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Processing of Plastics

by Albert Spaak*

An overview is given of the processing of plastic materials from the handling of polymers in the pellet and powder form to manufacturing of a plastic fabricated product. Various types of equipment used and melt processing ranges of various polymer formulations to make the myriad of plastic products that are commercially available are discussed.

In a recent report issued by the Stamford Research Institute (*1*), plastics consumption by the year 2000 was forecast at 227 × 10^9 lb. This represents roughly a tenfold increase over 1972 sales (Table 1). This is estimated at an annual growth rate of 8.1% for the rest of this century.

This report outlines briefly the handling and the processing of polymeric materials. Only some of the most basic processing methods are discussed, since each major processing area has specific variations used by specific manufacturing organizations to meet the needs of their markets.

Most of the material in this report has been covered in detail and is available in the trade literature (*2, 3*).

Material Handling

Federal and state laws are not the only reason that processors have automated their material handling requirements. Automated material flow systems are attractive to processors because it reduces labor and avoids spills and other inefficiencies that increase costs.

Polymeric materials can be purchased in a variety of shipping containers, such as multiwall paper bags, paper drum containers, metal and plastic drum containers, skidded boxes, bulk truck deliveries, and dry flow railroad hopper cars.

Processors using polymeric materials are no exception to the profit-motivated move to bulk buying of raw materials and automatic, contamination-free conveying systems. They know that exposing their raw materials to atmosphere is wasteful as well as hazardous.

Bulk plastics can be received in self-unloading bulk truck shipments or in larger amounts via bulk dry flow rail cars. Received materials are stored outside the processing plant in large outdoor silos equipped with filtering vents that meet stringent air pollution codes.

Vacuum pumps unload bulk truck and rail cars into the storage silos. A distribution box at the bottom of the silo provides material flow direction to any number of processing locations inside the plant.

In-plant blending, especially of powdered materials, is rapidly growing in popularity because custom blends are difficult to buy due to resin shortages. In such systems, raw materials, the basic resins are received in bulk, stored in a silo, and drawn into the blending area when needed for custom mixing. From the blender mixed materials flow in tubes automatically and directly to the processing lines.

Automatic weighing and flow controls assure quality and uniformity without manual labor.

Ultrasophisticated systems will even add the chemical additives automatically so that materials are never exposed from storage to the processing line.

* Plastics Institute of America, Stevens Institute of Technology, Hoboken, New Jersey 07030.

Table 1. Plastics, synthetic fibers, and synthetic rubber production.[a]

	Sales × 10^{-9}, lb (1973)	Production, common units		
		1973	1972	1971
Plastics				
Thermosetting resins				
Epoxies (unmodified)	0.22	223	184	169
Polyesters (unsaturated)	1.05	1,051	933	730
Urea resins	0.87	867	739	636
Melamine resins	0.17	170	171	168
Phenolic and other tar acid resins	1.39	1,338	1,453	1,194
Thermoplastic resins				
Polyethylene, low-density	5.80	5,803	5,274	4,458
Polyethylene, high-density	2.64	2,637	2,325	1,924
Polypropylene and copolymers	2.16	2,162	1,726	1,288
Styrene and copolymers	5.02	5,022	4,671	3,748
Poly(vinyl chloride) and copolymers	4.56	4,562	4,259	3,471
Total	20.19	20,186	18,255	14,889
Total plastics	23.88	23,884	21,735	17,786
Synthetic fibers				
Cellulosics				
Rayon	0.90	895	965	915
Acetate	0.46	462	429	476
Total	1.36	1,357	1,394	1,391
Noncellulosics				
Nylon	2.18	2,175	1,975	1,595
Acrylic	0.74	742	626	545
Polyester	2.90	2,901	2,339	1,831
Olefin	0.49	492	417	322
Glass Fiber	0.69	689	572	468
Total	7.00	6,999	5,929	4,761
Total synthetic fibers	8.36	8,356	7,323	6,152
Synthetic rubber				
Styrene–butadiene	3.39	1,512	1,476	1,416
Butyl	0.35	157	129	106
Nitrile	0.19	83	73	65
Polybutadiene	0.74	332	294	254
Polyisoprene	0.26	117	132	117
Ethylene-propylene	0.26	118	90	60
Neoprene and other	0.60	266	223	222
Total synthetic rubbers	5.79	2,585	2,417	2,240

[a] Data of Society of the Plastics Industry, Tariff Commission, Textile Economics Bureau, Rubber Manufacturers' Association, and Bureau of the Census.

Processing of Plastics

Blow Molding

A highly sophisticated process, blow molding uses a wide variety of equipment types to produce containers which range in size from less than an ounce to 55 gal and larger. This process is also used for the manufacturing of industrial and consumer parts unrelated to containers. In fact, any thermoplastic can be blow-molded with varying degrees of success. Commercially, however, many more containers are produced by blow molding than any other processes, and high-density polyethylene is used in blow molding more extensively than all other resins combined.

The blow molding process itself consists basically of heating a hollow tube of a particular plastic to its softening point, placing it between the faces of a cold mold and forcing high pressure air into the center of the hollow tube or parison. The hot plastic is expanded against the cavity of the mold and allowed to cool, in place. When the cooling process is completed, the mold is opened and the blow-molded article is removed (Figs. 1 and 2).

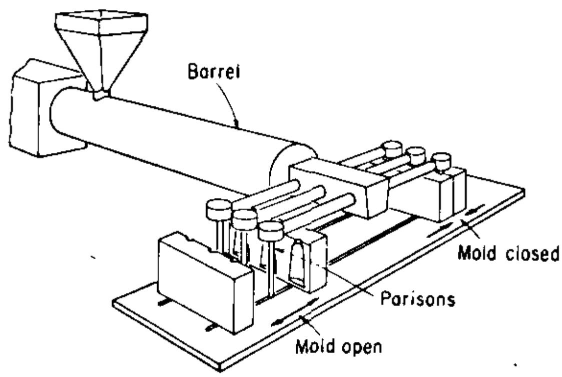

FIGURE 1. Intermittent extrusion. Two mold banks with multiple parisons.

All types of blow molding involve three basic steps: a hollow tube of molten resin called a parison is formed; the parison is positioned between molded halves; the parison is blown so it fills the shape of the mold.

Calendering

The process of calendering generates far greater output than any other type of process. Modern day calendar lines are designed with thruput capacities ranging from 2,000 to 10,000 lb/hr.

Poly(vinyl chloride) sheet and film make up the majority of plastics calendering production. Ionomers, ABS, polypropylene lubricated poly-

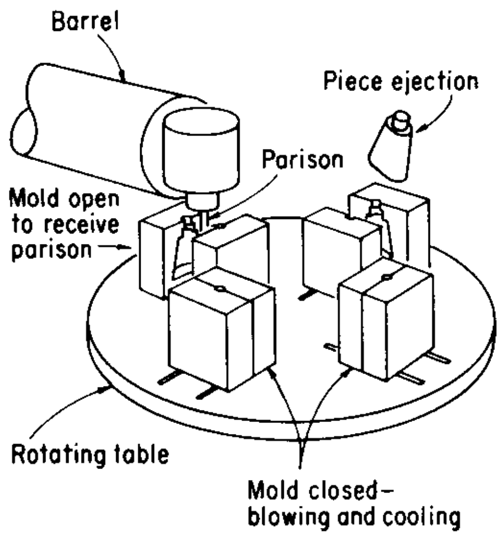

FIGURE 2. Intermittent horizontal rotation of turntable.

ethylene and rubber-modified polystyrene are among the other types of plastic materials which can be calendered.

The process of calendering has been devised to create sheets of thermoplastic plastics to a desired thickness. This is done by passing the polymer between a set of rollers (Fig. 3). Circulating water or steam is utilized to control the temperature of the rolls.

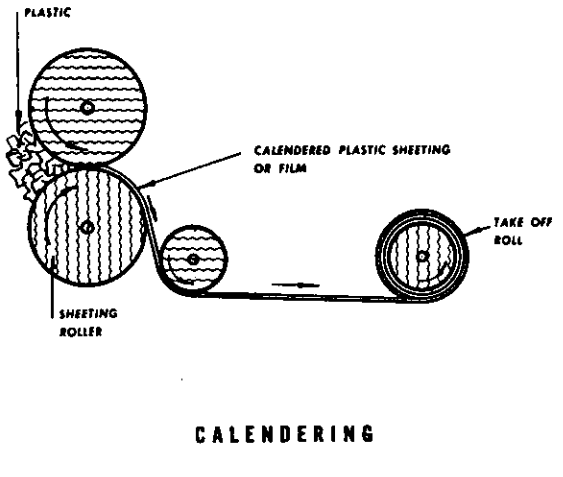

FIGURE 3. Calendering unit.

The calender generally operates in four-roll units made up of three banks, each bank being wider than the preceding one. The inverted "L" is the most frequently used roll arrangement for plastic sheeting. This configuration has several advantages in that the vertical three-roll stack provides greater stiffness and more rigidity.

Casting and Embedding

From the point of view of investment in tools and equipment, the two most convenient ways of handling liquid polymers are gravity and vacuum casting. Casting is a method used for insulating implanted electronic components, embedding museum specimens, obtaining impressions, or casting molds. Usually, liquid polymer is mixed with its crosslinking agent and poured about on object. To eliminate entrained air, the assembly can be placed in a vacuum chamber and cycled one or more times at a negative pressure.

Once the polymer has solidified and cured, the molded object is ready for use.

A refinement of this process includes the use of centrifugal force to increase the density of the resin by excluding entrapped air. This process is similar to gravity and vacuum casting with the exception that centrifugation occurs prior to solidifying.

Transfer Molding

In transfer molding a predetermined amount of thermoset polymer is heated and then forced by a ram into a hot mold cavity for curing. Although similar to compression molding in many respects, transfer molding provides greater control over the thickness of the part, minimizes flash at the parting line, and is more readily accommodating to inserts.

Compression Molding

A commonly used molding method which is applicable to large and small items of many various shapes is compression molding. Both thermosetting materials and thermoplastics can be compression-molded, since they undergo both physical and chemical changes. In this process, the open cavities of a heated mold are filled with the material which is caused to flow by closing the mold under high pressure (Fig. 4). This compresses the material and shapes it in accordance with the two mold halves which come together. A flash is created in this process

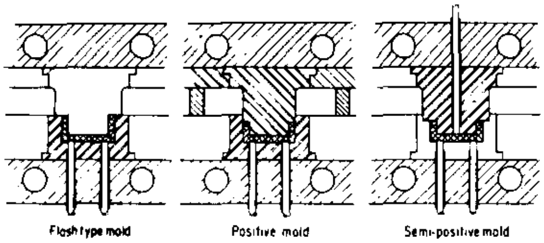

FIGURE 4. Three types of compression molds.

since excess material must escape at the parting line.

Coating

There are two methods of coating which are in general use. In the first method, webs or other substrates are coated with elastomerics or plastics from solutions. The substrate is generally fed through a solvated polymer bath, where the appropriate amount is applied and then fed through a heated chamber, which drives off residual solvent and crosslinks the film.

The second method of coating is extrusion coating. In this method, molten thermoplastic sheet is discharged from a slotted die onto a substrate or web of paper, cellophane, paper board, polyester, or polyolefin material of extrusion coating. The coating substrates and molten material are extrusion coated. The moving substrates and molten plastics are then combined in a nip between a rubber and chill roll and then wound into a roll form (Fig. 5). An item familiar to many people is the polyethylene-coated milk carton.

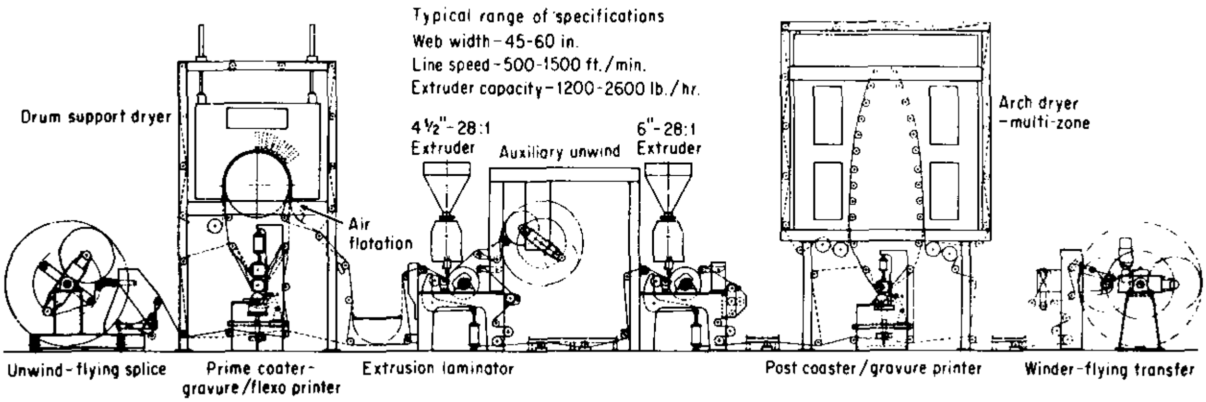

FIGURE 5. Tandem coating on typical flexible packaging line.

Powder Coating

The early development of adequate and suitable PVC materials was made possible largely thru the use of fluidized bed for the application of thermoplastic materials. The early successes and broad use of the fluidized bed and the use of electrostatic spray has encouraged manufacturers to offer additional material types. Some of these were earlier available as casting resins but they did require conversion to a form suitable for powdered coating. Available today are polyethylene, cellulose acetobutyrate, nylon, chlorinated polyethers, polytetrafluoroethylene, and polypropylene powders.

Thermoplastic materials can be used for producing heavy chemical and abrasion-resistant coatings on wire goods. Most of the materials applied before the introduction of the electrostatic spray were of this character.

A bed-fluidized plastic powder is created by constructing a container which has an upper open section and lower closed section, separated by a porous plate. The plastic powder is placed on the porous plate in the top compartment. Air brought into the lower section flows upward through the plate and powder. This fluidizes the powder, giving it all the physical properties of a fluid in such an expanded quantity. The powder must be kept uniformly aerated by using dry air and vibrating the bed.

The part which is to be coated is heated to a temperature above the fusion temperature of the powder. After heating, it is lowered into the bed to a point below the upper expanded surface of the powder. That powder which contacts the hot surface fuses and attaches itself to the part, which is manipulated while immersed so that all surfaces are equally exposed. When the part is withdrawn, any unused powder is dumped or blown from the part.

The electrostatic powder process is similar, but in this method the particles of coating are given an electric charge of one polarity and the item which is to be coated is given a charge of opposite polarity. When the two are brought into proximity, the electrical attraction which exists causes the powder to accumulate on the item's surface. The various equipment arrangements available are but different approaches to charging and distributing the particles about the article so the attraction can be effective.

Extrusion

Thermoplastics are converted from raw granular or powdered material to continuous lengths of finished products thru the extrusion process. These products include sheet, film sheeting, rod, pipe or specialized profiles, or filament. Wide use of the extruder is made in the application of insulation and also the jacketin gused in wire and cable. The process is also used quite often to coat a substrate of paper, foil or cloth with a continuously applied film of plastics (Fig. 6). Parisons for blow molding systems are supplied by extruders.

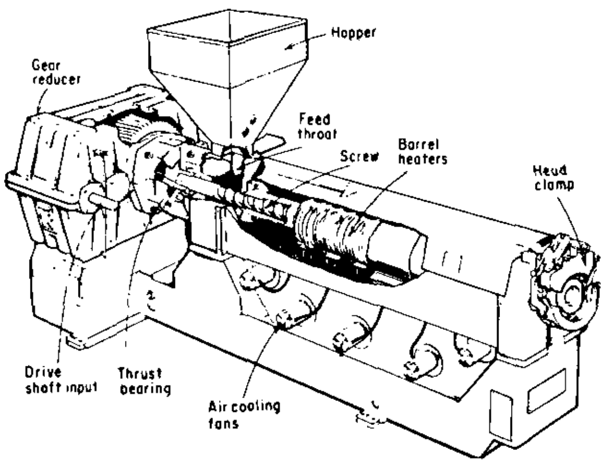

FIGURE 6. Cutaway view of a typical single-screw extruder with resistance heating and air cooling on barrel.

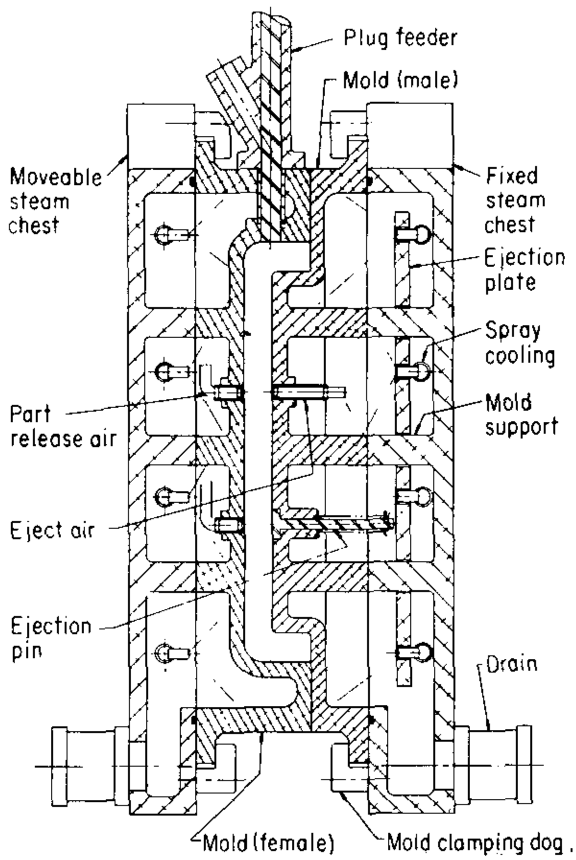

FIGURE 7. Typical expandable polystyrene mold mounted on steam chest.

Foam Processing

Expandable Polystyrene Molding: Molding expandable polystyrene is a two-step process. The raw material is in the form of small solid beads and contains a blowing agent. In the first step, heat is applied to reduce the density of the raw material by pre-expansion to the density which is required for the final molded part. The expanded beads are packed into a mold and reheated to seal the beads together, forming a closed-cell structure (Fig. 7).

Urethane Foam Processing: A metering-mixing and dispensing machine is used in polyurethane foam processing. It is important that the machine be of a recirculating type so that if the machine is operating but not dispensing, the flow of each component goes from the material reservoir to the metering pump through a heat exchanger to the mixing head.

To be considered a high foam processing machine, the equipment must be capable of delivering the components, such as a polyol and an isocyanate mixed at the proper ratio to a mold or cavity. It is important that there is capability for the components to all arrive at the mixture simultaneously and at the correct temperature to assure proper mixing and chemical reaction of the foam.

Extruded Polystyrene Foam: A three basic forms of polystyrene foam which are extruded are slab, sheet, and profiles. Polystyrene foam is widely used primarily because of two attractive features: its low cost and its outstanding physical properties, i.e., attractive appearance, thermal insulating qualities, cushioning ability, moisture resistance, and rigidity.

Foam Melt Methods: While a number of techniques are used to produce structural foam parts by injection molding or extruding a foamable melt, they must all have the availability to produce, in a single step, a structure of solid outer skins and integral foam interior. In addition, they must all have, in varying degrees, the ability to control wall thickness and foam density.

There are three advantages in structural foam molding which should be mentioned: lightweight, structurally adequate parts with finely, detailed surfaces can be produced; most processes are low-pressure types from which large parts can be processed with low-tonnage machines and economical molds; a strength and economy superior to that of solid molding is available because the rigidity varies directly with density.

Injection Molding

In injection molding, thermoplastic polymers are heated to a molten state and are forced under pressure into a relatively cooled mold where the polymer solidifies to form the object.

The viscous liquid is normally injected into the mold at pressures up to 20,000 psi. The force which is required to clamp the mold halves together normally ranges from 1 to 5 tons/in. of projected area of the part being molded. The tonnage required is influenced by the dimensions of the part, the type of material and the design of the part.

Normal scrap generated in the injection molding of thermoplastics materials can be ground into small particles and reused. This adds to the economical features of the process.

The products requiring intricate shapes and tight tolerances most readily lend themselves to injection molding. Thermoplastics, fast-curing elastomers, and thermosetting resins can be injection-molded.

There is a wide range of sizes and types of injection molding machines available. They can offer manual, semiautomatic or automatic operation. Their size rating is determined by the quantity of material which can be injected in one cycle, which can range from a fraction of an ounce in small laboratory models to several pounds in large production machines.

Two units comprise the injection molding machine: one for opening and closing the mold and the other for injecting the plastic material. A hydraulic or toggle-operated moving platen and a stationary platen comprise the first half. The mold halves are fastened securely to these platens.

A feed hopper, a controlled feeding device, and a heated injection extrusion screw which reciprocates to act as a plasticizer and plunger comprise the second half.

Various formulations of thermoplastics can be supplied by manufacturers for the most efficient production and the most desirable properties in the finished product. To be injection-molded, a plastic must have good flow properties. Flow, as related to injection molding is defined as the amount of travel a plastic material undergoes when it is subjected to heat and pressure.

Forging and Solid-Phase Forming

Complete melting of the material before forming has been involved in most commercial processing methods to date. Recently, however, *forming of thermoplastics in a solid phase* by applying well established metal working techniques has been studied extensively.

Variously known as forging and phase forming, forging refers to fabrication by bulk deformation of material in constraining dies by application of force. It requires the steps shown in Figure 8.

Forging has a number of advantages: (1) it enables the processor to form parts as thick as 1 in. or more with reduced cycle time that is

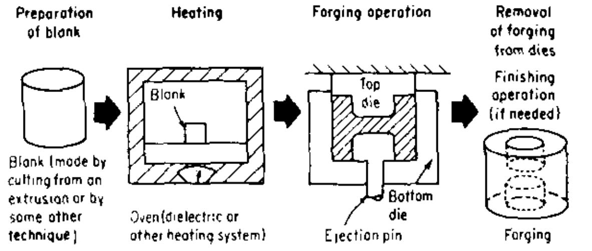

FIGURE 8. Schematic diagram of steps required in forging of plastics.

nearly independent of part thickness; (2) available forging presses in metalworking forge shops and compression molding presses can be utilized; (3) hard-to-work materials such as those with high molecular weight, those susceptable to rapid thermal degradation or materials with fillers and reinforcements can be feasibly forged; (4) products show improved mechanical properties because of preferential molecular orientation; (5) increased economy in cost of equipment and reduction of tooling cost is also possible for production items.

Rotational Molding

Rotational molding is also called rotomolding or rotocasting and differs from other techniques such as blow and injection molding in that hollow items of any size or shape as well as solid items can be readily made, and the resin melts in the mold and does not require a driving pressure.

In rotational molding, rigid or resilient hollow bodies are formed from powdered plastic materials or vinyl plastisols by being heated and rotated simultaneously in two planes perpendicular to each other. The plastic particles contact, melt or fuse, as the case may be, on the inner surfaces of the hot molds and build up in thickness until all the material is fused and the finished product is formed.

The most popular rotomolding system uses a horizontal rotating unit commonly called the carousel. This normally has three arms on which molds are mounted.

Rotational molding can be classified thermodynamically as an unsteady heat transfer process; i.e., the mold temperature never reaches equilibrium and is constantly rising or falling throughout the entire cycle; therefore, the temperature of the resin within the mold is also constantly fluctuating.

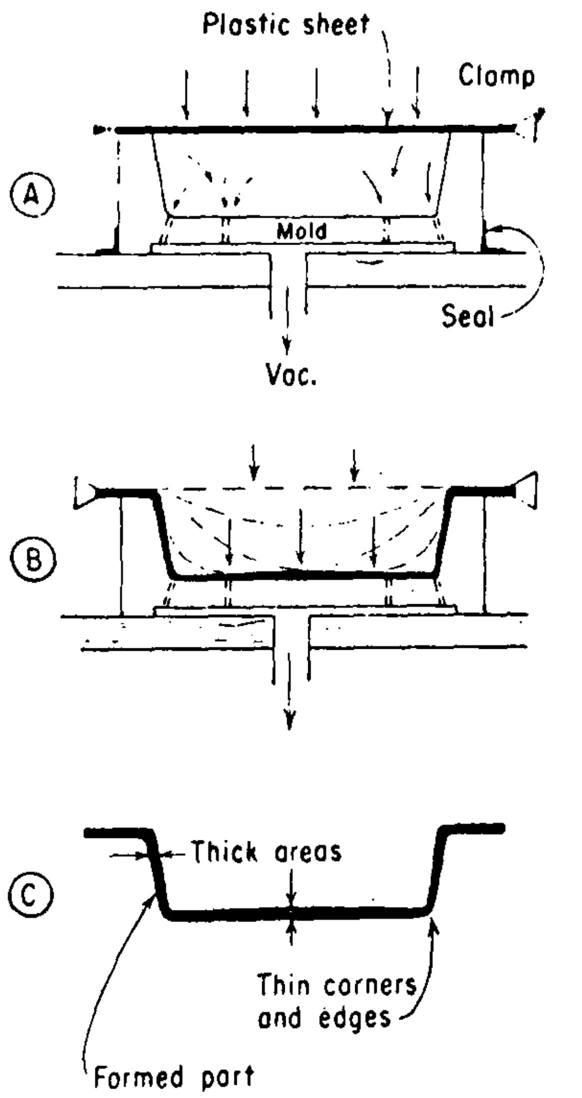

FIGURE 9. Thermoforming techniques. In straight vacuum forming, the plastic sheet is clamped and heated. A vacuum beneath the sheet (*A*) then causes atmospheric pressure to push the sheet down into the mold. (*B*) as the plastic comes in contact with the mold, it cools. (*C*) areas of the sheet reaching the mold last are thinnest.

Thermoforming

A heated plastic sheet can be made to conform to the shape of a solid mold through vacuum and/or pressure in the process of thermoforming. Heated to a compliant state, the plastic sheet is then securely placed over a sealed chamber containing the mold. The plastic is drawn over the mold when the vacuum maintained in a reservoir tank is opened (Fig. 9).

There are many basic types of thermoforming techniques. The most common are the single-station and rotary sheet-fed machines. One heating station and one forming station comprises the single-station machine; the rotary machine is made up of one loading (sheet) and unloading (finishing part) station, one or two heating stations, and one forming station.

The rotary machine operates in a manner similar to a merry-go-round owing to the fact that there is always a sheet in each of the three or four stations, providing a considerably greater output than a single station machine.

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