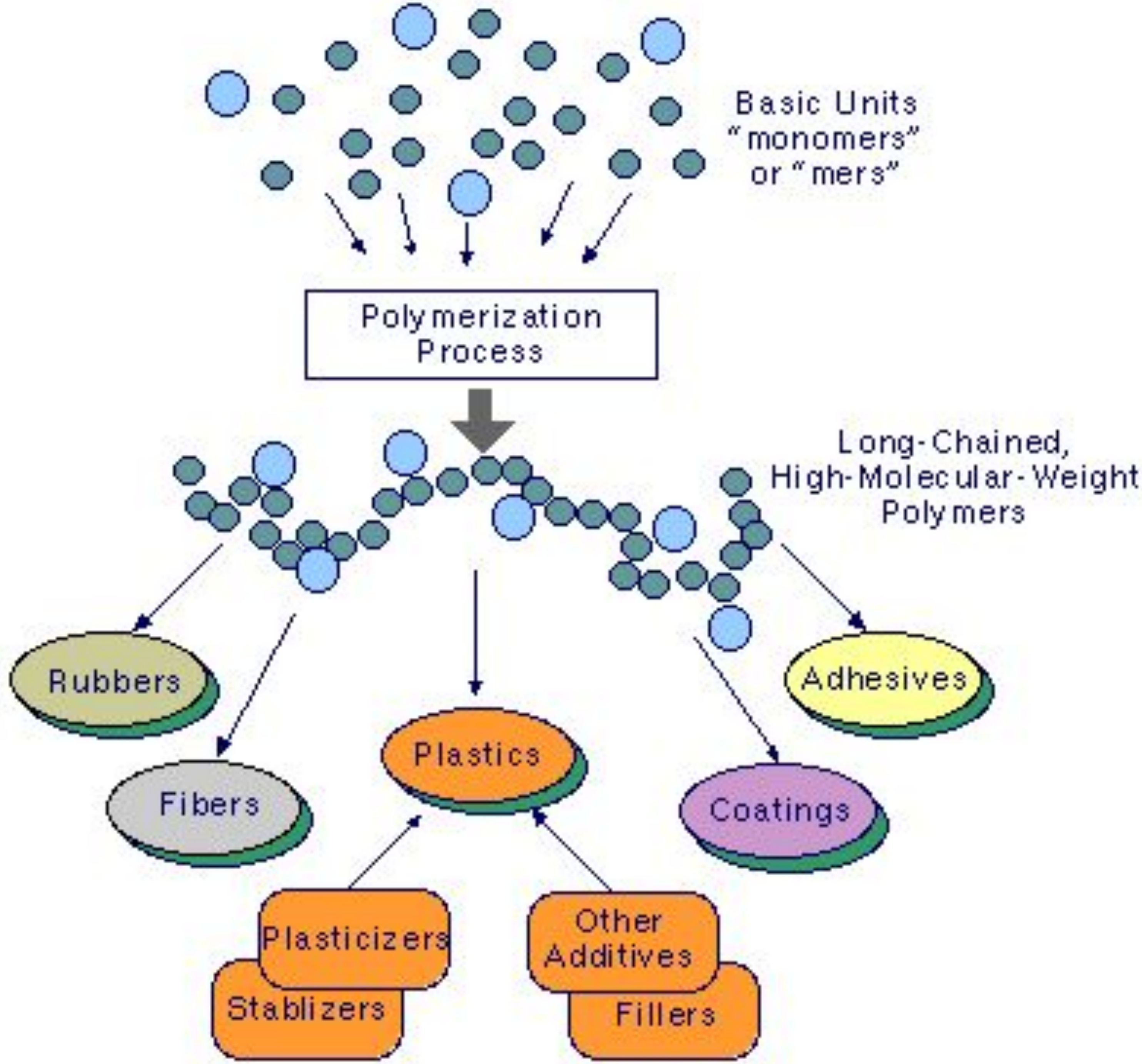
POLYMER PROCESSING

Processing is the source of much of the variability in properties of synthetic polymers. Different processing conditions determine the difference between a milk jug and, to a great extent, high strength PE fibers (ultra oriented). Processing is one component of a series of steps that lead to a plastic product or component from raw feed stocks. Although each commodity polymer has a somewhat different sequence of industrial stages involved in bringing it to market, a simple and fairly exemplary case is a polyethylene bottle of shampoo.

The various grades polymers are partly composed of blends of different branch content, molecular weight and density from different synthetic reaction conditions. For example, a film blowing grade of polyethylene might contain a blend of linear low density polyethylene, branch content metallocene polyethylene and low density polyethylene.

Polymers offer certain unique problems in processing. They are viscoelastic fluids which display high viscosity and broad transition temperatures. Machinery is large and involves a significant energy input. Polymers degrade (chain breakup) resulting in a loss of properties with exposure to high temperatures and stress for an extended period of time.

Some basic processing operations and machinery are extrusion, screw extruder, fiber drawing, injection molding, blow molding, dip coating, calendering, mixing/dispersion, melting, modification, and introduction of additives.


Basic Units
"monomers"
or "mers"
Polymerization
Process
Long-Chained,
High-Molecular-Weight
Polymers
Rubbers
Fibers
Plastics
Coatings
Adhesives
Plasticizers
Stablizers
Other
Additives
Fillers

Mechanical + Thermal

- Thermoplastic – solidified by cooling and reheated by melting
- Thermosets – retain their structure when reheated after polymerization (usually crosslinked)
- Elastomers – rubbers, deform readily with applied force
- Thermoplastic elastomers
- other

Major Processes

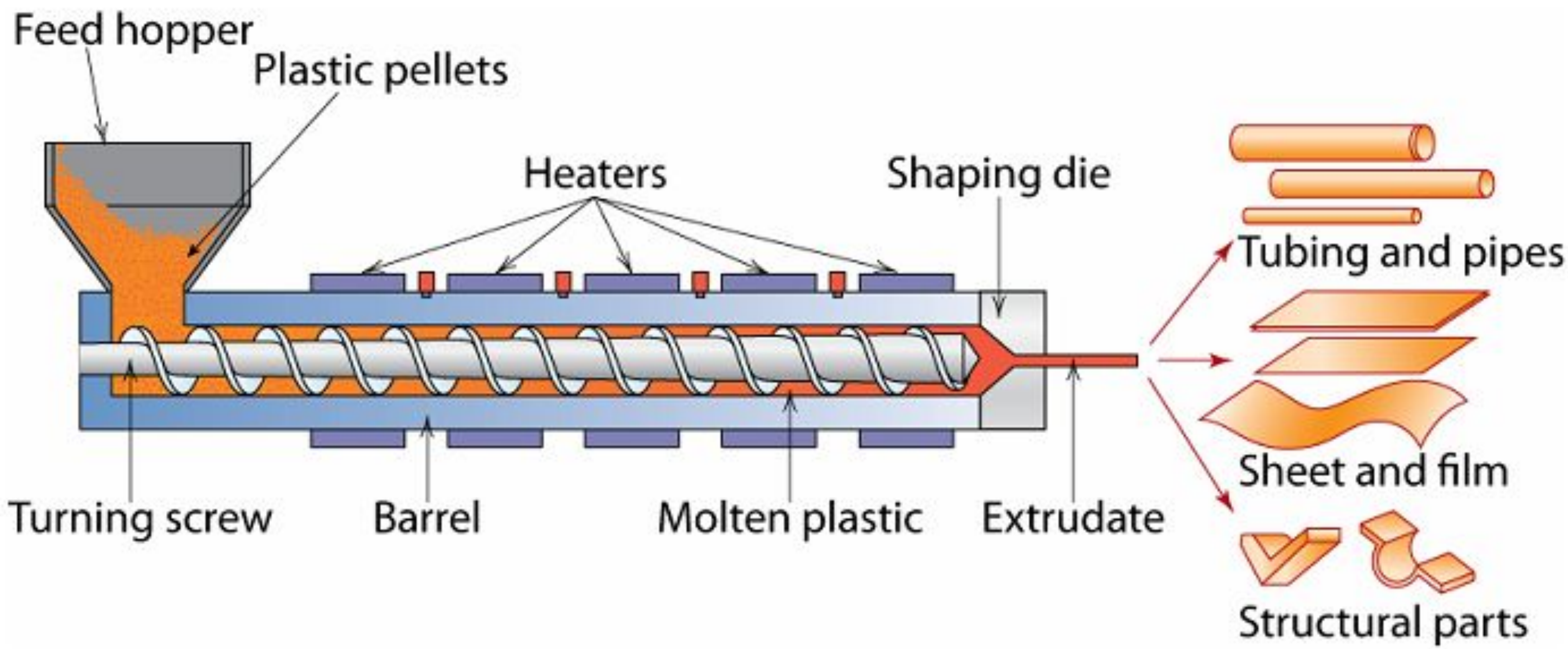
- Extrusion
- Injection Molding
- Blow Molding
- Thermoforming
- Rotomolding

Formulation

- Additives are used to modify properties and/or lower costs
- Additives: heat stabilizer, light stabilizer, lubricant, colorant, flame retardant, foaming agent, plasticizer
- Reinforcement: particulate minerals, glass spheres, activated carbon, fibers
- Blends, alloys, laminates

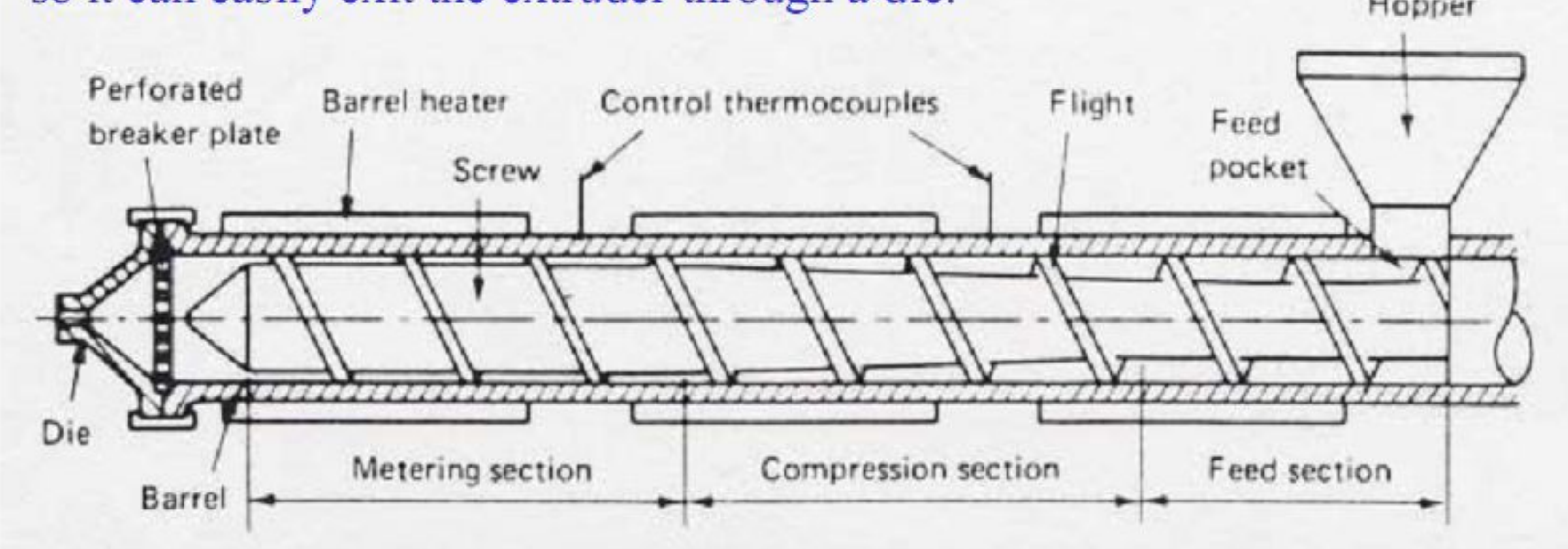
Reinforcing fibers	Boron, carbon, fibrous minerals, glass, Kevlar	Increases tensile strength. Increases flexural modulus. Increases heat-deflection temperature (HDT). Resists shrinkage and warpage.
Conductive fillers	Aluminum powders, carbon fiber, graphite	Improves electrical and thermal conductivity.
Coupling agents	Silanes, titanates	Improves interface bonding between polymer matrix and the fibers.
Flame retardants	Chlorine, bromine, phosphorous, metallic salts	Reduces the occurrence and spread of combustion.
Extender fillers	Calcium carbonate, silica, clay	Reduces material cost.
Plasticizers	Monomeric liquids, low-molecular-weight materials	Improves melt flow properties. Enhances flexibility.
Colorants (pigments and dyes)	Metal oxides, chromates, carbon blacks	Provides colorfastness. Protects from thermal and UV degradation (with carbon blacks).
Blowing	Gas, azo compounds,	Generates a cellular form to obtain a

Extrusion

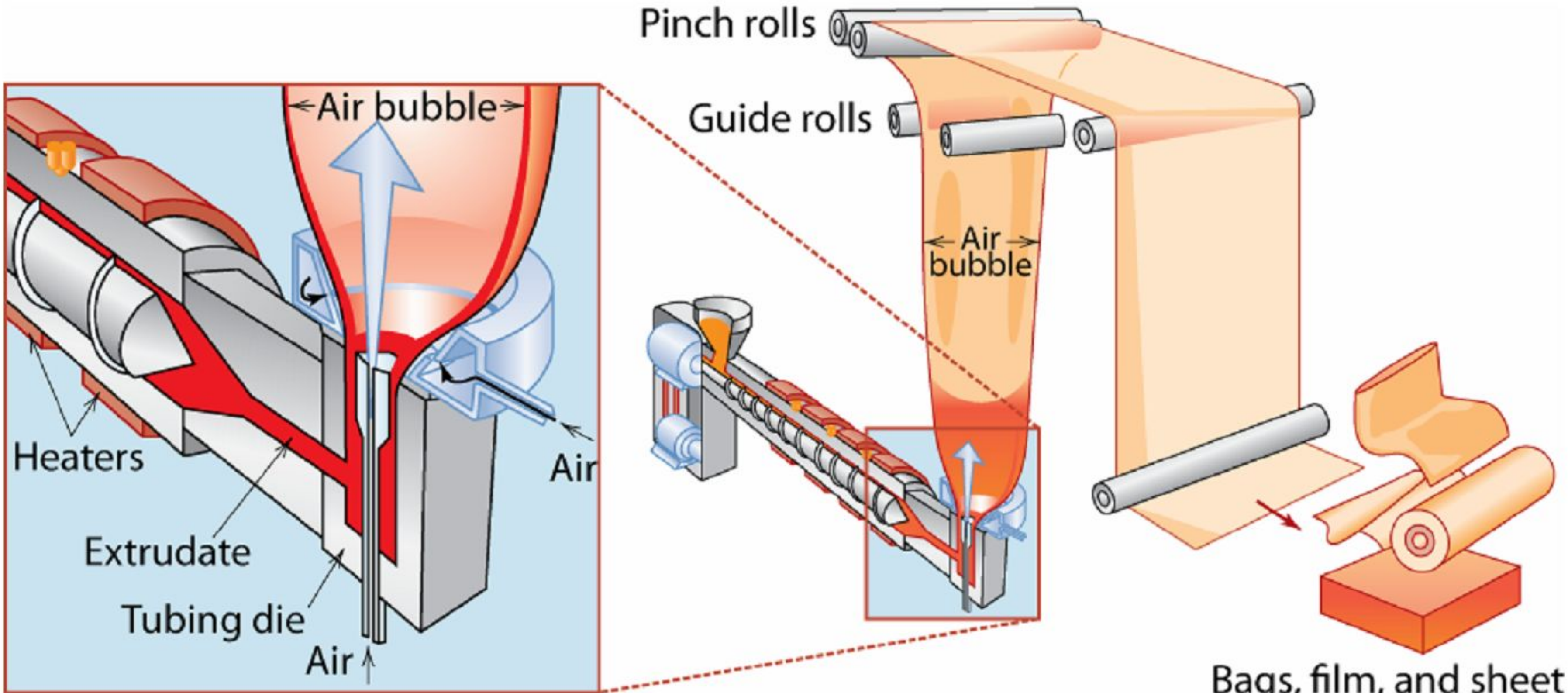

Feed hopper
Plastic pellets
Heaters
Shaping die
Tubing and pipes
Sheet and film
Structural parts
Turning screw
Barrel
Molten plastic
Extrudate

- Shaping: Die shape dictates the nature of the polymer product.
  - Circular die: Melt spinning of fibers
  - Slit die: Sheet casting
  - Annular die:
    - Film blowing
    - Pipes (ϕ > 12 mm) and tubing (ϕ > 12 mm)
    - Wire coating

- Extruder: Plastication
  - Cold polymer granules fed into a hopper and supplied to the screw by gravity
  - Granules advance between the flights of the screw and the hot walls of the barrel
  - As the polymer advances along the extruder, it becomes liquid (by melting or by passing through the glass transition)
  - The polymer becomes pressurized at it moves along the extruder, so it can easily exit the extruder through a die.

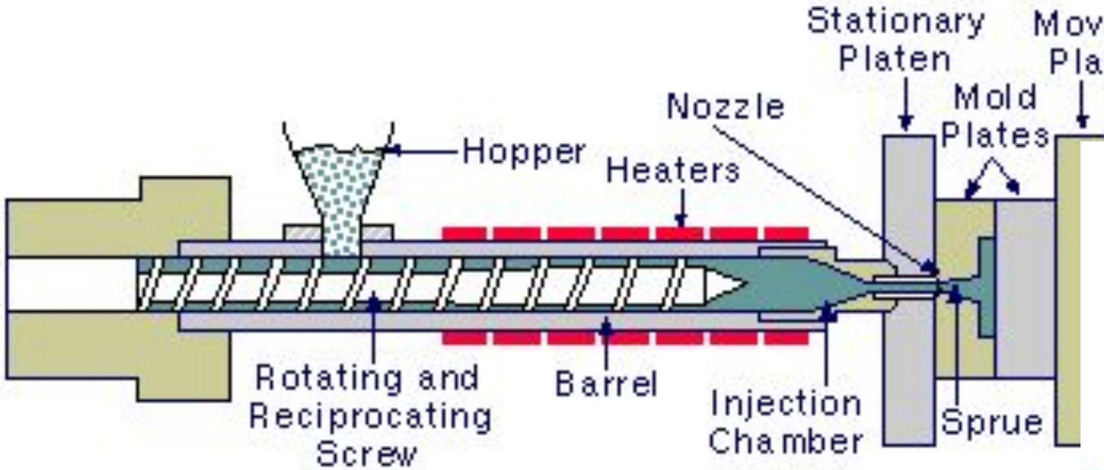


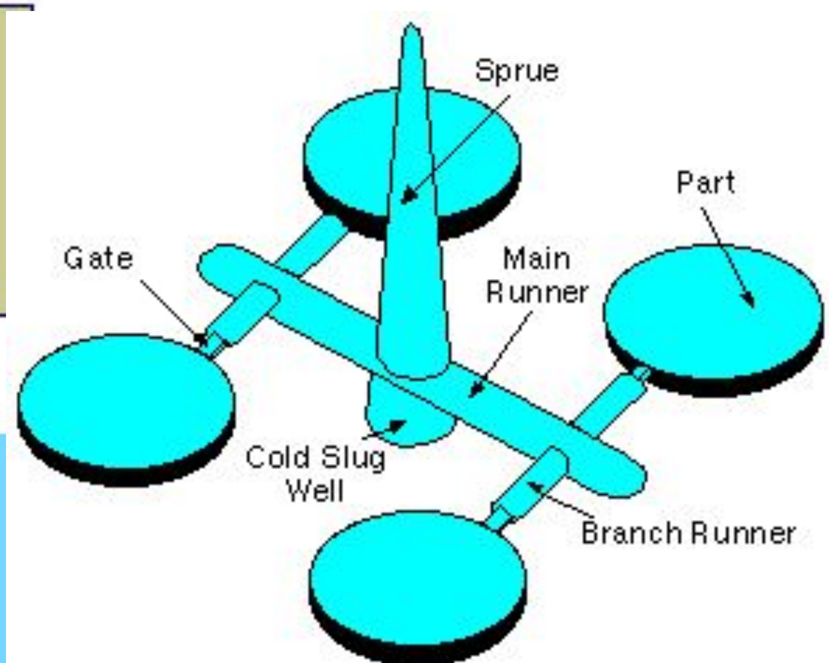
Blown-Film Extrusion

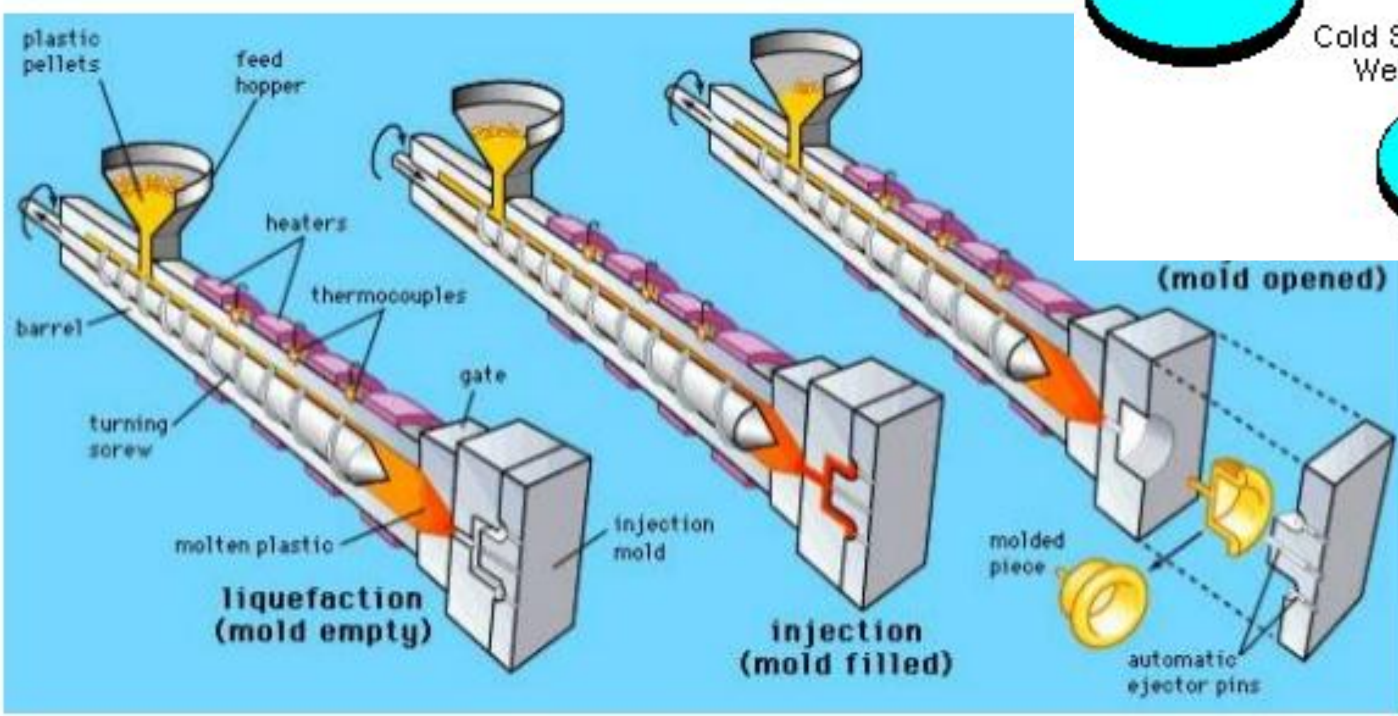


Adapted from Fig. 15.26, *Callister 7e*.
(Fig. 15.26 is from *Encyclopædia Britannica*, 1997.)

Injection Molding

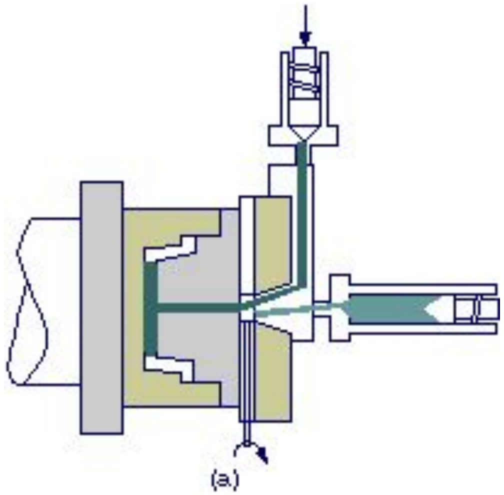




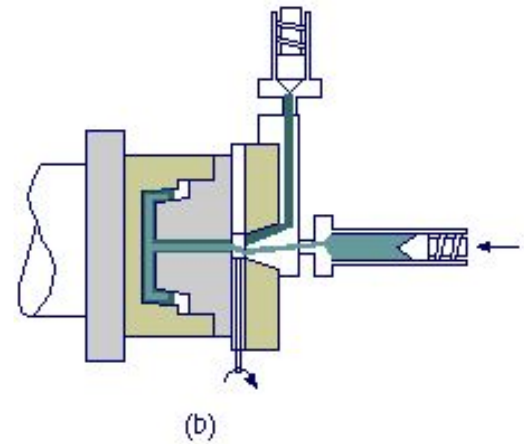


Co-injection Molding

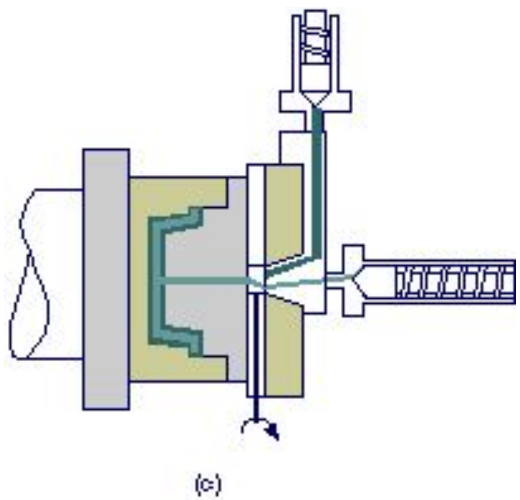
1. Inject Skin



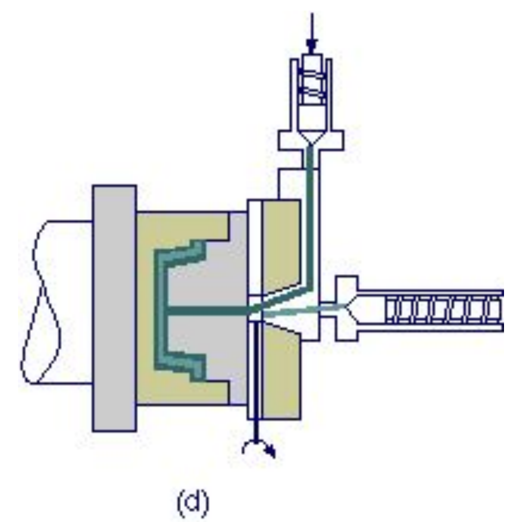
2.a. Inject Core



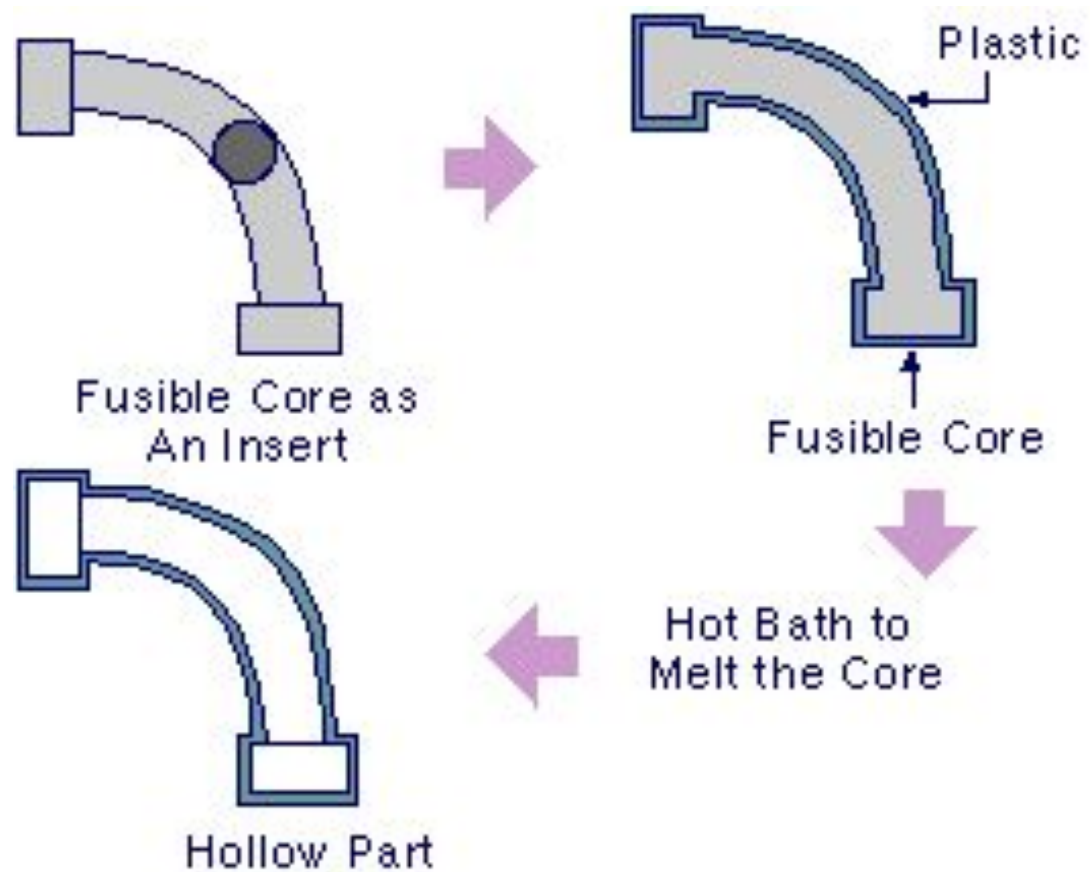
2.b. Continue injecting core until cavity is filled



3. Inject Skin again to purge sprue.

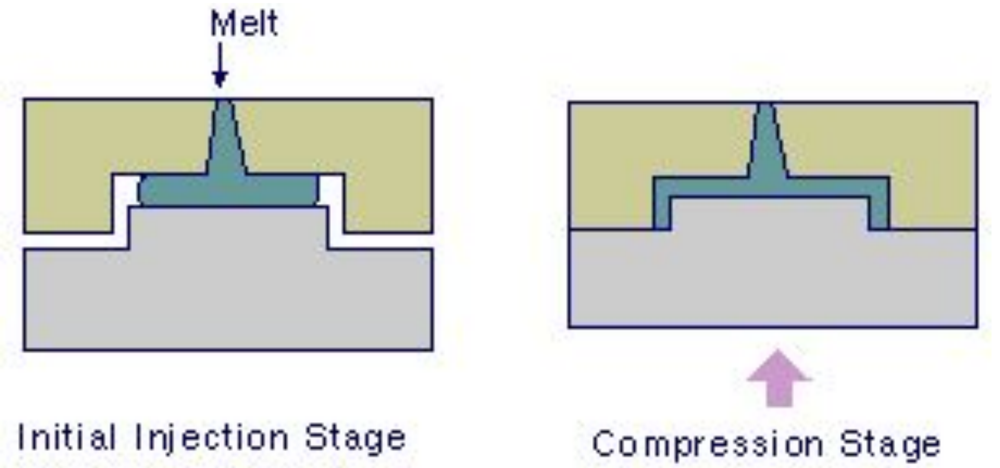


Injecting hollow parts with complex interior geometry

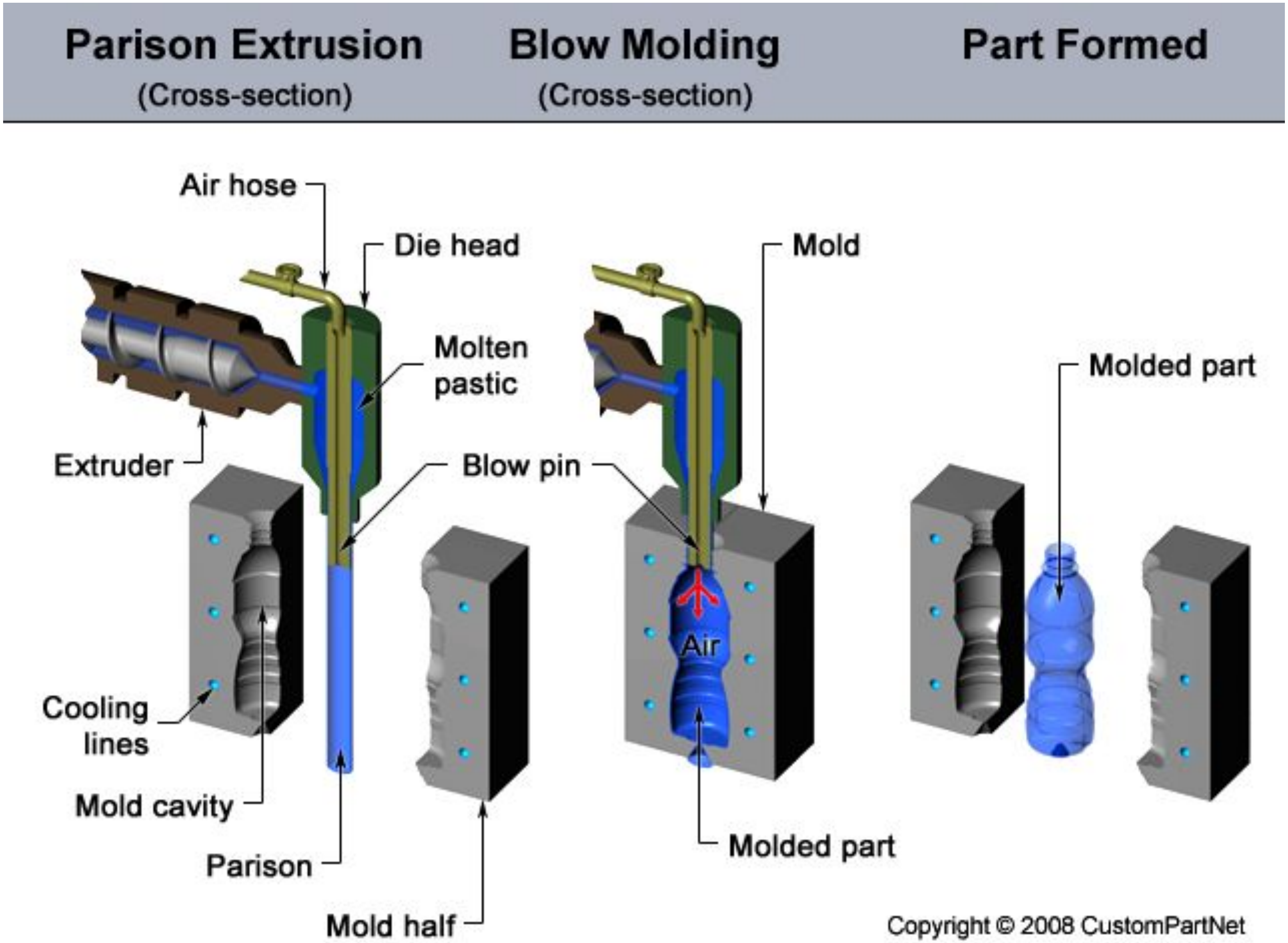


Injection – Compression Molding

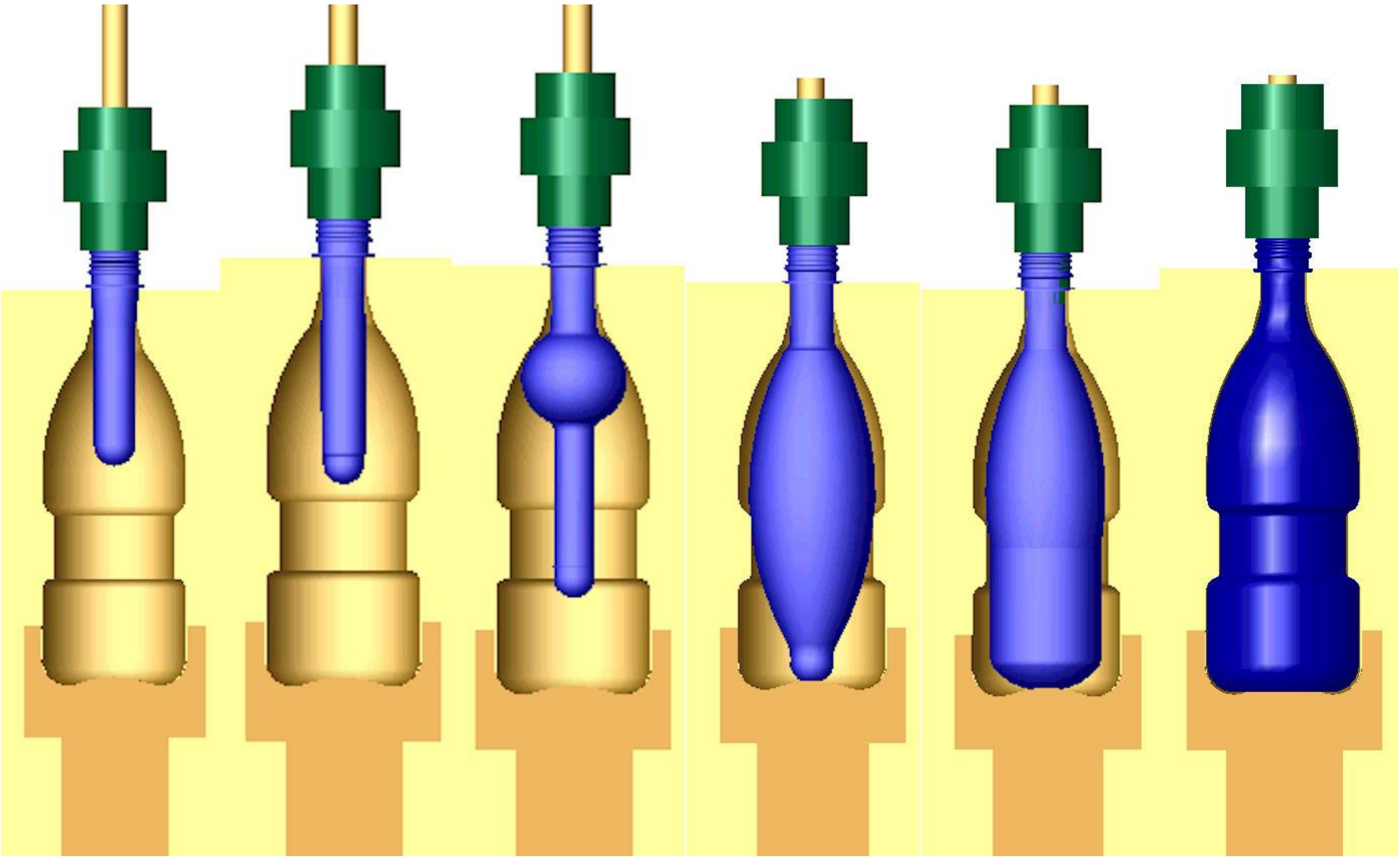
- Very similar to squeeze casting



Extrusion Blow Molding

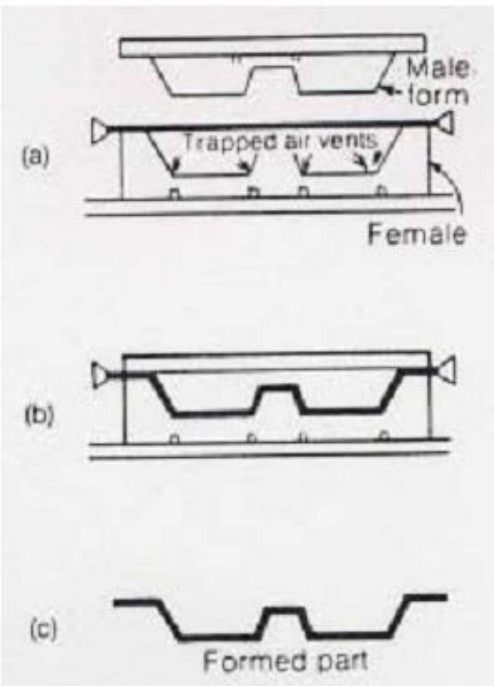


Injection Blow Molding

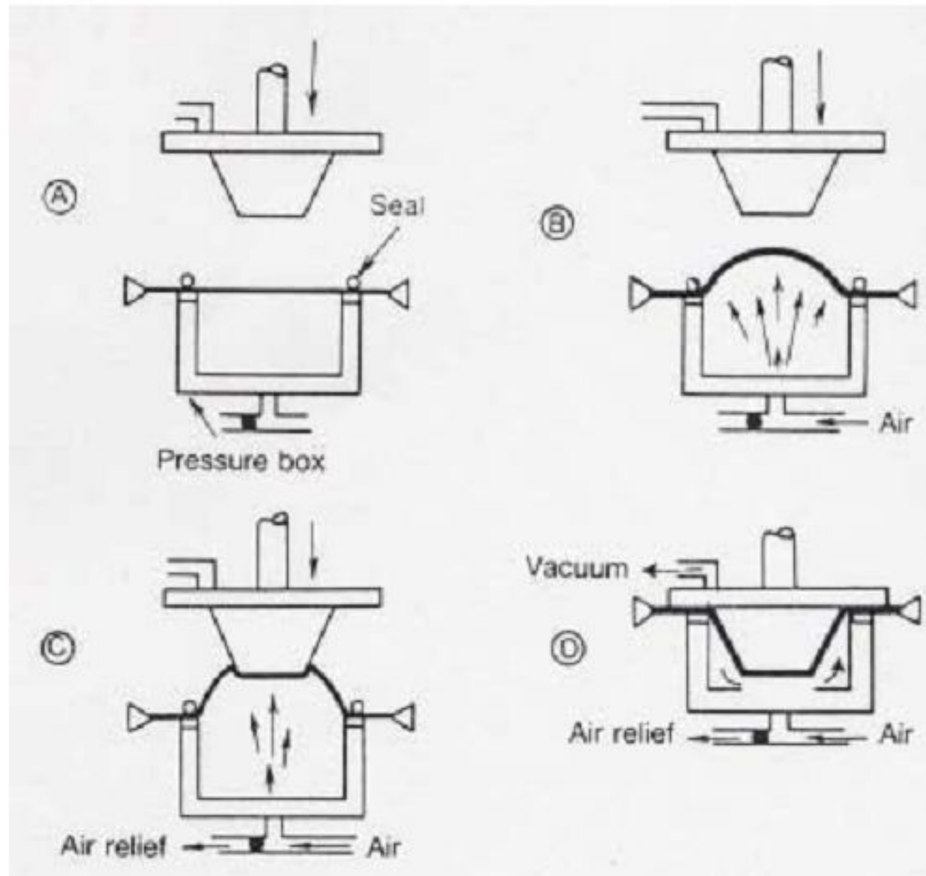


Thermoforming

- Application for large formings, thin wall packaging, short-run or prototype products. Much lower initial investment than injection molding.



With matched molds



Pressure-bubble vacuum-snapback technique

Calendaring

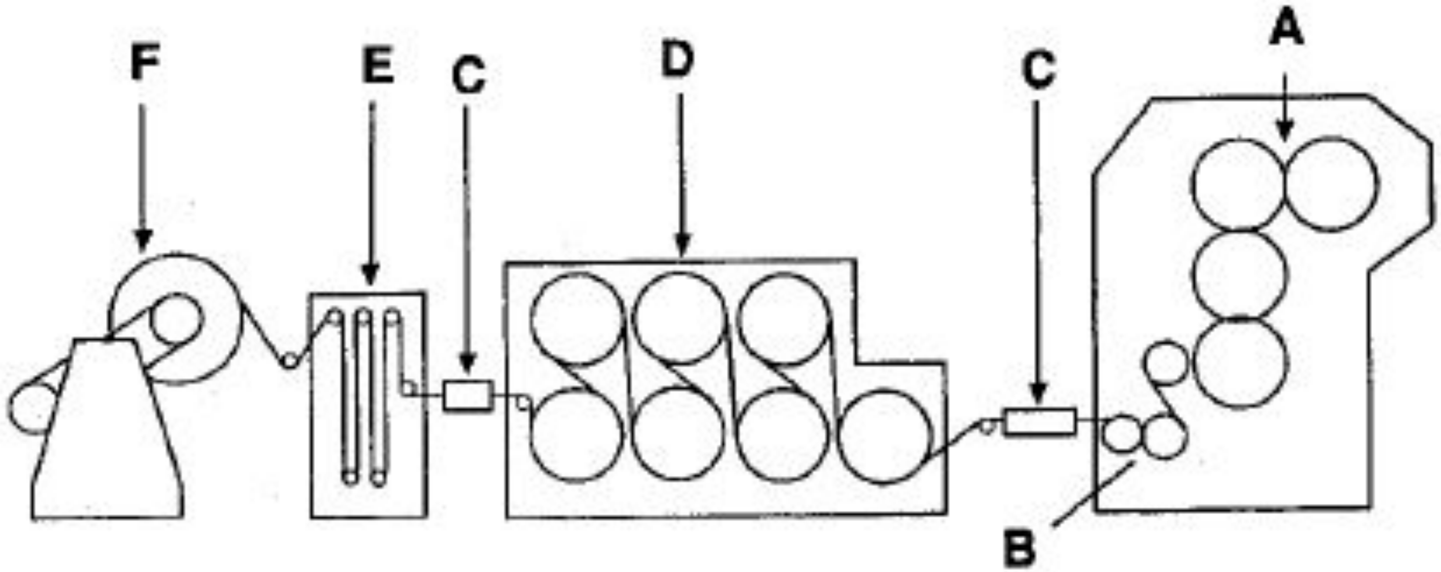


Figure 1.5 Schematic view of an inverted "L" calender plant for the production of plastic sheeting. Molten polymer is dropped into the calender system at **A**. Continuous sheet is formed by passing the melt between the rolls. One of the surfaces is given texture by an embossing roll, **B**. Thickness gauges, **C**, provide data for control of the process. The sheet is cooled, **D**, tensioned using wind-up accumulators, **E**, and accumulated on the wind-up roll, **F** (Holmes-Walker, 1975).

Thin and thick section calendaring is used to make wide sheets (8-12 ft).

Foams

- Major area: insulation for housing, sound control,…
- Materials: polystyrene, polyurethanes, …
- Reaction injection molding example

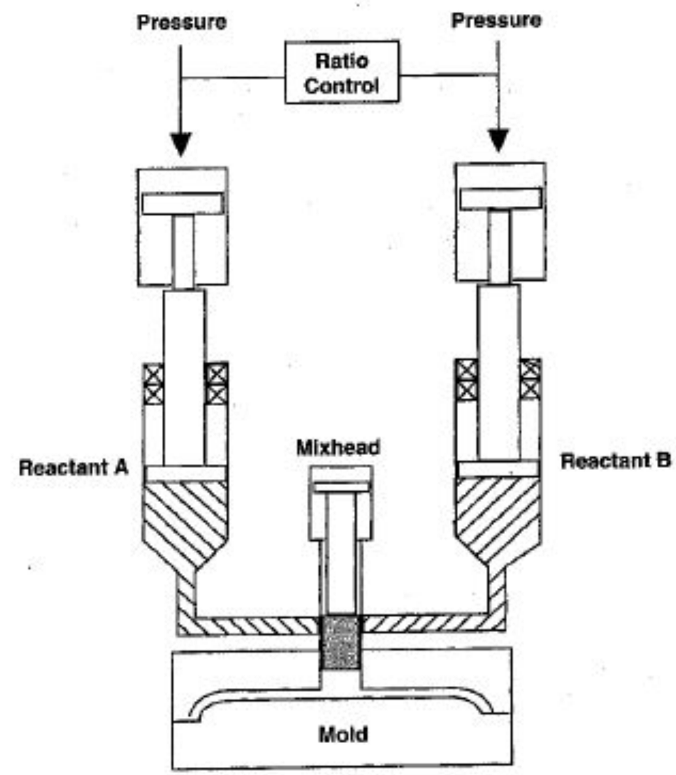


Figure 1.10 Schematic view of a reaction injection molding (RIM) machine. When the mixhead valve opens, two liquid reactants, A and B, flow at high pressure (100–200 bar) into the mixhead chamber. There they mix by impinging flow and begin to polymerize as they flow into the mold (C.W. Macosko, 1989).