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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

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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. Extrusion processes Basis

1.2. Industrial processes for the production of flexible packaging

1.2.1. 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

1.2.2. Film blowing

Processing parameters for the film blowing process

Draw ratio and blow up ratio

Frost line height

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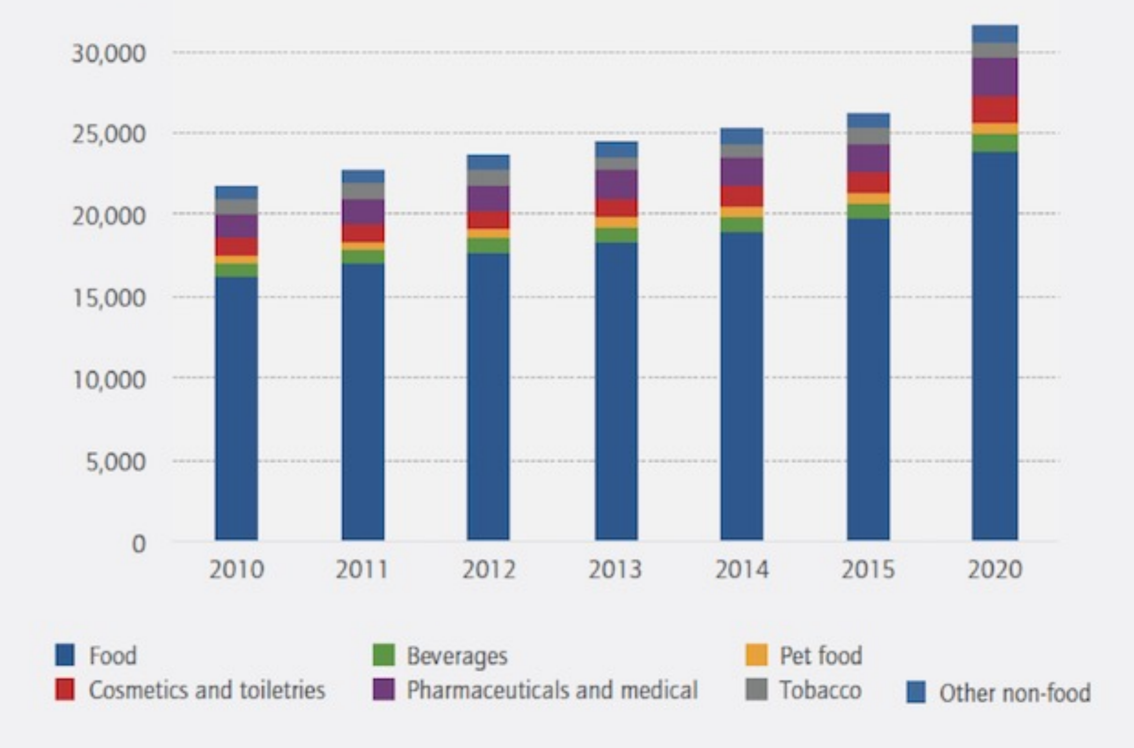
FILM CLASSIFICATION AND MARKET

The **flexible packaging** are classified on the basis of the thickness and represent a large piece of the market for plastic packaging:

sheet → is greater than 0.25 mm thick

film → is less than 0.25 mm thick



- The global consumer flexible packaging market value grew at an annual average rate of 4.4% during the period 2015–2020 to reach $114 billion
- **Food is grater than three-quarters of global consumer flexible packaging consumption in 2020**. Meat, fish, and poultry account for the largest usage food sector for flexible packaging, followed by confectionery and baked goods.

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FLEXIBLE PACKAGING STRENGTHS IN A CIRCULAR ECONOMY APPROACH

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SPECIFIC FEATURES OF FLEXIBLE PLASTIC PACKAGING:

- provides **excellent** and **tailored product protection**
- offers **great shelf appeal** and **differentiation**
- improves **consumer convenience** (*portion control, easy use and storage)*

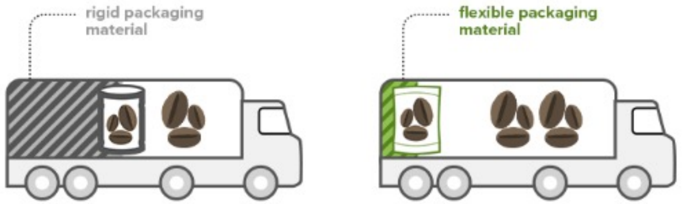
KEEPS GOOD THINGS IN AND BAD THINGS OUT

SIGNIFICANT SUSTAINABILITY BENEFITS OF FLEXIBLE PACKAGING

- increased product-to-package ratio
- less energy used
- reduces product waste
- fewer greenhouse gas emissions

LOW PACKAGING RATIO

LESS ENERGY FOR TRANSPORT



SMALL PART OF CARBON FOOTPRINT

LESS MATERIAL USED AND LESS WASTE

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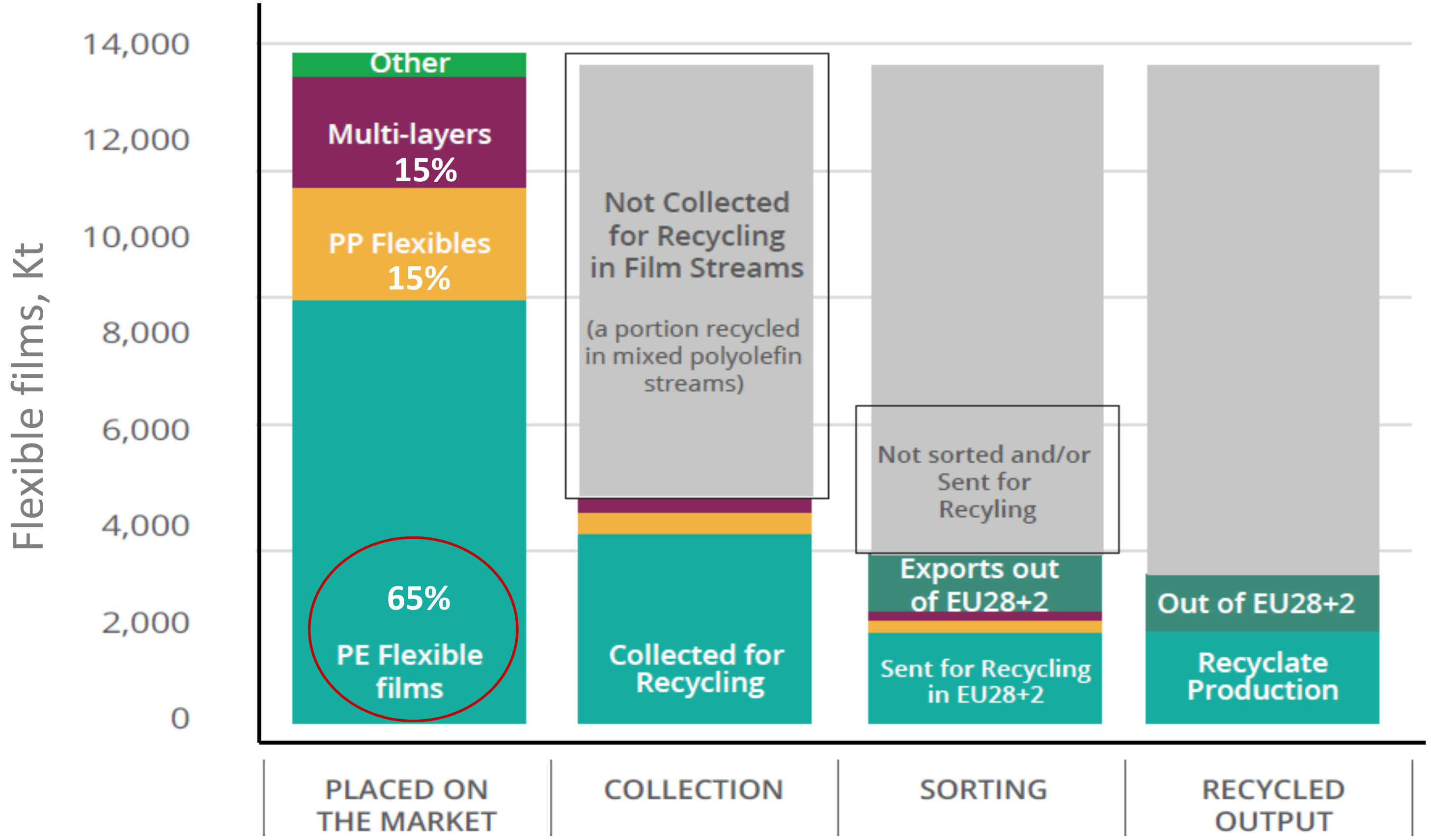
FLEXIBLE PACKAGING WEAKNESSES IN A CIRCULAR APPROACH

***Source:** " Flexible Films Market In Europe State of Play. Production, Collection and Recycling Data 2020" by PRE*



In Europe, **LOW RECYCLING RATES** for flexible packaging: only **23% of PE films** and **15% of all flexible films** were actually collected for recycling

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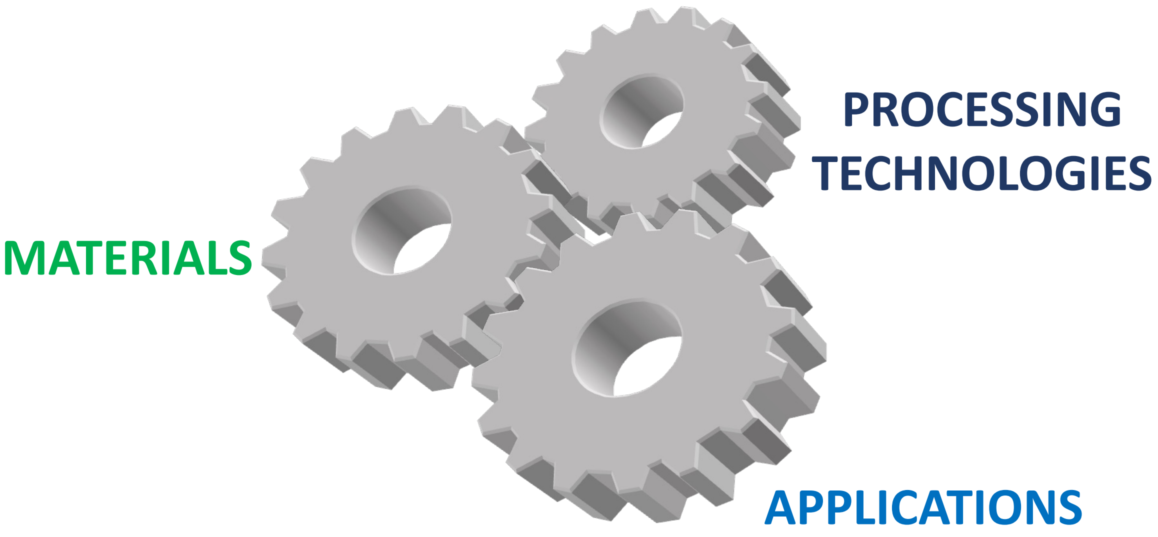
PROCESS-STRUCTURE-PROPERTIES RELATIONSHIP

REQUIREMENTS FOR PACKAGING FILMS:

- gas and vapor barrier
- high stiffness and mechanical strength
- good optical properties (transparency, color)
- size and surface uniformity
- seal-ability
- printability



The transformation processes and the corresponding operating parameters must be appropriately selected according to the peculiar characteristics of the raw materials and the specific properties required for the flexible films

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FILM PROCESSING TECHNIQUES

- CAST AND BLOWN FILM PROCESSING
- ORIENTATION TECHNIQUES
- COEXTRUSION

CAST FILM

BLOWN FILM

COEXTRUSION

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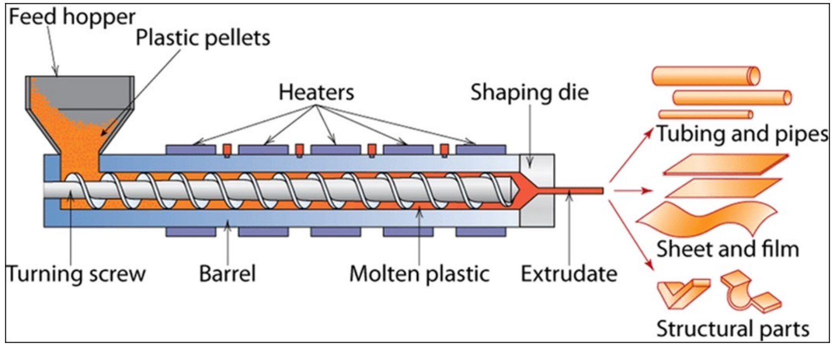
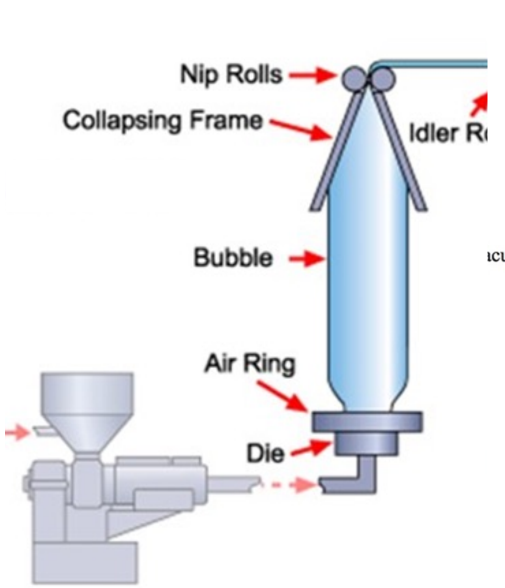
MAIN STEPS OF FILM PROCESSING

1. Extrusion
2. Film Formation
3. Cooling
4. Drawing
5. Collection





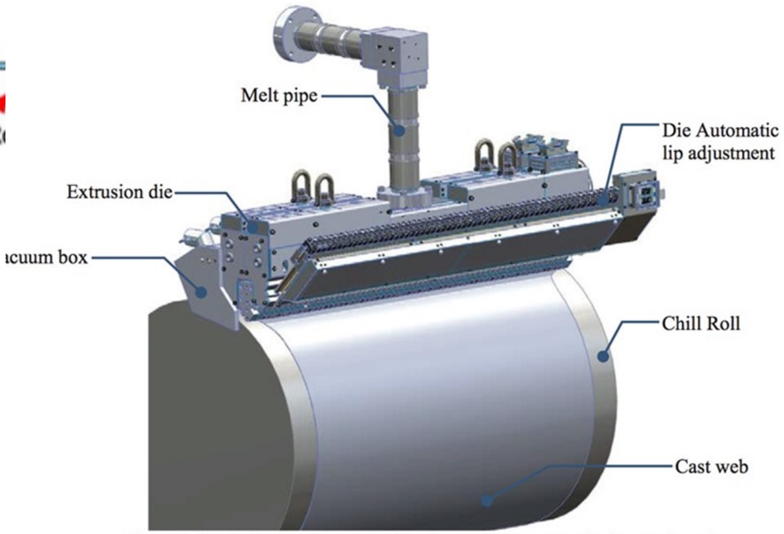


Figure 1. Typical monolayer cast film layout (Note: extruder is not shown)

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

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3.1.1 Extrusion process: description and equipment
3.1.2 Single screw extrusion process analysis

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Description of the process
Different types of cast film dies
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Processing parameters: Draw ratio, Chill roll temperature, Die to chill roll distance

1.2.2. Film blowing

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

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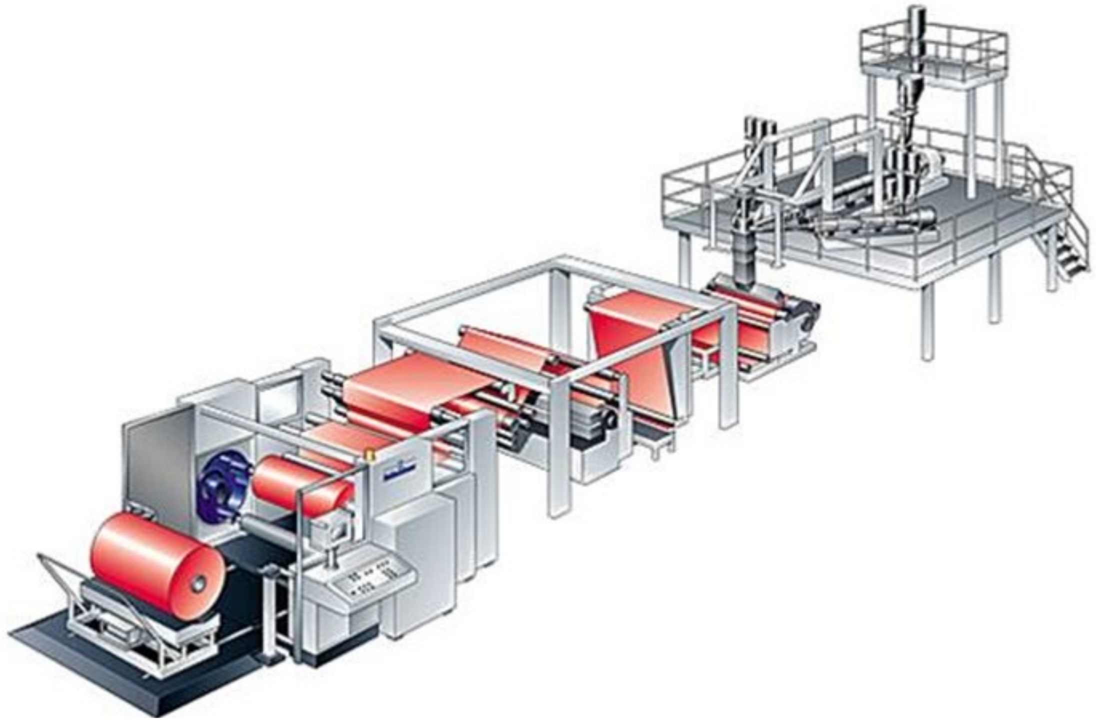
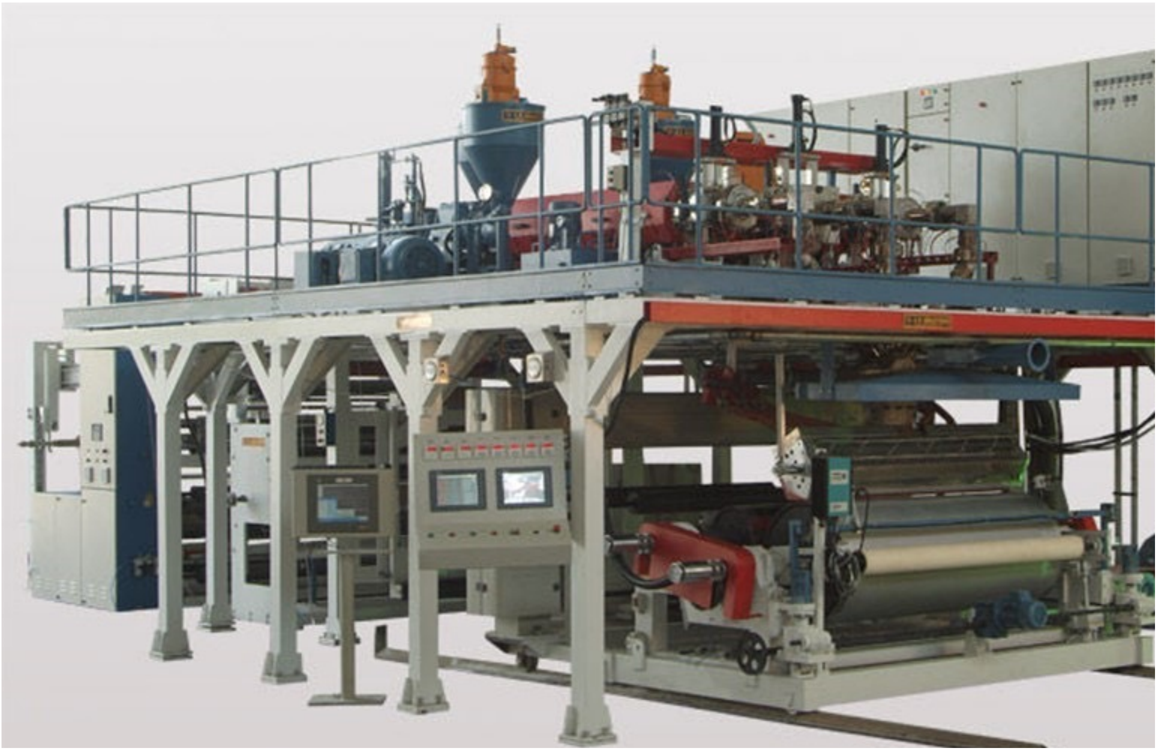
CAST FILM EXTRUSION

Cast film is produced by extruding the molten polymer through a slit-shaped flat profile. At the exit of the flat head, the film goes in contact with the chill roll, where the cooling phase begins. In the solid phase, the film is pushed through a measuring station, a surface treatment zone, a cutting station and finally it is wrapped in coils.





https://www.youtube.com/watch?v=ggqtl02N_-U

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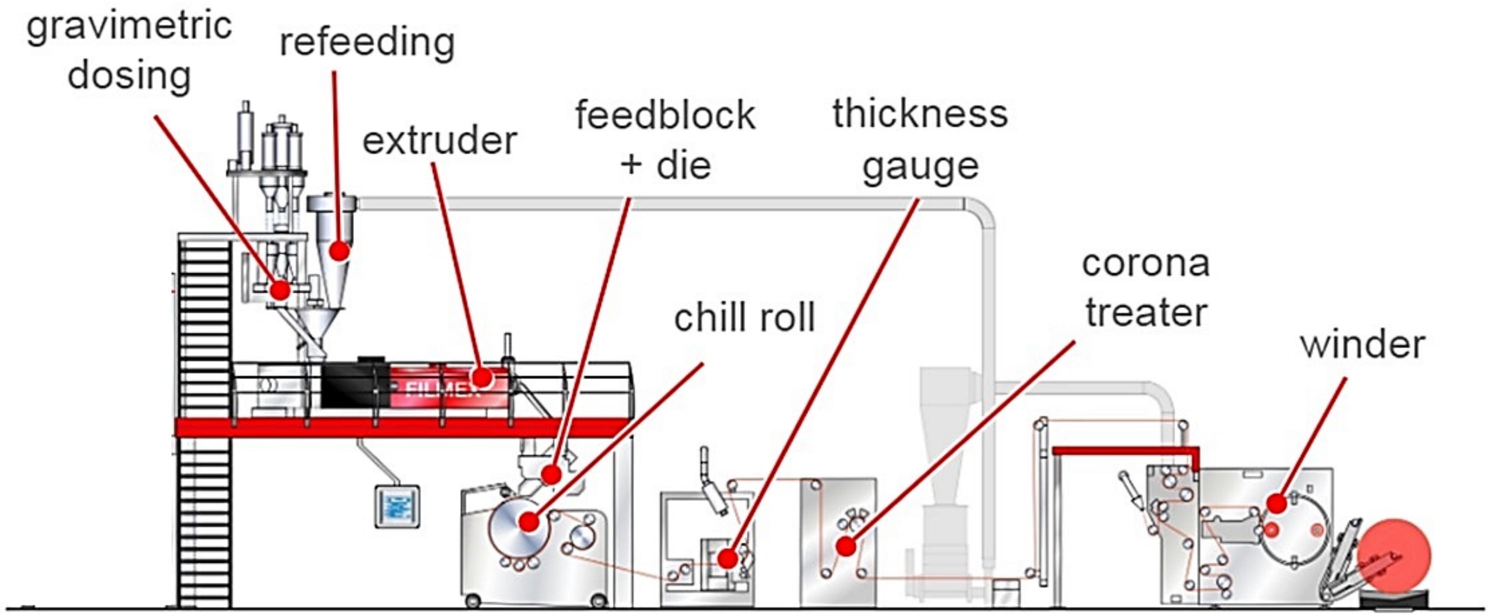
CAST FILM EXTRUSION PLANT



- **Extruder**, either single or twin screw, equipped with a slit-shaped flat die
- Polished chrome rolls (**chill roll**) for cooling and polishing the film **Vacuum** to remove air from behind the film to assist laydown on the casting roll
- **Puller rolls** to maintain constant tension on the film
- **Equipment for corona, flame, or plasma treatment** to improve adhesion for printing
- **Slitter** to cut the film to width
- **High-speed winder** to wind up the film

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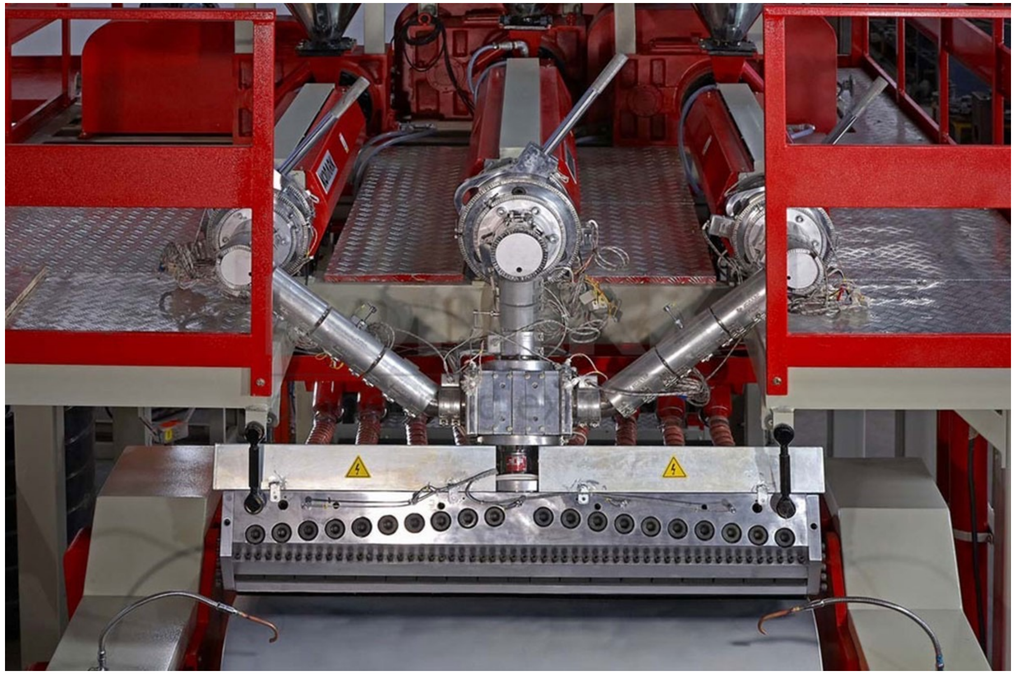
CAST FILM EXTRUSION: die



- The **cast film extrusion die** consists of a flat-shaped slot with a straight profile. The distribution of the melted polymer is achieved by means of a manifold and a distribution channel, followed by an area with smaller section.
- Through the cast film extrusion die the polymer is subjected to **shear deformation**

The molten polymer, which flows through the die along different paths, has different viscosity values since the section and speed change in each path.

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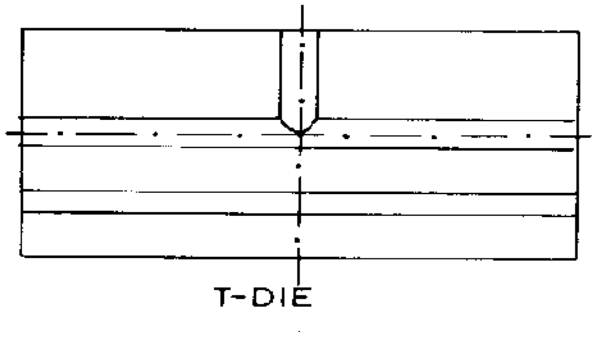
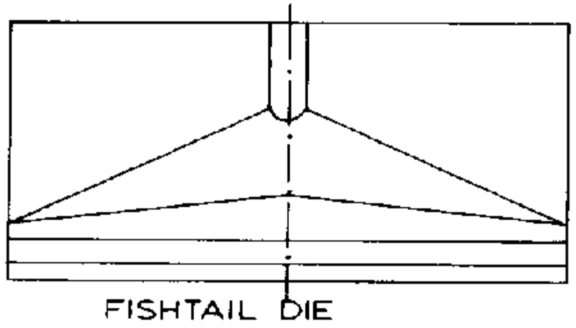
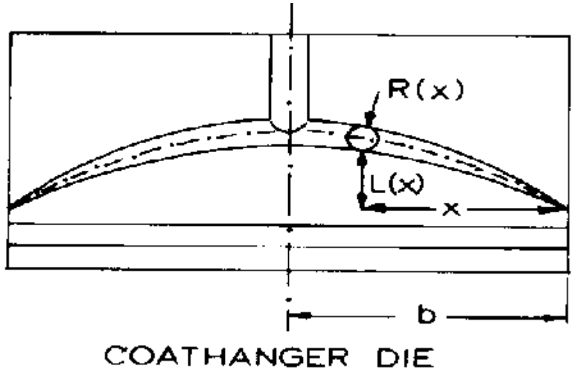
CAST FILM EXTRUSION: typical die design

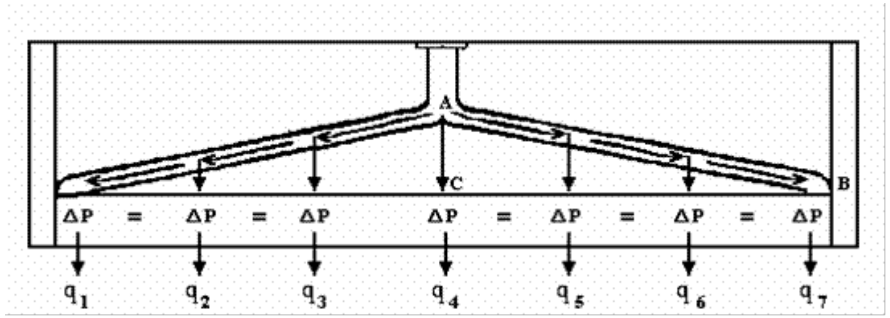






CRITCAL ISSUE:

It is necessary to size the melt path (cross sections of the extrusion die) so that the desired quantity of polymer reaches each point of the die (along its entire width) and at a uniform speed.



To ensure the same polymer rate at each exit point of the die, the flow rate (q) and the pressure difference (ΔP) between the entry and the exit of the extrusion die must be constant over the entire width of the film

UNIFORMITY OF FILM THICKNESS

The distance between the outer ends of the cast extrusion die (lips) can be adjusted along the entire width of the die, so it is possible to adjust the thickness of the film and/or reduce any dis-uniformity.

THE THICKNESS UNIFORMITY OF THE FILM DEPENDS ON:

- ✓ uniformity of polymer melt temperature
- ✓ homogeneity of the die temperature
- ✓ cleaning of the extrusion die from possible degradation products

It is possible to produce films of a width of 2 meters with a thickness uniformity of more or less 3% across the film width.

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CAST FILM EXTRUSION: processing parameters

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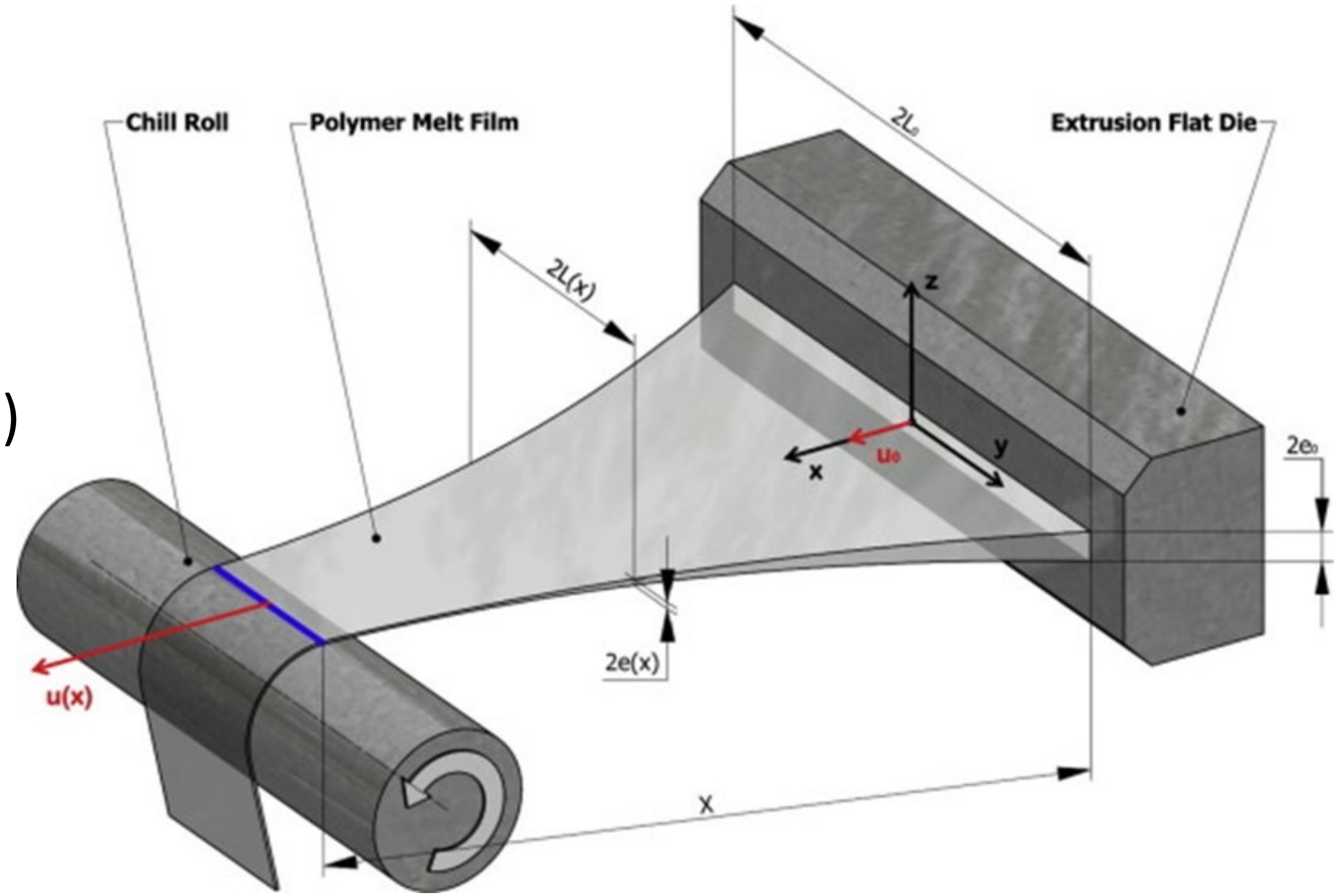
- EXTRUSION TEMPERATURE
- CHILL ROLL TEMPERATURE
- COLLECTION DISTANCE (distance between the die and the chill roll)
- DRAW RATIO



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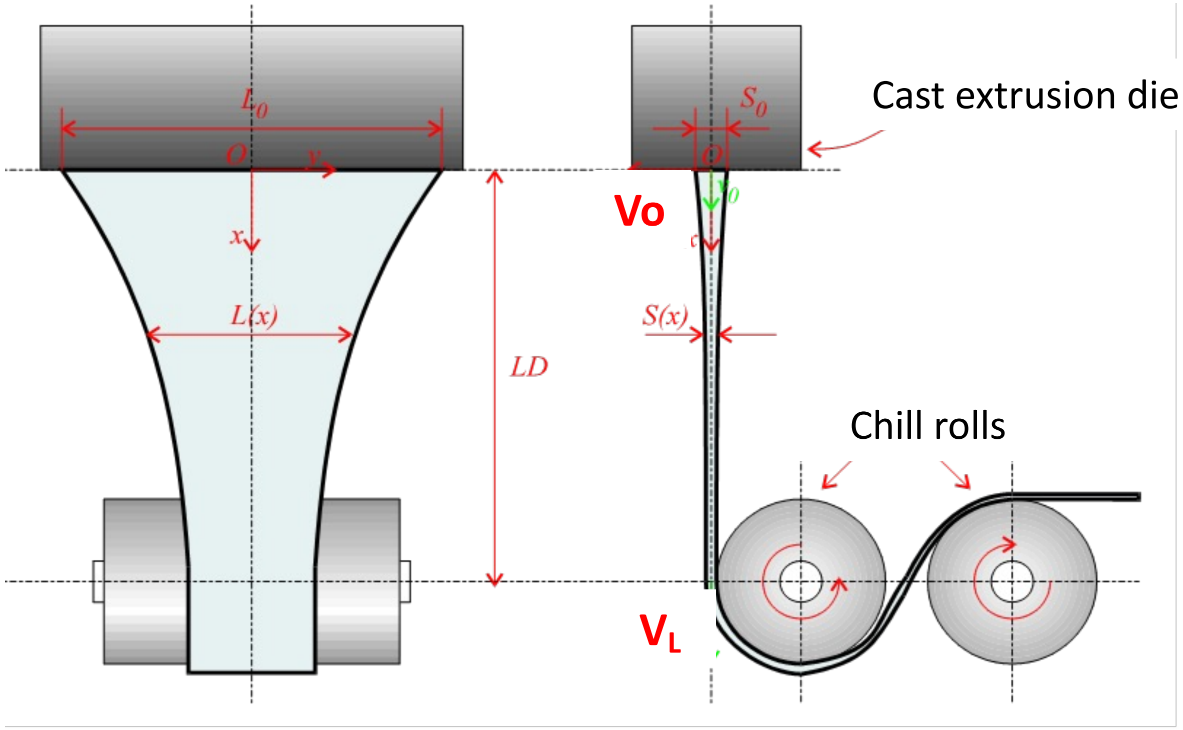
STRETCHING AND COLLECTING



THE VELOCITY PROFILE CHANGES ALONG THE STRETCHING DIRECTION

Melt deformation:

during collecting on chill roll the material undergoes an elongational deformation

↓

draw ratio:

$$DR=V_L/V_0$$

V_L= linear velocity of the roll

V_0= output rate of the melted polymer

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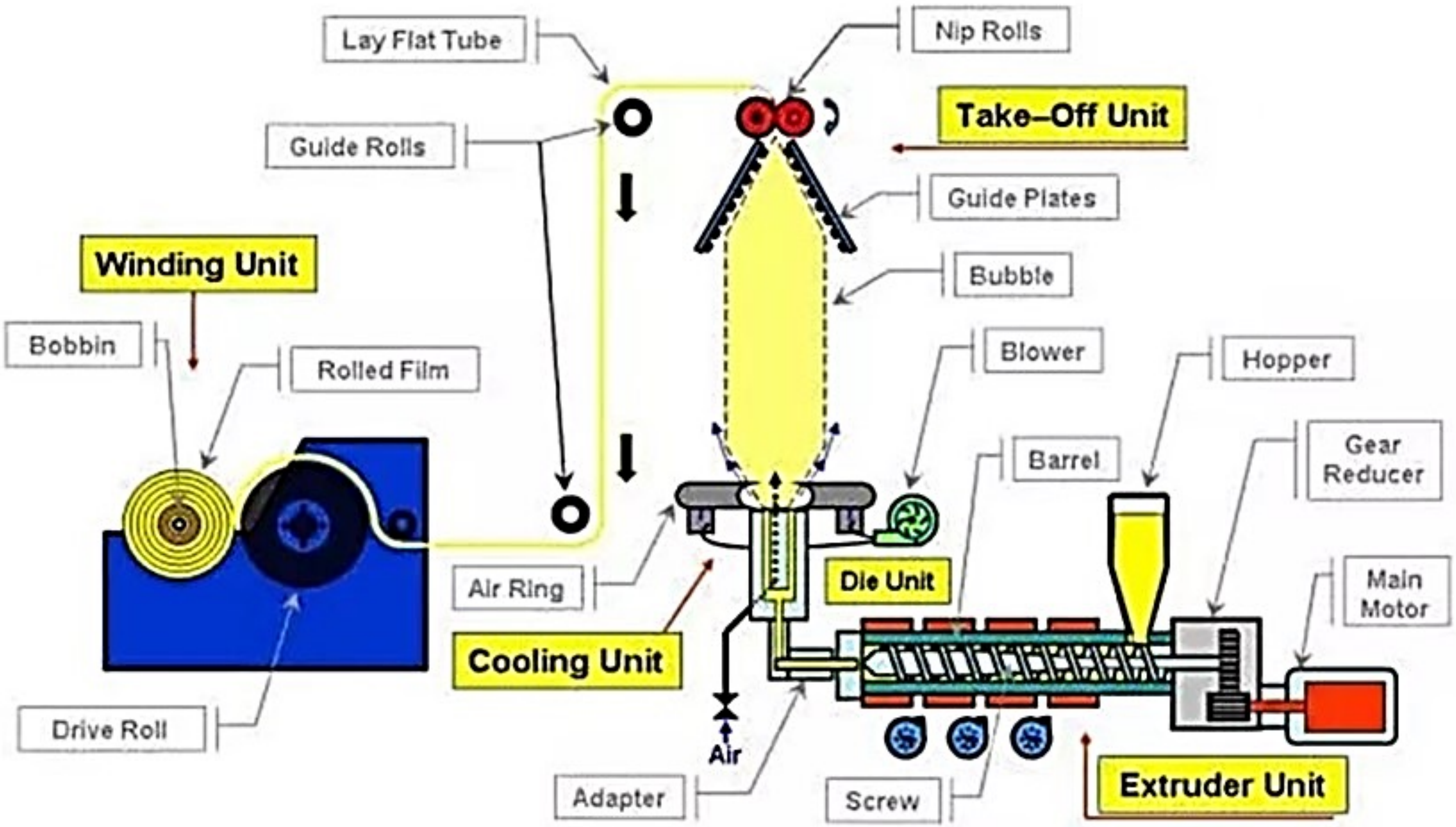
BLOWN FILM EXTRUSION: main units of the plant



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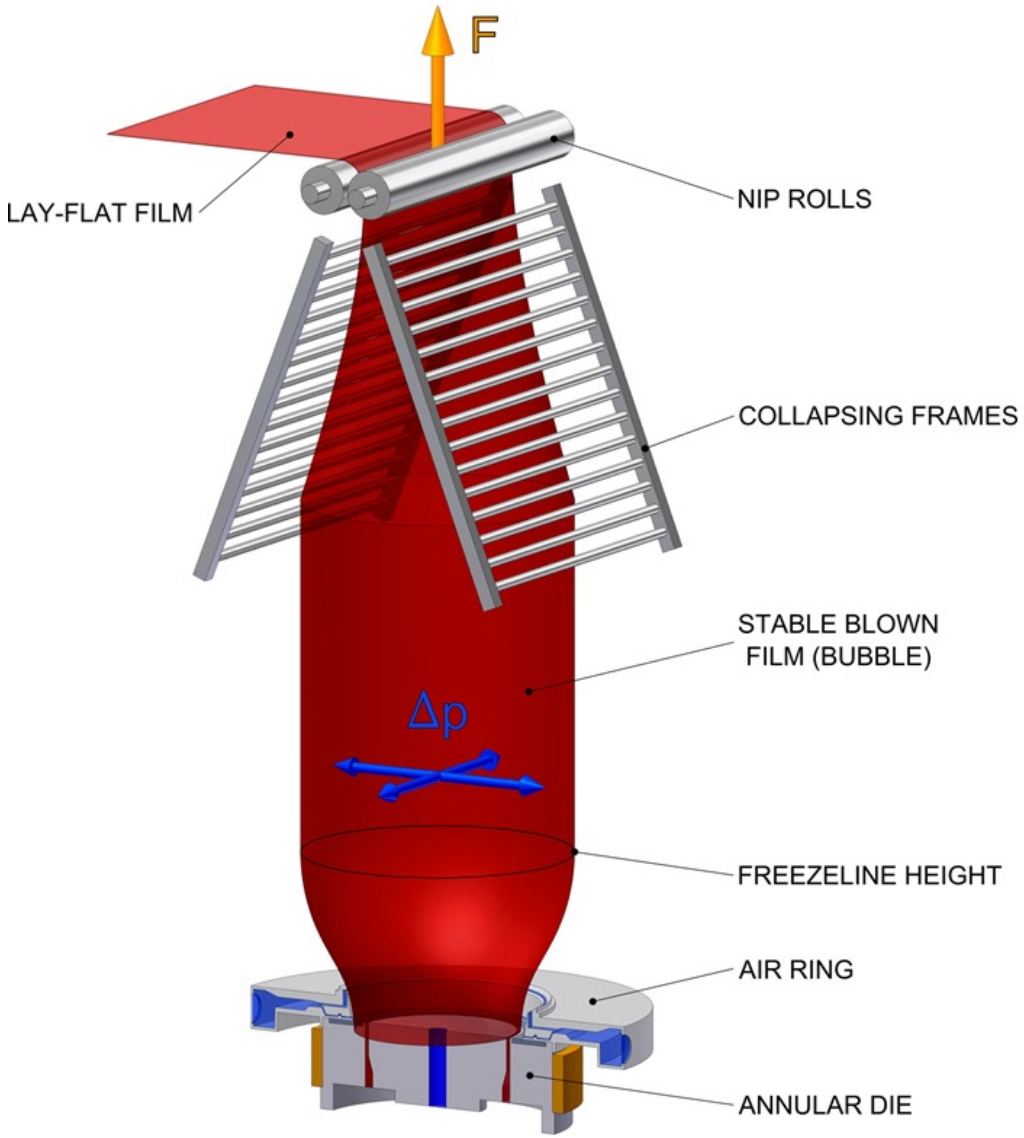
BLOWN FILM EXTRUSION: description of the process

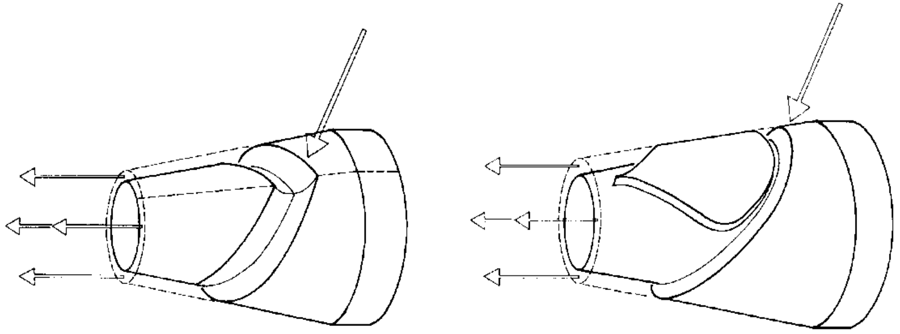
An **extruder** melts the resin and forces it through an **annular die**. The extruded melt, in the form of a tube, flows upward under the influence of a vertical, "machine direction" force, applied by means of **nip rolls** at some distance above the die. The tube is cooled by means of an "**air ring**" that directs air along its outer surface. Air is also introduced through a hole in the die to prevent the collapse of the tube of molten polymer. After the tube is threaded between the nip rolls to form an air seal, additional air is introduced, and at some level above the die lips the tube inflates in a radial direction to form a "bubble."

https://www.youtube.com/watch?v=nNgVzqfesog



BLOWN FILM DIES

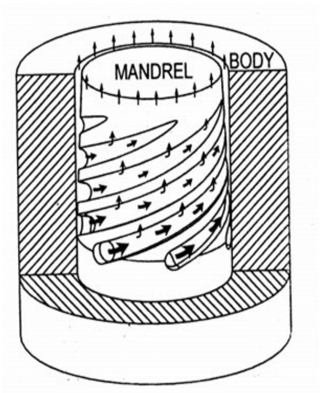
SIDE FED DIE

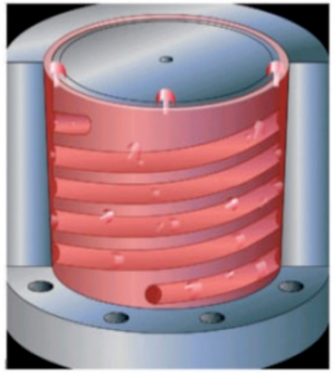


It is the simplest and least expensive die type, but it has some drawbacks:

- weld lines
- difficulty in maintaining film thickness uniformity

SPIRAL MANDREL DIE





The helical to axial transition provides a mixing effect that largely avoids weld lines and allows the flow to be distributed uniformly around the mandrel leading to velocity, hence gauge, uniformity at the die exit.

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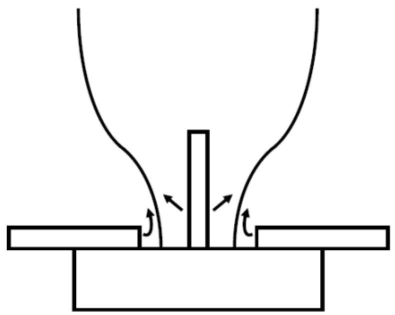
BUBBLE COOLING

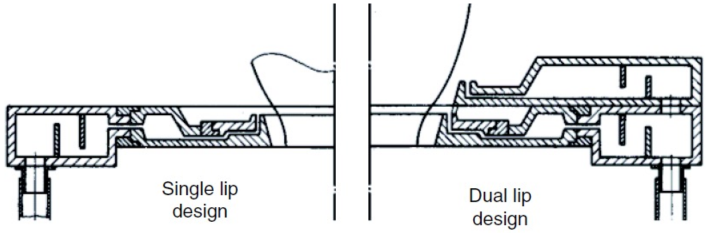
- It is generally accomplished by blowing a large volume of air on the film as it exits the die
- It may take place on only the outside of the bubble or on both the inside and the outside
- It is the limiting factor to maximizing throughput.



Three primary process variables are responsible for the efficiency of cooling:

1. **air speed** - at higher air speed, more heat is removed from the film per unit time
2. **air temperature -** Cooler air will remove heat more quickly, but using chilled air increases processing costs so a balance must be reached
3. **air humidity - if** ambient air is used, the humidity will vary seasonally and may affect cooling efficiency.

THE DEVICE RESPONSIBLE FOR COOLING IS THE **AIR RING.**



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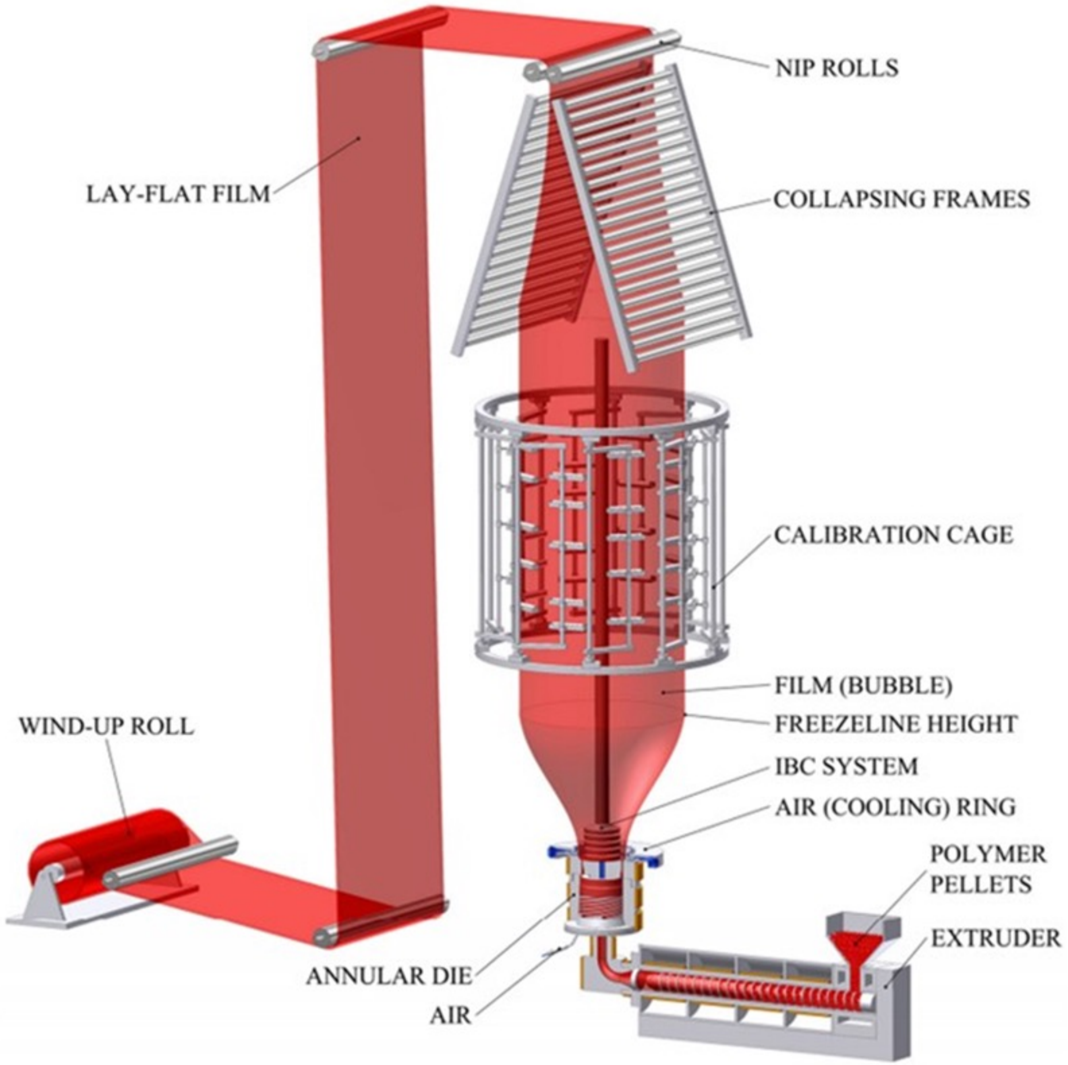
STABILIZING CAGE and COLLAPSING FRAME



Bubbles are usually stabilized externally using devices such as **CAGE**, to avoid movement of the bubble that will result in non-uniform wall thicknesses

- As the bubble moves upward and approaches the nip rollers, it is “pre-flattened” by the **COLLAPSING FRAMES** This device provides a smooth transition from a round tube shape to a flattened tube shape.
- The collapsing frame also helps eliminate wrinkles in the final product.

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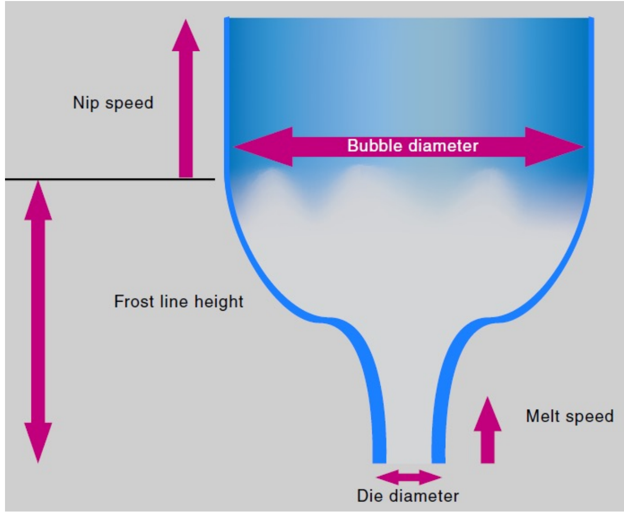
BUBBLE GEOMETRY

There are several parameters used to describe the geometry of the bubble:

- Die diameter
- Die gap
- Frost-line height (FLH)
- Bubble diameter (D_b)
- Film thickness
- Lay-flat width (LF)



- ✓ The "**FROST LINE**" represents the portion on the bubble where the brightness of the film abruptly decreases, denoting the transition of the polymer state from melt to solid. Conventionally, it represents the lowest point where the bubble is at its maximum diameter, since no further stretching occurs above this point. The distance from the die face to the frost-line is called the **frost-line height (FLH)**.
- ✓ Once the film passes through the nip rollers, the flatted film is characterized by a **lay-flat width**. Twice the lay-flat width is equivalent to the circumference of the bubble (or $D_b = 2\ LF/\pi$). This equation is a handy tool for determining the bubble diameter.

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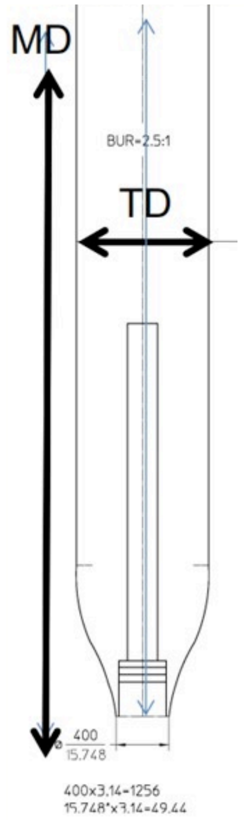
BUBBLE SHAPE

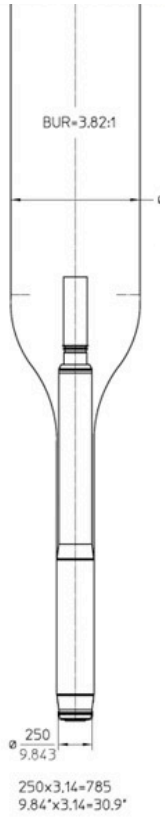


short neck

THE POCKET BUBBLE

- has little or no stalk, beginning its expansion almost immediately above the die face;
- tends to be quite stable due to the cooling air providing early solidification.

This shape is mostly used for **LDPE**, **LLDPE**, and **PP.**



long neck

LONG STALK BUBBLE

- TD stretching is delayed until the polymer reaches a lower temperature, allowing for a more stable melt and providing higher stress during TD stretching.

This type is used primarily for **HDPE** due to that material's relatively low melt strength.

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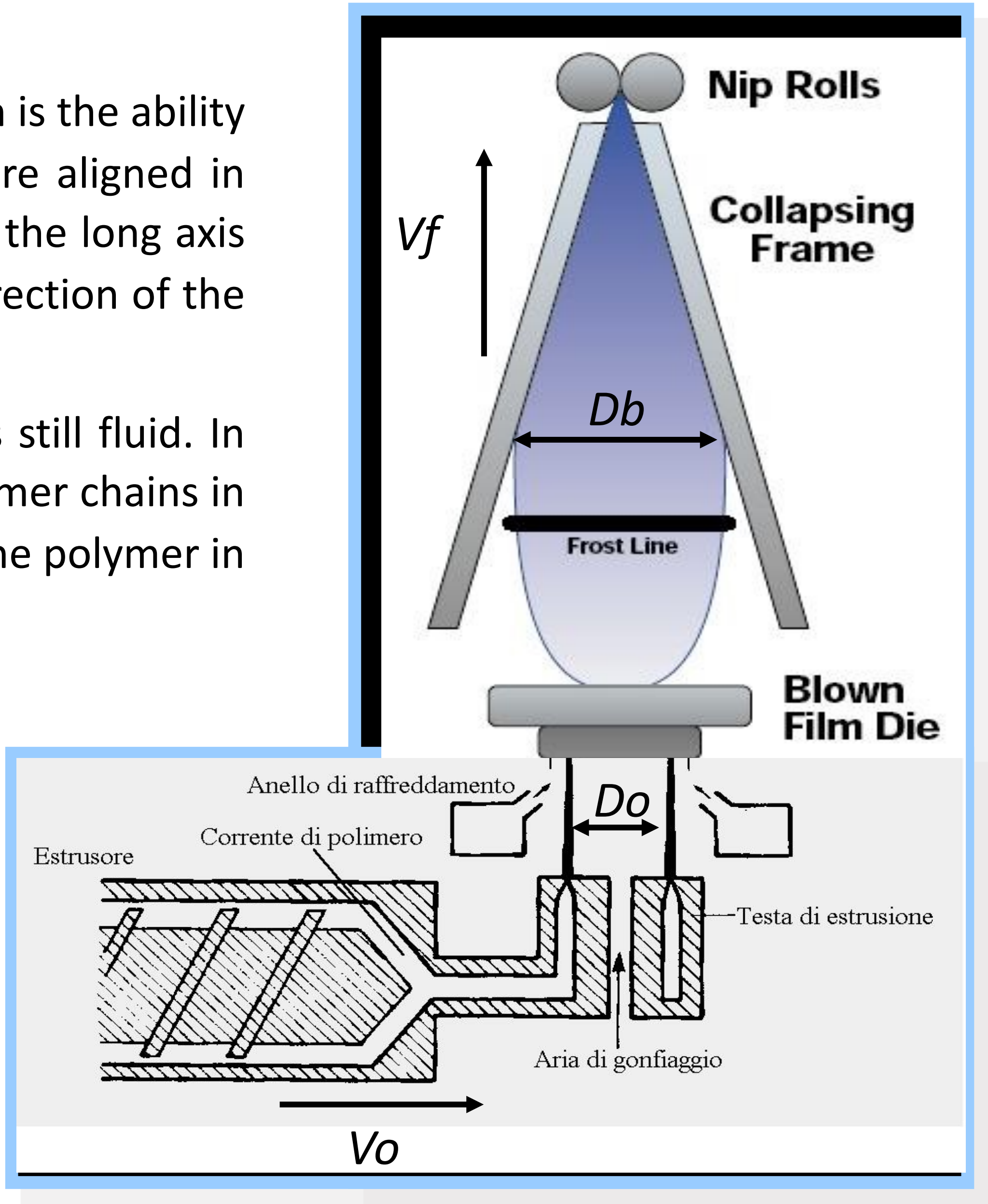
BIAXIAL ORIENTATION

- The most important processing characteristic of blown film extrusion is the ability to impart **biaxial orientation**, that means the polymer molecules are aligned in the plane of the film, i.e., in both the machine direction (MD, along the long axis of the bubble) and the transverse direction (TD, around the hoop direction of the bubble).
- The **deformation occurs before the frost line** where the polymer is still fluid. In this area the action of the nip rolls determines the stretching of polymer chains in the axial direction while the blowing air promotes the stretching of the polymer in the transverse direction.



To quantify the orientation:

- $TUR = V_f/V_0$ (Take Up Ratio)
- $BR = D_b/D_0$ (Blow Up Ratio)

PROCESS VARIABLES vs BUBBLE GEOMETRY

Several process variables work together to determine the bubble geometry:

- **Melt speed** (It is controlled by the screw speed, but it is not the same as the screw speed)
- **Nip speed**
- **Internal bubble volume**
- **Cooling rate** (speed and temperature of the cooling air)

There are several other process variables that influence bubble geometry, such as **process temperatures**, **die design**, **feed material composition**, and **polymer flow properties**, but these generally remain constant for a given run.

Variable to increase	Film thickness	Bubble diameter	Frost-line height
Nip speed	↓*	↑	↑
Screw speed	↑*	↑	↑
Cooling speed	↑	↓	↓*
Bubble volume	↓	↑*	↓

* Primary response

***Source:** Kirk Cantor, Blown Film Extrusion, An Introduction*

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