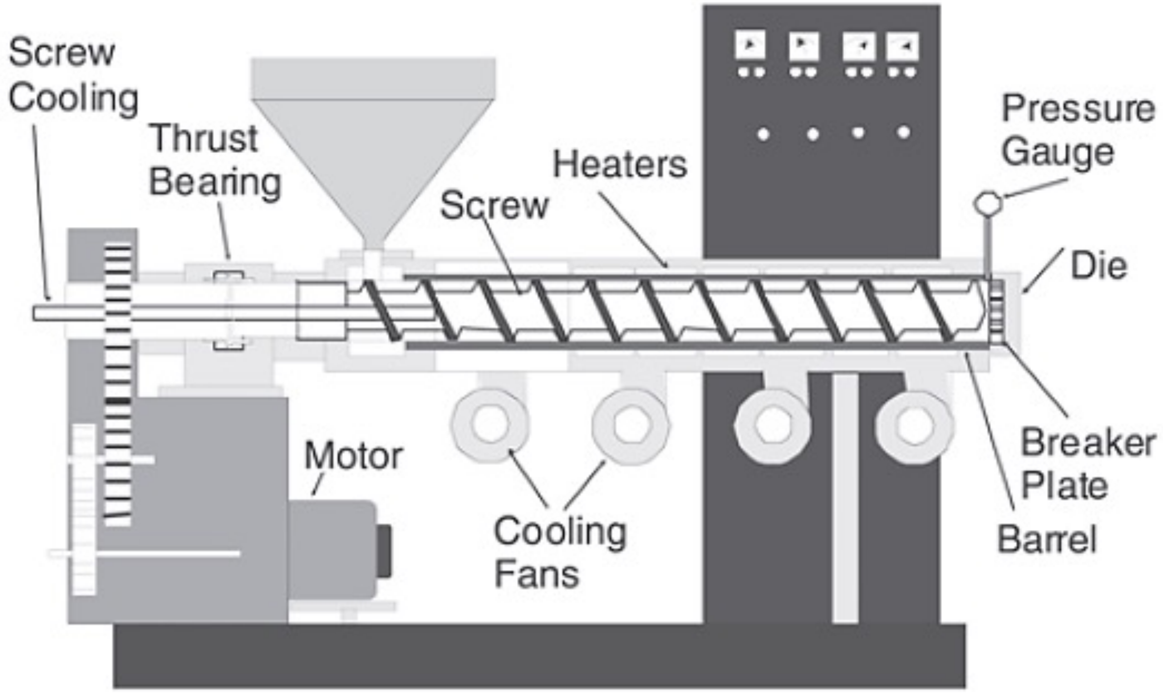
SINGLE SCREW EXTRUDER

The extruder is essentially a **PUMP** that is designed to **MELT, CONVEY** and **PRESSURIZE** fluids with high viscosity.



A standard extruder, that is a **SINGLE SCREW EXTRUDER,** is composed by a heated cylinder, called **barrel**, where a **screw** is allowed to rotate.

The barrel is usually heated by electrical heaters, so providing the thermal power needed for the melting of the material that is fed to the machine in the form of granules or powders by means of a **feeding hopper**.

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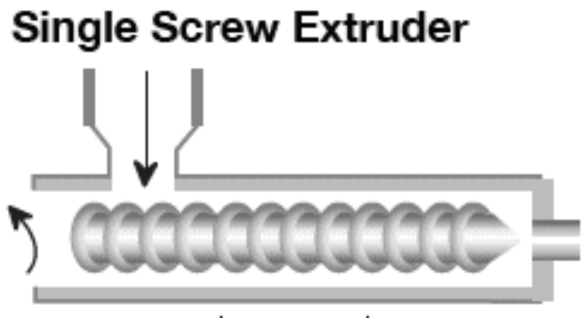
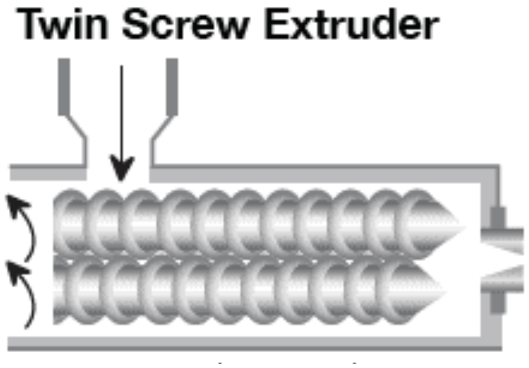
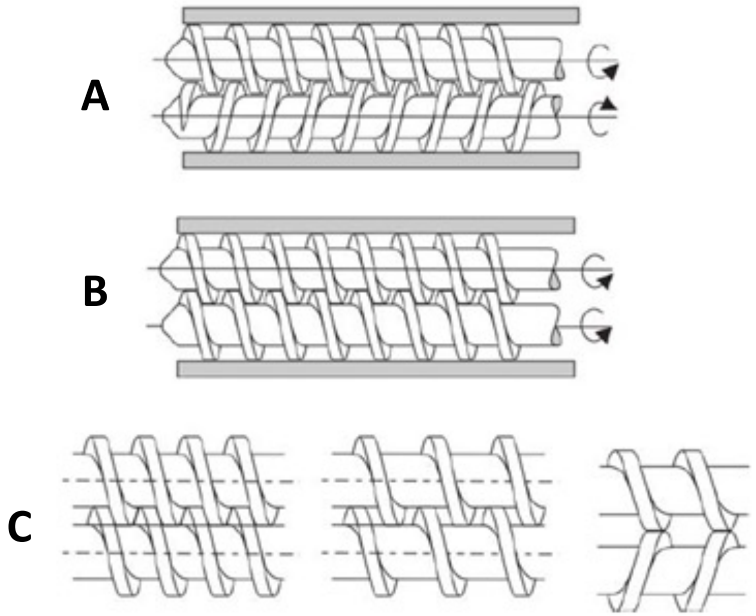
EXTRUDER TYPES







TWIN SCREW EXTRUDERS:

- have two parallel screws rotating in a barrel whose cross section is shaped in such a way to allow, on a certain extent, the interaction of the screws (**intermeshing** and **non-intermeshing** extruders);
- can be classified in **co-rotating** and **counter-rotating** machines on the basis of the direction of rotation of screws;
- show **higher mixing effect** and a **better control of the residence time** for the processed materials respect to single screw extruders.

A. Counter-rotating

B. Co-rotating

C. Degree of screw intermeshing

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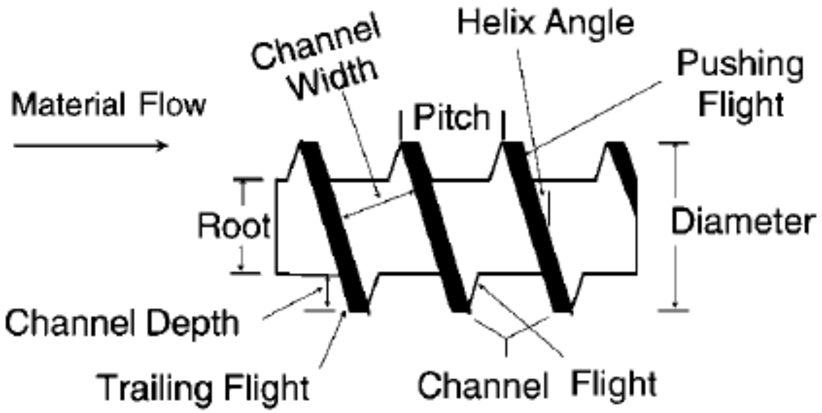
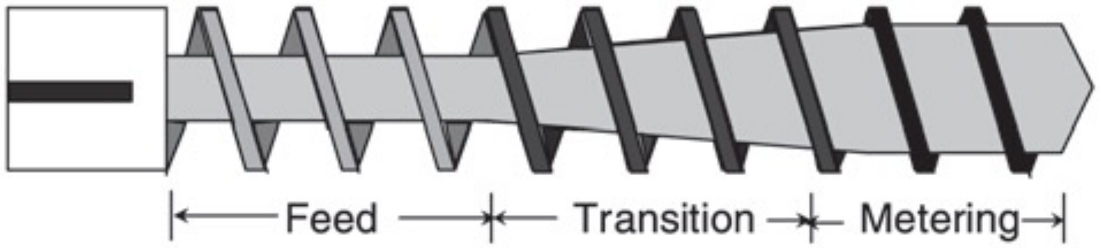
SCREW GEOMETRY



Usually the **screw length L** is related to the screw diameter D by the **ratio L/D**. This ratio allows to express the screw length in terms of a certain number of diameters.



The geometry, along a standard extruder screw profile, allows to identify usually three different sections:

a) feed

b) transition

c) metering

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OPERATIVE ZONES IN SINGLE SCREW EXTRUDER

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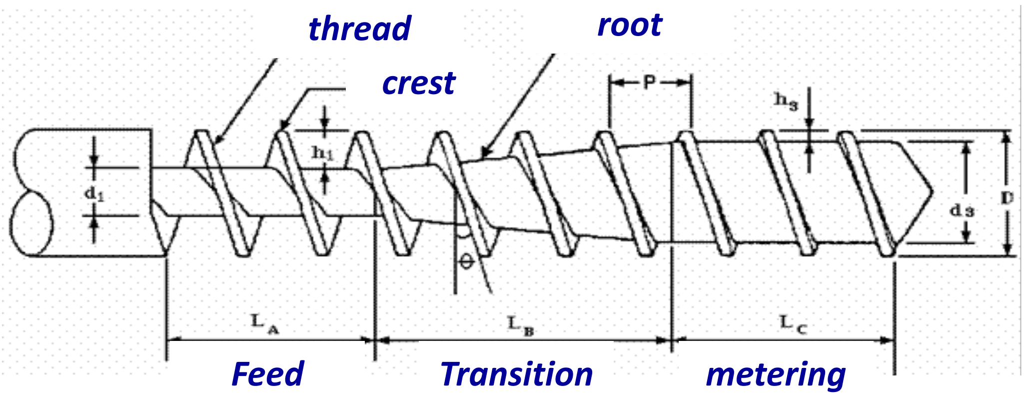
… based on GEOMETRIC CHARACTERISTICS OF THE SCREW



- In the **feeding zone,** the channel depth is high and constant, in order to easily transport and compact the solid polymer

- In the **transition zone** the channel depth decreases along the material flow direction, in order to promote polymer pressurization. The ratio of the cross sections at the beginning and the end of this area is called **Compression Ratio (CR)** of the screw.

$$RC = \frac{(D - h_1)h_1}{(D - h_3)h_3}$$

- In the **metering zone**, the height of the threads is constant while the screw root diameter is maximum, in order to mix and pressurize the melt to cross the die.

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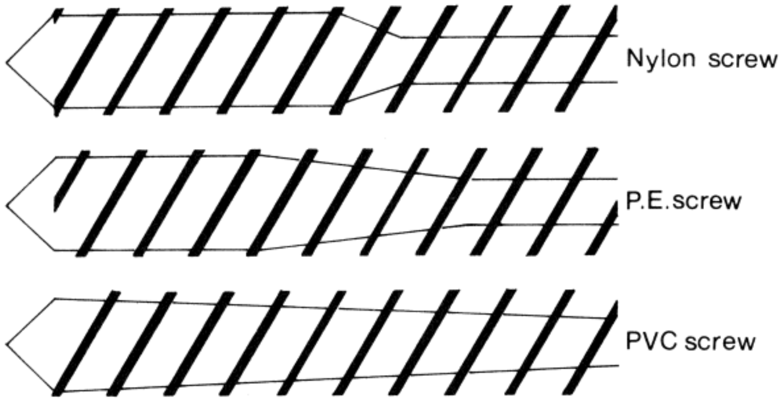
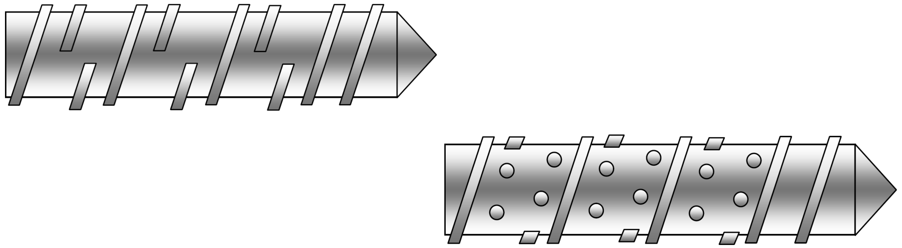
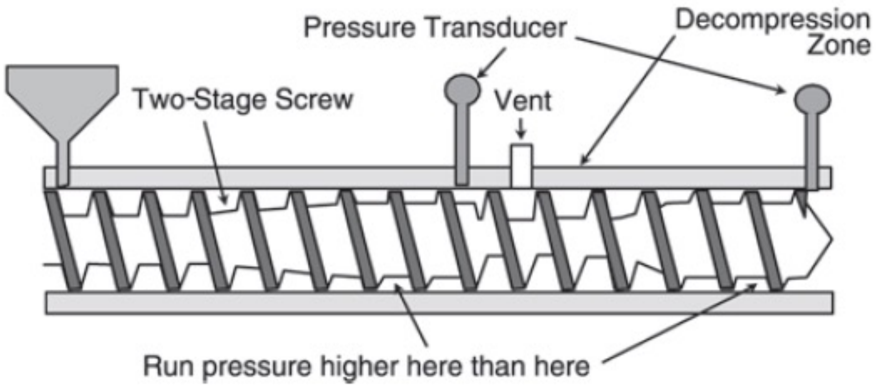
SCREW DESIGN



In the case of **amorphous polymers** (PVC) that gradually soften, the transition zone occupies almost the entire screw, while in the case of **polymers that melt rapidly** (nylon), this zone is shorter.



Some particular screw, the so-called **barrier screws** are designed to maximize both the melting effect and the homogenization of the melt stream in front of the barrier flights.



A **two-stage screw** in a vented extruder is used to remove volatiles and/or moisture from polymers.

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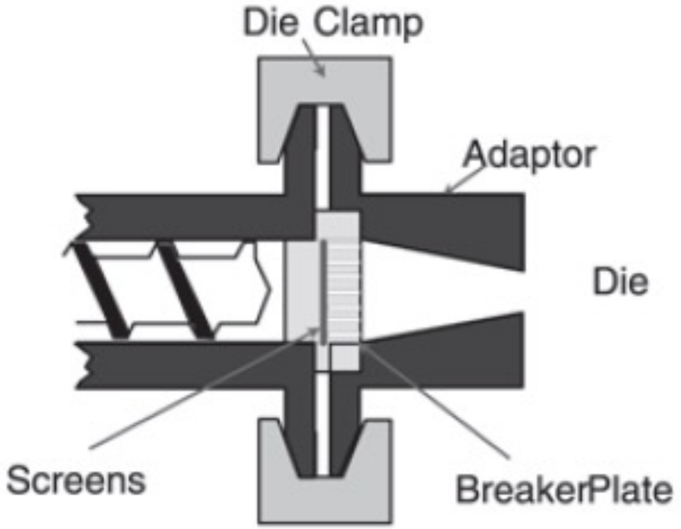
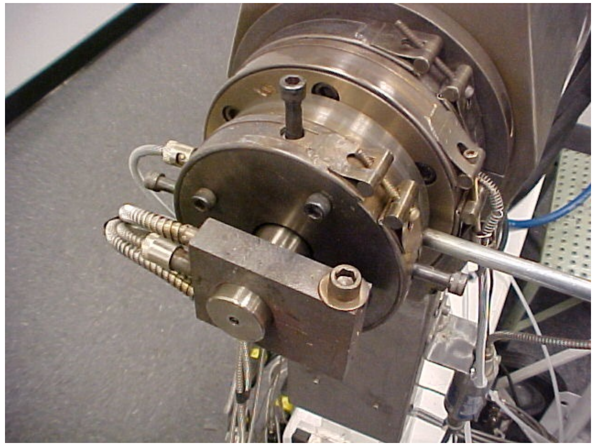
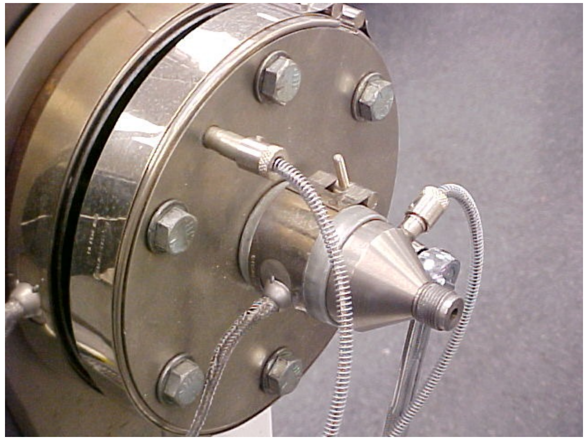
EXTRUDER HEAD ASSEMBLY

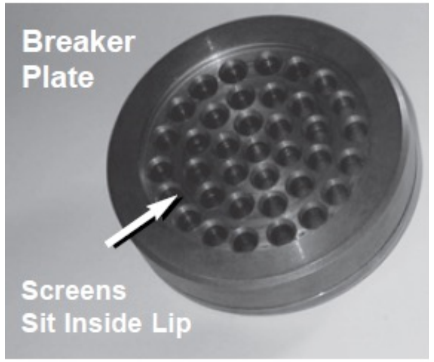






The extruder head assembly includes:

- **breaker plate**
- **adapter**
- **die**



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SINGLE SCREW EXTRUDER: functional zones

The description of a standard extrusion process can be related to the functional zones of the apparatus. Such zones correspond to the physical characteristics that the polymer takes over its motion from the hopper to the extrusion die of the system.

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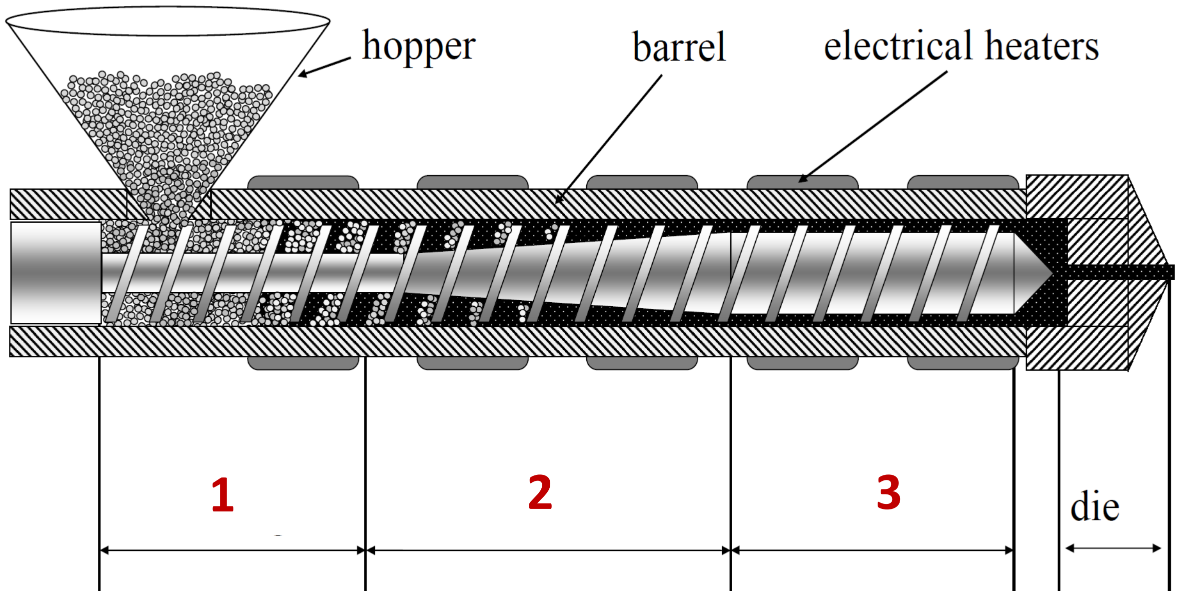
These functional zones are normally referred as:

1. **solids conveying zone**
2. **plasticizing or melting zone**
3. **melt conveying zone**



The **extruder screw** has to be designed with the **proper geometrical characteristics** which should promote the above mentioned processes.

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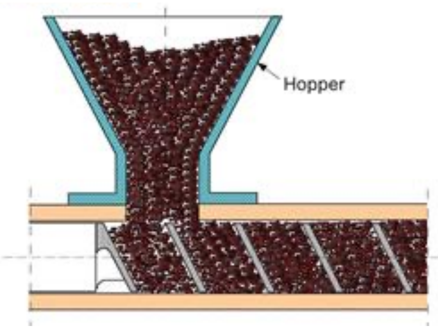
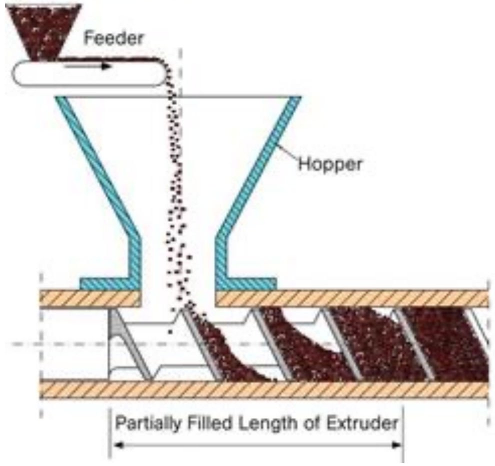
POLYMER FEEDING and SOLID CONVEYING ZONE

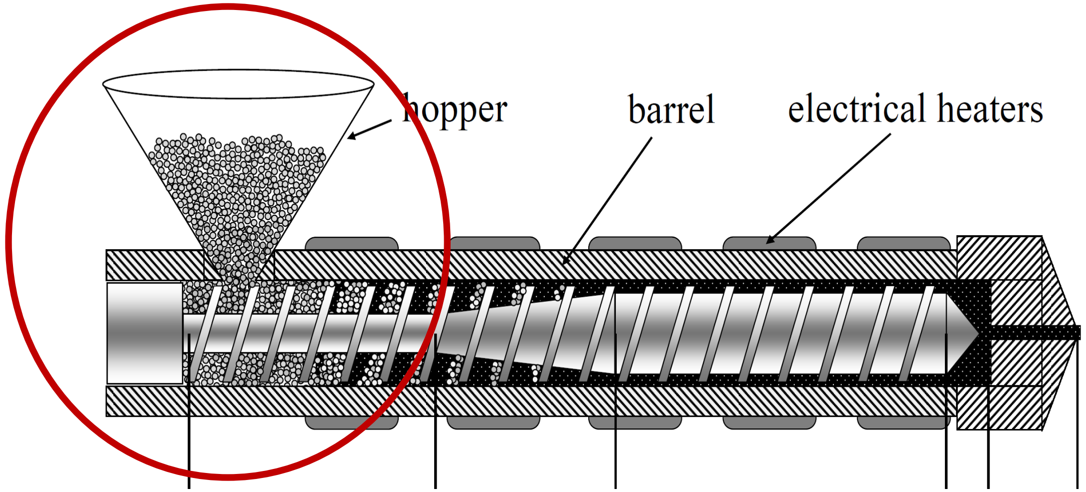
The feeding of an extruder can be performed in two ways:



"**flood feeding**" consists in the gravity flow of the polymer pellets from a hopper



"**starve**" or "**metered feeding**" is carried out by making use of gravimetric or volumetric devices which accurately control the amount of granulated solids delivered to the extruder in the feeding section.



To optimize the flow rate in this section, it is necessary to maximize the friction between the polymer and the barrel and minimize the polymer-screw friction force, so the material turns at a speed lower than that of the screw and is pushed forward the die.

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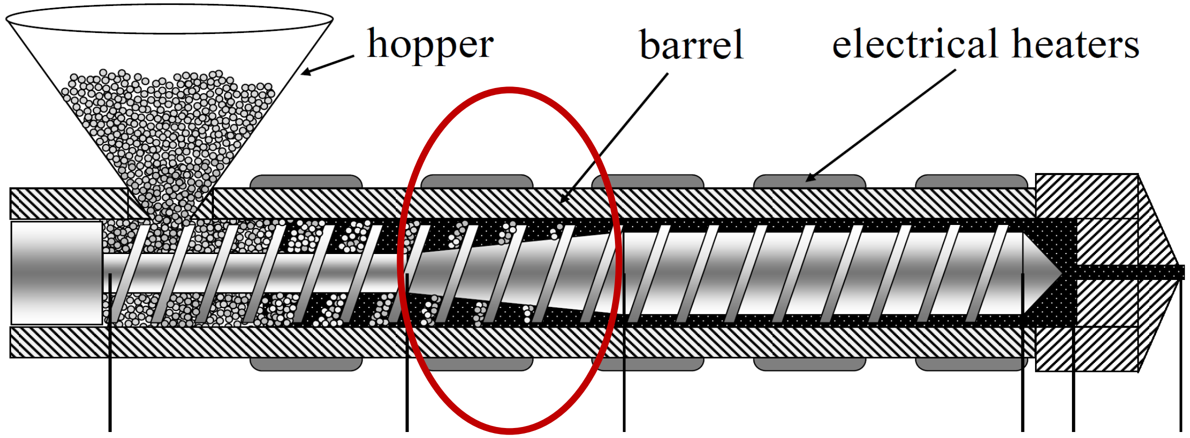
MELTING ZONE



- The melting zone starts in the point where the polymer begin to form a melted film at the barrel surface and extends to the point where all the material, which is located in the screw channel, is melted.
- In this section the screw has to accomplish the conveying of solid pellets, their complete melting, in as short as possible length, and has to transport the polymer ahead against a pressure gradient.
- The **raise in temperature**, that determine the polymer melting, is due both to heat transport from barrel (which is normally electrically heated) and to **frictional heat generation**.

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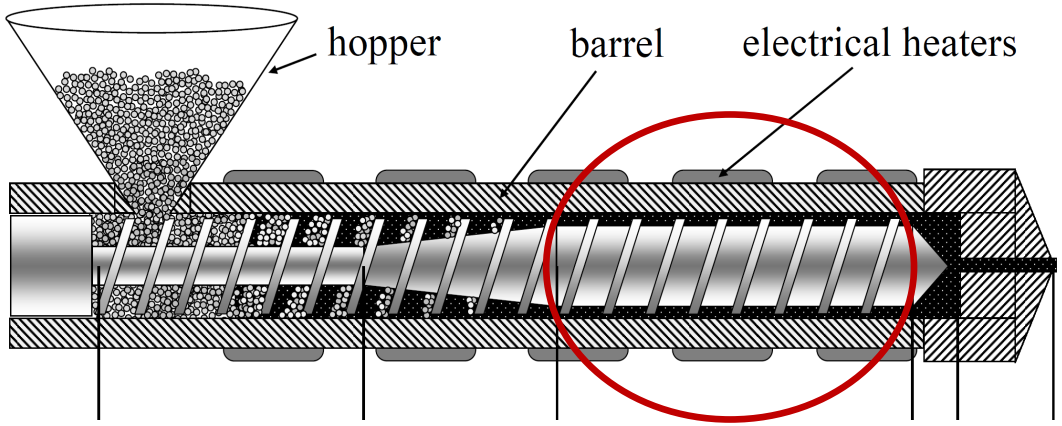
MELT CONVEYING ZONE



- The **POLYMER RHEOLOGY** plays a key role in this zone.
- The analysis of this zone is important in order to determine the **relationships** between:
  - the **melt flow rate**
  - the **process conditions**
  - the **geometric characteristics of the screw**
- In this zone the polymeric melt (high viscosity fluid) have to be **transported** and **pressurized** so it can pass through the extrusion head that exerts a resistance to flow.

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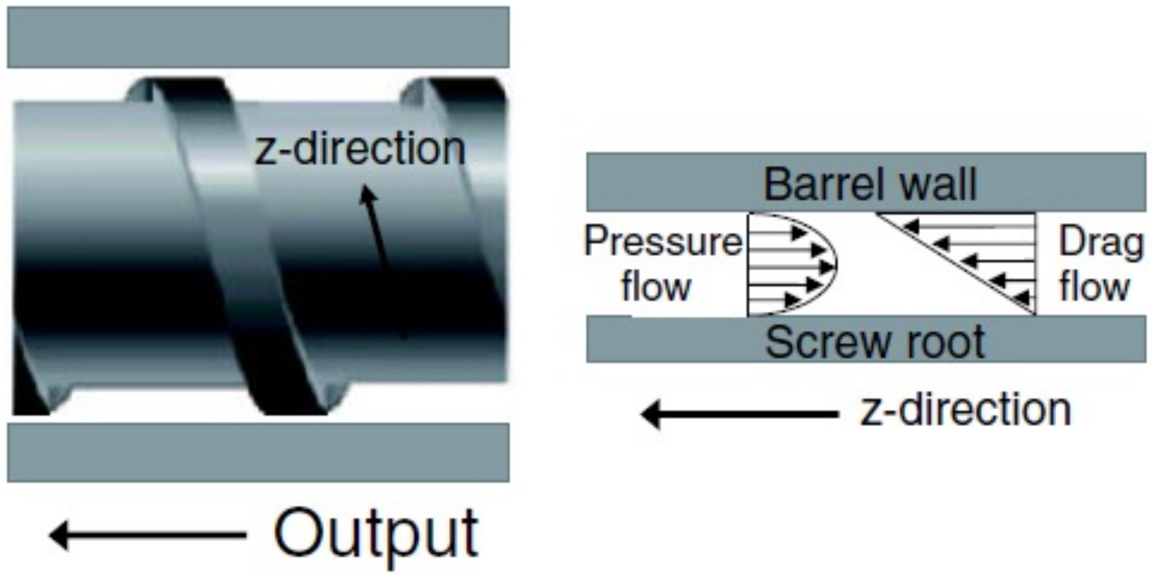
MELT CONVEYING ZONE

For the analysis of this zone it should be considered that **the screw always works coupled to a die.**

The **net flow rate** q that comes out of the extruder is given by the difference between the **drag flow rate** q_d and the **back pressure flow rate** q_p due to the presence of the pressure gradient:

$$q=q_d-q_p$$



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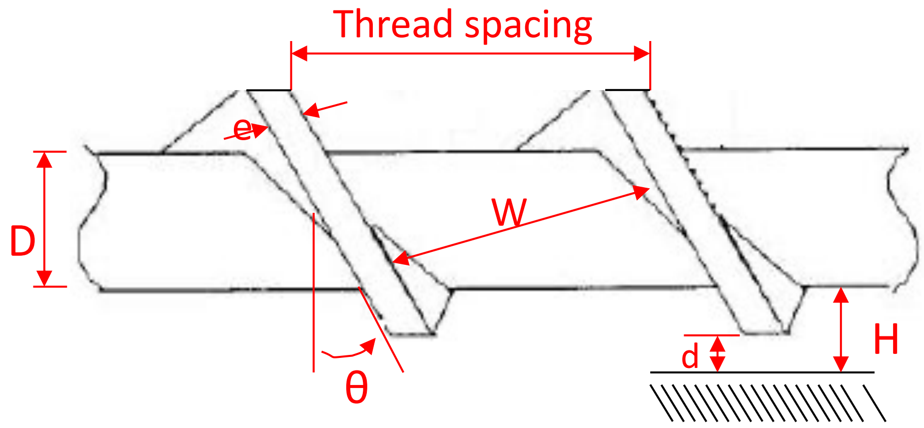
SCREW FLOW RATE

HYPOTHESIS FOR THE FLOW ANALYSIS:

- incompressible and Newtonian fluid
- isothermal and steady flow
- negligible leakage flow
- negligible gravitational and inertial forces



H << W
H << D
H > d

$$Q = Q_D - Q_P$$

$$Q_D = \frac{wH}{2}\pi D_b N \cos\theta$$

Drag Flow rate:
it depends on the screw speed (N)

$$Q_P = \frac{wH^3}{12\eta}\frac{\Delta P}{z}$$

Pressure Flow rate:
It depends on the polymer viscosity (η)

Collecting all the geometric factors (**A** and **B** are a **function of the extruder design parameters)** we have:

$$Q = AN - \frac{B\Delta P}{\eta}$$

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PARAMETERS TO CHECK IN EXTRUSION

Optimizing a particular extrusion operation depends on both **design parameters of the equipment** and **processing conditions**

- Extruder type—single or twin screw
- Extruder size—small or large
- Particular screw design being used
- Die design
- Throughput rate
- Downstream process
- Resin type and formulation
- Additives in the resin

Besides the processing conditions and equipment design parameters, an **understanding of the materials** and their transformation in each step is necessary.

- What is the formulation rheology and how does it change with temperature and shear?
- What are the proper drying conditions?
- How does moisture affect properties?
- What is the proper melt temperature?
- What is the material shrinkage?
- Is the polymer crystalline or amorphous?
- What are the cooling requirements (material Tg or Tm)?

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