POLYMER PROCESSING

MODULE - IV

BLOW MOLDING – THERMOFORMING – CALENDERING

Module 4:

Classification, Machinery, process details, analysis, defects, remedies:

Blow moulding,

Thermoforming,

Calendering [8]

BLOW MOLDING

•It is originally evolved from glass blowing technology.

•It was developed as a method for producing hollow plastic articles such as bottles and barrels.

•Advantages of blow molding are Possibility of irregular curves, Low stresses, Possibility of variable wall thicknesses, Favorable cost factors.

•The basic process involves producing a plastics parison or preform, placing this parison or preform into a closed two plate mold, injection of air into the heated parison to blow it out against the mold cavity, permit cooling of the expanded parsion, opening the mold and removing the rigid blow molded part.

•Blow molding techniques can be divided into major categories:

•Extrusion BM that uses an unsupported parison

•Stretch Injection BM process that uses a preform supported on a metal core pin.

BLOW MOLDING

•EXTRUSION BM:

•Initially a molten tube of plastic called the parison is extruded through an annular die. A mold then closes round the parison and a jet of gas inflates it to take the shape of the mold.

•In this process the extruder continuously supplies molten polymer through the annular die. In most cases the mould assembly moves relative to the die. When the mould has closed around the parison, a hot knife separates the latter from the extruder and the mould moves away for inflation, cooling and ejection of the moulding.

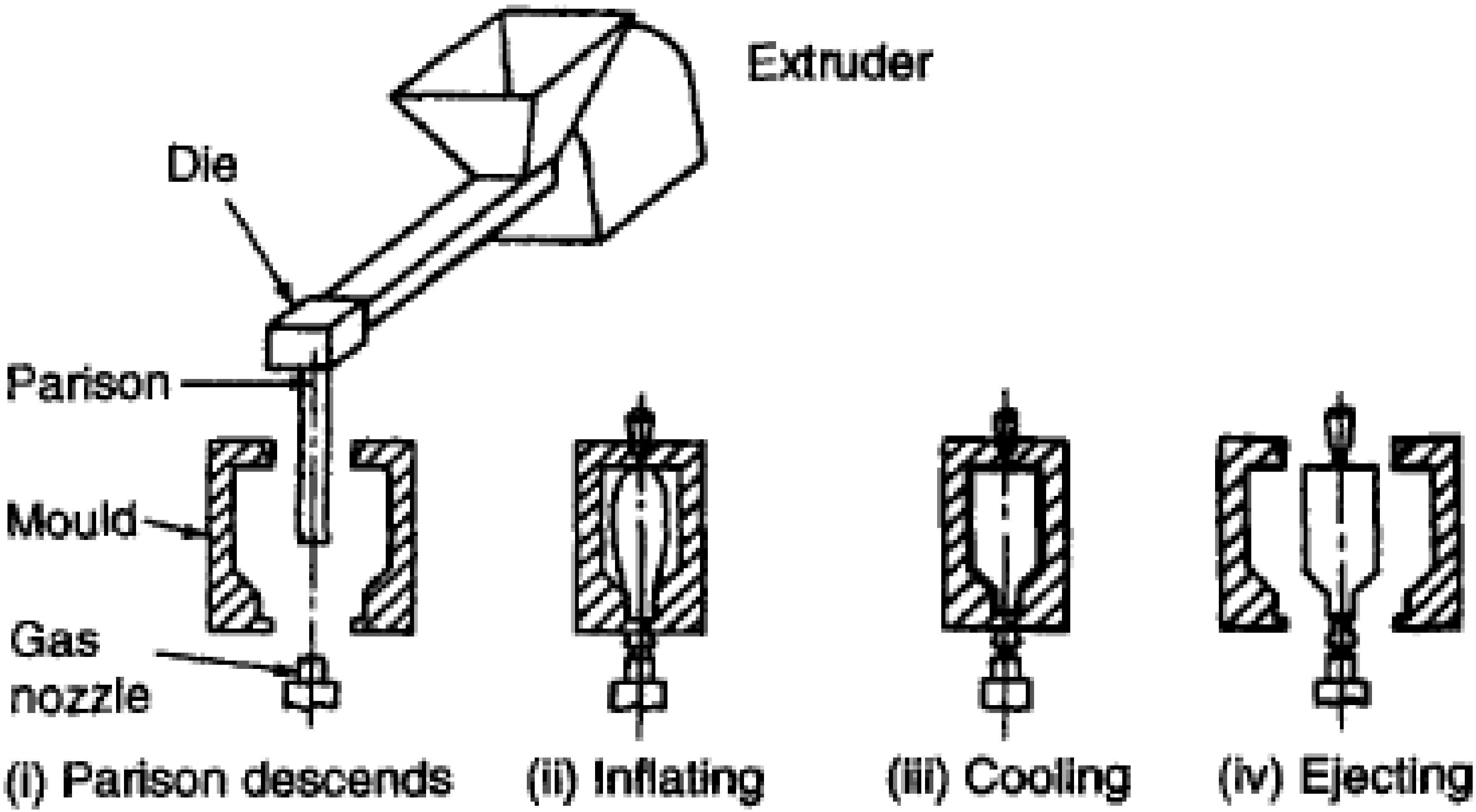
•Meanwhile the next parison will have been produced and this mould may move back to collect it or, in multi-mould systems, this would have been picked up by another mould. Alternatively in some machines the mould assembly is fixed and the required length of parison is cut off and transported to the mould by a robot arm.

• During molding, the inflation rate and pressure must be carefully selected, so that the parison does not burst.

•Extrusion blow moulding is continually developing to be capable of producing even more complex shapes. These include unsymmetrical geometries and double wall mouldings.

BLOW MOLDING

•EXTRUSION BM:



BLOW MOLDING

•EXTRUSION STRETCH BM:

•Molecular orientation has a very large effect on the properties of a moulded article.

•During conventional blow moulding the inflation of the parison causes molecular orientation in the hoop direction.

•However, bi-axial stretching of the plastic before it starts to cool in the mould has been found to provide even more significant improvements in the quality of blow-moulded bottles.

•Advantages claimed include improved mechanical properties, greater clarity **and superior** permeation characteristics.

•Cost savings can also be achieved through the use of lower material grades or thinner wall sections.

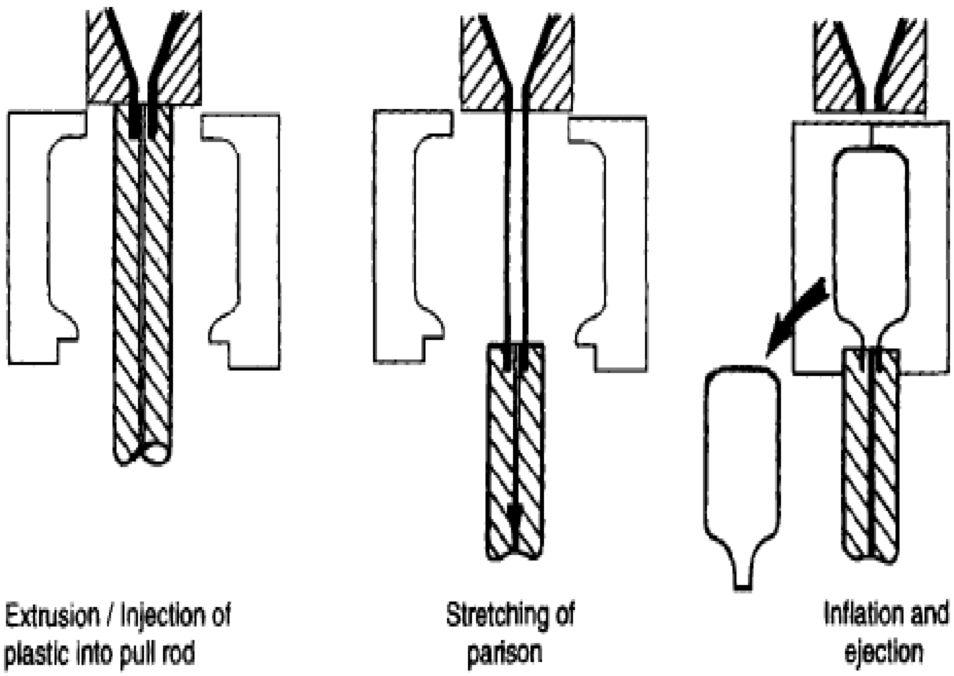
•Biaxial orientation may be achieved in blow moulding by

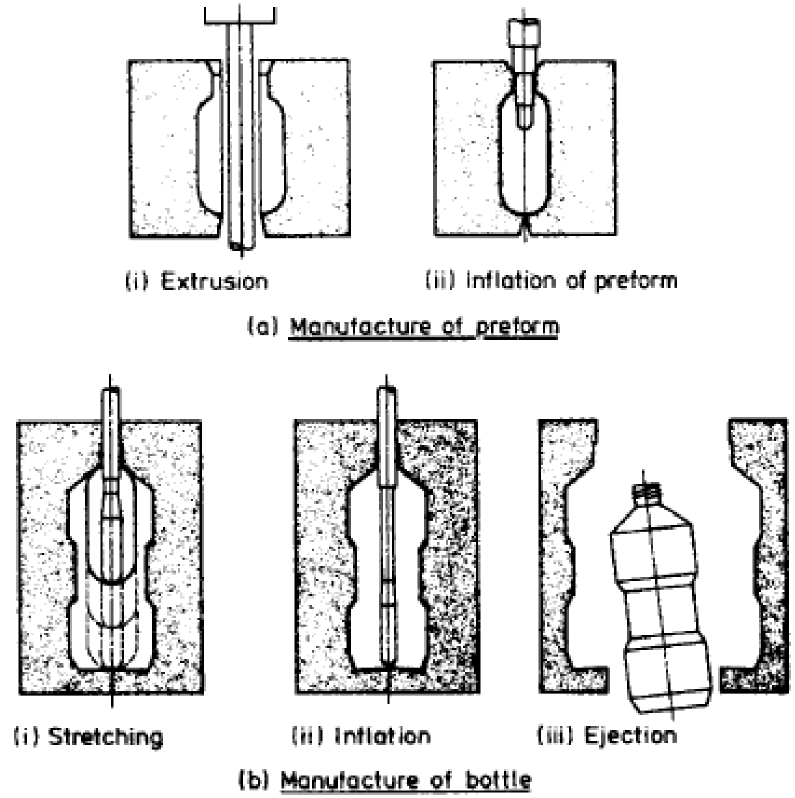
•(a) stretching the extruded parison longitudinally before it is clamped by the mould and inflated. In this case, molten plastic is extruded into a ring mould which forms the neck of the bottle and the parison is then stretched. After the mould closes around the parison, inflation of the bottle occurs in the normal way.

•(b) producing a preform 'bottle' in one mould and then stretching this longitudinally prior to inflation in the full size bottle mould.

BLOW MOLDING

•EXTRUSION STRETCH BM:





BLOW MOLDING

- INJECTION STRETCH BM:
- This is another method which is used to produce biaxially oriented blow moulded containers. However, as it involves injection moulding.
- It is now very widely used for the manufacture of bottles for soft **drinks.**
- Initially a preform is injection moulded. This is subsequently inflated in a blow mould in order to produce the bottle shape. In most cases the second stage inflation step occurs immediately after the injection moulding step but in some cases the preforms are removed from the injection moulding machine and subsequently re-heated for inflation.
- The advantages of injection blow moulding are that

(i) the injection moulded parison may have a carefully controlled wall thickness profile to ensure a uniform wall thickness in the inflated bottle.

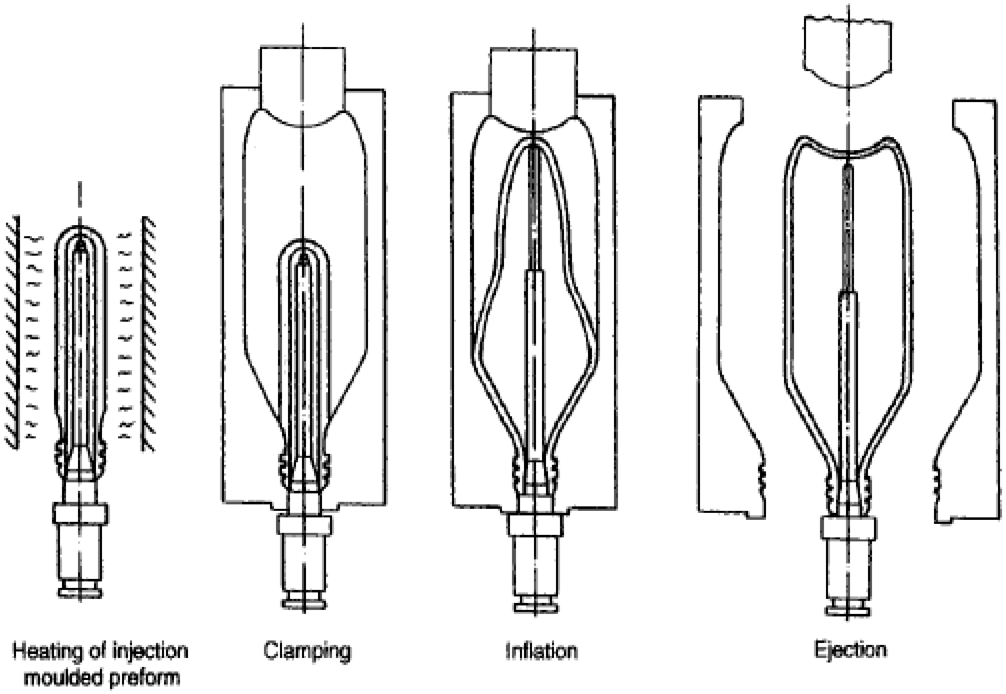
(ii) it is possible to have intricate detail in the bottle neck.

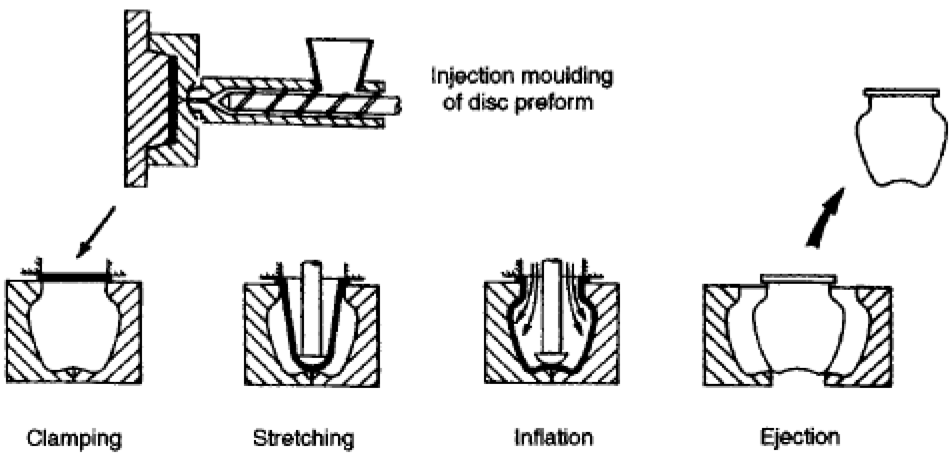
(iii) there is no trimming or flash

- It may be seen that the method essentially combines injection moulding, blow moulding and thermoforming to manufacture high quality containers.

BLOW MOLDING

- INJECTION STRETCH BM:





BLOW MOLDING

•EXTRUSION BM:

•Basic EBM consists of an Extruder, Cross-head die, Clamping arrangement and mold.

•EXTRUDER:

•It is a three step process – feed, compression and metering section and finally the plastic is in molten form and provides a consistent flow of materials to the extrusion head.

•EXTRUSION HEAD:

•After the plastic has been melted, the resin is fed into the extrusion head and further it contacts a mandrel.

•The melt stream divides, flows around the mandrel, welds together and makes a 90 deg turn so the flow is vertically downward.

•The resin then flows through an annulus formed by a mandrel and a die.

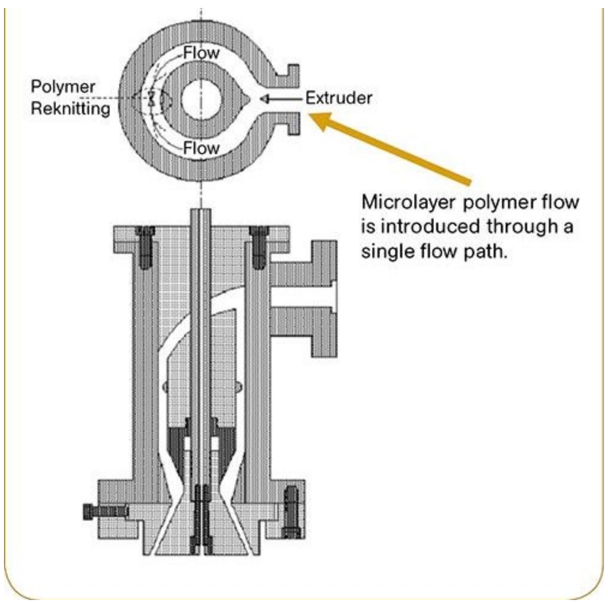
•The mandrel and die are sized to produce a blow molded part having the desired wall thickness.

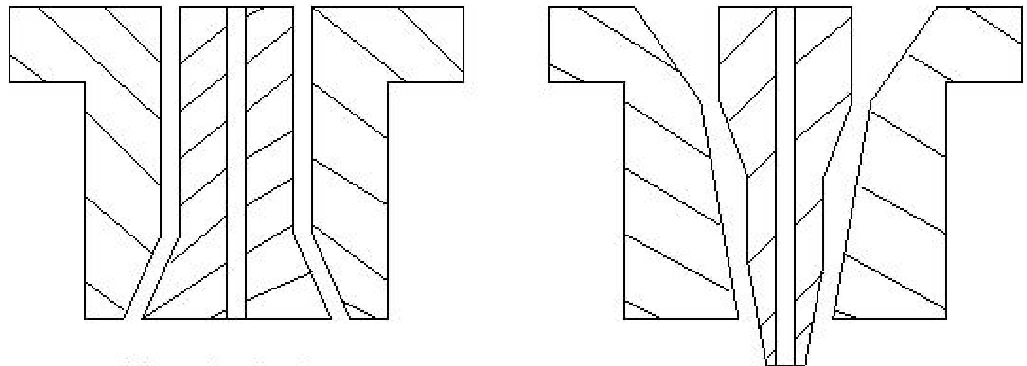
•The mandrels are mounted directly to the programming mandrel and are programmed up & down to open or close the gap between the pin and bushing.

BLOW MOLDING

•EXTRUSION BM:

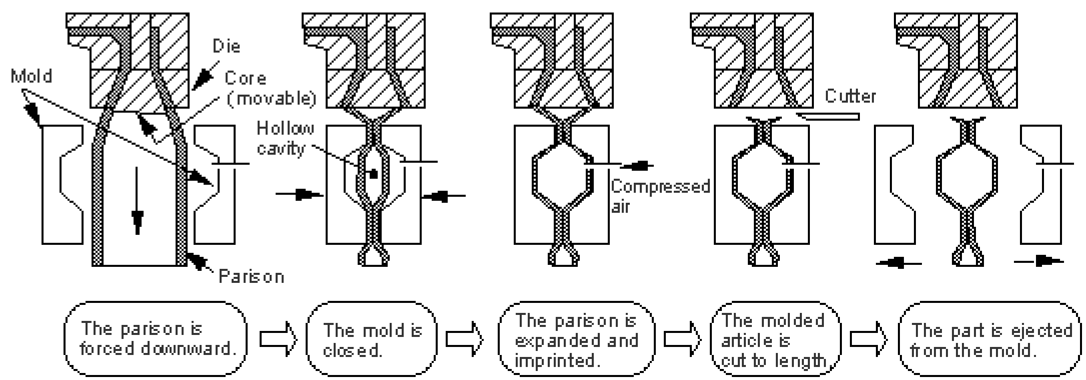
•Thus the parison wall thickness can be adjusted to allow for more materials in certain spots of the parison. This is commonly known as parison programming and is controlled electronically by the microprocessor.

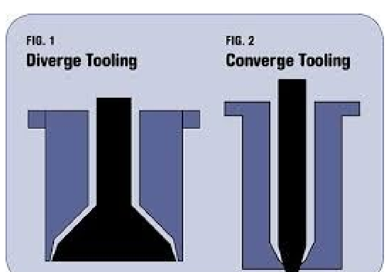




Diverging tooling

Converging tooling





BLOW MOLDING

•EXTRUSION BM:

•CLAMPING SYSTEM:

•The mold clamping methods are hydraulic or toggle mechanisms. Sufficient daylight in the mold platen area is required to accommodate parison systems.

•MOLD:

•Since BM is a low pressure process, mold material need not be selected on the basis of strength alone.

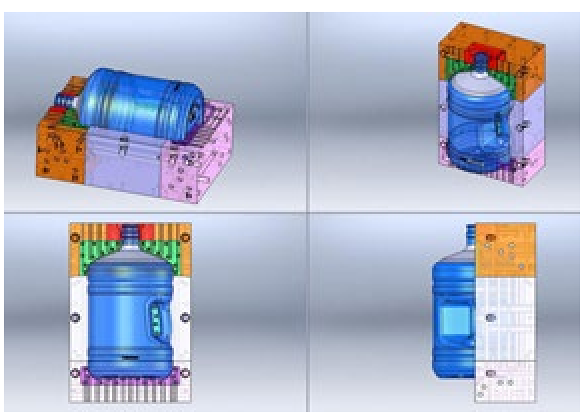
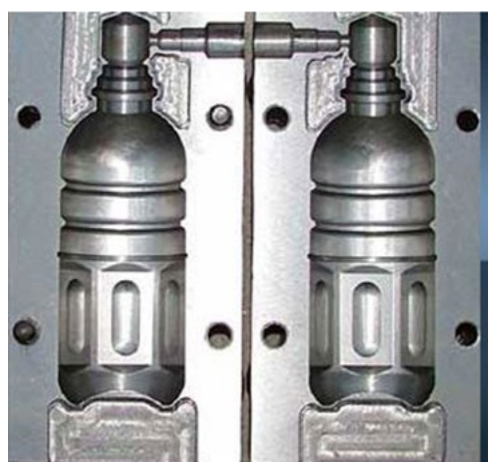
•Low cost, low thermal conductivity and good chemical resistance are usually of higher priority than strength.

•Aluminium alloys are the most commonly used blow mold materials.

•Thin areas such as pinch-offs and necks are fitted with beryillum copper.

BLOW MOLDING

- EXTRUSION BM:
- PINCH-OFF:
- It is a section of a mold where the parison squeezes and welded together.
- It has three functions:
- To withstand the repeated closing cycles of the mold and pressure of plastic material.
- It must push a small amount of plastic material into the interior of the part to slightly thicken the weld area.
- Cut through the parison to provide a clean break point for later flash removal.


BLOW MOLDING

- EXTRUSION BM:
- PARISON SWELL:
- Parison drops into the mold its length increases due to gravity force on the melt and its diameter and thickness should decrease somewhat due to stretching.
- Too much swell allows the parison to touch the mold walls unevenly and too little swell leads to uneven filling of hollow sections in the handles.
- Important to control parison swell to produce consistent products.
- This can be done by controlling injection temperatures and fill rates.
- PARISON INFLATION:
- Inflation air has three functions:
- To expand the parison against the mold walls.
- To exert pressure on the expanded parison to duplicate mold surface details.
- To aid in cooling the part.

BLOW MOLDING

- Advantages of EBM:
- High rate of production
- Low tooling cost
- Wide selection of machine manufacturers.
- Disadvantages:
- High scrap rate
- Limited wall thickness control

- Advantages of IBM:
- No scrap or flash is molded.
- Best wall thickness and material distribution control.
- Critical neck finishes.
- Best surface finish of parts.
- Disadvantages:
- High tool cost
- Injection molding is presently limited to smaller sizes.

THERMOFORMING

•THERMOFORMING:

•Thermoforming refers to a group of processes in which a softened sheet of polymer is forcibly deformed by applying air pressure or vacuum, into or onto a single surface mould, where it is cooled through conduction into the mould. The formed part is then trimmed from the clamped edges called web or trim.

•The term ‘thermoforming’ incorporates a wide range of possibilities for sheet forming but basically there are two sub-divisions - vacuum forming and pressure forming.

•VACUUM FORMING:

•In this processing method a sheet of thermoplastic material is heated and then shaped by reducing the air pressure between it and a mould.

•The principle is very simple. A sheet of plastic, which may range in thickness from 0.025 mm to ***6.5 mm, is clamped over the open mould.*** A heater panel is then placed above the sheet and when sufficient softening has occurred the heater is removed and the vacuum is applied. For the thicker sheets it is essential to have heating from both sides.

THERMOFORMING

•PRESSURE FORMING:

This is generally similar to vacuum forming except that pressure is applied above the sheet rather than vacuum below it. This advantage of this is that higher pressures can be used to form the sheet.

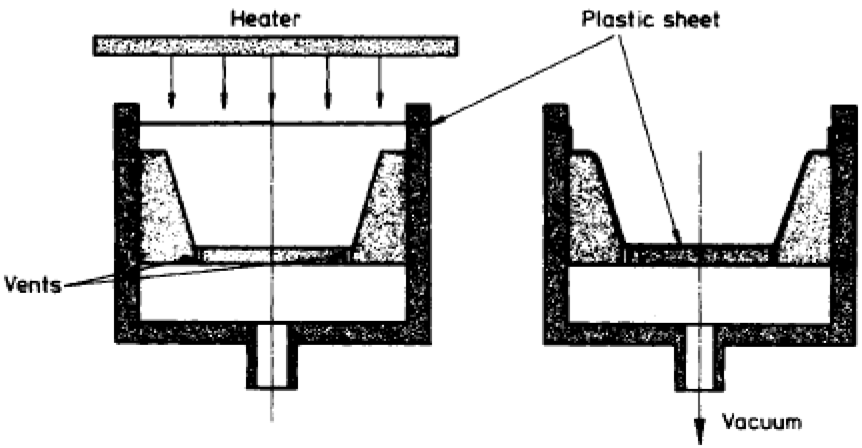


Fig. 4.51 Vacuum forming process

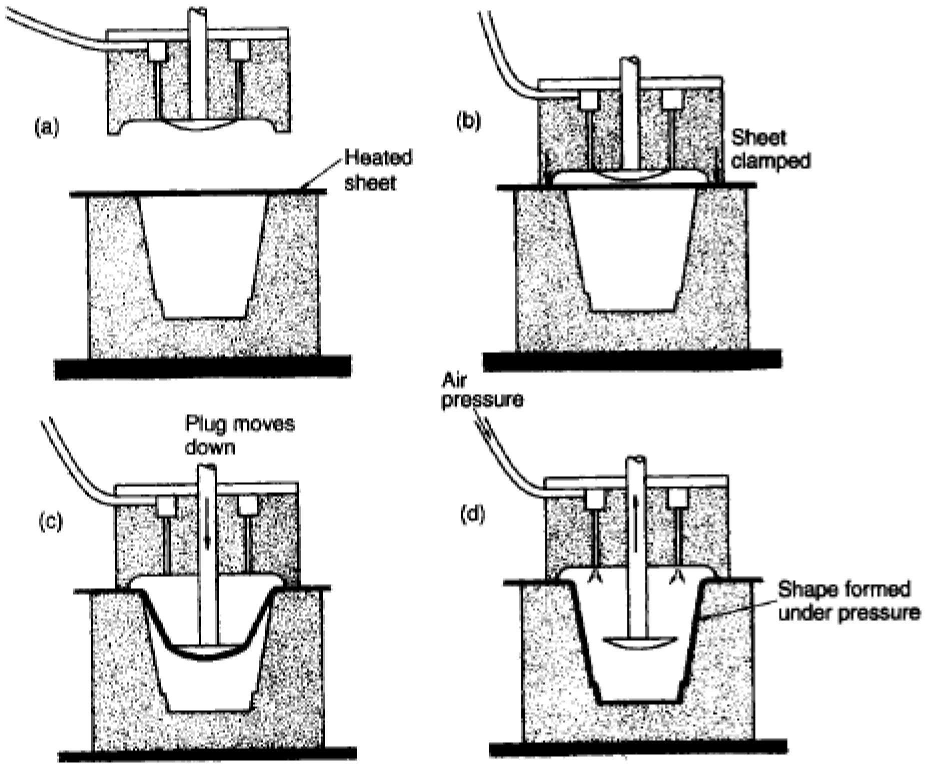
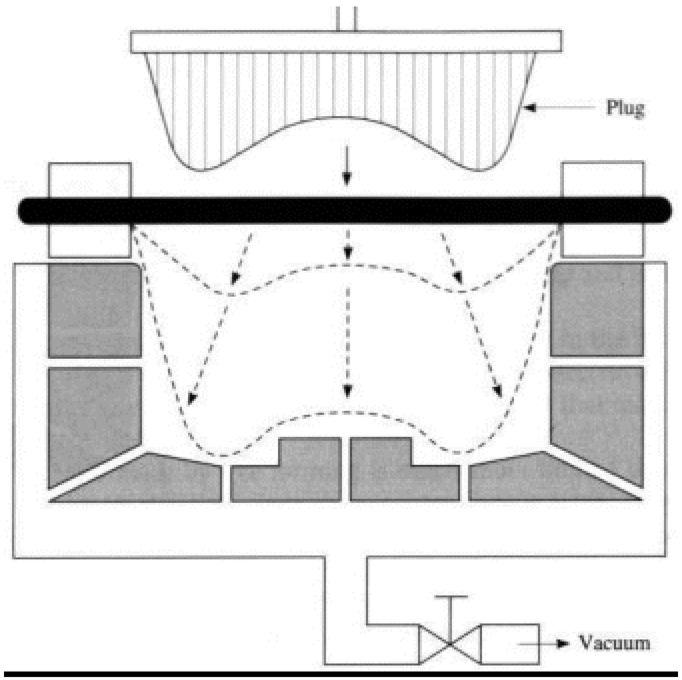


Fig. 4.52 Pressure forming process

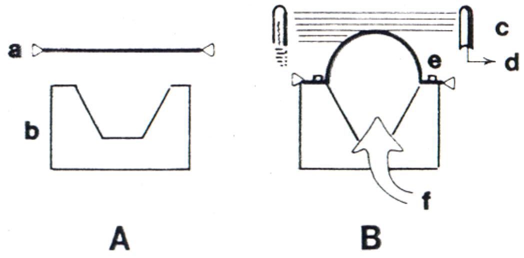
Plug Assist Forming

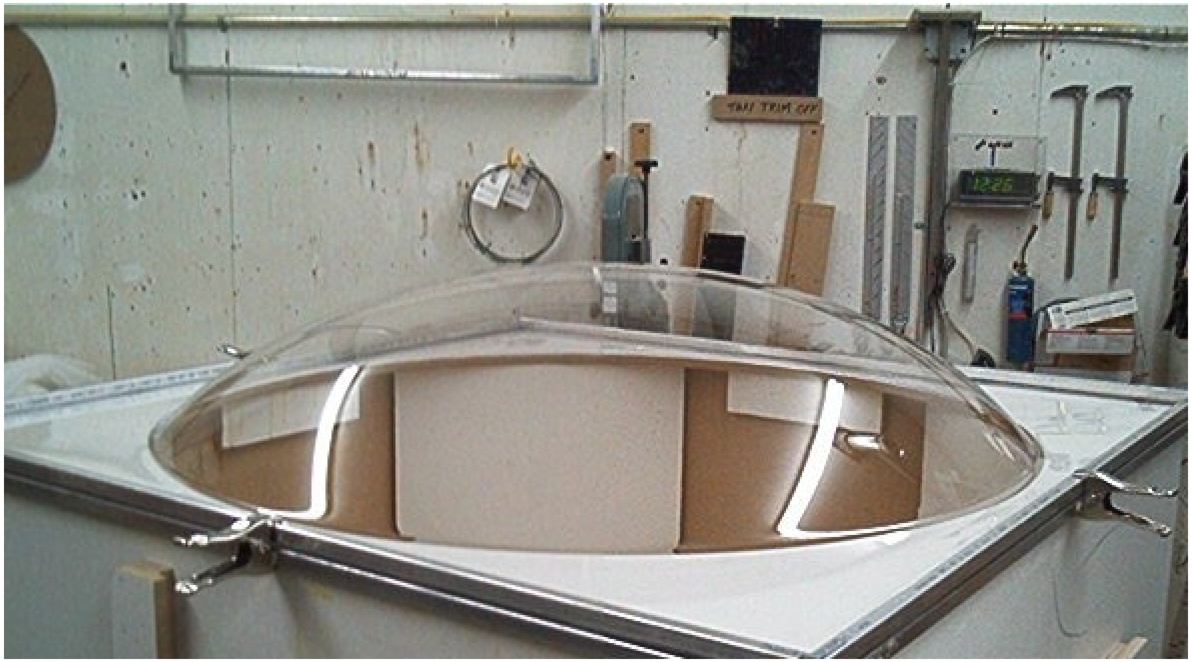
- Plug stretches the material for a more evenly distributed part



Free Forming

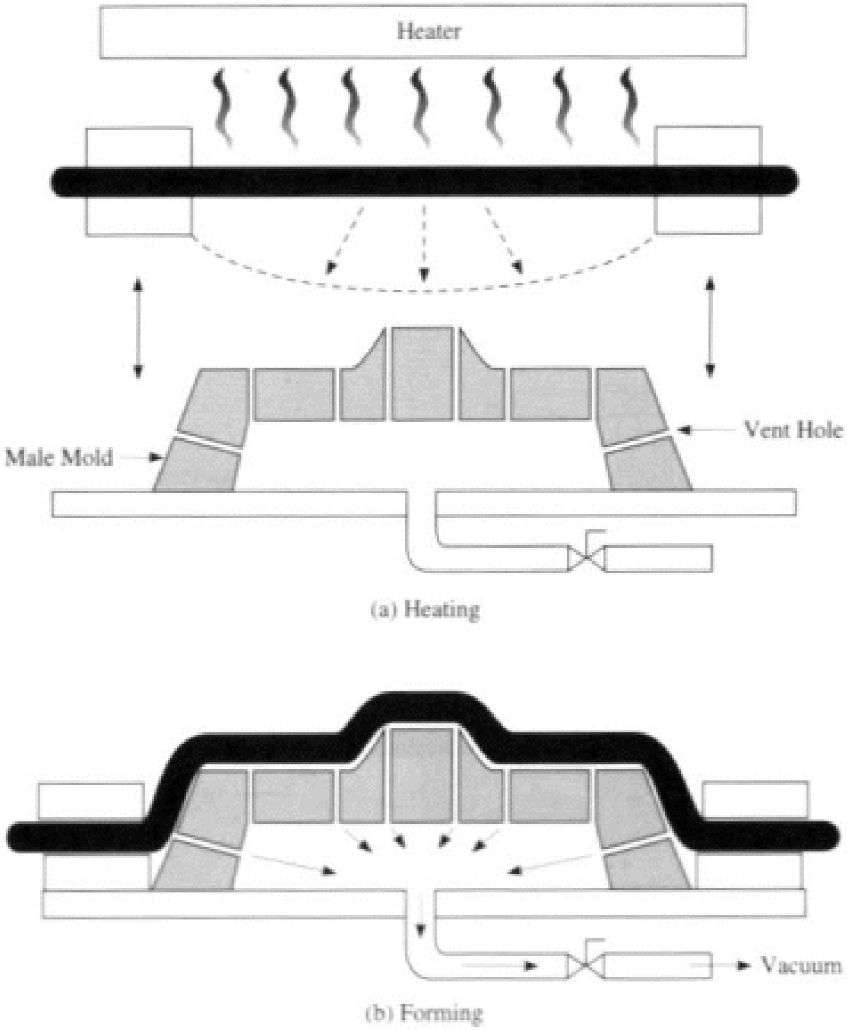
- Parts are blown
- No contact with mold surfaces
- Excellent optical clarity

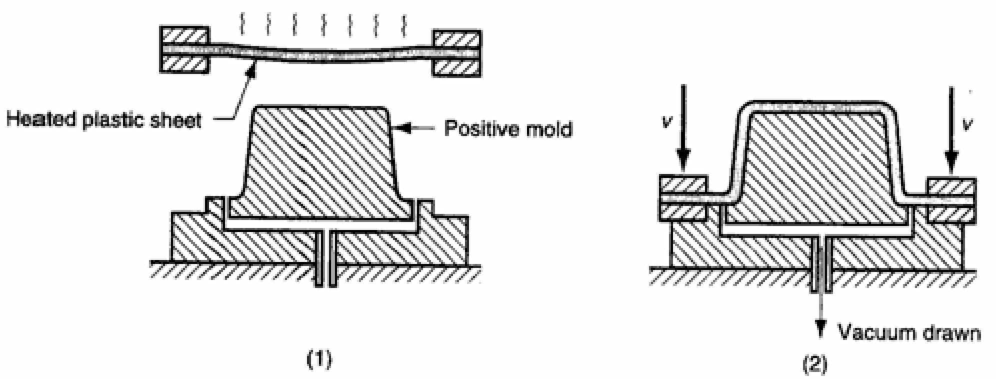




Drape Forming

- Mold "cavity" protrudes upward





THERMOFORMING

•MATCHED DIE FORMING:

•A variation of thermoforming which does not involve gas pressure or vacuum is matched die forming. The concept is very simple. The plastic sheet is heated as described previously and is then sandwiched between two halves of a mould. Very precise detail can be reproduced using this thermoforming method but the moulds need to be more robust than for the more conventional process involving gas pressure or vacuum.

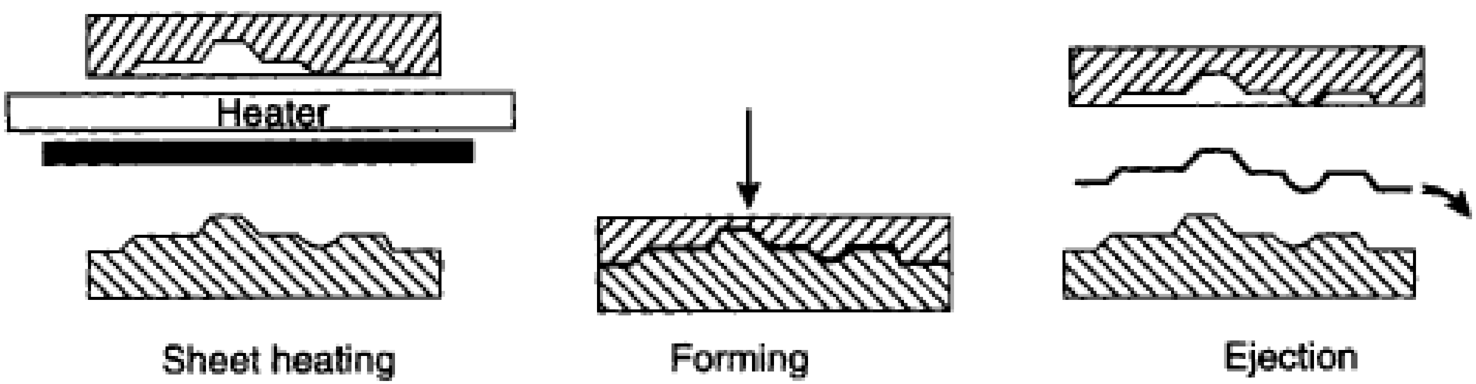
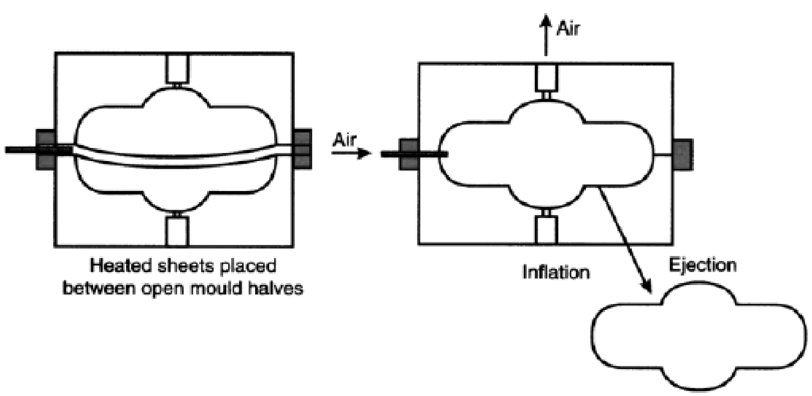


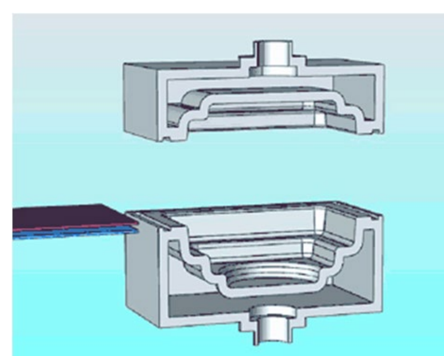
Fig. 4.53 Thermoforming between matched dies

<u>THERMOFORMING</u>

•DUAL SHEET FORMING:

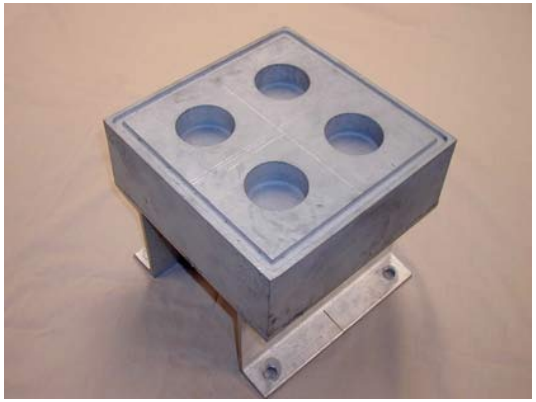
•This technique, also known as Twin-Sheet Forming. It is essentially a hybrid of blow moulding and thermoforming. Two heated sheets are placed between two mould halves and clamped**. An** inflation tube at the parting line then injects gas under pressure so that the sheets are forced out against the mould. Alternatively, a vacuum can be drawn between the plastic sheet and the mould in each half of the system. This technique has interesting possibilities for further development and will compete with blow moulding, injection moulding and rotational moulding in a number of market sectors. It can be noted that the two mould halves can be of different shapes and the two plastic sheets could be of different materials, provided a good weld can be obtained at the parting line.

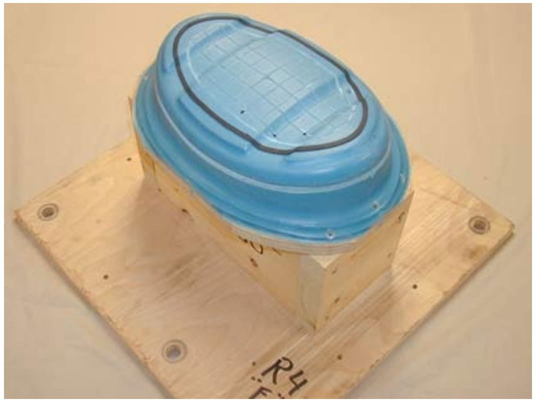


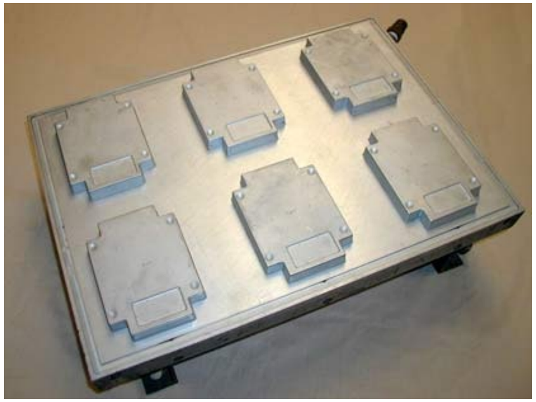


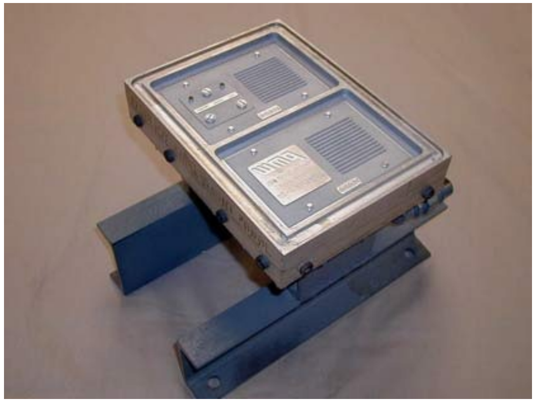
Equipment

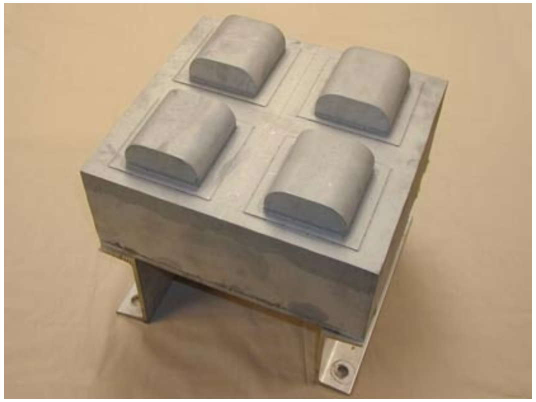
- Molds











THERMOFORMING

- **Advantages :**
- Low cost tooling
- Low volume production
- Low lead time for prototype testing,
- Low equipment costs for short runs.
- Large forming may be made economically
- Portable, can be taken to sites, useful for packaging
-
- **Disadvantages:**
- Limited to simple shapes with slight undercuts, good details not possible and pressure difference is low
- Poor material distribution
- Considerable finishing required, and wastage due to trimmings, which needs to be reground and recycled
- Energy intensive as plastic is heated twice, once to make the sheet and then to thermoform.

THERMOFORMING

EXAMPLES OF APPLICATIONS FOR THERMOFORMED PARTS

Packaging and Related Items

Blister Packs, Bubble Packs. Slip Sleeve, Vacuum Carded; Electronics. Audio/Video Cassette Holders ; Tools. Hand, Power; Wide-Mouth Jars; Vending Machine Hot Cup

Vehicular

Automotive Door Innerliners; Automotive Utility Shelves, Windshields; Motorcycle Windshields. Scooter Shrouds, Mudguards , Seats, Trays

Industrial

Tote Bins; Pallets; Parts Trays. Transport Trays; Equipments Case

Others

Advertising Signs, Lighted Indoor Signs Swimming and Wading Pools; Trays Baskets, Hampers, Carrying Cases Luggage; Boat Hulls, Prototype Concepts for Other Plastic Processes.

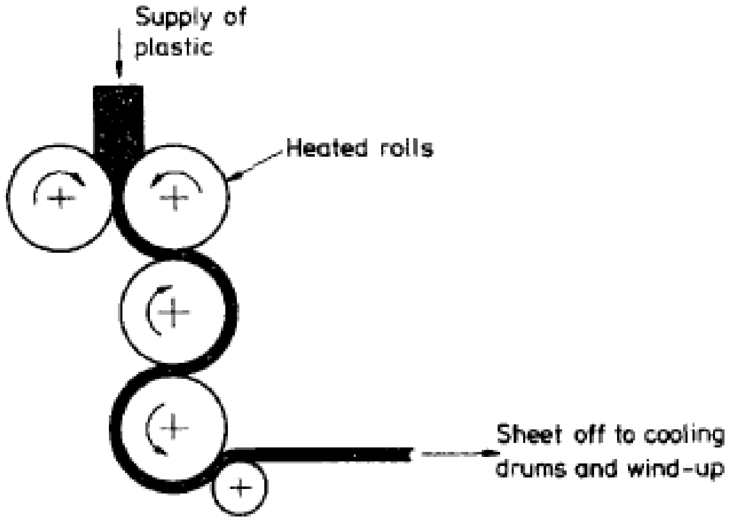
RAW MATERIALS:

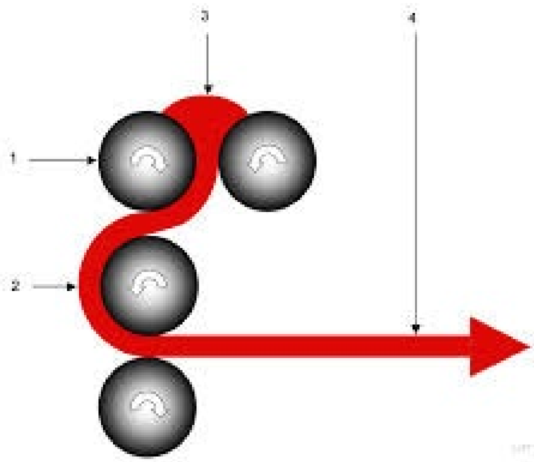
Thin gage sheet , usually upto 1.5 m. Heavy gauge sheet generally upto 12 mm thick supplied as cut sheet.   PS, ABS, PVC, PMMA, HDPE,PP,LDPE,

CALENDERING

•It is a method of producing plastic film and sheet by squeezing the plastic through the gap (nip) between two counter rotating cylinders.

•Calendering lines are used to manufacture PVC sheet, floor coverings, rubber sheet and rubber tires. Also used to emboss surfaces.





CALENDERING

•A typical calendar lines for manufacturing PVC sheet composed of:

•Plasticating unit Calendar Cooling unit

•Trimming Wind-up station

•In the plasticating unit, the material is melted and mixed by an internal batch mixer before it is fed between the nip of the first two rolls.

•First pair of rolls control the feeding rate, and subsequent rolls calibrate the sheet thickness.

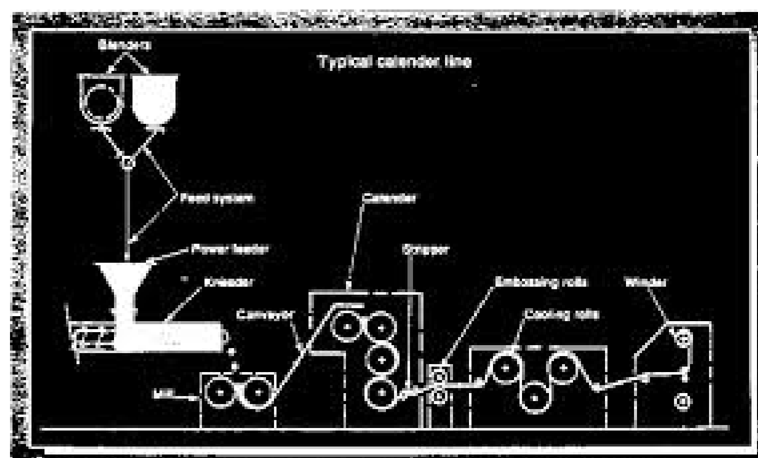
•Most calendar systems have four rolls.

•After main calendar system, it is passed through a series of chilling rolls where it is cooled on both sides.

•After cooling the film or sheet is trimmed & wound.

•No of rolls of a calendar determined by the nature of material processed.

•Rubber can be calendered on a two roll calender.



CALENDERING

•For thin sheets the speed of the winding drum can be adjusted to control the drawdown.

•Outputs vary in the range 0.1-2 m/s depending on the sheet thickness.

•Calendering can achieve surprising accuracy on the thickness of a sheet of tolerance of ±0.005mm, but to achieve that is essential to have very close control over roll temp and speeds.

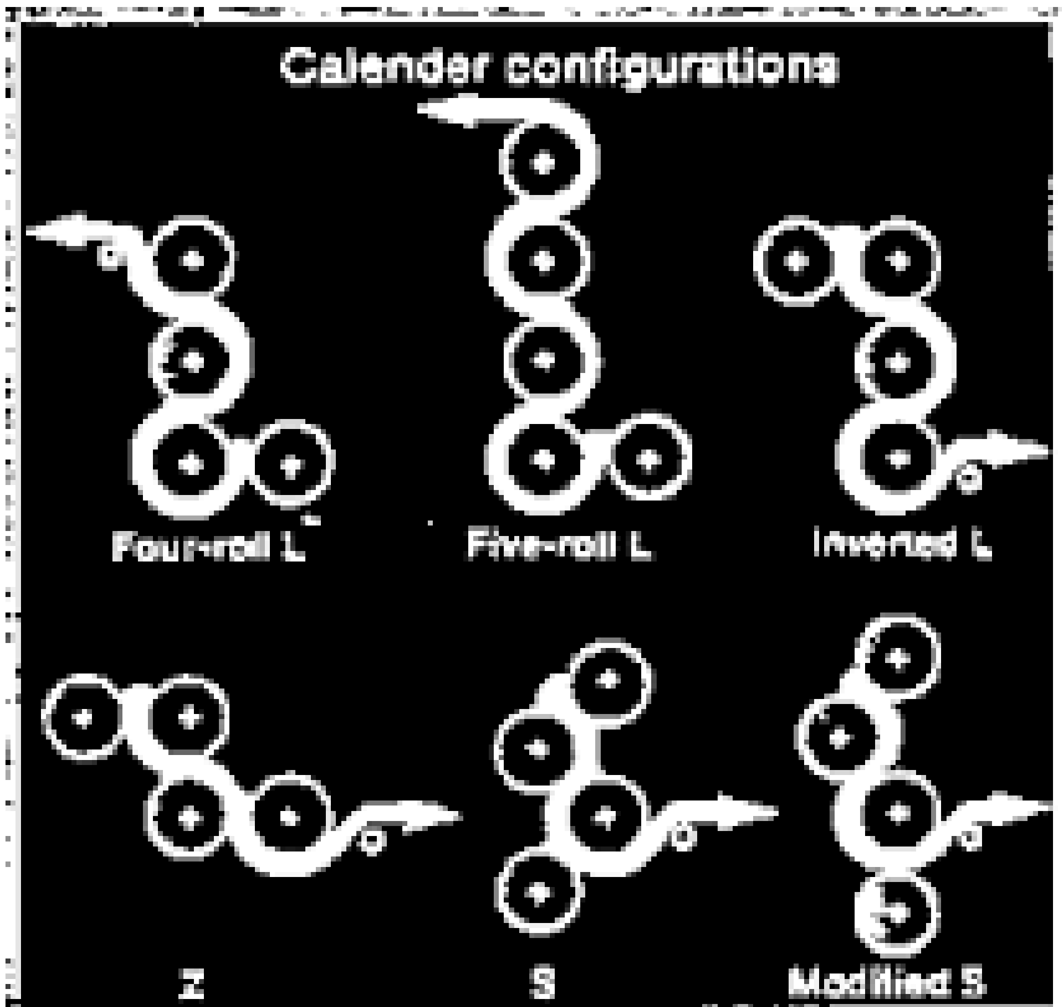
•It is a method of producing sheet and film, it must be considered to be a direct competition with extrusion.

•In general, in film blowing and die extrusion methods are preferred for materials such as PE, PP and PS but calendaring has the major advantage of causing very little thermal degradation and so its is widely used for heat sensitive materials such as PVC.

CALENDERING

•Calenders vary in respect of the number of rolls and of the arrangement of the rolls relative to one another.

•Types of calenders are:

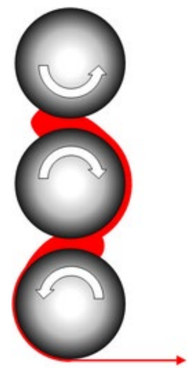


CALENDERING

- Calenders vary in respect of the number of rolls and of the arrangement of the rolls relative to one another.
- Types of calenders are:

I Type:

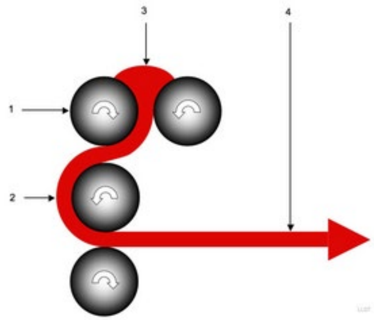
The I type, as seen in Figure, was for many years the standard calender used. It can also be built with one more roller in the stack. This design is not ideal though because at each nip there is an outward force that pushes the rollers away from the nip.



CALENDERING

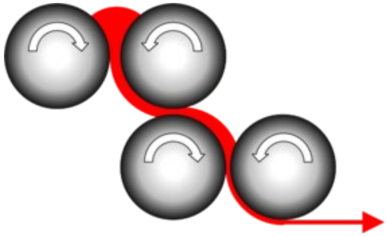
L Type

The L type is the same as seen in Figure 2 but mirrored vertically. Both these setups have become popular and because some rollers are at 90o to others their roll separating forces have less effect on subsequent rollers. L type calenders are often used for processing rigid vinyls and inverted L type calenders are normally used for flexible vinyls.



Z Type

The Z-type calender places each pair of rollers at right angles to the next pair in the chain. This means that the roll separating forces that are on each roller individually will not effect any other rollers. Another feature of the Z-type calender is that is that they lose less heat in the sheet because as can be seen in Figure 3 the sheet travels only a quarter of the roller circumference to get between rollers. Most other types this is about half the circumference of the roller.



CALENDERING

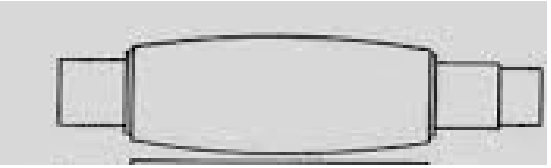
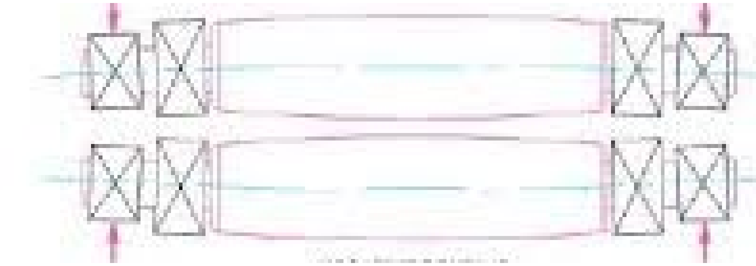
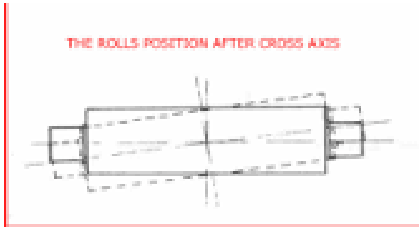
•To compensate for deformation three common methods are employed:

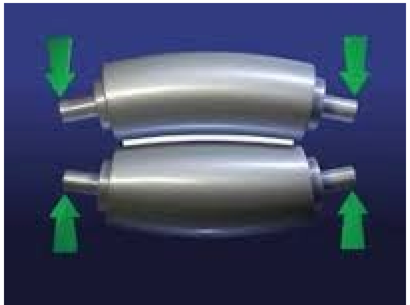
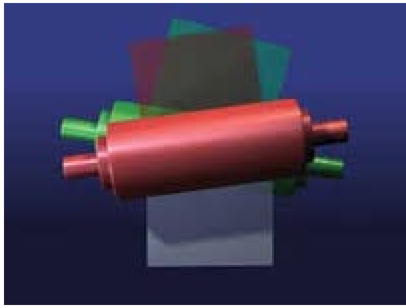
•ROLL CROWN: It indicates that the roll diameter at the centre is slightly greater than at the edges.

•ROLL CROSSING & ROLL BENDING are used for continuous adjustments of gap size distributions.

•In roll bending, a bending moment is applied on both sides of the roll by two additional bearings which can increase or decrease the bending due to forces.

•Roll crossing results in wider gap at the edges giving the same effect as increasing the roll crown.

CALENDERING

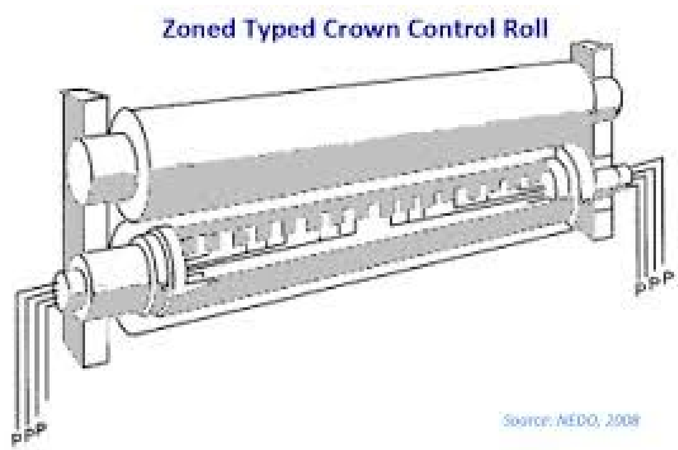
•ROLL HEATING: The calender are often required to be heated and then held at different temperatures.

•Rolls are commonly heated using steam/water for temp below 100 deg C.

•For above 100 deg C, high pressure hot water or heated oil are circulated through a central bore.

•The fluid heats the rolls and then maintain the temperature.

•ROLL SEPERATION FORCE: Forces which push the rolls apart are roll seperation force. Such forces are caused through squeezing a viscous material through a small gap at high speed.



CALENDERING

Advantages:

The best quality sheets of plastic today are produced by calenders; in fact, the only process that competes with the calender in sheet forming is extruding.

The calender also is very good at handling polymers that are heat sensitive as it causes very little thermal degradation.

Another advantage to calendering is that it is good at mixing polymers that contain high amounts of solid additives that don't get blended or fluxed in very well.

This is true because compared to extrusion the calender produces a large rate of melt for the amount of mechanical energy that is put in.

Due to this companies are able to add more filler product to their plastics and save money on raw materials.

Calenders are very versatile machines meaning that it is very easy to change settings like the size of the roller gap.

CALENDERING

DisAdvantages:

•Although the calendering process produces a better product than the extruding process there are a couple of disadvantages.

•One disadvantage is that the process is more expensive to perform which is a major deterrent for many companies.

•The calendering process also is not as good at too high of gauges or too low of gauges.

•If the thickness is below 0.006 inches then there is a tendency for pinholes and voids to appear in the sheets.

•If the thickness is greater than about 0.06 inches though there is a risk of air entrapment in the sheet.

•Any desired thickness within that range though would turn out much better using a calender process.

BLOW MOLDING

•ANALYSIS OF BLOW MOLDING:

•As mentioned previously, when the molten plastic emerges from the die it swells due to the recovery of elastic deformations in the melt. It will be known from the basic geometric analysis, that the following relationship exists:

•

$$B_{SH} = B_{ST}^2 \text{ (from Chapter 5)}$$

where B_{SH} = swelling of the thickness ($= h_1/h_d$)

B_{ST} = swelling of the diameter ($= D_1/D_d$)

therefore

$$\frac{h_1}{h_d} = \left(\frac{D_1}{D_d}\right)^2$$

$$h_1 = h_d(B_{ST})^2$$

BLOW MOLDING

•ANALYSIS OF BLOW MOLDING:

•Now consider the situation where the parison is inflated to fill a cylindrical die of diameter, ***Dm. Assuming constancy of volume and neglecting draw-down*** effects, then

$$\pi D_1 h_1 = \pi D_m h$$

$$h = \frac{D_1}{D_m} h_1$$

$$= \frac{D_1}{D_m} (h_d \cdot B_{ST}^2)$$

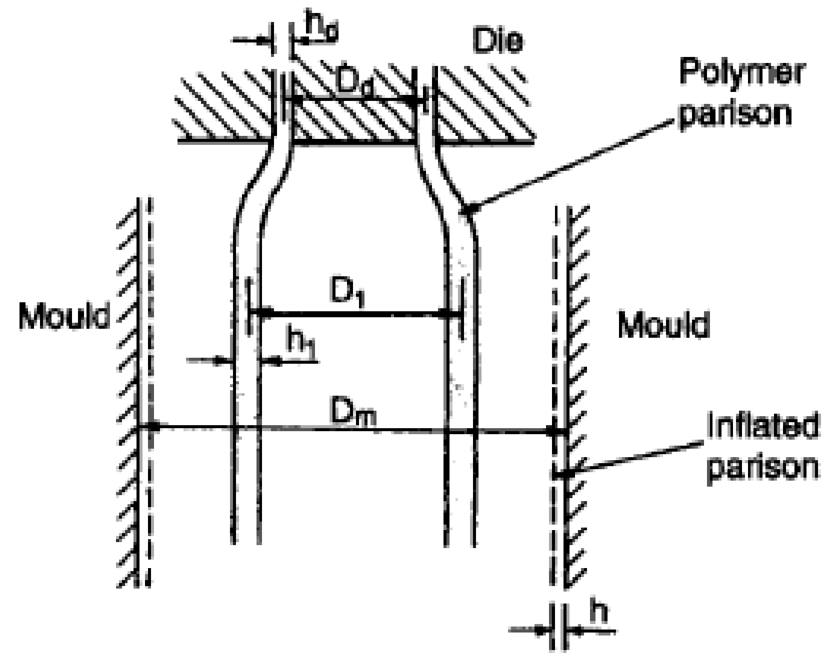
$$= \frac{B_{ST} \cdot D_d}{D_m} (h_d \cdot B_{ST}^2)$$

$$h = B_{ST}^3 h_d \left(\frac{D_d}{D_m} \right)$$

This expression therefore enables the thickness of the moulded article to be calculated from a knowledge of the die dimensions,

the swelling ratio and the

mould diameter.



BLOW MOLDING

•ANALYSIS OF BLOW MOLDING:

A blow moulding die has an outside diameter of 30 mm and an inside diameter of **27 mm. The parison is inflated with a pressure of 0.4 MN/m2** to produce a plastic bottle of diameter 50 mm. If the extrusion rate used causes a thickness swelling ratio of **2, estimate the wall thickness of the bottle. Comment** on the suitability of the production conditions if melt fracture occurs at a stress of 6 MN/m2.

Solution

From equation (4.18)

$$\text{wall thickness, } h = B_{ST}^3 h_d \left(\frac{D_d}{D_m}\right)$$

Now $h_d = \frac{1}{2}(30 - 27) = 1.5$ mm

$$B_{ST} = \sqrt{B_{SH}} = \sqrt{2} = 1.414$$

$$D_d = \frac{1}{2}(30 + 27) = 28.5 \text{ mm}$$

So $h = (1.414)^3(1.5)\left(\frac{28.5}{50}\right) = 2.42$ mm

BLOW MOLDING

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The maximum stress in the inflated parison will be the hoop stress, σ_θ, which is given by

$$\sigma_\theta = \frac{PD_m}{2h} = \frac{0.4 \times 50}{2 \times 2.42}$$

$$= 4.13 \text{ MN/m}^2$$

Since this is less than the melt fracture stress (6 MN/m^2) these production conditions would be suitable. These are more worked examples on extrusion

THERMOFORMING

ANALYSIS OF THERMOFORMING:

- If a thermoplastic sheet is softened by heat and then pressure is applied to one of the sides so as to generate a freely blown surface, it will be found that the shape so formed has a uniform thickness.
- If this was the case during thermoforming, then a simple volume balance between the original sheet and the final shape could provide the wall thickness of the end product.

$$A_i h_i = A_f h_f$$

where A = surface area, and h = wall thickness ('i' and 'f' refer to initial and final conditions).

<u>THERMOFORMING</u>

<u>ANALYSIS OF THERMOFORMING:</u>

A rectangular **box 150** mm long, **100** mm wide and 60 mm deep is to be thermoformed from a flat sheet **150** mm x **100** mm x **2** mm. Estimate the average thickness of the walls of the final product In conventional vacuum forming is used.

Solution

(a) The initial volume of the sheet is given by

$$A_i h_i = 150 \times 100 \times 2 = 3 \times 10^4 \text{ mm}^3$$

The surface area of the final product is

$$A_f = (150 \times 100) + 2(100 \times 60) + 2(150 \times 60)$$

$$= 4.5 \times 10^4 \text{ mm}^2$$

Therefore, from equation (4.28)

$$h_f = \frac{3 \times 10^4}{4.5 \times 10^4} = 0.67 \text{ mm}$$