KraussMaffei
Pioneering Plastics

How to configure your twin screw extruder for compounding

Polymer & Additives Academy 2024

Massimo Ricci | 9 May 2024

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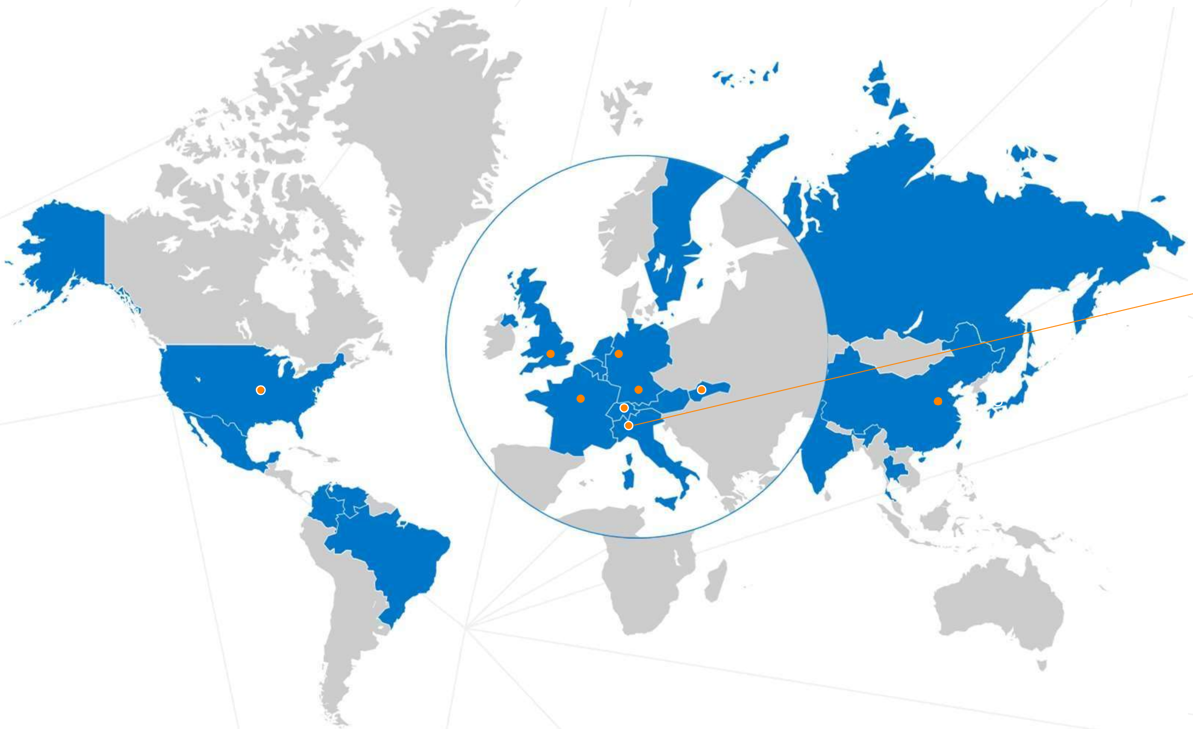


KraussMaffei
Pioneering Plastics

KMGI
Arese (Milan)
Italy

Expertise in all fields of plastics production and extrusion process

Application overview

APPLICATIONS | **TECHNOLOGIES**

Know-how di processo e supporto per tutta la gamma di prodotti

Shaped products

- PO pipes (poliolefine)
- PVC pipes
- PVC profiles
- Hybrid profiles

Compounding

- Compounding
- Extrusion and granulation of PVC

Flat & Foam products

- Film/Foil/Sheets
- Sheet, boards and beads espanded

Tire & Rubber products

- Rubber sheets
- Tyre rubber
- Pipe & profiles in rubber

Melt to Pellet

- Polymerization
  (LDPE, EVA, POE, Degassing)

Circular economy

- Re-/Up-cycling

Agenda

1. What is an extruder
2. Different kinds of extruders
3. The extrusion process
4. The co-rotating twin screw extruder
5. Compounding
6. Configure your barrel
7. Configure your screw
8. Choose the die head
9. Process parameters and residence time
10. Conclusions

What is an extruder ?

definitions

Extruder (latin : extrudere)

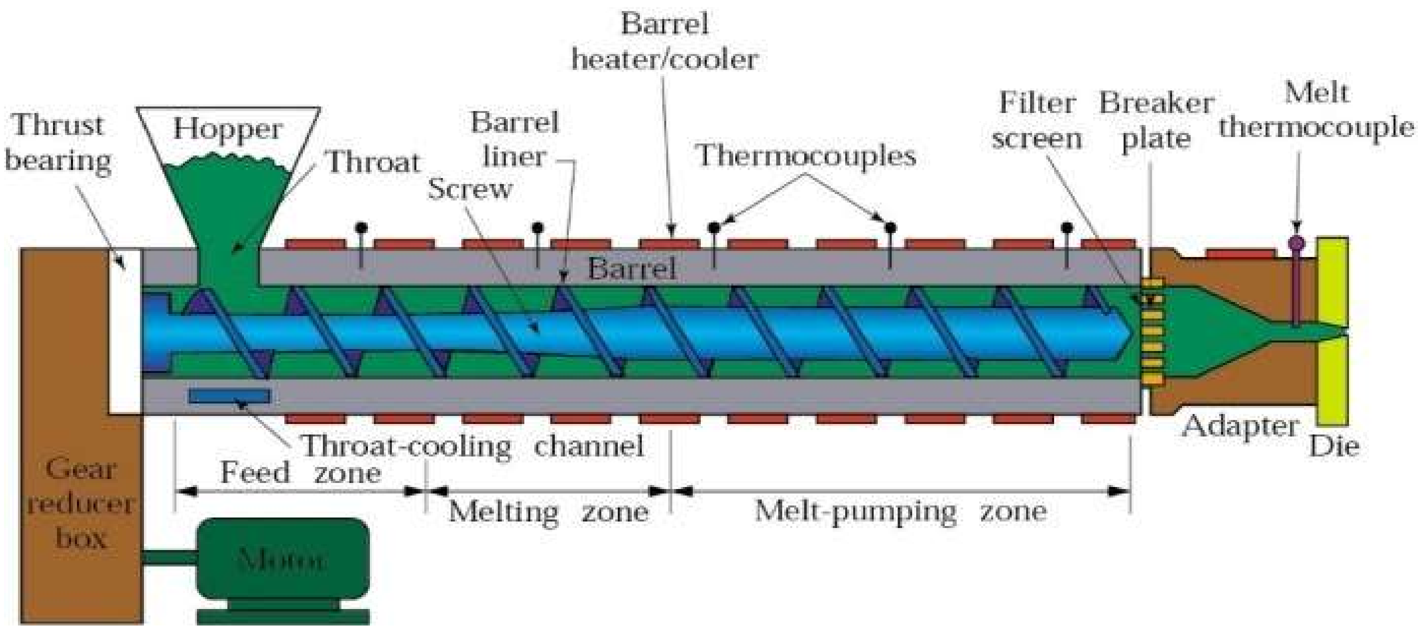
/ ik-ˈstrü-dər /

The **extruder** is a machine used above all in the plastics industry, which allows to obtain extrusions, i.e. shapes with a constant section predetermined by the shape of the die and with a length determined by the cutting interval.

What is an extruder ?
definitions

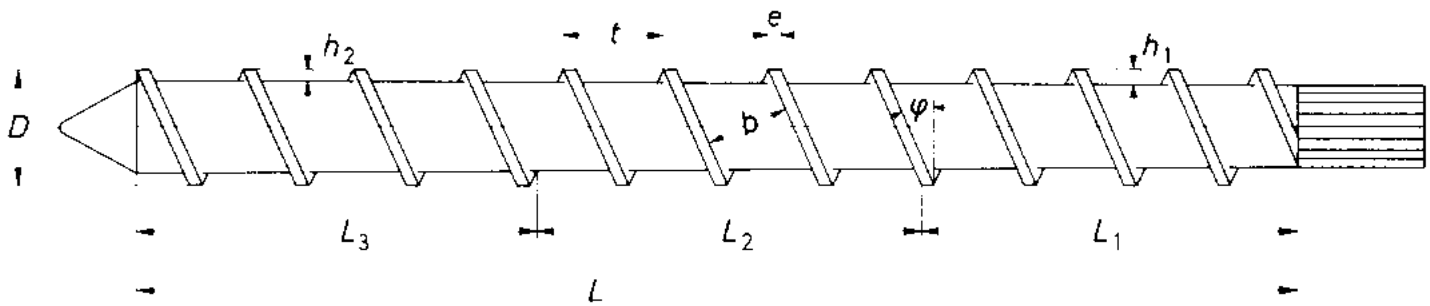
What is an extruder ?

definitions



What is an extruder ?

The screw is the heart of the extruder



- L = length
- D = diameter
- Da = outer diameter
- Di = internal diameter
- L/D = length / diameter ratio

- h = flight depth
- t = pitch
- e = width of flight land
- b = width of flight

The extrusion process

definitions

- The **extrusion process** consists in bringing a material to a fluid state and transporting it to pass continuously through a nozzle where it assumes the desired shape
- The materials (polymers anD others) in the form of pellets or powder or flakes, are gravity fed into the hopper of the **extruder** and drops on a rotating screw/s
- Screw rotation is provided by an electric motor. The screw design varies and is dependent on the material and final product design. **The rotation of the screw forces the plastic forward through a heated barrel**.

The extrusion process

definitions

- The plastic melt temperature is normally higher than the set temperature.
  This **additional heat** is generated through a combination
  of compressive force and **shear friction** (shear heat).

- When the plastic melt reaches the end of the screw the plastic melt
  is well mixed and pushed through through the die.
  The **die** gives the final product the desired profile and shape.

- After exiting the extruder the product is pulled and cooled.
  The cooling method is dependent on the profile and shape of extrudate.

The extrusion process

definitions

Depending on the die shape, different products can be formed using various available extrusion processes listed below:

Pipe Extrusion

This extrusion type is used for the **extrusion of tubes and pipes**. In this process, air with positive internal pressure may also be applied. The tubes or pipes after exiting the die are pulled into a cooling tank were they are normally water-cooled.

Blow Film Extrusion

This type is used for the **production of plastic films** tubes through a continuous sheeting. In this process the film tube melt is cooled before leaving the die, producing a semi-solid tube and blown to expand to a desired size and film thickness. This process is used for manufacturing of products such as shopping bags.

The extrusion process

definitions

Sheet Extrusion

This type is used for the **extrusion of plastic sheets** or films that are too thick to be blown. After exiting the die, the sheets are pulled and cooled through a series of cooling rolls, which also regulate the sheet thickness.

Co-extrusion

Coextrusion is a process in which **two or more polymer materials are extruded together** to produce different multilayer structures

Extrusion for compounding

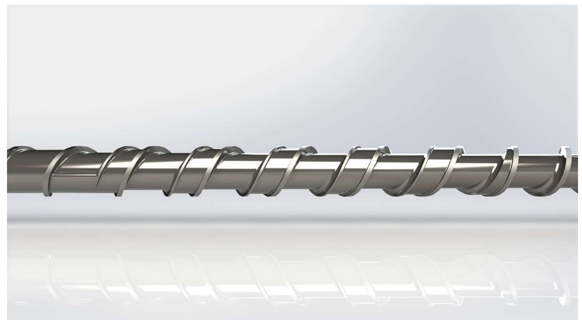
Compounding extrusion is a process **that mixes one or more polymers with additives** to give plastic compounds. The feeds may be pellets, powder and/or liquids, but the product is usually in pellet form, to be used in other plastic-forming processes such as extrusion and injection molding

… others : Hot Melt Extrusion for pharma application, reactive extrusion …

Different kind of extruders

definitions

- ❖ Single screw
- ❖ Conical twin screw
- ❖ Counter-rotating twin screw
- ❖ **Co-rotating twin screw**



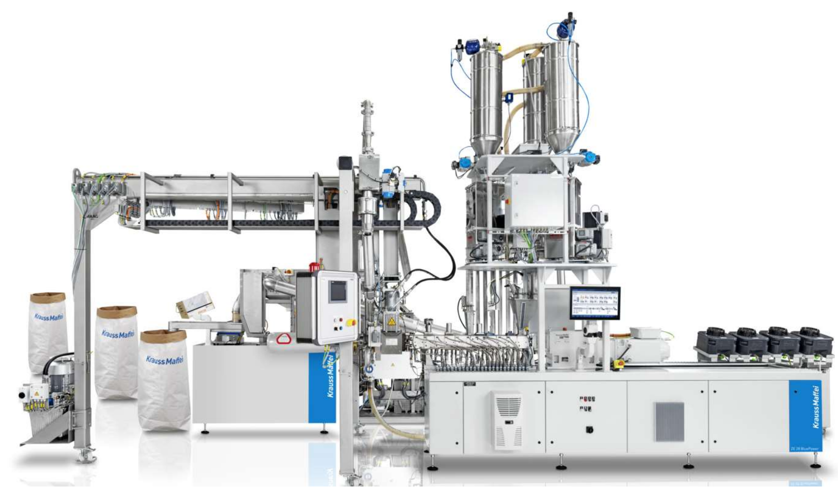
- ❖ Co-kneader (patented)
- ❖ Ring-extruder (patented)

Co-rotating twin screw extruder

Ideal technology for compounding

The co-rotating twin screw technology is generally used to :

- **create an intermediate pellet** for the later injection moulding step :



Co-rotating twin screw extruder

Ideal technology for compounding

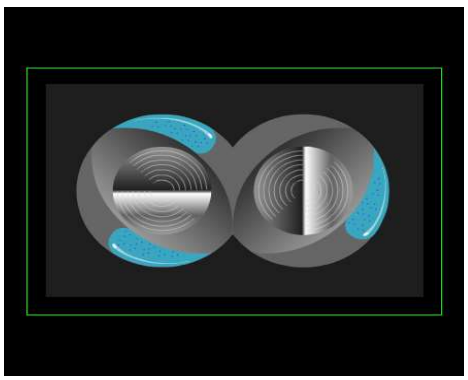
The co-rotating twin screw technology is generally used to :

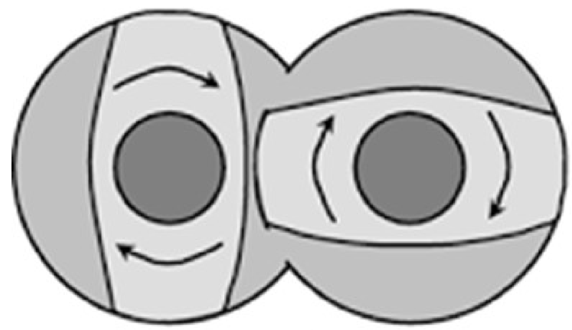
❖ **bypass the pelletizing** step and go directly to the **direct extrusion** of a manufact :

Co-rotating twin screw extruder (TSE)

definitions

The **co-rotating twin-screw extruder** is made up of **two identical** screws that rotate in the same direction with the same thread: these **are two intermeshing single** screws placed side by side in the same cylinder, where the shear forces due to friction are caused by the interaction between the screw and the cylinder.





Intermeshing occurs when the thread profile of one of the two screws penetrates the profile of the channel of the second and vice-versa: in practice when **the thread of one screw touches the core of the other** and vice versa.

Co-rotating twin screw extruder

definitions

The intermeshing screws are also **self-cleaning**, because the tolerance between the two screws is very narrow: this results in a **better removal of polymer** from one screw to the other and consequently leads to self-cleaning

Compounding

What is compounding ?

The co-rotating twin screw technology is the **prevalent technology** used for compounding

- **Compounding is a process that mixes one or more polymers with additives or fillers**

- The feeds may be pellets, powder and/or liquids, but the product is usually in pellet form, to be used in other plastic-forming processes such as extrusion and injection molding.

- Polymers (aka as carrier or resin) are progressive substitutes for metal and wood, but their relatively poor performance regarding strength and stiffness, limits their ability to compete in many applications

Properties are given to the polymer !

Polymers in compounding

All thermoplastics materials

Standard Thermoplastics

- Low-density polyethylene (LDPE)
- Linear low-density polyethylene (LLDPE)
- High-density polyethylene (HDPE)
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinylchloride (PVC)
- Polyethyleneterephtalate (PET)

High-Performance Polymers

- Polyetheretherketone (PEEK)
- Polyphenylenoxide (PPO)
- Polysulfone (PSU)
- Fluorpolymers
- Polyimide (PI)
- Liquid crystal polymers (LCP)

Engineering Plastics

- Styrene Acrylonitrile (SAN)
- Acrylonitrile-Butadiene-Styrene (ABS)
- Polyamide (PA 6, PA6.6, PA 12)
- Polybutyleneterephtalate (PBT)
- Polycarbonate (PC)
- Polymethyl methacrylate (PMMA)
- Polyoxymethylene (POM)

Other Materials

- Thermoplastic elastomers (TP,- S, -V, -U)
- Elastomers, e.g. SBR, EPDM, silicon rubber
- Thermosets
- Flooring compounds
- Powder coatings, photocopy powders
- Ceramics and catalyst compounds
- Pharmaceuticals and foodstuffs

Additives or fillers in compounding

Great variety of materials

Reinforcements (abrasive)

- Glass Fibres
- Graphite Fibres
- Carbon Fibres
- Boron Fibres
- Whiskers
- Basal Fibres
- Titanium Fibres
- Synthetic Fibres
- Glass Beads
- Polymeric Hollow Beads

Fillers (abrasive)

- Calciumcarbonate
- Kaolin
- Wood Flour
- Wollastonite
- Barium Sulphate
- Silica
- Carbon Black
- Mica
- Talcum
- Metallic oxide/ metallic powder

Reactive Additives (abrasive+corrosive)

- Antioxidants
- Heat / UV Stabilizers
- Plasticizer
- Process Aids
- Color Pigments
- Static Inhibitors
- Microbicidal Additives
- Blowing Agents
- Primer
- Peroxide / Silane
- Flame Retardants

How to set up your twin screw extruder

3 + 1 steps

Step 1 → **CONFIGURE YOUR BARREL**

Step 2 → **CONFIGURE YOUR SCREW**

Step 3 → **CHOOSE THE DIE HEAD**

Step 4 → **SET-UP THE PARAMETERS – PROCESS CONDITIONS**

Step 1 : configure your barrel

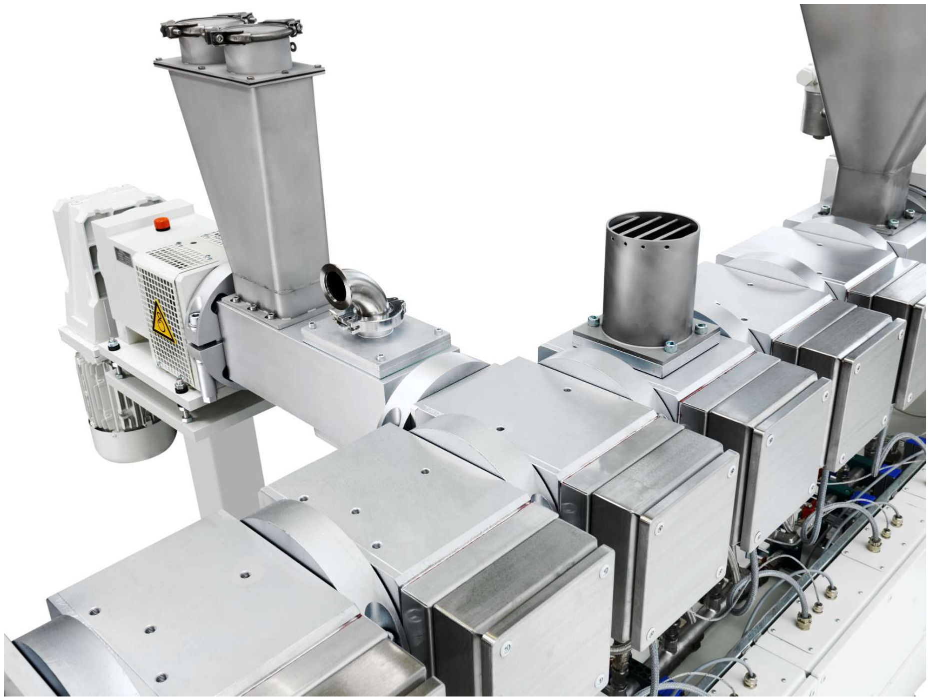
xxxxxxxxxxxxxx

Viewing the twin-screw extruder as a series of unit operations, the process engineer has the opportunity to address:

- Solids conveying;
- Melting of polymers;
- Customizable mixing of additives into the melt;
- Liquid injection;
- Downstream addition of additives;
- Venting (atmospheric and vacuum);
- Pumping;
- Heat Transfer;
- Chemical reaction, in the case of reactive extrusion.

Step 1 : configure your barrel

Design and modularity



The barrel sectors are flanged to each other by means of bolts or c-clamps

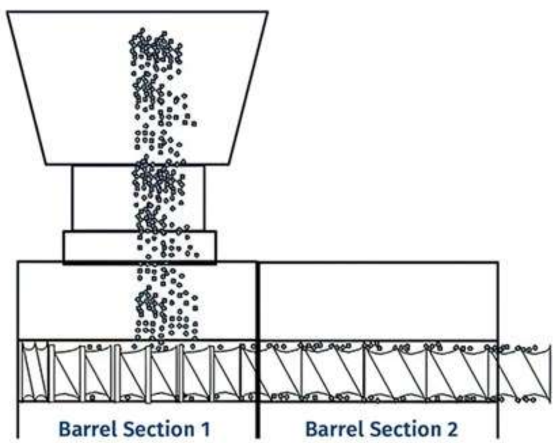
Step 1 : configure your barrel

Barrel sectors : different openings for different processing tasks

Step 1 : configure your barrel

The feed zone

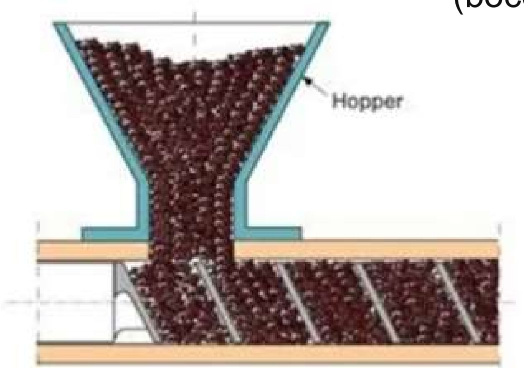
- When designing the screw in the feed zone, the intent is to collect the material as it drops into the feed throat and quickly convey it into the extruder. A typical feed section is shown.



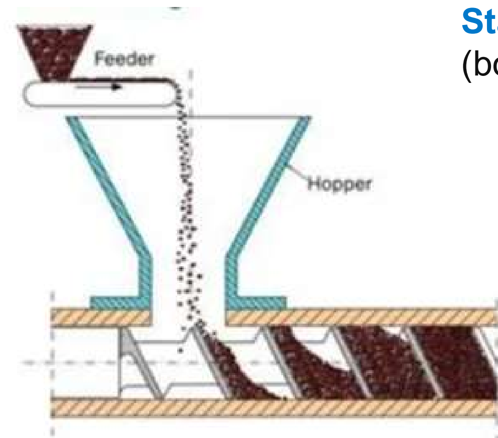
Step 1 : configure your barrel

feeding

flood feeding
(bocca piena)



Starved feeding
(bocca affamata)



When **flood feeding**, the screw takes in as much material as it can handle, and the bottom section of the hopper is **fully filled with material**.

Flood feeding is **typically used in single screw** extrusion where the feed hopper is filled, and **the extruder screw rpm determines the feed rate.**

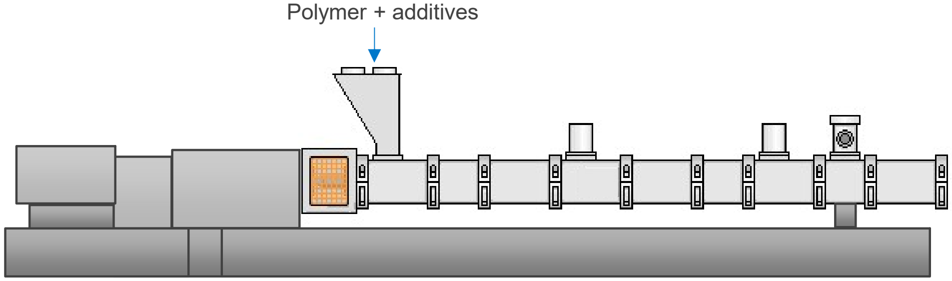
When **starve feeding**, the material is metered into the machine with a feeder, and the bottom section of the hopper is **not fully filled with material.**

Starve feeding is **typically used in twin screw** extrusion where a feeder is used to meter the material into the system at a predetermined rate where **rpm and throughput are independent of each other**

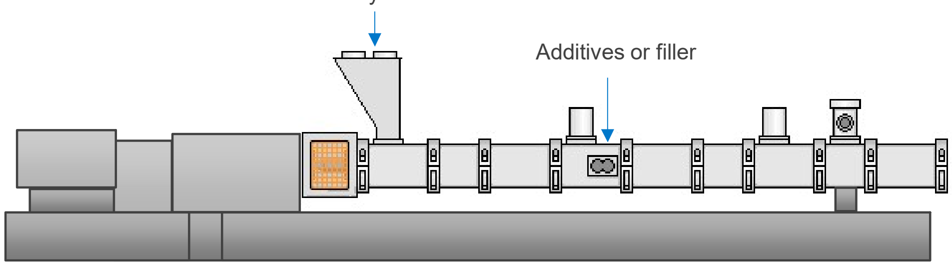
Configure your barrel

Different type of feeding therefore, machine configurations

Premix feeding



Split feeding



Advantages of the premix process :

- lower investment costs than for split-feed (use of gravimetric systems, no side stuffers) through the use of volumetric dosing high pigment and additive loading possible easier cleaning (only one dosing unit)
- high pigment and additive loading possible
- easier cleaning (only one dosing unit)

Advantages of the split-feed :

- process easy handling of the formulation via the extruder or feeder control system
- no complicated premix steps facilitates the production of larger mono batches
- **allows the gentle incorporation of shear-sensitive pigments**

Step 2 : configure your screw

Different zones in the screw

Similar to the barrel, the screw is engineered to fulfill a range of functions or specific objectives within the desired process :

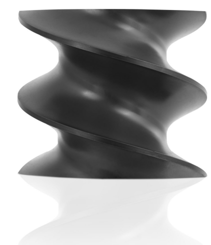
- Feeding
- Conveying / Transport
- Melting / Plastification
- Mixing (dispersive / distributive)
- Degassing
- Pressure build-up

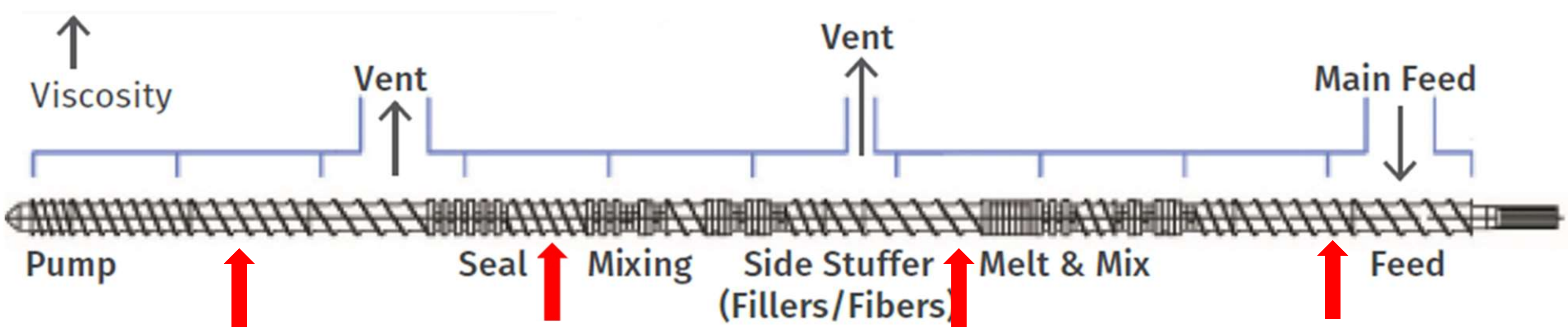
Step 2 : configure your screw

Different shape for different effect on the product

Step 2 : configure your screw

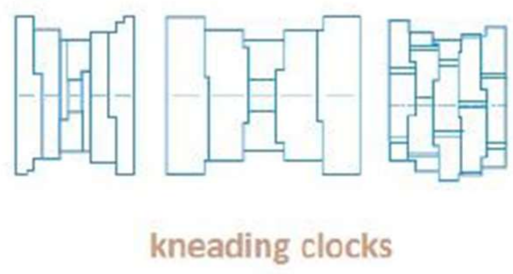
Each screw elements serves a distinct function : conveying

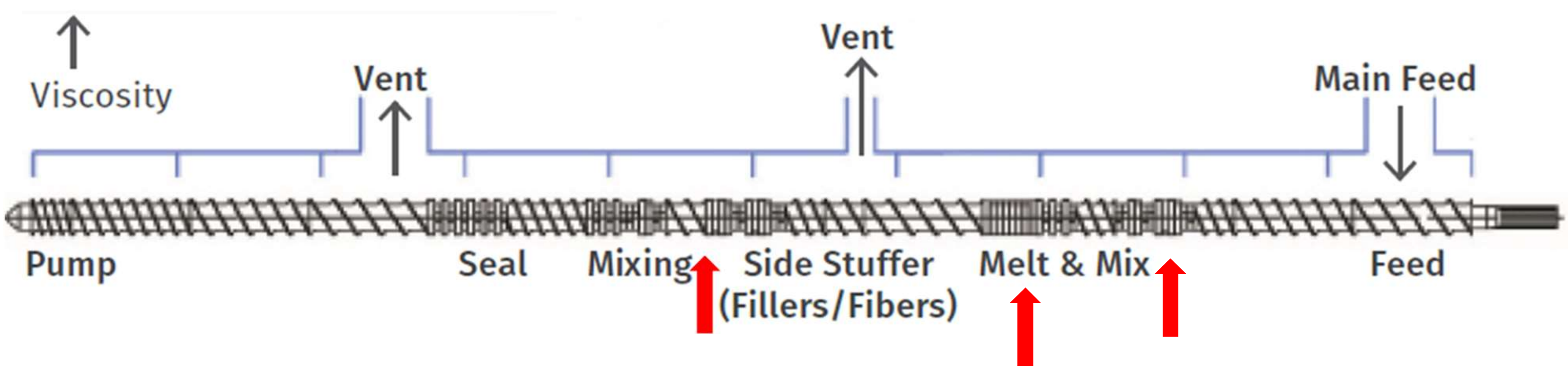




Step 2 : configure your screw

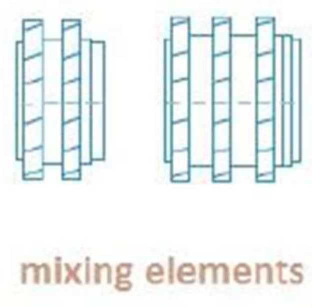
Each screw elements serves a distinct function : melting - kneading

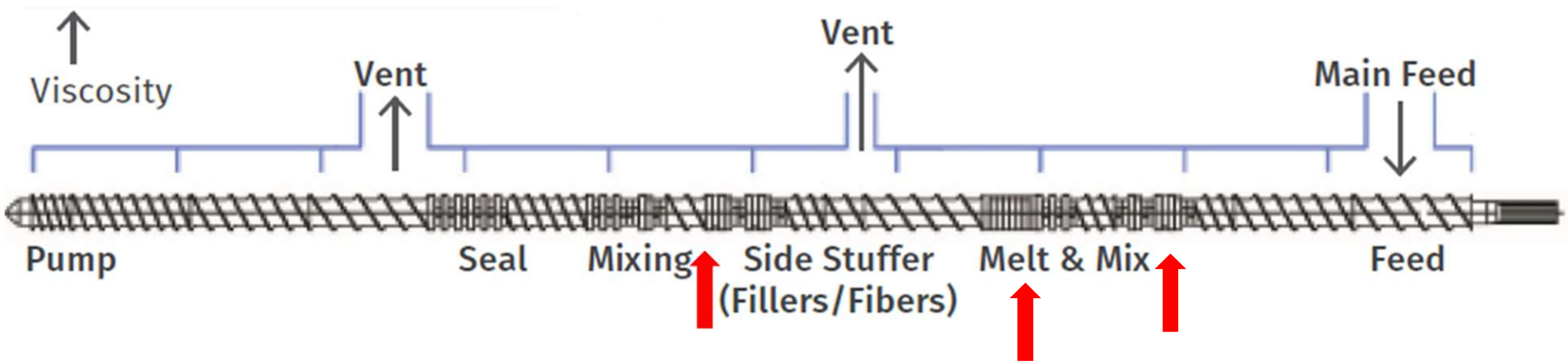




Step 2 : configure your screw

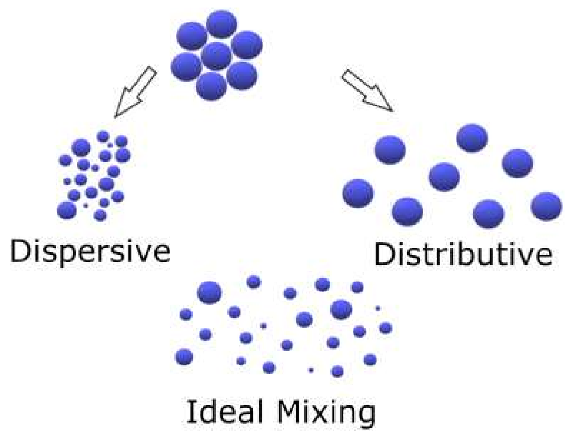
Each screw elements serves a distinct function : mixing

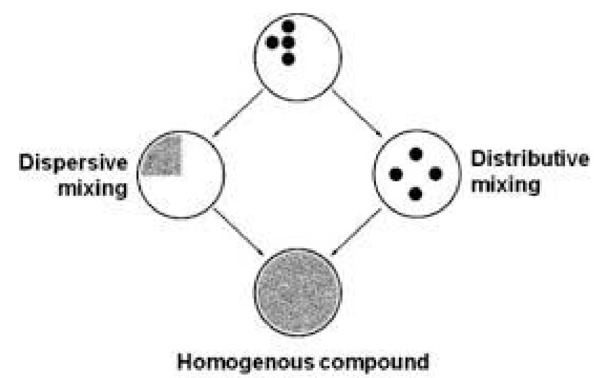


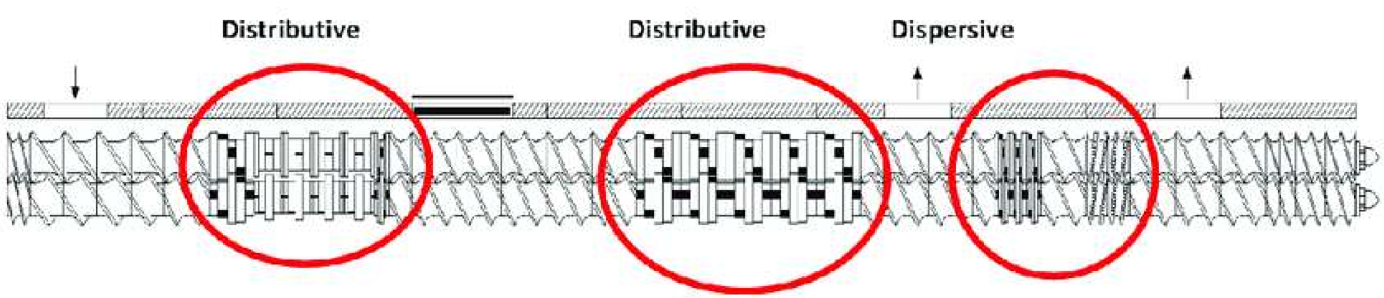


Types of mixing : dispersive and distributing mixing

definitions



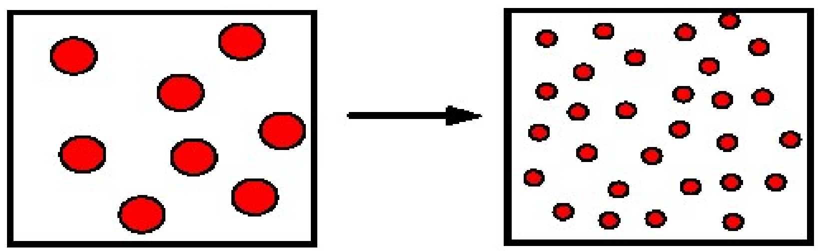




Types of mixing : dispersive mixing

Into the twin screw extruder

A **mechanical action** on the fluid composition. The intensity of this mechanical action depends on the nature of the ingredients and the process objective



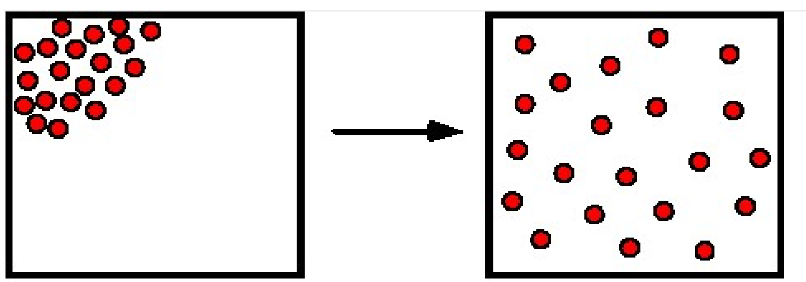
Mixing dispersivo (intensivo)

It consists in **breaking the agglomerates** of the material until elementary particles are obtained

Types of mixing : distributive mixing

Into the twin screw extruder

It obtains the **uniformity** of the compound thanks to an optimal **spatial distribution** of the components. **It does not act on the structure of the components** and therefore does not have to overcome any type of cohesive resistance; it is also called extensive or simple mixing



Mixing distributivo (estensivo, semplice)

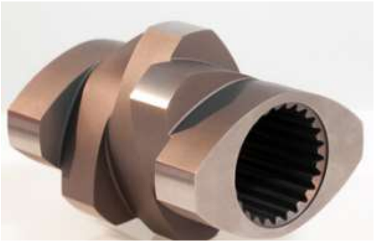
Distributive mixing performs two fundamental functions within a (polymeric) melt, which are: **to increase the interface between the components** of the melt

Types of mixing

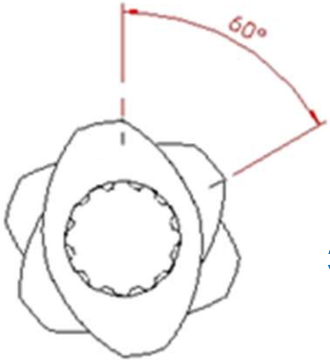
Kneading elements

Many formulations require either or both mixing mechanisms. The goal is to achieve a **homogenous mix** with minimal degradation by minimizing energy-consuming flows through correct choice of screw elements.

The "kneading elements" is the most common type of TSE mixing element :



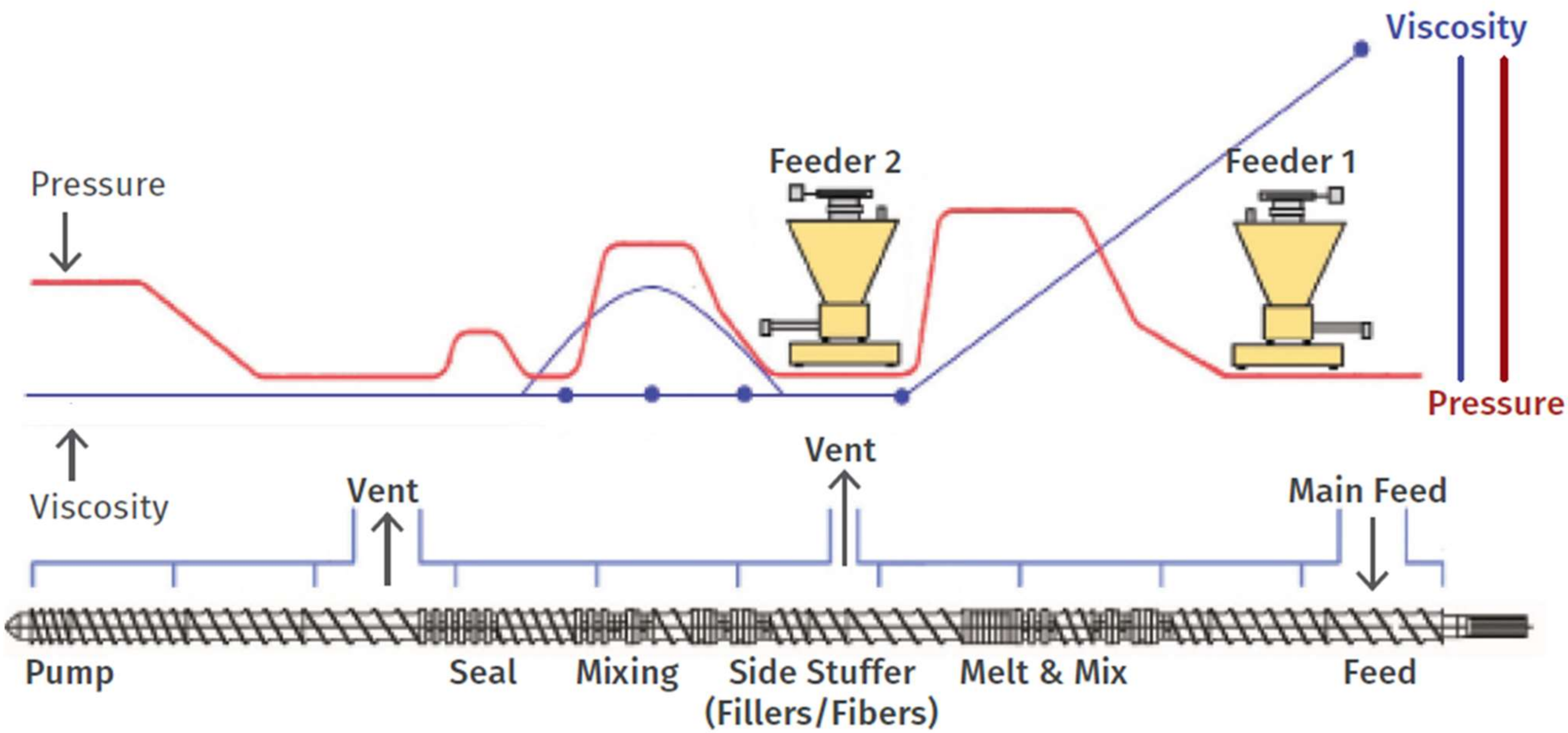
- ❖ The main function of the kneading screw element is mixing, which is used for the distribution and dispersion of the materials.
- ❖ The discs composing the kneading elements are realized in order to have a staggering angle
- ❖ **the larger the angle, the stronger the shear**



30° 45° 60° 90°

Configure your twin screw extruder

Pressure (and viscosity) behaviour during the extrusion process



Configure your twin screw extruder

Machine length and residence time

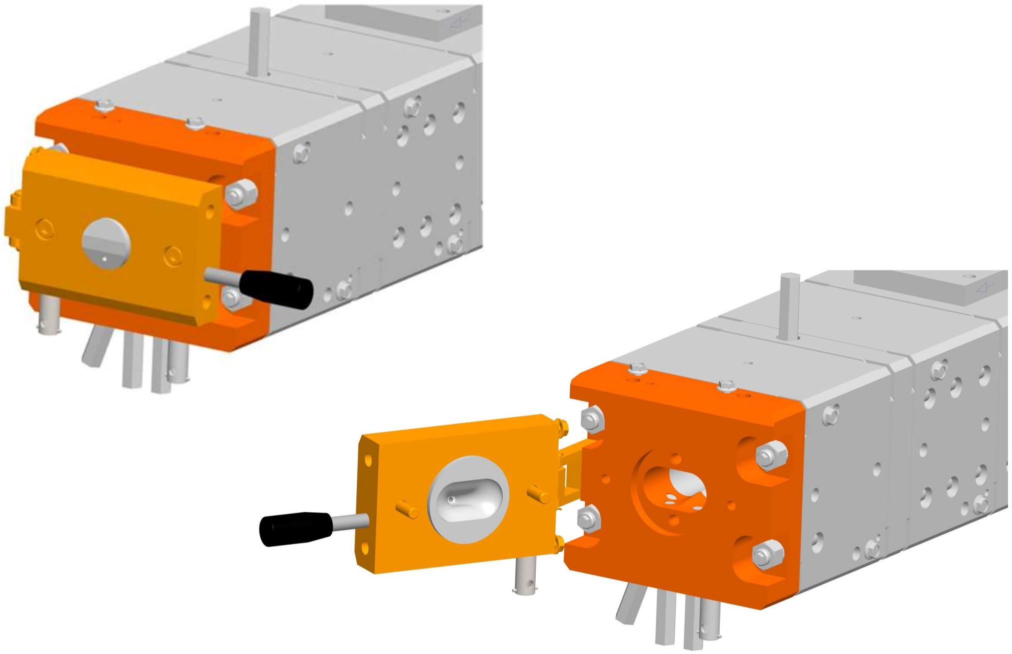
How long will be the machine ? **Long enough to complete the process !**

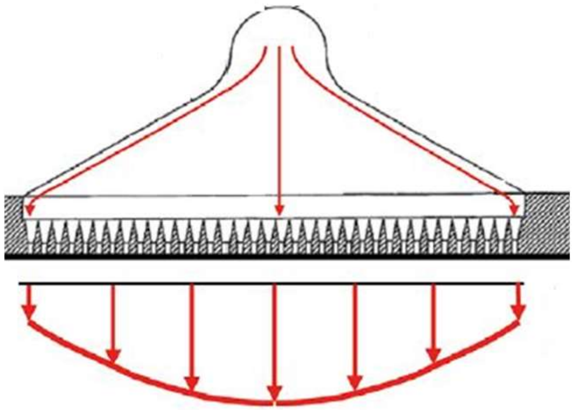
Residence time definition:

The **total time** that a fluid volume element has to pass through the extruder is called the residence time.

Step 3 : choose the die-head

The important component needed for the extrusion of the shape

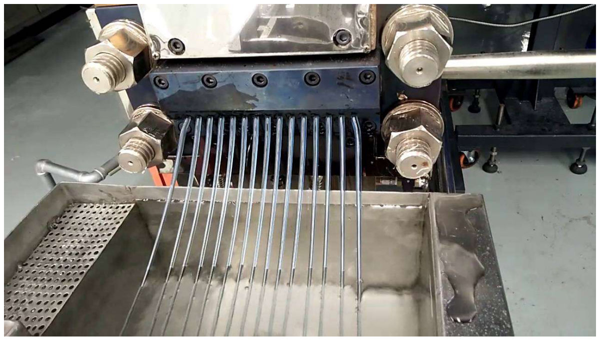


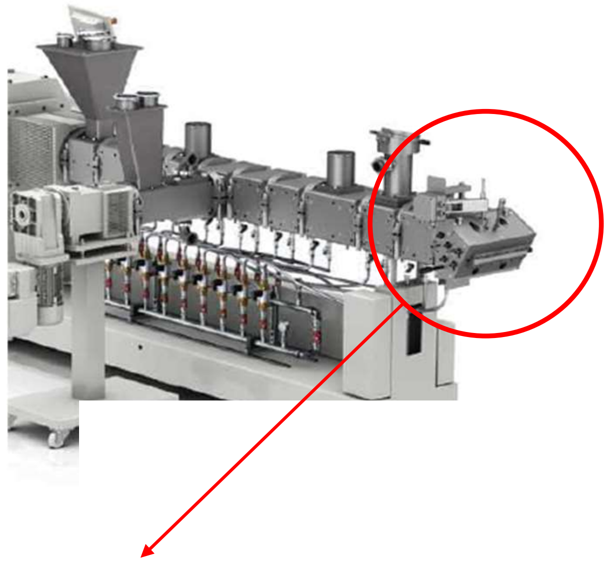


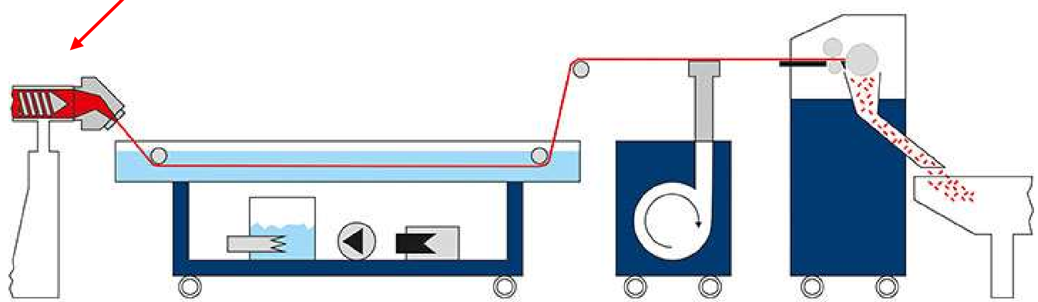
- Transition from melt phase to solid
- Distribution to the nozzles
- Shaping
- Temperature + pressure control

Step 3 : choose the die-head

The part needed for the extrusion of the shape







Step 4: set-up the process parameters

Parameters and variables

The following parameters will be set, measured and monitored:

- Barrel and die temperatures
- Screw speed

Other parameters :

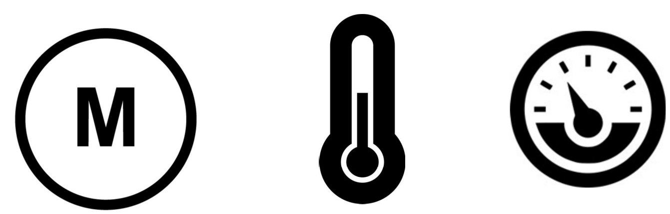
- Ambient temperature, Relative humidity,
- Temperature and moisture of product
- Cooling water temperature
- Vacuum level at vent port (when applicable)

CONTROL DISPLAY / HMI

The most important variables are “the three M’s”:

melt pressure, melt temperature, and motor load

They must be continuously measured and monitored.



Conclusions

The steps to the final configuration

- **Material Analysis:** Knowledge of the rheological properties of the material to be extruded, such as viscosity, shear stress, melting temperature, degree of corrosion or abrasion are essential in choosing the geometry and the material screw construction.

- **Preliminary Research:** importance of scientific literature and analysis of previous designs are a starting point for any new design.

- **Modeling and Simulation:** New technologies allow modeling and simulation software to create a model of the screw in order to predict its behavior during the extrusion process

Conclusions

The steps to the final configuration

- **Lab testing :** from theory to practice, testing geometries to measure process parameters, such as temperature, pressure, flow rate and quality of the extruded material.

- **Feedback from production :** refining the screw geometry based on test results until the desired performance is achieved.

- **Final Validation**: the validation of the screw design through small-batch production, ensuring that the screw will function effectively in a real-world 24-hour production environment.

Thank You ! Grazie ! Danke ! Merci ! Gracias ! Obrigado !

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