Qenos

08 POLYETHYLENE BLOW MOULDING

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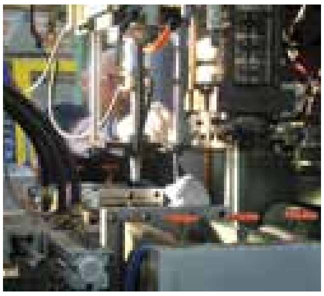
TECHNICAL GUIDE

Alkatane®



Front Cover
The Qenos Technical Centre operates a range of commercial and laboratory scale extrusion and moulding equipment for the injection moulding, blow moulding (pictured), film extrusion, pipe extrusion and rotational moulding markets. Qenos produces a full range of *Alkatane* HDPE grades for blow moulding applications ranging from thin walled high speed milk and juice bottles to high molecular weight 1000L cubes. *Alkatane – Super Clean. Super Safe*.

A GUIDE TO POLYETHYLENE BLOW MOULDING

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INTRODUCTION

The suggestion that containers could be moulded from a pre-formed polymer tube appeared for the first time in US Patent 237168 which was filed on 28 May 1880 and published on 1 February 1881. The applicants were the Celluloid Novelty Co. and the Celluloid Manufacturing Co., New York. Between the obscure earlier beginnings and the present stage of technology lies a period of more than 130 years development; the dynamic phase of development which has taken place in our time has been vitally influenced by polyethylene.

EXTRUSION BLOW MOULDING AND EXTRUSION BLOW MOULDING MACHINES

Basic Processing Principles

The suggestion that containers could be moulded from a pre-formed polymer tube appeared for the first time in US Patent 237168 which was filed on 28 May 1880 and published on 1 February 1881. The applicants were the Celluloid Novelty Co. and the Celluloid Manufacturing Co., New York. Between the obscure earlier beginnings and the present stage of technology lies a period of more than 130 years development; the dynamic phase of development which has taken place in our time has been vitally influenced by polyethylene.

Extrusion blow moulding can be divided technologically into a two-stage process which begins with plastication. The first stage comprises the production by extrusion of a pre-form which can be blow moulded, the second, blow moulding and cooling in the mould. A continuously extruded or batch-wise produced tube generally known as a parison is required as the pre-form.

Two different methods of extruding the parison enable containers ranging from a few mL up to 5,000 L capacity to be produced.

- With containers up to 30 L content, the parison is extruded continuously. This is achieved by a system of rotating moulds or by parison transfer to the blow moulding tool with the aid of a gripping device.

  Through the use of multiple die heads, moulds and clamping units; or the arrangement of moulds on a rotating table or carrier chain, output can be raised considerably with minimum space requirement.

  Extrusion heads today are often fitted with devices for regulating parison wall thickness (parison programming). These can even out longitudinal wall thickness variations arising from the type of article being made. Wall thickness variations around the circumference of the parison can be corrected to a limited extent by modifying the die gap. The parison is cut off as it leaves the die by means of the die itself or a gripping device, or by a heated knife or a hot wire cutter.
- Parisons for containers from 5 to 5,000 L are produced on plants with a melt accumulator. The method to be selected in the lower part of this range (i.e. containers from 5-30 L) depends on the moulding compound, type of article and plant.

  The plastication unit – usually one or more single screw extruders – supplies an accumulator with the required volume of melt. This is called on at the appropriate moment and forced out through the die by hydraulic pressure in a fraction of the plastication time. In this way the parison is prevented from necking or breaking off at the die (under its own weight), and from premature cooling.

  By careful matching of the plastication unit, extrusion pressure and hydraulic resistance of the blow head, backflow of the melt into the plastication barrel can be avoided without an interposed valve system.

Plastication Systems

In extrusion blow moulding machines the following plastication systems (arranged in order of importance) are used:

- Slow running single-screw extruders with screw lengths of 20-25 d (screw diameter),
  - Conventional design with smooth barrel and compression screw,
  - Barrel with a grooved intake zone (mechanical feed aid) which is cooled, with little or no compression in the screw channel.
- Reciprocating screws of conventional design
- High-speed single-screw extruders
- Twin-screw extruders
- Ram extruders

Before the processing operation of the different plastication systems is examined in more detail, a few general aspects are discussed.

Basic Design of Plastication Systems

The barrels of screw extruders are divided into 3-5 heating zones and fitted with cuff heaters (heat rating 2-4 W/cm^2). Both resistance and ceramic heater bands are used. When the extruder is properly designed to match the moulding resin and the melt flow paths after the plastication barrel, then the sole function of external barrel heating is to compensate for radiated heat losses. This means that by far the greatest part of the plastication energy required is supplied to the resin through the screw drive.

Many extruders are additionally fitted with an air, oil or water cooling system to increase their versatility. Permanent control of melt temperature through the barrel or screw cooling system is uneconomic and moreover is indicative of an incorrectly designed screw.

The prescribed temperatures are monitored by a two or three point control system.

Screws may be provided with mixing elements to improve the homogeneity of the molten resin and to promote even temperature throughout. In designing and fitting these mixing elements it is vital to ensure that the shearing force which they exert on the melt is small in relation to the mixing action (Figure 1). With high molecular weight polyolefins, other considerations play a part, for example, the relaxation behaviour of the melt.

Figure 1: Extruder Screw with Mixing Elements

Shear Rate

The output of an extruder is limited in the first instance by the quality of extrudate required. Although good homogeneity is desirable, it is important for the melt not to be degraded under conditions of high shear. This consideration inevitably imposes maximum screw speeds, which depend on the type of resin, the design of the screw channel, the screw diameter and the residence time of the melt in the extruder.

The following may be taken as guide values for shear rate:

HDPE $\dot{\Upsilon} = 56\ s^{-1}$ (medium and high molecular)

The shear rate can be calculated approximately by means of the following equation:

$$\dot{\Upsilon} = \frac{\pi.n.(D-2.t)}{t} \qquad (1)$$

where

D = barrel diameter (mm)
t = channel depth (mm)
n = screw speed (s^{-1})

These guide values relate to the resin in melt form, i.e. the values in the extrusion zone must be taken as the basis.

Throughput Efficiency

Besides the geometrical dimensions of the screw, the main factor determining residence time of the melt in the extruder is the throughput efficiency which can be attained. This is primarily a function of processing technique.

Throughput efficiency is calculated as the quotient of the actual throughput measured at the particular production point, and the maximum possible, i.e. the theoretical throughput:

For a conventional single-screw extruder the following formula (2) applies:

$$F = \frac{Q\ actual}{Q theor.} = \frac{V\ actual}{V\ theor.} \qquad (2)$$

Where

Q	output by weight	g/min
V	output by volume	L/min
Q_{theor}	$(h-s)\ t\ (D-t) \,.\, \pi \Upsilon_{melt} \,.\, n$ (3)	g/min
h	screw pitch	cm
s	width of flight land	cm
t	channel depth in the shallowest zone of the screw	cm
D	barrel diameter	cm
n	screw speed	min^{-1}
Q_{actual}	measured throughput	g/min
Υ_{melt}	melt density at processing temperature	g/cm^3

Thus

$$\eta_F = \frac{Q_{actual}}{(h-s)\ t\ (D-t) \,.\, \pi \,.\, \Upsilon_{melt} \,.\, n} \qquad (4)$$

(Guldin's law)

The melt density at processing temperature can be obtained from existing graphs.

Basic Requirements for the Plastication System

Basically from the processing point of view an extruder should have the following characteristics:

- Efficient plastication of the polyethylene melt (even temperature distribution)
- Capability for homogenization of mixtures containing a variety of constituents including pigments and uv stabiliser masterbatches
- Production of an extrudate free from faults (e.G. Bubbles due to trapped air or moisture)
- No degradation of the polyethylene as a result of excessive thermal or mechanical stress
- Economic operation

From the point of view of economic operation, the amount of energy supplied to the moulding resin should be no more than is required to obtain satisfactory plastication and homogenization. The dissipation of excess heat energy by cooling the barrel or screw is not logical. When necessary, equilibrium between energy supplied and the actual energy required should be achieved by optimizing the screw design.

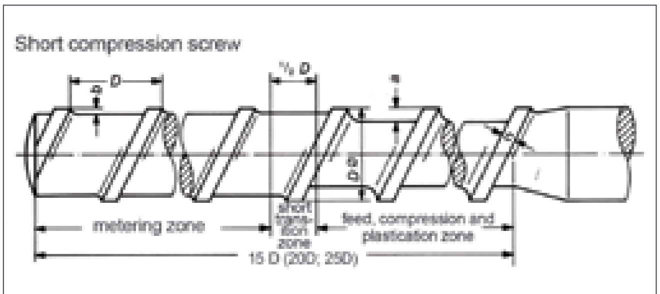
A further rule in economic plant operation is that the extruder should never be run at more than 85% of its maximum capacity, i.e. the extruder should be matched with subsequent processing units so as to utilize them fully when it is operating at 85% capacity.

Single-screw Extruders

Slow Running Extruders of Conventional Design

The machines normally employed today are fitted with screws 20 D in length (in some cases up to 25 D) with screw diameters ranging from 45 – 150 mm.

For plastication units with a smooth, cylindrical bore and a cooled hopper feed, compression screws as illustrated in Figure 2 are used.



D mm	c mm	a mm	b mm
45	6	8.00	2.00
60	8	10.00	3.30
90	10	13.50	4.50
120	12	15.75	5.25

Figure 2: Screws for Processing Polyolefins

Specific Power Requirement

An important criterion for determining whether technically ideal plastication is being obtained is the amount of power used by the drive motor. The following values will give useful guidance:

HDPE 0.22–0.30 kWh/kg

The specific power requirement takes account of power losses in the motor and gearing and of unavoidable radiation heat loss. The theoretical plastication energy requirement can be obtained from the enthalpy curves for the various plastics shown in Figure 3.

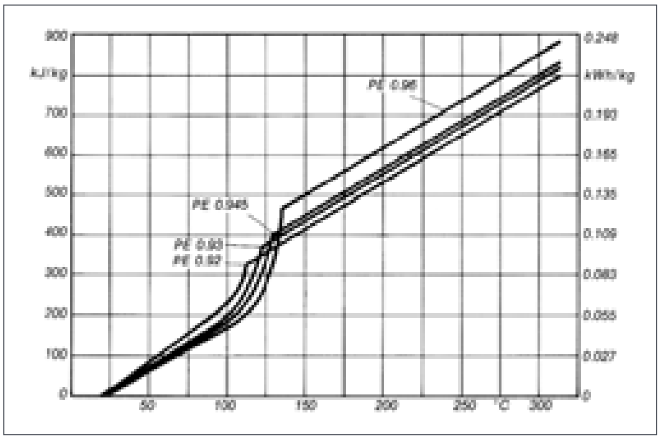


Figure 3: Enthalpy of Various Polyethylenes as a Function of Temperature

Output

The throughputs of extruders of varying size can be roughly estimated by means of the specific throughput Q/n [kg.min/h], i.e. throughput at a screw speed of $n = 1\ min^{-1}$, Figure 4. In the same way for a given throughput on a specified machine, the required screw speed can be roughly estimated if the relation between Q/n and screw diameter is known. This is

$$Q = n \,.\, Q/n \text{ or } n = Q.n/Q \qquad (5)$$

It is not usual to quote a unit for Q/n since Q is normally specified in kg/h and n in min^{-1}. For the estimate, the curves Q/n = f(D) were plotted for the design of a single-start screw processing HDPE with an assumed throughput efficiency η_F of 0.5. The screw dimensions (metering zone values) on which the calculation was based are shown in Fig. 4.

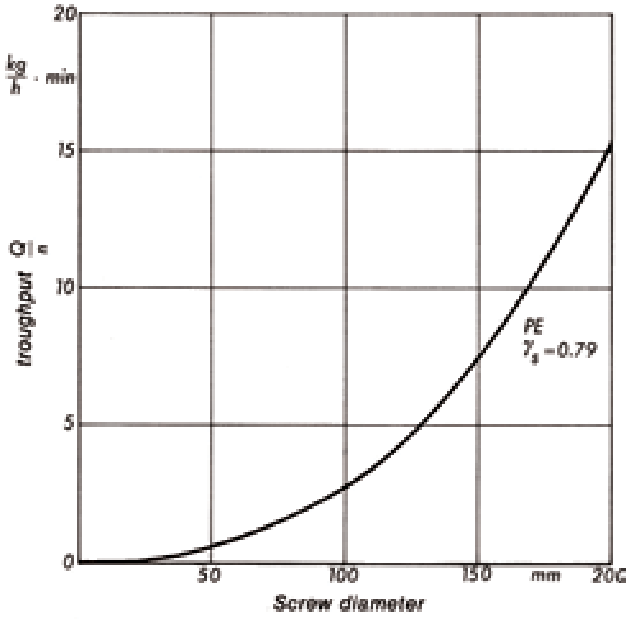
According to equation

$$Q = \eta_F \,.\, Q_{theor} \,. = \eta_F \,.\, (h - s) \,.\, t \,.\, \eta \,.\, (D - t) \,.\, n \,.\, \gamma_{melt}$$

Becomes

$$Q/n = 0.5 \,.\, (h - s) \,.\, t \,.\, \eta \,.\, (D - t) \,.\, \gamma_{melt}$$

The throughput efficiency of conventional extruders depends on screw design, screw speed and the polyethylene grade used. For short compression screws it may lie between 0.35 and 0.42 and for decompression screws between 0.40 and 0.52.



screw diameter	45	60	90	120	150	200
pitch h	45	60	90	120	150	200
width of flight land s	4.5	6.0	9.0	12.0	15.0	15.0
channel depth t	2.0	3.5	4.0	4.7	5.2	5.8

Figure 4: Specific Throughput Q/n as a Function of Screw Diameter

Reciprocating Screw and Reciprocating Barrel Extruders

A feature of the technology for blow moulding large containers is an accumulator in which plastic melted in the extruder barrel can be held in readiness for the next cycle. Here at the same time residual stresses can be relaxed and temperature variations equalized. Systems comprising accumulator head and parison die (i.e. extrusion heads) have been developed for processing high molecular weight HDPE melts.

In injection moulding machines, screw plastication units which incorporate space for melt accumulation at the front of the barrel, i.e. in front of the screw tip, have been known since the mid-1950s. The adaptation of these units to the requirements of blow moulding led to the development of reciprocating screw and reciprocating barrel extruders, Figure 5 and 6.

The plastication units employed for this purpose are extruders with a length of 12-20 D. Shorter screws generally require leads of less than 1 D to achieve the residence times necessary for plastication. Moreover, multi-flight screws are used here. During the actual moment of extrusion the screw is sometimes stationary. The screw, or barrel together with the screw, acts as an extrusion ram. As with injection moulding machines, it is obviously an advantage to drive the screw by a hydraulic motor. While the screw is stationary, the energy no longer required for the drive can then be used to force the melt from the accumulator.

The great disadvantage of this technique is that each time the screw starts up again a high torque demand is made. For this reason drive units have to be of a more robust design than usual.

The particular advantage of these machines on the other hand is that the melt first fed into the accumulator is also the first to leave. This permits rapid changeover of colorants or grades. It also ensures that no part of the melt remains for too long in the accumulator and suffers consequent degradation. Nevertheless these machines – like all accumulator machines – are used only for thermally stable moulding resins.

Figure 5: Dual Parison Blow Moulding Machine

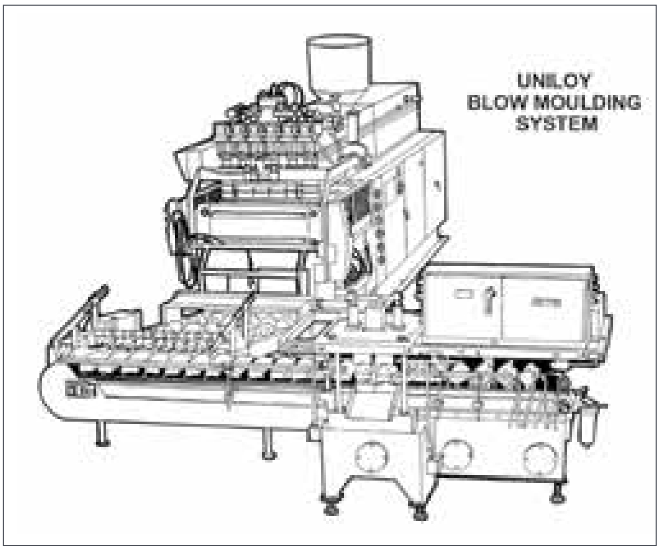


Figure 6a: Reciprocating Screw Machine

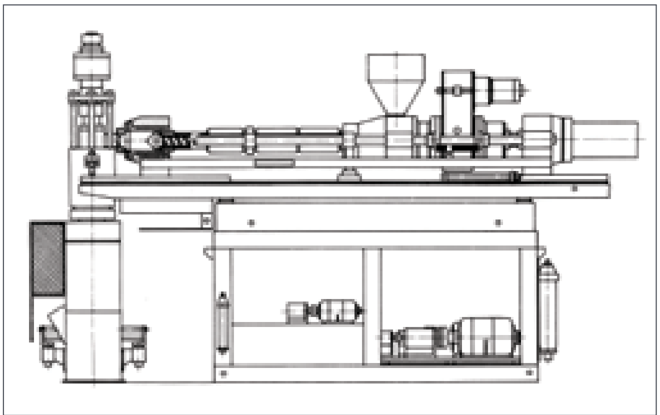


Figure 6b: Reciprocating Barrel Machine (works diagram: J. Fischer, Lohmar)

Reciprocating Screw Machines

The plastication screw is designed for reciprocating movement in the barrel. At the start of plastication the screw tip closes up to the end of the barrel. As molten polyethylene is fed into the accumulator a cushion of melt builds up which – as in reciprocating screw injection moulding machines – gradually forces the screw backwards. By balancing the extrusion head resistance and melt build-up pressure acting on the backward moving screw, it is possible to control within certain limits the flow of melt through the head and also the pressure required for good plastication during the accumulation phase.

As the screw moves backwards, its effective plastication length and hence the residence time of the melt in the extruder steadily decreases. This factor limits the axial length of the melt accumulation space and thus its volume, quite apart from influencing the quality of the melt reserve (inhomogeneity and non-uniformity of temperature) throughout the length of the accumulator. The limit of accumulator length is 2-3 D, depending on the length of the extruder.

Reciprocating Barrel Machines

In one development of the reciprocating screw machine, this problem has been avoided by designing the screw and barrel as a single reciprocating unit. By this means the effective length of the screw remains constant throughout the plastication phase. Theoretically an accumulator of any required size could be fed with a melt of constant quality. However, the realization of this principle is impracticable because of the vast amount of technical research effort which this process requires.

High Speed Extruders

The plastication extruders discussed in the following paragraphs are of minor importance in relation to the machines previously described.

High speed extruders are single-screw machines with short barrels (8-12 D), whose screws operate at high peripheral speed. A 35 mm screw at 600 rpm attains a peripheral speed of 1.1 m/s. At these speeds the screw channels are often only partially filled. Mastication of the melt takes place by conversion of mechanical energy to frictional heat. The amount of shear heat generated can be controlled by adjusting the gap between the conical screw tip and counter-cone. These autothermally (adiabatically) operating extruders are used primarily for LDPE and low molecular HDPE grades because of the high shear effect on the moulding compound. With most other thermoplastics the permissible shear deformation is exceeded, with consequent degradation of the material.

Twin-screw Extruders

Only in a few cases are twin-screw extruders used for extrusion blow moulding. For polyolefin processing, twin screws rotating in the same direction are used on some plants.

Ram Extruders

Ram extruders which force out the melt in batch-wise manner are used rarely, and then only as a plastication unit on small blow moulding machines. They are very low in cost because of their simple design, and correspond in principle to the plastication and injection unit of a ram injection moulding machine with gravimetric or volumetric feeding but with a parison extrusion head instead of an injection moulding die. Since the plasticating and homogenizing effect of these units is inferior to that of screw machines, they are rarely used. Even the advanced design with an independently heated torpedo does not overcome the technical inferiority of this machine in comparison with screw plastication systems.

Extrusion Dies for Continuous Parison Production

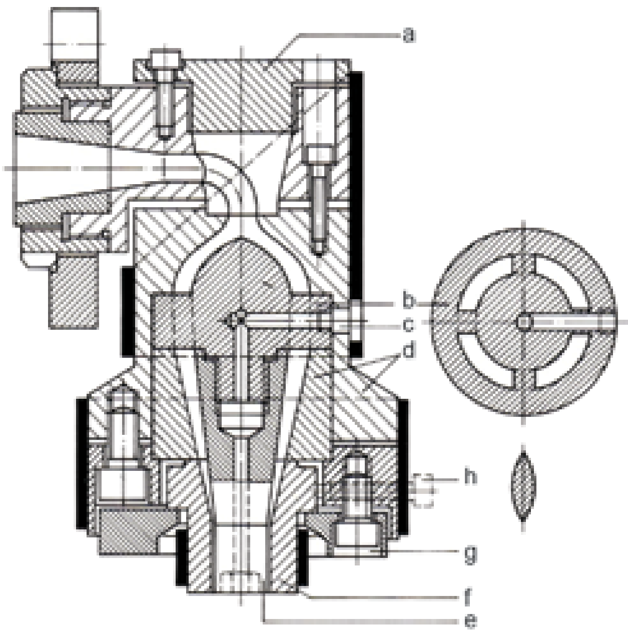
In most cases the parisons required for blow moulding containers are extruded from heads arranged vertically to the extruder axis. Extrusion heads inclined at other angles to the extruder or directly in line with it, in which the parison is guided into the subsequent mould are also used. The principle is the same with all arrangements, only the transition zones between the barrel and head vary. A distinction is made between:

- Axial flow crosshead with spider support
- Radial flow crosshead with through mandrel.

axial Flow Crosshead with Spider Support

The axial feed ensures uniform distribution of melt pressure and hence of the melt stream in the melt distribution zone.

The torpedo is held by a specially streamlined spider – a construction which allows the melt distribution zone, including the transition to the flow channel, to be designed with optimum flow characteristics, Figure 7. This ensures that even when the machine is operating under pressure with high throughputs, undesirable secondary streams and stagnation zones are prevented.



a divided plug with elbow bend
b torpedo with streamlined spider support
c bore for compressed air
d extrusion head housing with interchangeable linings
e die core
f die orifice
g retainer ring
h screws for adjusting die

Figure 7: Axial Flow Crosshead with Bend to Divert the Melt Stream, Torpedo and Parison Die

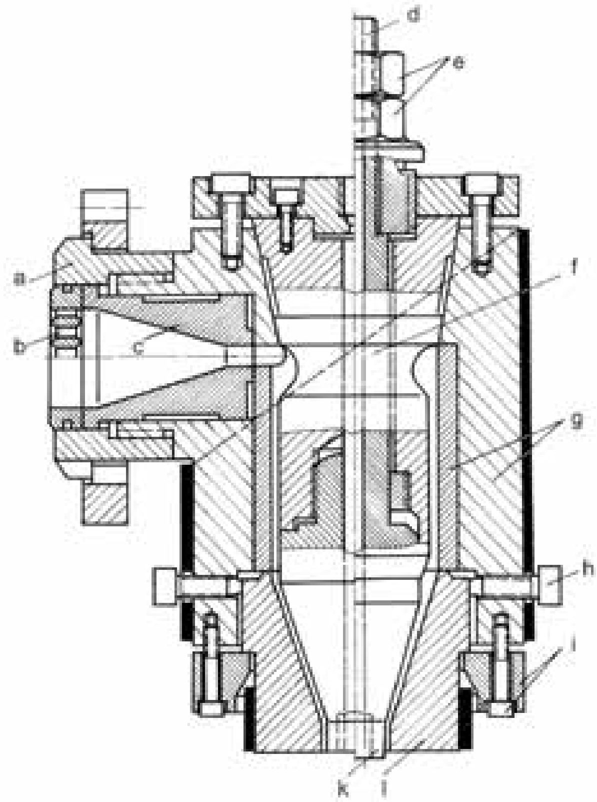
Wall thickness around the circumference of the parison is controlled by aligning screws at the die orifice. Control of wall thickness along the length of the parison is possible with a suitably shaped die (conical core) by means of an axially movable mandrel or variable orifice.

The melt stream is divided by the spider holding the torpedo. When the split streams reunite after the spider, weld seams are formed which frequently appear as flow lines or give rise to thin spots in the wall of the finished moulding.

The spider is designed as shown in Figure 7. and can either be positioned as indicated there or flanged in between the upper and lower parts of the housing. It is provided with a bore for the passage of support air which is frequently required in blow moulding. The streamlined arms of the torpedo support are arranged radially or tangentially. Designs with a coaxial centre piece and radially arranged arms, or in the form of an elongated S are known. These prevent division of the melt stream being carried right through the wall cross-section. Flow lines can be further minimized by means of restrictor beading and counter current spiral channels. Through careful balancing of the cross-sectional ratio between the spider zone and die ring gap, the particular residence time of the melt under the spider, and the choice of spider design, flow lines can be virtually eliminated. The selection of these conditions is determined by the resin used and the type of blow moulded article (thin or thick-walled container) made.

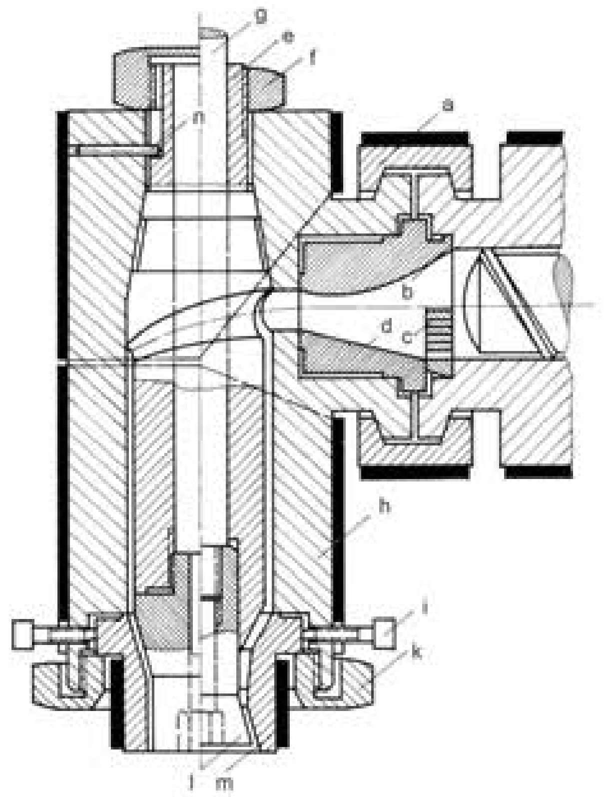
Radial Flow Crosshead with Through Mandrel

For processing of polyethylene, the radial flow crosshead with through mandrel has proved most suitable. The melt stream is distributed either by a circular groove or a heart-shaped device. Irrespective of the various designs used to divert and distribute the melt stream, the mandrel can be mounted from above, Figure 8, or from below, Figure 9. In both cases a tapering guide ensures correct alignment and reliable sealing. Both designs have advantages and disadvantages. In favour of the top-mounted mandrel arrangement is the fact that it is not obstructed by the blow moulding machine. It is therefore particularly suitable for frequent cleaning on changeover of colour or product, and for clamping units which are installed in the extrusion zone. The bottom mounted mandrel on the other hand allows wall thickness control by variation of cross-section.



a connecting piece
b countersunk breaker plate
c adaptor
d,e die gap adjustment in intake zone
f mandrel with circular groove
g extrusion head housing with stainless steel lining
h adjusting screws
I retaining ring with screws
K die core
l die orifice

Figure 8: **Radial Flow Crosshead for Parison Dies with Top Mounted Mandrel and Circular Groove for Distributing the Melt Stream; Right of Diagram Shows Die Gap Adjustment in Intake Zone**



- **a** split clamping flange
- **b** restrictor
- **c** breaker plate for supporting a screen pack
- **d** adaptor
- **e** bottom-mounted through mandrel
- **f** retaining screw
- **g** sliding rod for die adjustment
- **h** extrusion head housing
- **i** adjusting screw
- **k** retaining ring
- **l** die core
- **m** die orifice
- **n** adjusting pin

Figure 9: Crosshead with Bottom-Mounted Through Mandrel and Flat Distribution Channel in a Heart Shape; Right of Diagram Shows Adjustable Die Gap

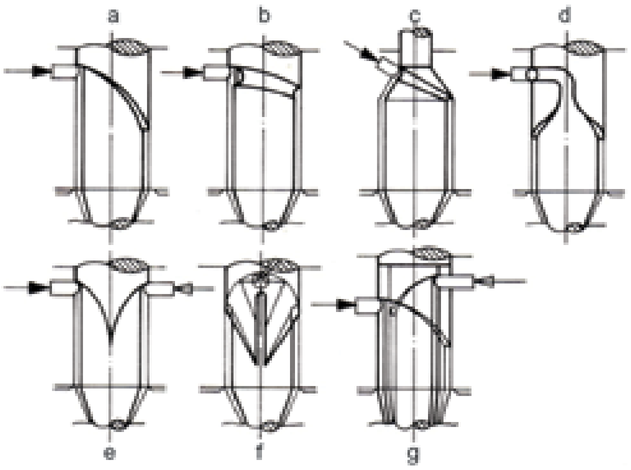
Design with Circular Groove

The melt is distributed on an overflow principle from the circular groove which is fed from above on as wide a front as possible. Only one seam is formed. Opposite the flow channel there is a stagnation zone in which the melt may reside for some time. This region increases in size with increasing mandrel diameter. Mandrels with a circular groove are therefore suitable only for processing melts with good heat stability, particularly HDPE. Here, too, cleaning at regular intervals is recommended. From the design point of view, given a circular cross section, a ratio of $d_R : d_p = 0.2 : 1$ is recommended, where d_R is the diameter of the circular groove, and d_p the diameter of the mandrel. This ratio can be applied to other designs as well. For control of the melt stream with coaxial dies, an adjustable retaining ring mounted above the die intake has proved successful.

Design with Heart-shaped Channel

For blow moulding, crossheads which represent a compromise between the ‘classic’ heart-shaped channel (Figure 9) and the (inclined) circular distribution groove have proved successful. By trial modification of the geometry, a rheologically optimum design can be determined for each moulding compound, and stagnation zones reduced to a minimum. Trials have shown that with polyethylene melts, which have a markedly high intrinsic viscosity, excessive vertical elongation of the heart-shaped channel has an adverse effect on the weld seam.

Of the many possible modifications of the heart-shaped channel, Figure 10 shows a series of designs which have proved successful in blow moulding. Axial and radial wall thickness control of the parison is effected with these designs as with the axial flow crosshead.



a mandrel with heart-shaped channel greatly elongated in vertical direction

b distribution channel with wedge-shaped crosspiece above the restriction point opposite the flow channel

c design with tapered cross section in the distribution zone

d design with two diametrically opposed distribution channels

e design with diametrically opposed heart-shaped channels greatly elongated in the vertical direction, and two flow channels for the production of a two-colour parison

f design with feed channel for a coloured or transparent stripe

g design for internal or external coating

Figure 10: Modified Mandrel with Heart-shaped Channel

Parison Dies

The wall thickness dimensions and surface quality of the parison and hence of the finished moulding are fundamentally influenced by the design of the parison die. Construction of the die is determined primarily by the length of the pinch off seam. In addition, it is frequently necessary for the wall thickness of the parison to be regulated during extrusion. The most common die designs are:

- Dies with cylindrically parallel annular gap and compression section in the inflow zone
- Dies with expansion inserts
- Tulip dies for extrusion with adjustable die gap (suitable for regulating wall thickness)
- Dished or trumpet-shaped die for extrusion with adjustable die gap (suitable for regulating wall thickness)

From the rheological viewpoint it is an advantage for the orifice and core or lips to end flush at the bottom. In dies with an annular gap, the core may project or be recessed a few mm without any adverse effect on extrusion of the parison. If the core is recessed too far, looping may result. In such cases the parison frequently sticks to the hot die. These effects occur also when the temperature difference between the orifice and core is too great. Then the parison curls preferentially towards the die part with the higher temperature. Curling and sticking may also be observed on expansion dies with an excessive diameter taper (in the inflow zone of the die). Finally, lateral deflection of the parison due to inaccurate centring of the die and inappropriate die correction can also cause sticking to the die orifice.

These effects seriously interfere with production, for example in blow moulding by the calibration method.

If release agents are used in blow moulding, it should be remembered that they may cause problems in subsequent operations such as printing, labelling or embossing of containers. Wetting the parison with release agent as it emerges from the core or introducing recycled material containing release agent causes defective welds. These phenomena may appear briefly or be repeated frequently.

Given optimized extrusion and blow moulding conditions, the surface quality of the container is largely determined by the design and inherent properties of the die. The die walls should be polished. To protect them from damage the bottom edges of the die are bevelled off. This also prevents the parison from sticking during stress relaxation in the stop phases of the extrusion cycle. The die inflow must be designed on good rheological principles. Abrupt tapering of cross sections should be avoided as this assists the formation of secondary streams and stagnation zones.

Notches and grinding marks in the die may cause flow lines on the surface of the container, which cannot as a rule be completely removed by blow moulding techniques. From the viewpoint of processing technique, careful cleaning and maintenance is no less important for dies than for the much more expensive blowing moulds. Hardening and/or chrome-plating to increase wear resistance is recommended when the die design has been finalized.

Dies with Cylindrically Parallel Annular Gap

Design with Conical Inflow Zone

The outer inflow angle α_M (M = die orifice) – starting from the centre axis should if possible be <15-20°, and the difference between the outer and inner inflow angle α_K (K = die core) should not exceed about 5°. The relative die length

$$L_D = l_D / a_D \qquad (6)$$

(D = die, a = die gap, l = length) depends on the blow moulding requirements imposed on the parison; it is usually $5 \leftarrow L_D \leftarrow 20$.

Container weight and wall thickness distribution can be controlled by adjusting the die gap in the inflow zone, but only within narrow limits. This technique is particularly effective with melts having pronounced swell characteristics, and with short die lengths (LD < 10). Here it is important that the shear and tensile stresses to which the melt is subjected as it enters the die are quickly relieved.

Against this disadvantage can be set certain advantages: radial wall thickness variations are smaller than with other die designs; modification of the die to compensate for wall thickness variations which may arise around the circumference of containers with contours not ideally suited to blow moulding can be carried out more simply than with longer dies (LD20). When thin-walled HDPE parisons with a large diameter (→ 80 mm) are extruded, longitudinal folds may develop. These are formed with increasing parison length because swelling is obstructed below the die. Since the weight of the parison acts perpendicularly below the die, the parison, with circumference (diameter) increased by swelling, develops folds until at the centre its diameter approximates to that of the die. This effect is assisted by weld lines. In accumulator processes the melt remains in the die for some time before extrusion and during this period stress relaxation can take place. During extrusion the lower part of the parison swells less and the parison takes on the appearance of a pear; this too encourages the formation of longitudinal folds. This problem can be countered by using a dished or trumpet-shaped die or inflating the parison with support air to a pillow shape as an intermediate stage.

Expansion Dies

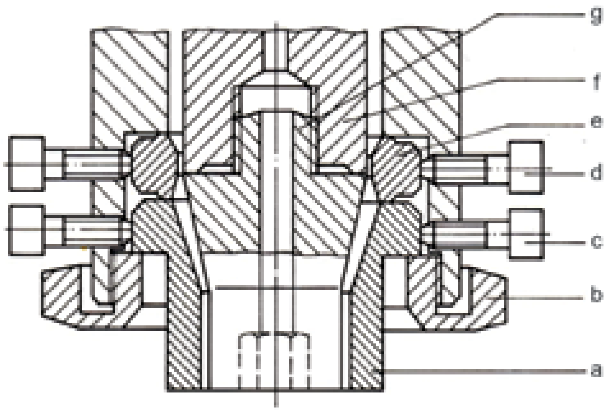
The characteristic feature of expansion dies is the diverging diameter of the inlet. These dies are used in blow moulding when the die diameter has to be greater than that of the flow channel. With expansion dies, not only die length, but also the diameter taper and cross section of the inflow zone have a great effect on parison swell, since shear deformation in the die is preceded by deformation due to biaxial tensile stress. In the case of melts with marked swelling characteristics, this can in certain circumstances cause necking below the die. As die length increases (longer residence time in the die) these inflow effects are mitigated, so that with dies of adequate length, swelling produced by elastic shear deformation can take place.

In view of this behaviour, the outer inflow angle α_M – starting from the centre axis - should be as large as possible, i.e. about 150°. The difference between the outer and inner inflow angle will depend on the cross sectional taper required.

Dies with Conical Core

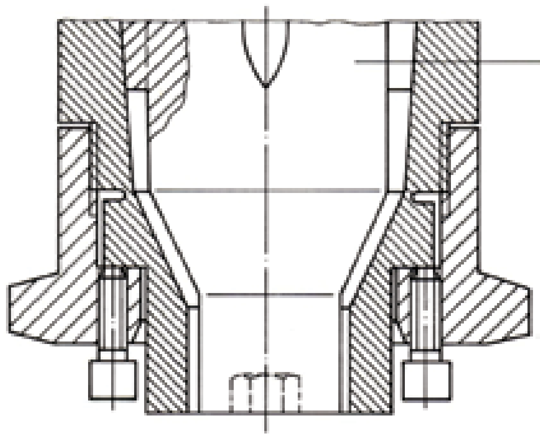
The conical dies shown in Figure 11 are suitable for manual die gap adjustment to regulate container weight and for programmed adjustment during extrusion to control the ultimate wall thickness of the blow moulded container. The die gap is adjusted on radial flow crossheads with through mandrels, by moving the core with a spindle and on axial flow crossheads by raising and lowering the orifice. Excessive recessing or projection of the core can cause problems (see Parison Dies section). Die gap adjustment can be carried out without changes in inflow conditions, or can be combined with modifications to the inflow zone to ensure that total flow resistance is kept as low as possible. The constant extrusion pressure obtained by combined modifications which harmonize flow resistance in the die gap and inflow zone has to be weighed against the higher extrusion rate made possible by increasing the die gap without changes to inflow design. In die design it is important to select a fit such that the adjustable moving part does not seize and yet is not too loose. Mechanisms to prevent un-intentioned movement of the adjustable part are advisable with narrow weight tolerances.

Programmed die-gap adjustment on a time or cam-operated basis can be effected by hydraulic, mechanical or pneumatic means. To maintain a constant parison weight and length, the die gap adjustments should be reproduced in successive cycles throughout production. This requires some form of automatic control or arrangement in which the forces acting on the moving part and hence the pressure levels in the control cylinder and die head, should correspond to each other, and alter only within acceptable limits. On control devices with a pneumatic control cylinder, it is necessary to determine the length ratio of the lever arms for a given pressure p_Z (Z = control cylinder) and the resulting ratio between the stroke travel of the die part and that of the cylinder piston.

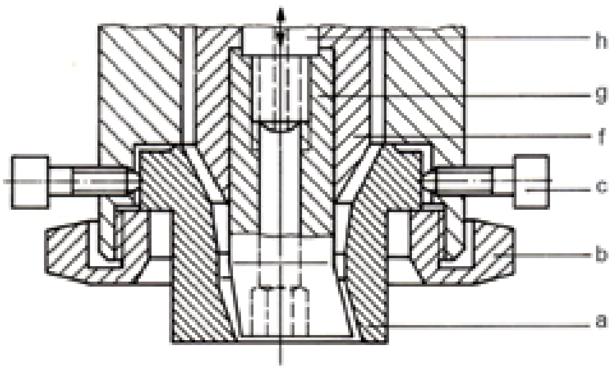


Top
die with conical inflow zone and adjustable choke ring (interchangeable)

a orifice
b retaining ring
c, d adjusting screws
e adjustable choke ring (interchangeable)
f mandrel or torpedo
g core



Centre
die with torpedo (f), spider supports and elastically deformable extrusion head housing for die alignment (diagrammatic sketch)



Bottom
Conical die for (programmed) adjustment of die gap; – left: conical or tulip die (with parabolic design); right: dished or trumpet die

f mandrel
g interchangeable core
h sliding rod for programmed die gap adjustment by a device shown in Figure 9.

Figure 11: Conical Dies

Conical and Tulip Dies

The conical die shown in Figure 11 should have an outer inflow angle – starting from the centre axis – of between 15 and 25° and an inner inflow angle of between 10 and 15°. It is an advantage to incorporate a cylindrical parallel section in the inflow zone. This parabolic design is known as a tulip die.

These designs are suitable for dies with a small diameter. Die gap correction to compensate for radial wall thickness variations in containers with contours not ideally suited to blow moulding must be limited to the last 4/10 of the die length.

Dished and Trumpet Dies

The dished die shown in Figure 11 (bottom right) is known as a trumpet die when its design is hyperbolic. The divergent angle of the die β_D - starting from the centre axis – should if possible not exceed 20°. The parallel die gap allows stress relaxation of the melt as it flows through the die; this elimination of stresses is further assisted by a cylindrically parallel section in the die. By this means weight and swelling effects on wall thickness distribution are mitigated and a contribution towards a smooth surface finish is made. If there is scaling on the inside surface of the moulding, it is worth checking the edges of the core. Die correction to compensate for wall thickness variations in containers with contours not ideally suited to blow moulding should not exceed half the die length. This design is particularly suitable for the production of thin-walled parisons, since troublesome longitudinal folds are prevented.

Melt Accumulators

For processing with melt accumulators, only moulding compounds with good heat stability can be considered. There are three main reasons for the development of melt accumulators:

- Process technology. With non-rotating clamping units, no new parison can be extruded when the closed mould remains under the extrusion head. By interposing a space for melt accumulation, the melt supplied by the extruder can be held ready and extruded in phase with the cooling cycle.
- Melt strength. The parison elongates under its own weight. The extent of this elongation depends on the melt strength of the thermoplastic, the length and thickness of the parison and the extrusion time. The heavier the parison is, the more rapidly it must be extruded.
- The reason for this is that the amount of loading under its own weight which the parison can sustain depends on the cross section of the parison i.e. loading capacity increases with the square of linear dimensions, while the weight of the parison increases with the cube.
- Parison cooling. The parison cools during extrusion, and in extreme cases may be cooled to an extent where blow moulding is no longer possible.

There are three main accumulator designs:

- Accumulators integral with the plastication unit (reciprocating screws, reciprocating barrels, ram extruders)
- Separately mounted accumulators (ram accumulators)
- Accumulators integral with the extrusion head (tubular plunger accumulators).

These designs have a number of features in common which will be discussed before dealing with each design in more etail.

To prevent the formation of an air cushion while the accumulator is being filled, the inflowing melt should displace the extrusion ram. The stroke of the ram is controlled by an adjustable limit switch and is set according to the required weight of parison. Here the specific volume of the melt must be taken into account, Figure 12. If compressibility is neglected.

$$V_{sp} = V \cdot G_s \qquad (7)$$

Vsp	preset volume of the accumulator	cm^3
V	specific, temperature-dependent volume of the melt	cm^3/g
G_s	parison weight	g

The parison is hydraulically extruded. Extrusion pressure is determined by extrusion rate, flow resistance and melt flow properties. The critical shear stress should not be exceeded (melt fracture). If both easy flowing and very high molecular HDPE grades are included, the selected extrusion pressure may be anything between about 10 and 80 MPa; a throttle valve permits infinitely variable pressure regulation. By gradually reducing the extrusion pressure and hence the extrusion rate, it is possible to counter the growing influence of parison weight with increasing parison length. This is a useful technique to be applied when wall thickness regulators are malfunctioning. Over-rapid acceleration of the parison through the extrusion die causes annular line marks which in translucent and transparent containers can be attributed to reduced wall thickness. Not surprisingly this phenomenon is encountered again if extrusion is interrupted for any reason such as when collapsing the tube in order to expand it to a cushion or pillow-shaped pre-form.

In all designs with an accumulator barrel, the cross section of the extrusion ram and the auxiliary ram is usually the same size. Excessive heat transfer to the hydraulic cylinder is prevented by cooling and/or the use of long expansion screws. Furthermore the retraction of the ram after extrusion assists in reducing heat transfer by conduction.

In choosing the fit between the accumulator ram and barrel, it has to be decided whether a leakage flow between the two is desirable or not.

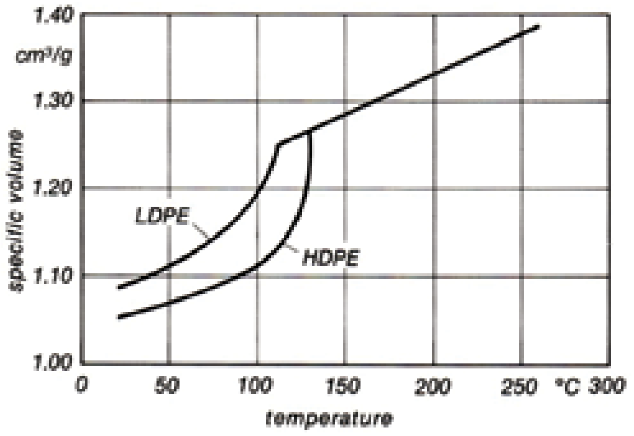


Figure 12: Specific Volume of HDPE and LDPE as a Function of Temperature

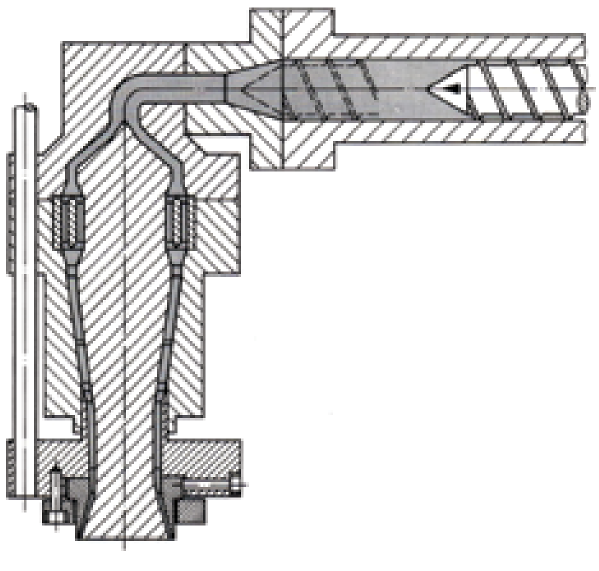


Figure 13: Reciprocating Screw Accumulator

Accumulators Integral with the Plastication Unit

This accumulator design has already been fully discussed in the section on reciprocating screw and reciprocating barrel extruders. Reciprocating screw units, Figure 13, gave rise to the development of the reciprocating barrel unit, Figure 14.

Reciprocating screw accumulators are constructed with capacity up to 4,000 cm^3 and reciprocating barrel accumulators with capacity up to 25,000 cm^3. Output rates up to 2 kg/s are achieved.

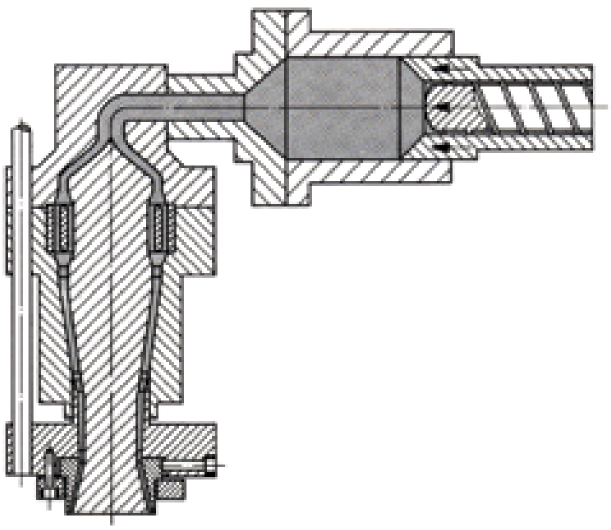


Figure 14: Reciprocating Barrel Accumulator (design: J. Fischer, Lohmar)

Separately Mounted Accumulators (ram accumulators)

Ram accumulators may be designed independently of the extruder and extrusion head, and may be connected to the extruder in almost any position. Various designs and arrangements are shown in Figures 15–17.

Accumulator capacities can go up to 40,000 cm^3; the output rate is about 1 kg/s.

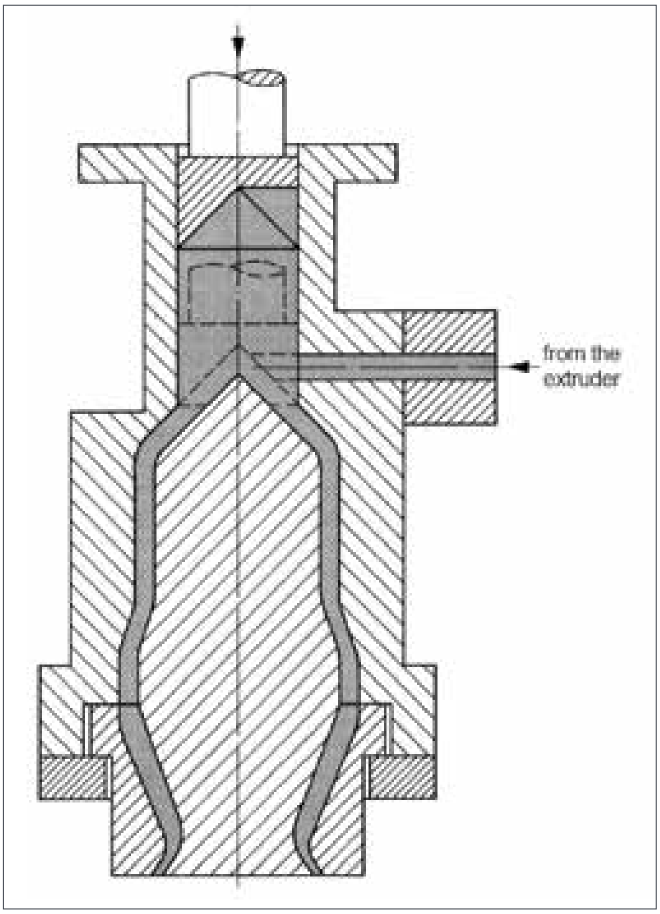


Figure 15a: Ram Accumulators
(design: J. Fischer, Lohmar)

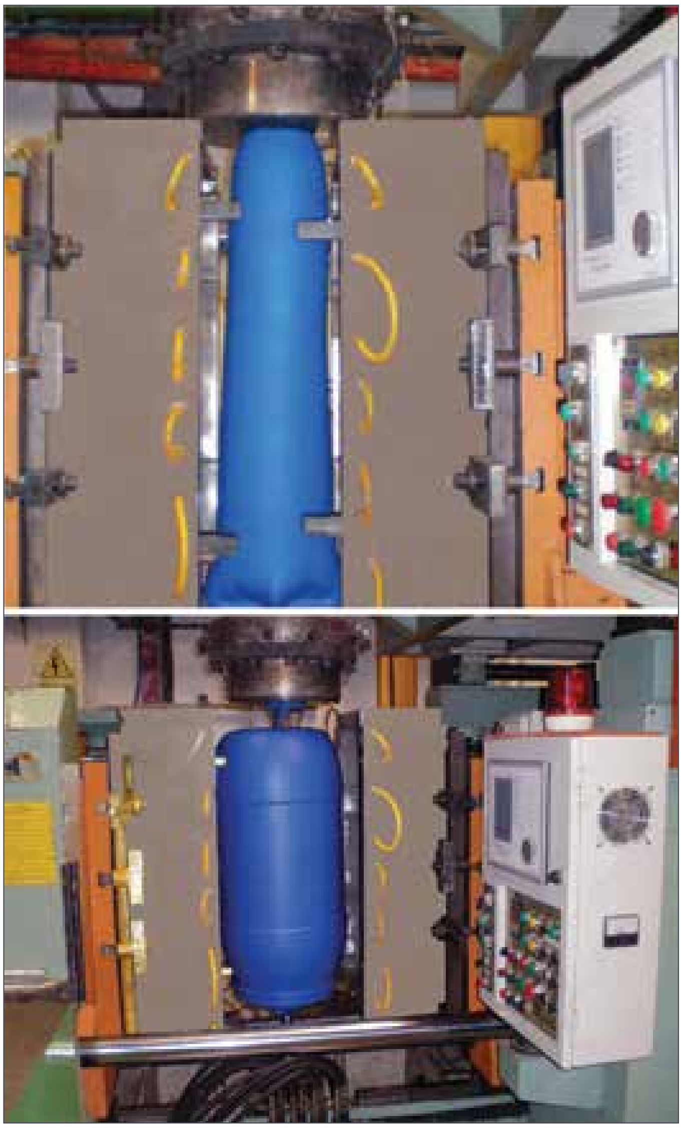


Figure 15b: Ram Accumulator used to Blow Mould Large Volume Drum

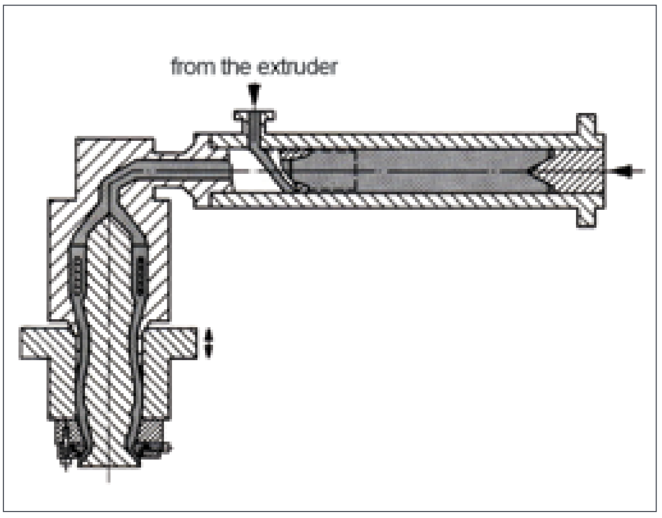


Figure 16: Ram Accumulator (design: Beckum, Berlin)

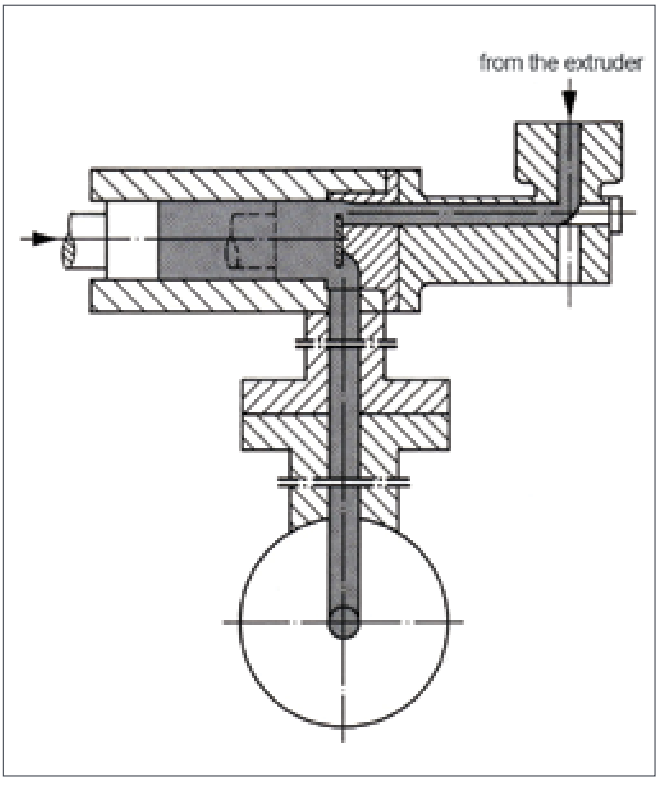


Figure 17: Ram Accumulator (design: Siemag, Hilchenbach/Dahlbruch)

Accumulators Integral with the Extrusion Head (tubular plunger accumulators)

With tubular plunger accumulators (Figures 18-21), it is possible to extrude both low and high shot weights (up to 200,000 cm^3) in a very short time. Extrusion rates up to 12 kg/s are possible. Large volume accumulators are fed by several extruders (up to four 140 mm single-screw extruders). Blow moulded containers up to 5,000 L capacity (heating oil storage tanks) are produced by this method. Tubular plunger accumulators have proved particularly successful for processing high molecular weight HDPE.

The high viscosity and pronounced elastic memory properties of the melt make it necessary to balance carefully flow channel cross-sections, mandrel supports, mandrels and extrusion head dimensions. In this respect the tubular plunger accumulator head has been clearly shown to offer the most advantages. The melt is fed into the annular accumulator laterally via a heart-shaped guide channel, or centrally via a mandrel support.

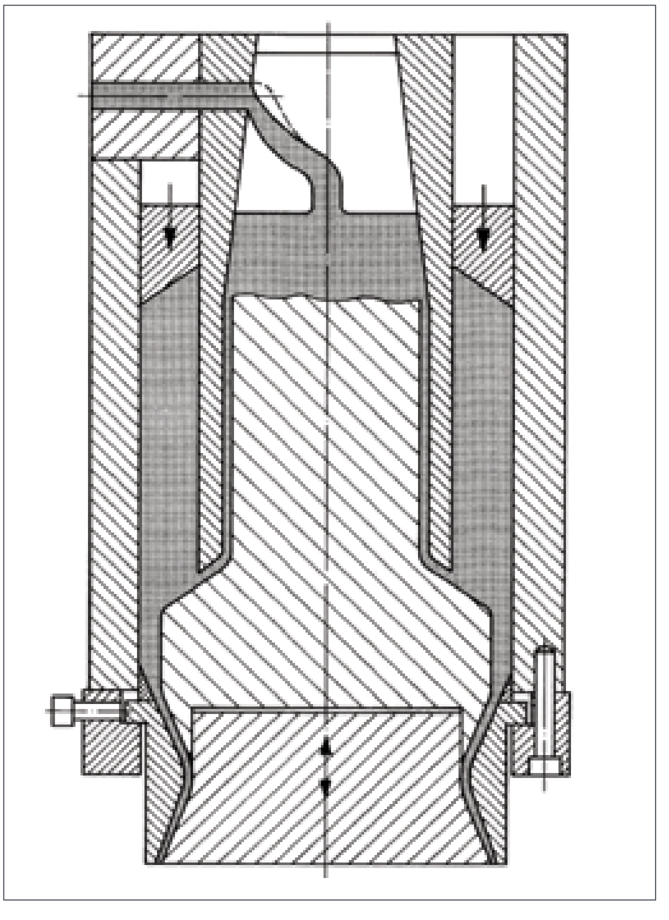


Figure 18: Tubular Plunger Accumulator (older design) (design: Kautex-Werke, Hangelar)

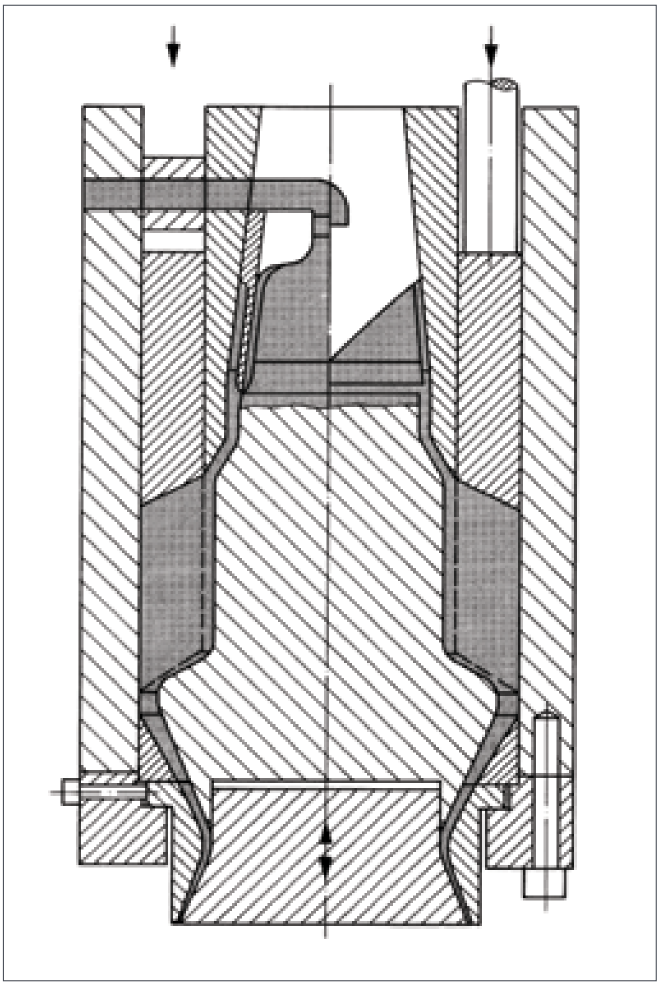


Figure 19: Tubular Plunger Accumulator (more recent design) (design: Kautex-Werke, Hangelar)

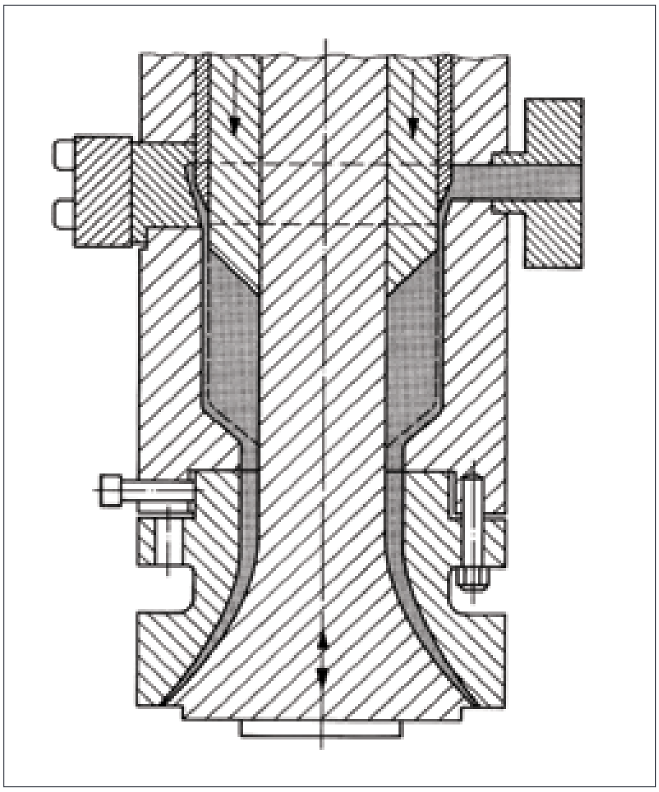


Figure 20: Tubular Plunger Accumulator (design: Battenfeld, Meinerzhagen and Bekum, Berlin)

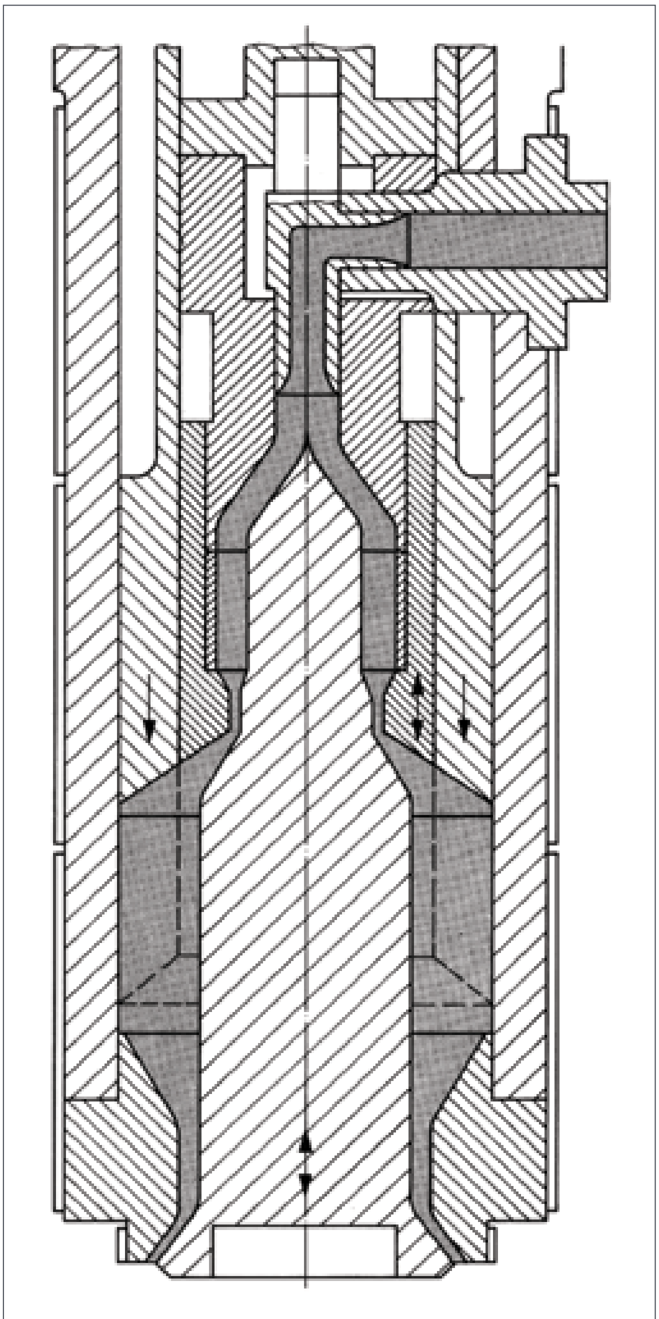


Figure 21: Tubular Plunger Accumulator (design: J.M. Voith, Heidenheim)

Between extrusion cycles the melt has time to relax and small local temperature variations can be equalized. Flow marks due to the mandrel support or the heart shaped curve are thereby mitigated or disappear completely. Another advantage of the annular accumulator space is that the molten tube is pre-formed and thus leaves the die in a less oriented state.

Factors Determining Extrudate Quality

In addition to being affected by the design of the screw and barrel, melt quality can be influenced by means of back pressure in front of the screw tip.

Adaptor and Associated Equipment

One effective means of regulating back pressure is through the dimensioning of the flow cross section in the adaptor between the extruder and extrusion head or accumulator.

Breaker Plates, Screens, Restrictors and Adjustable Throttle Valves

The extrusion head is bolted with the adaptor onto the extruder barrel flange. The breaker plate is located in the adaptor. Its function is to increase extrusion pressure and to homogenize the melt stream. In HDPE processing, weld lines caused by the breaker plate are usually visible on the finished moulding.

In special cases, breaker plates are used in conjunction with screen packs.[1]

Screen packs consist of two outer support screens with 200-400 meshes/cm^2 and a number of fine screens with 1,000-4,000 meshes/cm^2. These screens act also as melt filters. They are fitted in front of the breaker plate or between two breaker plates. Screens made of stainless steel wire are preferable to screens of non-ferrous metal.

Non-ferrous metal screens in combination with sulphur containing pigments and other additives such as antistatic agents and flame retardants can lead to melt discoloration.

If the screen pack becomes blocked, the extrusion pressure rises.

In extrusion blow moulding, blocking is frequently caused by the introduction of contaminants with recycled material. Behind the blocked parts of the screen, areas of stagnant melt can form and be subject to thermal degradation. These are the origin of streaky or cloudy discolorations, or dark specks on the finished product. With some bore sizes the screen can even break away and be pushed through the breaker plate. In extrusion blow moulding with screen packs, rapid changeover is important. Hydraulic cassette devices are available, which allow screen changes to be made without interrupting production.

1. When processing is carried out without a breaker plate and screen pack, which is frequently the case, these are replaced by an unrestricted annular opening.

If processing is carried out without a breaker plate but a facility for increasing extrusion pressure is still required. a restrictor with a D/5 to D/20 tapered opening can be used. The most suitable bore should be determined empirically with a set of restrictors. It goes without saying that the entry and exit of the restrictor should be streamlined.

Extrusion with adjustable back pressure and pressure measurement, is a standard feature of blow moulding. Adjustable throttle control is provided in the case of multiple moulds (in parallel or series arrangement) for rapid equalization of the melt stream.

Back Pressure Regulation in Melt Accumulators

In melt accumulators it is possible to regulate the plastication pressure in the screw channel be means of a throttle valve in the return line of the accumulator hydraulic system.

Additional Facilities in Extrusion

Auxiliary Air Supply, Support Air and Inert Gas Blanket

Auxiliary Air Supply

By connection to the compressed air service, the bore which runs axially through the mandrel or at an angle through the core, torpedo and support can be used to ensure that if the free end of the parison is unintentionally closed (broken off, cut off, or squeezed together) during extrusion, the parison will not collapse when extrusion is resumed. It also provides a means of cooling the torpedo and die with compressed air at the first signs of thermal degradation of the moulding compound.

Support Air

The auxiliary air supply channel serves additionally as a passage for the support air required to inflate open parisons into a cushion or pillow shape and for pre-inflation. To ensure reproducible control of the support air rate, a reducing valve with a fine pressure gauge is fitted. Overfeeding of the support air causes production stoppages. If the rate of support air flow is too high, open parisons may collapse and closed parisons will be inflated prematurely which in the case of multiple heads can lead to fusion with adjacent parisons. In the case of closed parisons, excessive pre-inflation results in reject wastage and production stoppages, since the mould is prevented from full closure by film formation outside the pinch off pockets, and in certain circumstances the dowel holes may become blocked with melt. Excessive pre-inflation also causes surface scarring which is usually around the centre of the finished moulding and is due to contact between the outside of the parison and the vertical mould walls before blowing takes place.

Parting-off the Parison

In extrusion blow moulding, parting-off the parison is a basic feature of the process – except where parisons are fed tangentially into a rotary or chain machine, or drawn off by the 'hand over hand' method. With all the various methods of calibration it is essential for the parison (before or after mould closure) to remain open on at least one side. and for the cross section of the separated parison to be minimally distorted. For economic reasons the parison should be as short as possible.

The parison can be parted-off below the die by

- Pulling off
- Pinching off
- Cutting off and squaring with a knife or shearing arrangement
- Cutting off with a heated blade

All methods have their advantages and disadvantages, and the choice of method must be determined by the particular circumstances. Both the blowing method used and the characteristics of the plastic must be taken into account.

Pulling Off

The pulling off method is used in the case of moulds arranged on a vertically rotating wheel, in parison transfer systems, and with semi-automatic demoulding of larger containers when the parison is extruded intermittently into the open mould below the die. For this method to operate successfully, it is essential to ensure a sufficient pull-off rate (difference between rate of mould travel and average extrusion rate). The pull-off length, i.e. the distance between the mould and die, should be as short as possible. With low viscosity melts there is a danger of film formation due to plastic extension of the clamped length of parison. In the case of partially crystalline plastics with high viscosity and marked swelling, on the other hand, pulling off can cause fibrillation and necking-down of the parison. It is therefore necessary to test whether the inner width of parison which remains is suitable for insertion of the calibrating mandrel.

Pinching Off

Pinching off is used in the case of parison transfer by means of a jaw or gripper arrangement, or when mould closure takes place immediately below the die. For further details of this method see Parison Transfer section.

Cutting Off and Squaring with a Knife or Shearing Arrangement

The parison can be separated from the die by means of a knife. In this operation, only low knife speeds are required (peripheral speed ~1 m/s). By correct positioning of the knife and suitable choice of the material from which it is made, it is possible to ensure that the die edges are not damaged. Cross sectional distortion of the cut parison can be countered by the use of support air. The ensuing parison emerges with an open, non-distorted. free end. Since this method requires a flush fit for the core with the die orifice, it is used only in special cases. In cutting with a cold knife it is essential for the knife to rotate at sufficient speed (peripheral speed ~5 m/s). Cutting should preferably involve a 'drawing' action. Tensioning of the parison – for example by a rise-and-fall movement of the extruder or by movement of the mould or transfer arm – helps to obtain a clean cut. With HDPE, parison swell also contributes to clean cutting, since this phenomenon is accompanied by lengthwise contraction.

In cutting with a shearing arrangement, although the parison is not pulled to one side it is nevertheless pressed flat. For this reason, shear cutters are used in extrusion blow moulding only when the parison is cut immediately below the die (while blowing with support air) and the shears then move aside for the next length of parison.

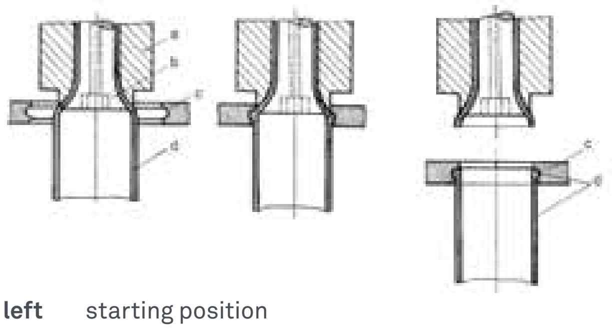
Heated Blade Cutters

Heated blade cutters are made of non-scaling metal and have a sword-shaped cross-section. They are heated to a dark red or cherry red by an electric current. The blade carrier must be insulated from the device which moves it, and be earthed from possible leak voltage. For heating, the mains voltage is stepped down to a 24 or 6 volt supply. Heated blade cutters may need resharpening after a few hours and replacing after about a week. When heated blade cutters are used to cut parisons containing inorganic pigments, plate-out or incrustation frequently forms on the blade. This makes it necessary to adjust the blade temperature upwards. For this reason it is advisable to provide an infinitely variable or graduated temperature control.

Parison Transfer

On machines with moulds located laterally or perpendicularly outside the immediate extrusion zone, a transfer arm conveys the parison and suspends it in the mould; at the same time the transfer arm can also effect parison separation by pulling off or pinching off. Transfer arms for lateral and vertical parison transport have been developed.

Both calibration with a blow mandrel introduced before mould closure, and with a blow mandrel inserted into the closed mould require a parison with at least one open end. For secure holding of parisons which are open at the top, it has been suggested that the transfer jaws could be provided with channels and openings for suction adhesion (which can if necessary be assisted by a studded structure). Alternatively a kind of flange can be formed on the parison by means of longitudinal grooves or an annular groove in the transfer jaw (see Figure 22). In some circumstances it may be necessary or an advantage to form a 'head' on the parison by retarding the movement of the transfer arm while maintaining a constant extrusion rate. Cooling the transfer arm also assists in this. Lateral deflection or swinging of the free parison end is prevented by a support arm (bent fork) which is swung out from the closing mould via a hinge mechanism and springs back to position. To eliminate weight and swelling effects on axial wall thickness distribution, a transfer arm has been developed which pulls the free parison end away from the die at a constant rate. Further control of wall thickness can be achieved by programmed die gap adjustment.



left	starting position
centre	pinching off and flange formation
right	parison transfer
a	die orifice
b	die core
c	transfer jaw or claw with annular groove
d	parison

Figure 22: Die Design for Formation of a Holding Flange on the Open Parison to Facilitate Parison Transfer

BLOW MOULDS

Materials for Mould Construction

General

Economic blow moulding of thermoplastics is dependent not only on the processing techniques described, and on mould design, but also on wear resistance, thermal conductivity and other partly chemical, partly physical properties of the materials from which the mould is made. Table 1 shows some of the important properties of various mould construction materials. In selecting a material for this purpose, consideration must be given not only to the processing requirements of the product but also to technical and cost aspects of mould construction.

Economic reasons and the need to finish orders on schedule, frequently make it essential to use multiple moulds and/or several blow moulding machines in a production run. This means among other things that tolerance limits for dimensions and volume are required. Adherence to these is governed largely by mould design factors such as the cooling system. The time required for mould construction is no less important as far as production is concerned, since it determines when production can start, and thus whether orders can be finished on schedule. Mould construction costs are an important factor in the calculation, particularly in the case of large containers, complicated parts and multiple moulds. All these considerations taken together culminate in the demand for a low-cost, technically suitable mould which can be constructed quickly and has a long life. In addition to construction materials, properties and costs, it is very important to take into account the particular production process for which the mould is to be used. Thus in selecting the construction material, not only mould size, i.e. cavity volume or mounting platen dimensions, but also the lengths of the runs are decisive factors. A distinction can be made between

- Moulds for long runs and continuous operation
- Moulds for short runs and prototypes

Construction materials may be classified in three categories

- Iron and steel
- Non-ferrous metals
- Casting resins

and are discussed below in the above order.

Table 1: Metal Construction Materials

Material	Coefficient of linear expansion α K^{-1}	Specific Gravity γ_{20} g/cm³	Specific heat c cal/g . deg (J/g . K)	Specific heat c Cal/cm³ . deg (J/cm³ . K)	Thermal Conductivity λ cal/cm . s. deg (J/cm . s . K)	Temperature Conductivity a cm²/s
Aluminium	22.0 – 25.0 x 10^{-6}	2.60 – 2.70	0.210 (0.879)	0.560 (2.345)	0.547 (2.290)	0.977
Bronze, 90 Cu, 10 Sn	18.0 x 10^{-6}	8.76	0.092 (0.385)	0.806 (3.375)	0.100 (0.419)	0.124
Cast iron, 3 % C	8.6 - 15.0 x 10^{-6}	7.60	0.115 (0.481)	0.870 (3.643)	0.139 (0.582)	0.160
Cast iron, 1 % Ni	9.0 - 15.0 x 10^{-6}	7.60	0.115 (0.481)	0.870 (3.643)	0.119 (0.498)	0.136
Copper	17.0 x 10^{-6}	8.93	0.092 (0.385)	0.820 (3.433)	0.939 (3.932)	1.145
Cu/Co/Be alloy	~ 17.0 x 10^{-6}	8.80	0.100 (0.419)	0.880 (3.684)	0.439 (1.838)	0.499
Cu/Be/Co alloy	~ 17.0 x 10^{-6}	8.80	0.100 (0.419)	0.880 (3.684)	0.211 (0.883)	0.239
Brass, 70 Cu, 30 Zn steels	19.0 x 10^{-6}	8.40	0.092 (0.385)	0.770 (3.223)	0.261 (1.093)	0.339
C8WS	10.0 - 14.0 x 10^{-6}	7.85	0.115 (0.481)	0.905 (3.789)	0.178 (0.745)	0.197
105 W Mn Cr 6	10.0 - 14.0 x 10^{-6}	7.80	0.113 (0.473)	0.880 (3.684)	0.094 (0.393)	0.107
X 45 Ni Cr Mo 4	10.0 - 13.8 x 10^{-6}	7.85	0.110 (0.461)	0.860 (3.601)	0.081 (0.339)	0.094
X 40 Cr 13	10.5 - 12.0 x 10^{-6}	7.70	0.110 (0.461)	0.850 (3.559)	0.060 (0.251)	0.064
Zinc	35.0 x 10^{-6}	7.10	0.093 (0.389)	0.660 (2.763)	0.300 (1.256)	0.455

Iron and Steel

For tooling with mechanical functions such as mounting guiding, sliding, pinching off, cutting and punching is normally used. The various steels recommended here are therefore intended for parts with an exclusively shaping function.

Mounting Platens and Bars

The usual tool steels are used for mounting platens and bars.

Guide Elements

Casehardened steels such as

16 MnCr 5. Standard No. 1.2161
105 WCr 6, Standard No. 1.2419

are preferred for the guide pins and bushes. (see Mountings & Guide Elements section).

Mould Inserts

Wear-resistant steels should be used for the mould inserts because of the high edge stress during pinching off and the tight mould closure required. The following steels recommended:

145 Cr 6. Standard No. 1.2063,
105 WCr 6, Standard No. 1.2419,
X 165 CrMoV 12, Standard No. 1.2601,
X 210 Cr 12, Standard No. 1.2080.

(for finish and hardness data see Mould Inserts section).

Blow Mandrel, Calibration Mandrel, Blow Needle

For the blow mandrel and inserted calibration mandrel shown in Figure 41. the usual tool steels such as 16 MnCr Standard No. 1.2161 are used. For the cutting head of the inserted calibration mandrel shown in Figure 41, steel X 210 Cr 12, Stand No. 1.2080 can be used on account of its higher wear resistance.

The normal commercially available cannulae may be employed as blow needles.

Shaping Tools

For container moulds particularly e.g. bottle mould fabrication by machining from the steel block is the preferred method. This is not least because experience has shown that in the mass production of blow moulded articles, separation of the pinch-off should be accomplished easily and as fully automatically as possible with no visible pinch-off seam.

Of the various tool steels the following may be mentioned:

Cr 45. Standard No. 1.1191
16 Min Cr5, Standard No. 1.2161
19 NiCrMo 15, Standard No. 1.2764

These have proved generally successful in the construction of moulds for plastics processing and can be polished and chrome plated if necessary. When corrosion resistant moulds are required steels such as

X 40 Cr 13, Standard No. 1.2083
X 35 CrMo 17, Standard No. 1.4122

are available.

Steel Plate for Welded Construction

Moulds for large, geometrically simple articles such as container liners can be welded together from steel plate. The critical mould wall thickness is 4-8 mm depending on the blowing pressure and size of moulding.

Rounded corners and edges are obtained by the use of machined parts or by corner infill welding. With machined parts, the seams should if possible be outside the edge region. The type of seam will depend on the relative positions of the parts to be welded.

The basic rules to follow in a design suitable for welded construction are:

- The number of welded seams should be as small as possible
- Welded seams should not be located at positions of maximum stress
- Seams should not cross each other

Subsequent machining operations include the finishing of the mould cavity, pinch off and weld edges and parting surface. Finally there remains the fitting of the guide elements and cooling water connections.

Cast Steel and Cast Iron, Meehanite Casting

The machining of large moulds is often very time-consuming. Special machines such as duplicating milling machines are occupied for long periods, and another factor to be taken into account is the loss of material, which can greatly exceed 50% in the case of moulds provided with cooling chambers around the cavity. On account of this, casting also comes into consideration for the production of large moulds. In view of modifications and repairs which may be necessary at a later date, it is an advantage if the cast material can be welded.

Cast Steel

The possibility of producing a suitable blank mould from cast steel should be investigated jointly by the steel founder and mould maker. In this preliminary work, it is necessary to determine not only the optimum design for the casting, including the cooling system. but also the most suitable alloy. In addition to sand-cast steel, castings made by the Shaw process have found a number of applications. This is a patented process developed in the UK which supplies castings with a good surface quality, and thereby enables the time spent in finishing operations to be reduced.

Cast Iron

Cast iron is only rarely used in the construction of moulds for plastics processing. The surface quality obtained is not sufficient to meet the high demands made.

Meehanite Casting

Meehanite casting is a patented process for the production of cast iron which contains an evenly dispersed proportion of graphite in the sorbitic – pearlitic microstructure and has good, uniform strength properties. The surface of Meehanite cast iron can be electroplated. Large moulds are occasionally made of this material.

Service Life

With suitable care, the service life of steel blow moulds is more than 10 million cycles and thus exceeds the longest mass production runs so far known. Interchangeable inserts (such as neck and bottom inserts in bottle moulds) should however be reconditioned at regular intervals so that the pinch-off can be separated easily and cleanly. The time after which reconditioning becomes necessary depends on the properties of the plastic, the grade of steel used and the care with which the blow moulding machine has been set up. In LDPE processing, several million cycles may be completed before reconditioning is necessary; with other plastics, reconditioning may be required after a few hundred thousand cycles.

Non-ferrous Metals

Aluminium and Aluminium Alloys

The characteristic properties of aluminium and aluminium alloys are: low specific gravity, very high thermal conductivity, weathering resistance and chemical resistance to many substances. They form a protective layer against oxidation. The strength values of these metals show that surface damage can easily be caused if proper care is not exercised.

Beryllium/ Cobalt/ Copper Alloys

Table 2 compares the strength values of two alloys. Thermal conductivity is shown in Table 1. Alloy 1 is preferred for blow moulds. Hardening is carried out at about 480°C for two to three hours.

These alloys have adequate corrosion resistance for normal use: they can be chrome or nickel plated.

Table 2: Properties of Beryllium/ Cobalt/ Copper

	Composition			
Alloy	Be %	Co %	Cu %	Strength, hardened (N/mm^2)
1	0.50	2.50	remainder	~800 – 900
2	2.50	0.50	remainder	~1150 – 1500

Bronze

Bronze if often used in the construction of blow moulds. Its good thermal conductivity and castability should be mentioned. However its range of application is restricted by low strength values.

Brass

Blow moulds for short runs can also be made of brass. The good thermal conductivity, strength, the suitability for hard soldering and machinability of this material should be mentioned. Since brass is very suitable for machining, brass plates are also used as engraving plates.

High-grade Zinc Alloys

For the construction of larger blow moulds, high-grade zinc alloys are preferred. When provided with steel inserts which may either be cast in or fitted subsequently, moulds of this type have proved successful in bottle production as well. Among the reasons for using these alloys is their good thermal conductivity and, in alloys with aluminium and copper, the dimensional accuracy obtainable. These alloys are, however, more susceptible to corrosion than zinc itself. On exposure to a corrosive atmosphere, zinc forms a strongly adherent surface layer which protects against further attack.

The mechanical properties of these materials are:

Tensile yield point	about	170 – 190 N/mm^2
Compression yield point	about	180 – 200 N/mm^2
Tensile strength	about	260 – 300 N/mm^2
Compressive strength	about	500 N/mm^2

The high-grade zinc alloys G-ZnAl 4 Cu 3 and G-Zn Al 6 Cu 1 are used for blow mould construction. It should be noted that these materials creep under pressure even at room temperature and surface damage may easily be caused if proper care is not exercised.

Service Life

Zinc alloy moulds with adequate wall thickness have a service life scarcely more than a tenth of that for steel moulds. In this case reconditioning of the weld edges is naturally required much earlier, unless steel inserts are use.

Casting Resins

For prototypes and short runs, moulds made of synthetic resin (methacrylate, polyester or epoxy resins filled with metal powder) are sometimes used. Epoxy resins are notable for their good dimensional stability.

Mounting and Guide Elements, Fitting

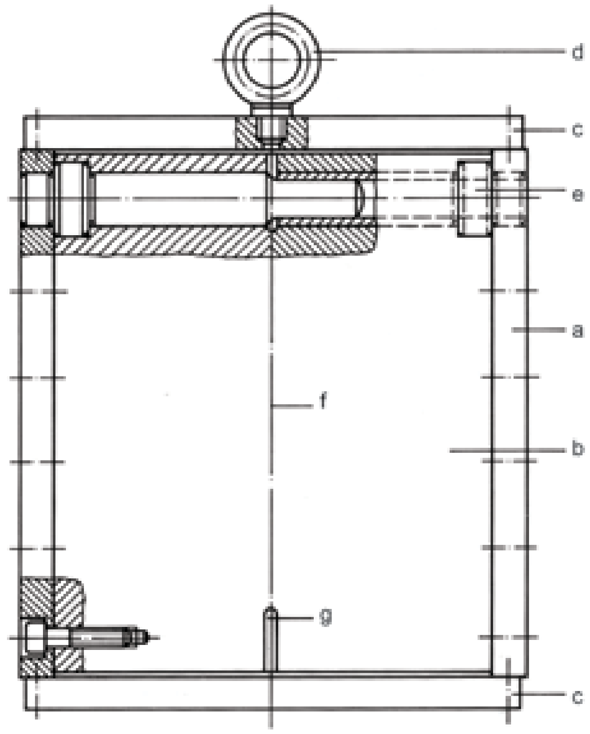
Mounting and demounting of the mould is made considerably easier if the base plates or bars project slightly beyond the sides. The usual means of mounting the mould is by direct bolting on to the mounting plate, although clamps are also frequently used. Damage to the mould and accidents due to unintentional opening of the mould during fitting can be avoided by using safety looking bars. Tapholes for eyebolts should be provided on the upper side of heavy moulds or on the transverse bar. Mounting plates with T grooves help to speed up fitting.

Of particular importance are the base plates for fitting horizontally or vertically arranged multiple moulds, unless the two parts of the mould are manufactured from a single block. In some cases, base plates can also serve as cover plates for the mould cooling chambers.

The two parts of the mould are located by two to four bolts and their bushings. Both guide elements are generally hardened. The hole for the bushing is designed as an H7 fit, and the external diameter of the bushing as n6. The guide length of the bolt is a g6 fit and the seated part is n6. The bolts are made of casehardened steels (56-60 Rockwell hardness), and the bushings usually of oil-hardened steels (55-58 Rockwell hardness).
To prevent warping during hardening, the locating bolts should not be too slender. The guide length of the rounded-end bolts is one and a half to two times the bolt diameter. Depending on the size of the mould, the bolt diameter is between 10 and 30 mm. The bolts and bushings must be recessed 1-2 mm so that the mould can close without hindrance. The bushings should not be press fitted in blind holes; the borehole, stepped down towards the rear, should pass right through the mould and should be accessible from the outside (Figure 23). Plastic melt forced into the hole can then be removed quickly and easily. This is especially important in moulds made from light metal alloys since otherwise the mould may fracture under closing pressure. A design with pinned fitting of the mounting plate to the mould block is also shown in Figure 23.

The guide elements should be fitted at a suitable distance from the mould cavity. This is especially important for moulds where the preform is squeezed from all sides and/or the parison is pre-blown. Opening of the mould on the bend is facilitated by a lateral slot about 3-5 mm wide in the mould parting line.

As a rule the mould is designed for a centre-fed parison. However, there are cases where a laterally offset and/or inclined mould is more advantageous for blowing.



a mounting plate
b blow mould
e opening
f mould parting line
g slot for parting the mould halves on the bend

Figure 23: Mould Block with Transverse Bars (C) and Eyebolt (D) for Mounting

Mould Cooling

An ideal mould cooling system should allow mouldings to be cooled sufficiently and as far as possible uniformly in an economically acceptable cooling time.

The heat to be exchanged is usually transferred to the cooling medium by contact with the surfaces of the cavity wall. Another possibility is cooling the inside of the moulding by purging with compressed air or liquid nitrogen (see section on intensive cooling with liquid nitrogen for further details). If the throughput per die G=G/t (where G in grams = weight of the moulding including pinch-off and t in sec = length of the working cycle) is known, and the number of mould cavities is n, the amount of heat to be removed in kJ/h can be calculated from the formula:

$$Q = 3.6n \, . \, \dot{G} \, .\Delta H \qquad (8)$$

Where ΔH is the enthalpy value in kJ/kg which as increment of enthalpy value H is determined from the melt temperature and the demoulding temperature. Figure 3 shows the enthalpy values for various polyethylenes plotted against temperature.

The time required for heat exchange depends not only on the amount of heat to be removed and the heat penetration coefficient, but also to a considerable extent on the shrinkage and crystallisation properties of the plastic. Too rapid cooling can cause internal stresses and in certain cases undesirable shrinkage voids. Too slow cooling on the other hand leads to a coarse crystalline structure, and in thick-walled mouldings the heat build-up can cause oxidative damage to the inner surface.

In assessing heat penetration, it should be remembered that the thermal conductivity of plastics is low in comparison with metals and, as Figure 24 shows, usually changes with temperature. Furthermore, blown mouldings have variations in their wall thickness. Greater cooling is required round areas with material accumulation, for example at the base and neck of bottles. Temperature differences throughout the mouldings when it is removed from the mould cause uneven shrinkage which can lead to internal stresses and distortion, particularly in the case of plastics with a large volume contraction on cooling, and a strong tendency to orientation (especially partially crystalline plastics). This can make printing of the blown bottles extremely difficult or even impossible.

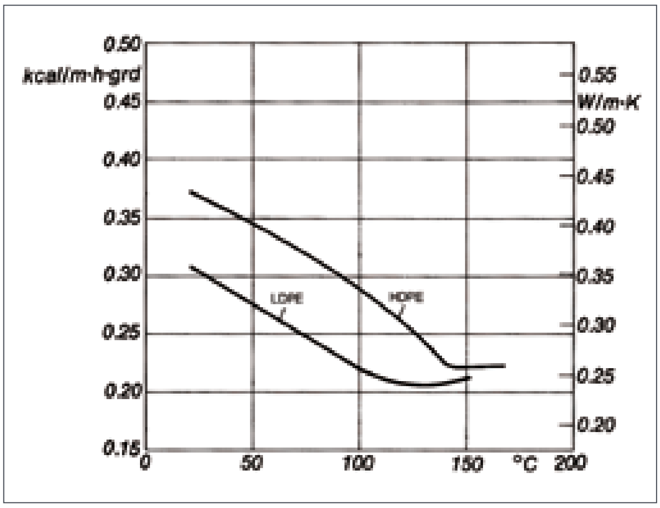
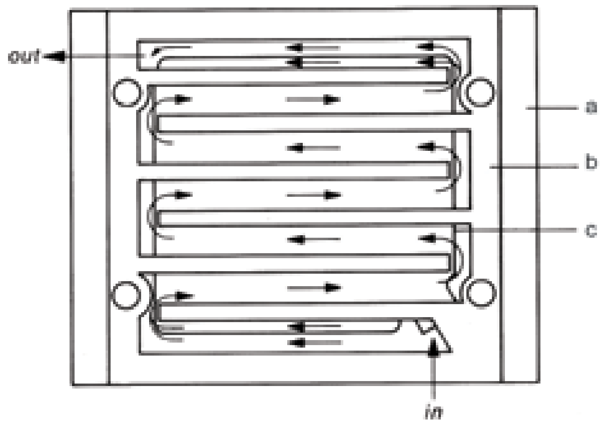


Figure 24: Thermal Conductivity of Polyethylene as a Function of Temperature

Apart from cooling the mould cavity, it is important to ensure that the often very large pinch-off is cooled as quickly as possible. Cooling of projecting, free-hanging portions of parison can be accelerated by an air blower.

The connections to the cooling medium inlets and outlets should be suitably located from the production point of view and readily accessible. Temperature control of the mould by means of several cooling circuits has proved successful; in bottle moulds for example, the base, body and neck regions are cooled by separate, individually adjustable circuits. For production with the shortest possible cycle times, moulds made of a beryllium/copper alloy which can be hardened to 45 Rockwell hardness are suggested. In addition, moulds made of aluminium and zinc alloys are recommended because of their high thermal conductivity. Here it should be noted however that because steel inserts are usually required in critical areas, this increased thermal conductivity cannot as a rule be fully utilized.

Cooling may be by a channel or chamber system. A channel system consists of vertical cooling channels connected in labyrinthine form as shown in Figure 25 by means of milled-in deflection channels, and a chamber with suitable inserts (or cooling coils in the case of cast moulds). In order to increase the heat transfer on the water side by means of turbulence, spiral copper strips can be inserted in the cooling channels.



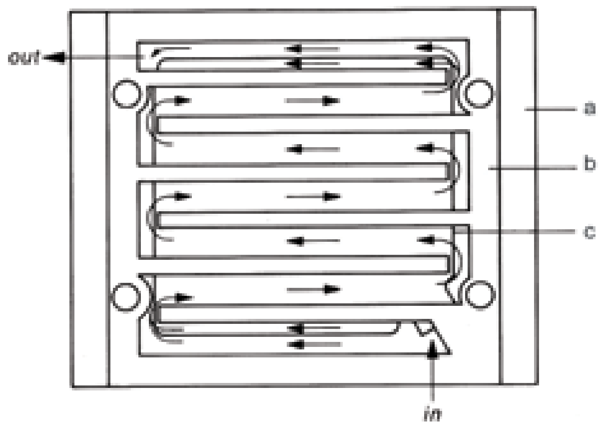
a continuous rod with stoppers
b inserted copper spiral

Figure 25: Cooling Channels with Labyrinth-type Water Flow

Minimum distances between cooling channels have been calculated in the case of steel injection moulds. Results are shown in Table 3. Because of the relatively low pressure used in blow moulding, these values are also applicable to mould construction materials of lower strength. In most cases however these distances are still not observed. With cooling channels of normal width (10-20 mm), the distance from the centre of the cooling channel to the mould cavity surface should be three times the channel width, and the distance between the centres of the cooling channels themselves should be up to four times the channel width, Figure 26.

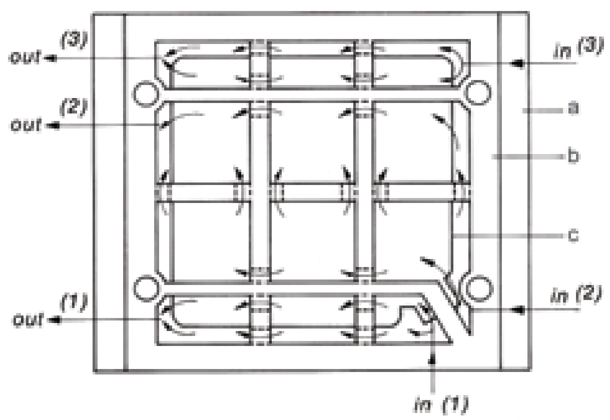
Table 3: Cooling Channel Spacing

Diameter of cooling channel (d) mm	6	8	10	12	14	16	18	20
Distance of cooling channel from mould cavity surface mm	4	6	8	12	15	20	25	30
Distance between cooling channels								0.67 d



a mounting plate
b blow mould
c visible contours of mould cavity for a canister with filler connection at one corner

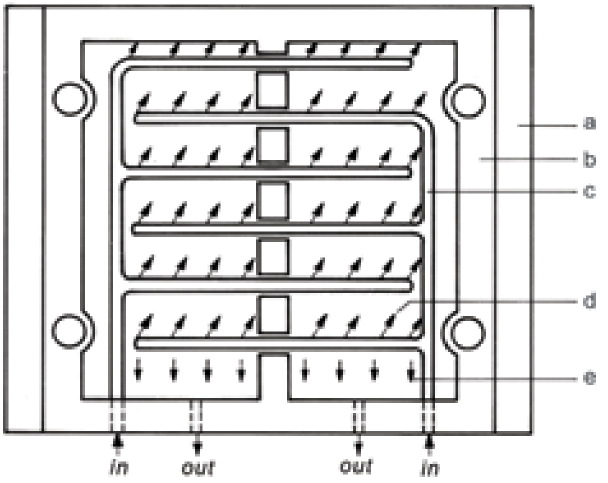
Figure 26: Channel System with Labyrinth-type Water Flow Produced by Baffles



a mounting plate
b blow mould
c visible contours of mould cavity for a canister with filler connection at one corner

Figure 27: Cooling a Blow Mould by means of Three Cooling Circuits and Cooling Chambers

More uniform heat penetration is achieved with cooling chambers, see Figure 27. These help to maintain a uniform wall thickness and, if necessary, they can be stepped to fit the contours of the mould. The minimum wall thickness of steel moulds is about 8-10 mm. Large cooling chambers should be supported on pillars or spacers on the base plate, and in critical cases the permissible distance between supports must be calculated. In cooling chambers, heat transfer may be brought about by deflecting the flow by means of baffle plates (T-shaped for small moulds) and overflow cooling or, for large moulds, by sprinkler (boundary layer) cooling, see Figure 28.



a mounting plate	**d** jet of water
b blow mould	**e** cooling water outlet
c sprinkler system	

Figure 28: Sprinkler (boundary layer) Cooling

The blowing mandrel should if possible be included in the cooling circuit. For this purpose, a circular channel with a partition down the middle or a dip pipe is used, or, if the mandrel is slender, a double helical path can be utilised for the cooling water, see Figure 29.

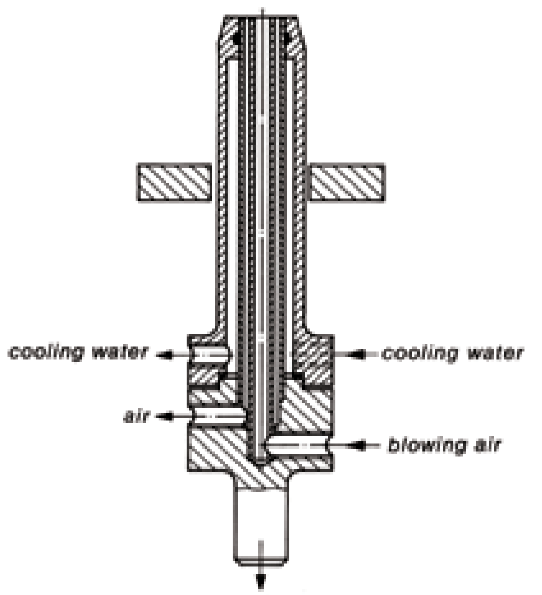


Figure 29: Section Through a Blowing Mandrel for Compressed Air Cooling

In the course of production, rust forms in the cooling channels or deposits build up on the surfaces. As a result, heat transfer on the water side is considerably impaired, cooling water demand rises and cycle time is prolonged. The water contact surface should therefore always be overdesigned in relation to the values obtained in accordance with standard heat transfer calculations. Frequently, it is worth considering the use of a circulated cooling water system which operates with demineralized water to ensure constant heat transfer performance.

Intensive Cooling with Liquid Nitrogen

General

In the blow moulding of containers, cooling is usually the main bottleneck in production. As a rule the heat from plastic melts is removed via water-cooled moulds. The cooling water temperature ranges from 12 to 18°C. Cold water cooling is also used. In this case, the water is cooled to 5-10°C with the aid of brine. More intense cooling of the mould is not possible since condensation would otherwise form inside the mould and might have an adverse effect on the surface of the moulding. Condensation forms inside the mould, when the mould temperature reaches or falls below the dew point.

Another recognized method of cooling is with compressed air from the blowing mandrel. Most processors use compressed air as an additional cooling aid, i.e. the compressed air required for blowing is removed during the cooling period and so takes away heat from the moulding. The cooling period comprises between 50 and 80% of the total cycle time, depending on the characteristics of the machine, the particular model and the complexity of the moulding. The cooling methods so far described at one time constituted the state of the art as it then was. However, for some time now various methods of intensive cooling have been under development.

Besides the N_2 method described below, two other intensive cooling methods have been developed. These operate on the basis of CO_2 and a highly compressed air/water mixture respectively. However, both methods require a higher investment.

Cooling with Liquid Nitrogen

The task here is to inflate and cool the moulding with a very cold liquefied gas. This must be introduced into the moulding through a single line. The problem is to replace the usual two-phase cycle of blowing and cooling, often with different media, by a single phase and a single medium.

This is made possible by the fact that throughout the gas inflow phase, the low boiling nitrogen passing through the mandrel is capable of continuous transition from the liquid to the gas state.

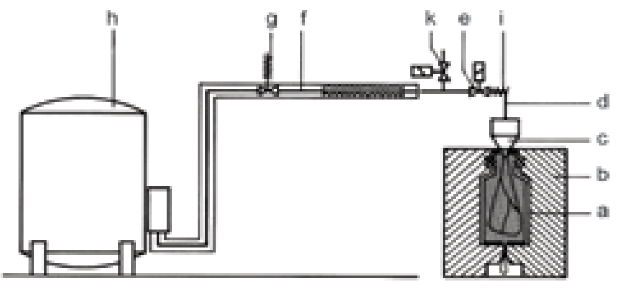
Before the blowing stage commences, evaporated, i.e. gaseous nitrogen at a relatively high temperature occupies the free space in the blowing mandrel and in the connection between the blowing mandrel and the valve on the supply line. The nitrogen has vaporized in the warm blowing mandrel and in the warm blowing line. At the start of the blowing stage the programme-controlled supply valve opens and liquid nitrogen flows in from a pressurized feed tank. However, since the mandrel and connecting line to the valve are warm, this liquid nitrogen immediately vaporizes at the same time undergoing a large increase in volume. Hence at first only gaseous nitrogen flows out of the mandrel.

This is used to inflate the moulding and in some cases even to expand it to its final shape. The vaporizing nitrogen sharply cools the mandrel and connecting line to the value with the result that after the initial blowing phase the nitrogen is only partially vaporized. In consequence a gas/liquid mixture flows into the partially or completely inflated moulding and cools it down. It is an advantage during this final phase to `breathe' the moulding as more liquid nitrogen flows in. This can be done by venting the mandrel or by a three-way valve.

As a result of the sudden drop in pressure, the liquid nitrogen comes out of the mandrel in a very fine spray, so there is no danger of cold shock to the plastics material. However, it is important to ensure that as liquid nitrogen first flows in, no droplets come into direct contact with the internal wall of the moulding. For this reason the mandrel orifice cross section and the feed tank pressure must be carefully matched so that in the initial blowing phase gaseous nitrogen is forced out of the mandrel at approximately the speed of sound. As soon as the first drops of liquid appear in this gaseous flow, they are atomized at the mandrel orifice and are split up more finely than would be possible with a spray nozzle. This ensures that no liquid nitrogen contacts the internal wall of the moulding at the start of cooling.

With tall mouldings, it is advisable for the mandrel orifice to be designed along the lines normally used in steam turbine construction, i.e. with a divergent opening (Laval nozzle). Large container mouldings often require several mandrel orifices.

Figure 30 shows the whole plant in simplified form. The moulding has already been inflated in the mould. Liquid nitrogen is fed from the tank to the moulding via a supply line, programme-controlled valve, non-insulated line and the blowing mandrel. The non-insulated line, like the mandrel, has a high heat capacity. The mandrel can be lifted off in the usual way to vent the mould. A heating element is arranged around the non-insulated line (d) to ensure that whatever happens only gaseous nitrogen comes out of the mandrel when blowing commences. The vent-off valve enables the line to be purged with nitrogen and cooled to operating temperature on machine start-up.



a plastic container moulding
b mould
c blowing mandrel
d non-insulated line
e solenoid valve
f supply line
g safety valve
h liquid nitrogen storage tank
i heating element
k vent-off valve for running the line cold

Figure 30: Diagram of Plant for Intensive Cooling with Nitrogen

Economic Aspects of Intensive Cooling with Nitrogen

Before intensive cooling is adopted, a processing plant should have the following facilities available:

- An efficient extruder with a plastication capacity of about 30-50% above that required,
- A nitrogen supply source located close to the point of consumption since nitrogen prices depend among other factors on transport costs,
- An optimum mould cooling system which if possible should include a cooling plant to lower the temperature of cooling water,
- Fully automatic separation of the pinch-off or simple manual removal so that increased output does not create additional labour costs,
- Full utilization of existing machine capacity, i.E. Three shift working.

If these requirements are met, cooling with nitrogen can in an ideal situation reduce cooling times to about one third of the normal time.

Mould Parting Line and Inserts

Mould Parting Line

The mould should always be divided at the most favourable sectional plane of the article from the point of view of blowing. This generally gives two equal halves with a flat parting surface. In the case of asymmetrical container mouldings and complicated mouldings, the avoidance of mould release difficulties caused by undercuts, in addition to the most favourable blowing ratio, influences the position of the parting line[1]. For this type of article, split moulds with interlocking inserts, and also inserts which swing away horizontally or vertically when the mould opens or closes such as inserts for the container base are often necessary. They may be moved by mechanical, hydraulic or pneumatic means. Loose inserts are often used as well.

For cylindrical mouldings, the parting line runs through the axis. In the case of oval cross sections, the mould parting line runs through the major axis. Moulds for square articles can be parted either parallel to the side surfaces or diagonally. Diagonal parting is less common in spite of easier mould release and a lower inflation ratio because the excessive stretching in the corners opposite the parting line during blowing may lead to undesired thin areas in the finished moulding.

1. The inflation ratio is defined as the quotient formed from the mean circumference of the moulding and that of the parison. For axially symmetrical mouldings, the inflation ratio is $A=d_F/d_S$ where d_F is the diameter of the mould cavity and d_S the parison diameter. A is usually $\pi/2$ to 3, and in special cases up to 7.

Mould inserts

Inserts should be shaped so that line marks on the moulded article caused by contact with the insert surface are as far as possible invisible.

Mould Inserts with a Shaping Function

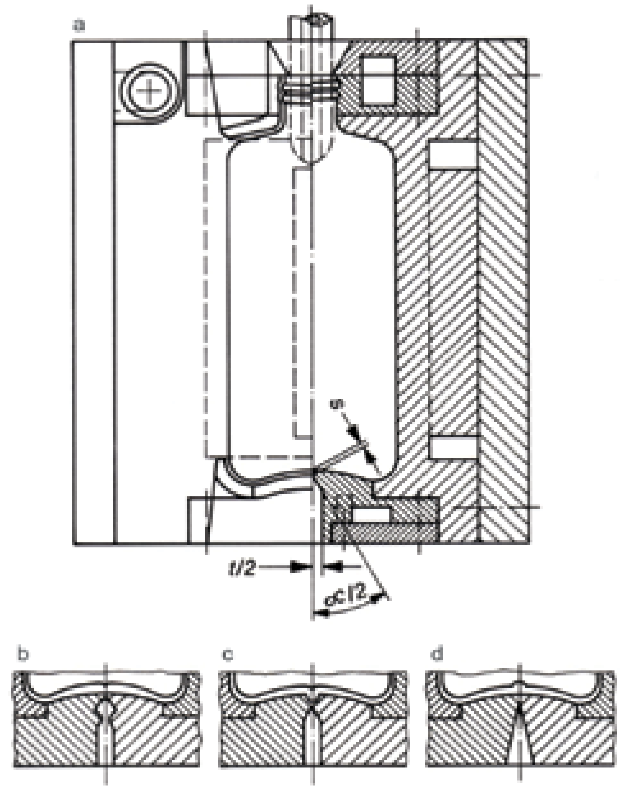
It is particularly important to ensure that mould inserts with a shaping function can be efficiently cooled. In special cases, construction materials with a high thermal conductivity are used and cooling is aided by a stream of air.

Mould Inserts with Technical Function

Construction materials for inserts with a technical function were listed in the previous Materials for Mould Construction section. Hardening up to a Rockwell hardness of 60-62 is normal. On mould closure the welding edges are loaded with almost the full clamping pressure because the cooled plastic between the moulding and pinch-off is pressed to a thin film. For this reason, reconditioning at regular intervals is necessary. Service life depends not only on the design and hardness of the insert but also on the compressibility of the plastic, the cycle time and in certain cases, filler and pigment content. In HDPE processing, bottle moulds usually need reconditioning after about 100,000 cycles whereas with LDPE the number of cycles before reconditioning may be twice to ten times as many.

Welding Edges and Pinch-off Arrangements

The welding edges and pinch-off arrangement of the mould must be designed so that when the mould closes, the parison is sealed at both ends and can be blown easily. In addition to a high-quality welded seam on the moulding, simple separation of the cooled pinch-off with as little flash as possible is desirable for production reasons. The length of the welding edges and volume of the pinch-off pockets must ensure that no film forms outside the pinch-off pockets which could prevent the mould from closing completely. In mouldings where lateral nipping of the parison is required, the welding edges and pinch-off pockets run round the circumference.



S welding edge width
α opening angle of pinch-off pocket
t width of pinch-off pocket

Figure 31a-d: Design of Welding Edges and Pinch-off Pockets

The design shown in Figure 31a has proved the most successful in spite of the notched welding seam. The welding edges should not be knife-sharp but broad, flat surfaces aligned with the mould parting line; if the welding edge is too sharp, the parison will be cut off when the mould closes. The welding edge width depends on the plastic being processed; in some cases the edge should be slightly bevelled on the mould cavity side. For LDPE, a welding edge width of 0.1 mm is recommended whereas for HDPE, widths of 0.3 mm and more are usual. The welding edges open out at a total angle of between 20 and 60°, and preferably between 30 and 45°. into a pocket with parallel or slightly diverging edges (see Optimization of the welding edges and mould closing operation section).

The depth of the recess around the pocket should be about 9/10 of the wall thickness of the parison in each mould half. This means that the parison is nipped when the mould closes and is cooled by contact with the mould. To assist the nipping action, compression bars may be provided just below the section where the pocket opens out, on one or both sides (Figure 31b). This causes a thickening in the welding seam and provision must be made for there to be sufficient melt in the pinch-off pocket.

With increasing wall thickness, it becomes more difficult to obtain high quality welding seams, which is an important point in the case of heavy duty containers. This applies particularly to the upper welding seam because the parison hangs from this section until the mould closes and it is blown. One remedy – apart from delaying the final phase of mould closure – is to thicken the outside of the welding seam in the form of a ridge. The width of this ridge (groove in the pinch-off arrangement) should correspond to the adjacent wall thickness of the moulded container. The groove edges should be rounded to avoid notch effects. The deeper the groove, the greater the strength of the welding seam, particularly when the groove has a trapezoidal or triangular cross section (Figure 31c). If the mould operates with a reduced speed in the final stages of closure, the welding edge width can be reduced to 0.1-0.2 mm, even in the production of HDPE bottles.

The design shown in Figure 31d produces welding seams with an inner reinforcing beading. These seams are of high quality, particularly in the case of polyolefins. The welding edge width in this design is 0.3 or 0.5 mm and above (up to 4 mm). A pocket opening angle of 15-30° is recommended, depending on the parison thickness. This design requires an increased mould closing force and if the welding edge is wide the pinch-off has to be trimmed back afterwards. As in the case of the design with compression bars, tests must be made to ensure that no cold non-fusible melt is forced into the welding seam as the mould closes. Figure 32 shows the resultant deep notch which greatly impairs the strength of the welding seam. This fault is caused not only by the mould temperature being too low but also by over-rapid mould closure.

In some moulds the pinch-off is automatically parted after the mould has closed by means of toothed inserts or bolts which are operated by a programme-controlled compressed air cylinder. It is also possible for the pinch-off to be parted as the mould opens by means of folding plates.

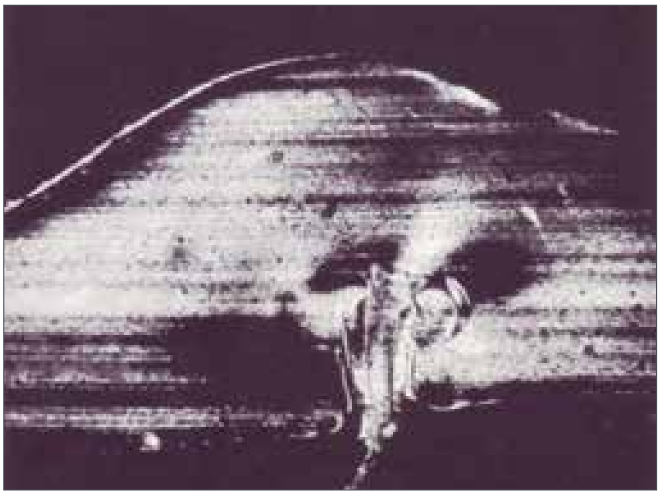


Figure 32: Thin Section through the Base Weld Seam of an HDPE Bottle

Optimization of the Welding Edges and Mould Closing Operation

Optimization trials are only worthwhile if an analogy with moulds producing articles of a different shape and volume In the blowing process, the can be found.

Optimization trials carried out with moulds for the manufacture of 60 L cans (Figure 33), 100 cm^3 round-shouldered bottles, as well as 5 litre and 600 litre containers showed that the following values are generally applicable:

Total angle of pocket opening	30°
Width of compression bars L	2-3 x welding edge width
Gap between compression bars X	0.1 x pocket width c
Recess depth t	2 x parison wall thickness d
Optimum delayed closing travel W_v	4 x parison wall thickness d

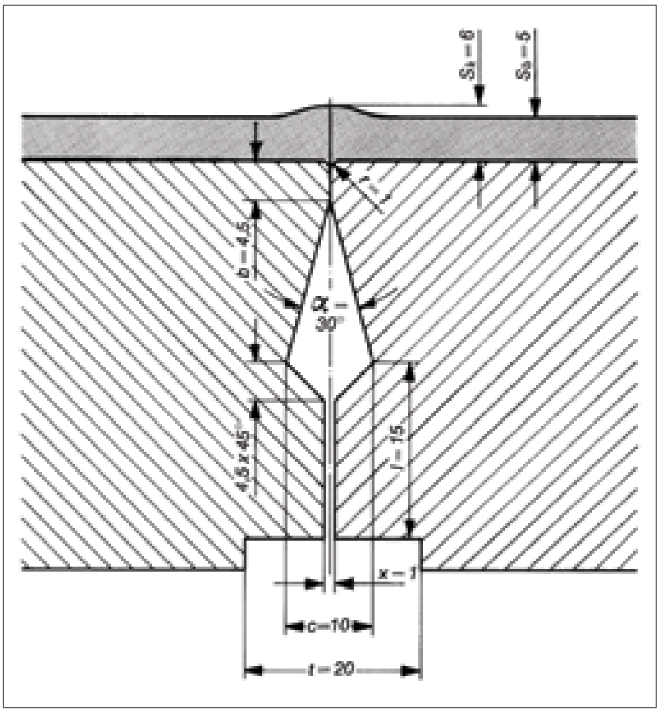


Figure 33: Optimized Mould Base for a 60 L Can Made from HDPE

In order to determine the optimum design of the mould base, the values for the welding edge width b and pocket width c must be known. The results of the optimization trials show that the welding edge width b is a function of container volume H, and that the pocket width c is dependent on both volume, and parison wall thickness d.

Mould Cavity

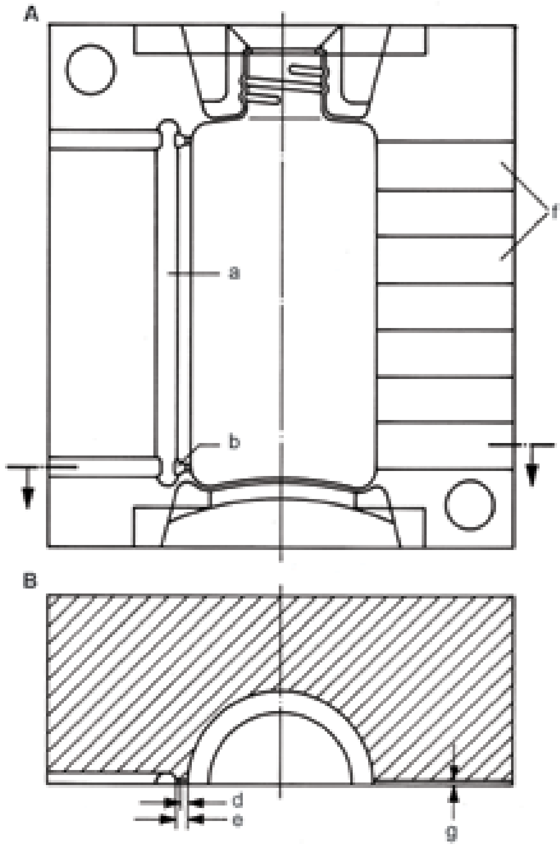
Cavity Venting

In the blowing process, air enclosed in the mould cavity must be almost completely expelled so that the moulding can cool on the wall of the mould. Local trapped air pockets give the moulding a pitted or rough surface known as 'orange peel' effect and insufficient venting can cause poor reproduction of the mould lines. Venting is particularly important in moulds with increasing cavity volume, in moulds where the parison is squeezed peripherally and in moulds with cavity recesses (e.g. for engraving).

In many cases, the air can escape through the mould parting line. Venting channels as shown in Figure 34A, located about 3-5 mm from the edge of the mould cavity help to facilitate free escape. Funnel-shaped inlet holes with a diameter of 0.1-0.2 mm also aid venting, and slits in the parting line about 0.1 mm deep and 10 mm wide as shown in Figure 34B have also proved successful.

Additional vents are often required around the corners and edges and in recesses (e.g. threads, engravings, reinforcing and decorative ribs). Vents with a diameter of 0.1-0.2 mm as shown in Figure 35 (a, b, c) have proved suitable. They end in large blind holes, bored from outside to within a distance of about 0.5-1.5 mm from the mould cavity. The size and number of the vents depend on the processing conditions including blowing pressure.

Another method of venting which has been adapted from injection moulding consists of inserting hexagonal pins in circular vents so that six sections with a camber height of 0.1-0.2 mm are left free. These can be run into an annular groove at a depth of 0.5-1.5 mm as shown in Figure 35 f, g. If inserts are used, additional venting channels can be provided in the fitting points as shown in Figure 35 k. The width of the slits should be less than 0.05 mm to prevent them from causing visible marks on the finished moulding. Plugs or plates made of sintered metal have been used in moulds for large containers (see Figure 35 h, i). Large flat areas should be provided with several vents.



A facilitating free escape by means of a groove a at a distance e from the cavity edge; venting in base and shoulder edges by funnel-shaped venting channels b; d= 0.5 mm

B venting slits in the parting line f (0.1 mm deep, 25 mm wide); g= 0.1 mm

Figure 34: Venting of Mould Cavities in the Mould Parting Line

Vents: a 0.1-0.3 mm diameter, b 0.5-1.5 mm, c blind hole, d camber height of the free circular section 0.1-0.2 mm, e slit depth 0.5-1.5 mm, f annular groove, g bolt with venting slit, k ventilation channel in the fitting point of an insert. Mould cavity venting by means of plugs and plates made of sintered metal, h plate made of sintered metal, i vent.

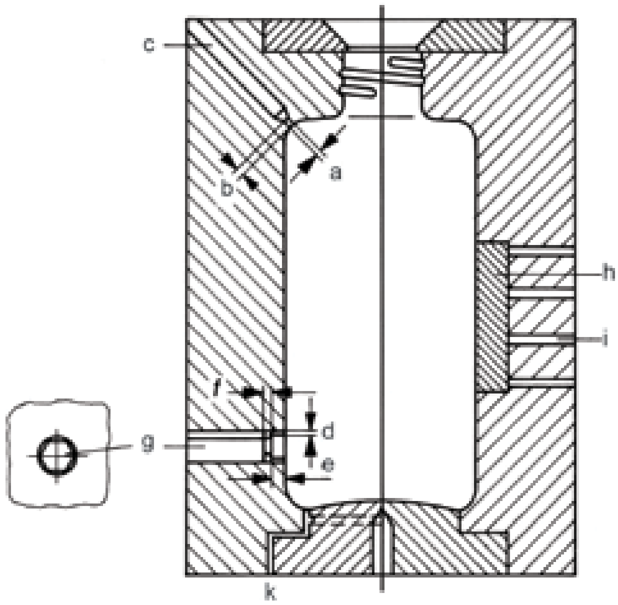


Figure 35: Suitable Methods for Mould Cavity Venting

Surface of the Mould Cavity

Mould cavity surfaces should be smooth and free from grooves. Polishing to a high surface finish is not generally necessary, as this does not significantly improve the surface gloss or smoothness of the moulding. Moulds with slightly roughened cavity surfaces have proved most suitable for HDPE and LDPE. Rough surfaces help venting and counteract the formation of pitted areas. Chrome-plating has not proved successful. The chrome peels off easily, particularly along the contact edges of the mould halves.

Roughening is best carried out by sandblasting but etching is also a possible method. The blasting medium can be quartz sand, corundum or steel shot. Care should be taken to ensure that the sand does not chip the mould surface. The grain size depends on the mould cavity volume and the desired surface smoothness of the moulding. This is especially important for bottles that will be printed by the offset process. Grain sizes below 0.1 mm have proved successful for this purpose, and for larger containers grain sizes of up to 0.2 mm and more are used. Very rough mould cavities give unsatisfactory results.

Steel blow moulds are not generally hardened. To increase the wear resistance of moulds with a calibration mandrel, the neck insert should however be tempered. The same applies to the base insert. For these parts, dimensionally stable, heat treatable steels hardened to 55 to 58 Rockwell hardness are recommended.

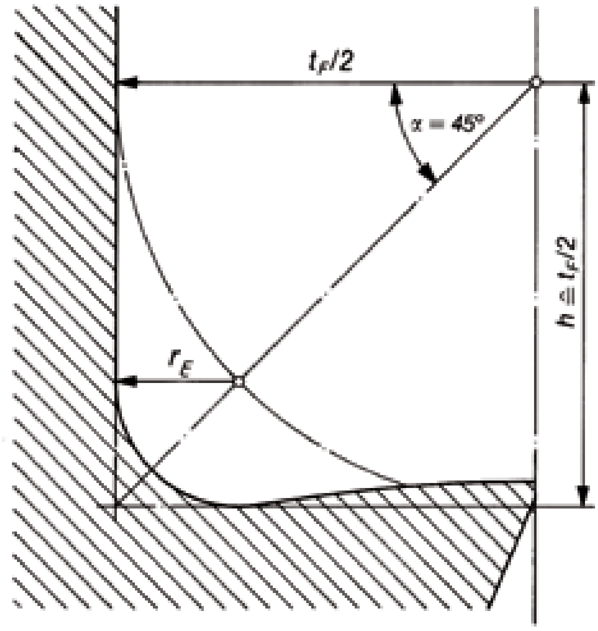
Corner and Edge Rounding

In order to maintain an even wall thickness in blown articles, it must be assumed when designing the article and the mould that the sections of the parison resting against the mould wall when blowing commences will be stretched subsequently only minimally if at all. Corners and edges that are formed last must therefore be suitably rounded off. For cylindrical mouldings, the radius of the edge rounding should be not less than 1/10 of the container diameter; for parts with an oval cross section this applies to the smallest diameter. The minimum permissible value for corner rounding on square mouldings can readily be determined graphically as shown in Figure 36. According to this, the radius for corner rounding is

$$r_E \geq \frac{t_F}{2}(1 - \sin 45^\circ) \geq 0{,}15\ t_F \qquad (9)$$

However, it should if possible be slightly larger because of the multi-axial stretching.

In order to avoid notch effect, all edges on threads, ribs, corrugations and ornamental strips should be rounded off. If especially high shock resistance is required, for example for thin-walled disposable packs, fancy designs must be abandoned. No ridge will appear along the mould parting line if both mould halves are carefully aligned. Inserts, such as base inserts in bottle moulds, should not be used. These design principles apply also to heavy duty containers.



t_F depth of mould cavity
h reference dimension
r_E radius for corner rounding (minimum permissible value)

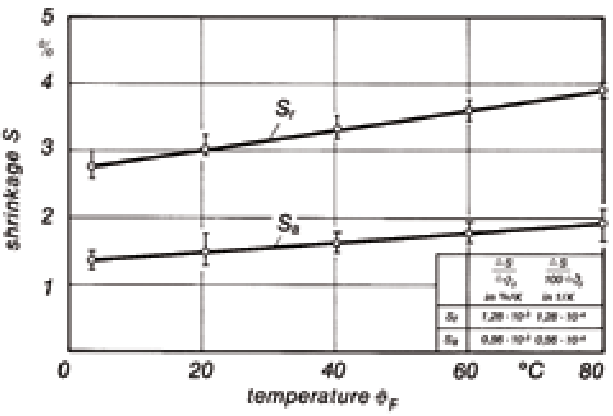
Figure 36: Graph for Determining the Corner Rounding of Square Mouldings

Recommendations for Mould Design

Shrinkage

In mould design, an allowance must be made for the effective degree of shrinkage. Unlike in the case of metals, the shrinkage of thermoplastics cannot be considered as a constant obtained from the temperature difference and the linear coefficient of thermal expansion. The degree of shrinkage depends not only on the material but also to a considerable extent on processing conditions. With high molecular weight materials, both the shrinkage characteristics of the material and also its potential for orientation must be taken into account. In blow moulding, shrinkage around the circumference as a result of molecular orientation may be greater than longitudinal shrinkage.

Figure 37a shows curves for the shrinkage S in different directions of an axially symmetrical thin-walled HDPE container plotted against the mould cavity temperature (a = axial shrinkage, r = radial shrinkage; the rotation axis was in the same direction as the longitudinal axis of the parison).



S_H (average wall thickness) = 0.66 mm

extrudate temperature (190°C)

temperature of blow mould, blowing pressure (9 bar)

A inflation ratio (2:1)

t(P,L) cooling time at a specified blowing pressure P with a current of purging air L = 10s

Figure 37a: **Axial and Radial Shrinkage of an Axially Symmetrical High Shouldered HDPE Bottle as a Function of Mould Cavity Temperature (measured after 14 days storage at room temperature)**

Figure 37b shows shrinkage as a function of the average wall thickness of the bottle, as well as of the cooling time in the blow mould at a specified blowing pressure with compressed air convection cooling. As the graph shows, even after the moulding has cooled as near as possible to room temperature ϑ_R, a relatively large degree of shrinkage can still be measured even after prolonged storage. As in the injection moulding of thermoplastics, one speaks of mould shrinkage (measured 24 h after demoulding) and of post-shrinkage which ceases only after a fairly prolonged period of storage. With partially crystalline plastics, the post-shrinkage period is determined mainly by cooling conditions in the mould. The amount of post-shrinkage is inversely proportional to mould temperature. This phenomenon is due to a rearrangement in the macromolecular structure. Mouldings subject to orientation shrink more in the orientation direction than in all other directions.

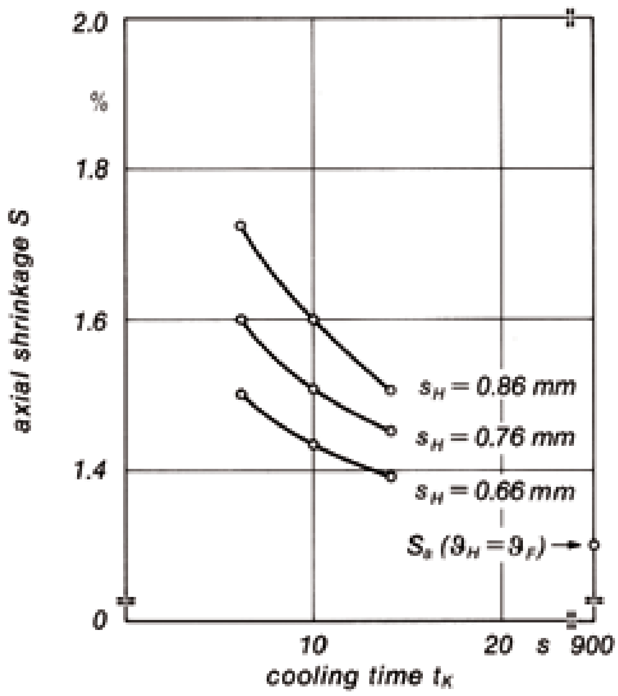
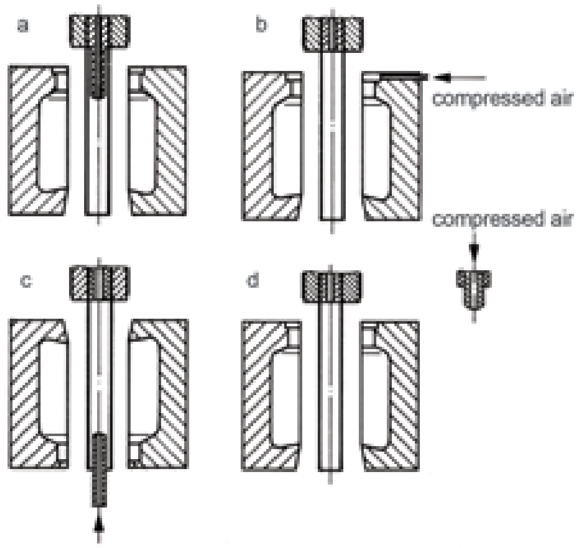


Figure 37b: **Axial Shrinkage of Rotationally Symmetrical High Shouldered HDPE Bottles with Various Wall Thicknesses as a Function of Cooling Time in the Blow Mould Under Blowing Pressure with Compressed Air Convection Cooling Melt Temperature 190°C, Mould Temperature 14.5°C, Inflation Ratio 2.1 : 1, Blowing Pressure 0.9 MPa**

Local shrinkage variations in blow moulded articles cause warping and distortion. With axially symmetrical mouldings, shrinkage variations due to wall thickness can be overcome if provision is made for the fact that shrinkage increases with wall thickness. With elliptical cross sections, shrinkage variations produce a saddle-shaped distortion. This can be remedied by making the body of the moulding slightly convex. Flat side walls are apt to become bowed. Convex walls are one answer here, while another is the provision of transverse, longitudinal or criss-crossing ribs. It will be seen then that appropriate die profiling to eliminate wall thickness variations around the circumference of mouldings with an unsuitable cross section for blow moulding, and programmed die adjustment to control wall thickness in the longitudinal direction are of great importance.

Choice of Blowing Method

One essential point in the design of a blow mould is the proposed blowing method, Figure 38.



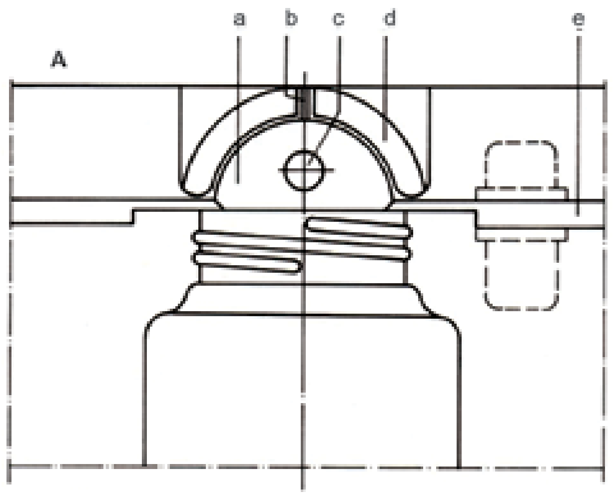
a Plax method
b Mills method
c Kautex method
d Bekum method

Figure 38: Blowing Methods Named After the Inventor or Machine Manufacturer

If internal calibration of a single discharge neck opening is desirable or required, it has to be decided whether the method proposed is suitable. If several neck openings require calibration, additional auxiliary mandrels may be used. When blowing with a hollow needle inserted centrally or laterally into the parting line, the blowing chamber (because of the later cut-off referred to as "lost feed head") should be sufficiently large. This applies particularly if side nipping of the internal parison is to be prevented[1].

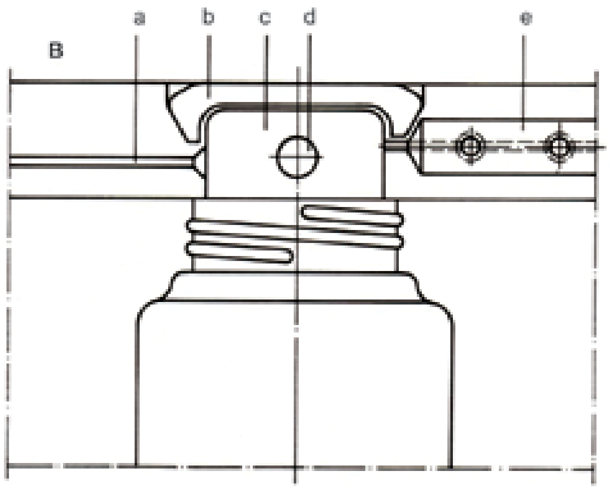
With very fine blowing cannulae, a preset breaking point on the blow moulded article must be provided for ready venting; this takes the form of a crater-shaped hole in the blowing chamber. If side blowing cannulae are used (Figure 39), it must also be decided whether a twin mould cavity would be more advantageous because blowing can then be carried out via a blowing chamber. This also applies to multiple moulds arranged side by side that are fed by multi-die parison heads.

1. The internal parison is that section of parison surrounded by the mould cavity when the mould closes, and chopped off at the two open ends only



A Neck with bevelled edge to increase sealing surface, centrally inserted blowing needle, and dome-shaped "lost feedhead" blowing chamber
a blowing chamber
b channel for centrally inserted blowing needle
c bore for ejector pin
d cutting edge and pinch-off pocket
e knife insert to mark the parting line

Figure 39a: Mould Design with "Lost Feedhead" Blowing Chamber for Wide-necked Containers



B Mould construction with laterally inserted blowing needle
a preset breaking point with venting channel
b cutting edge and pinch-off pocket
c "lost feedhead" blowing chamber
d bore for ejector pin
e threaded groove for needle holder and channel for insertion of blowing needle

Figure 39b: Mould Design with "Lost Feedhead" Blowing Chamber for Wide-necked Containers

Ejectors

When blowing is carried out from below, the mould does not usually require any special ejectors, since the blown moulding is stripped off the blowing or calibration mandrel. This can be accomplished as the mandrel is lowered after mould opening by an ejector plate, sleeve, fork or gripper, or by the excess pressure still present in the moulding. Stripping off can be aided by a blast of air directed inside and/or laterally onto the moulding. The blown moulding can be withdrawn horizontally by means of a system which comprises a clock-actuated moving chain with a number of vertically arranged blowing mandrels. This enables cycle times to be reduced through post-cooling. It is also possible as the mould opens for the moulding to be gripped at the base pinch-off by jaw clamps and after withdrawal of the calibration device for it to be dropped into a chute or removed from the mould area and deposited as appropriate.

When blowing is carried out from above the same methods of demoulding are used. The calibration mandrel can be withdrawn after mould opening and the moulding stripped off, or before opening if ejectors or clamping jaws are fitted above.

In moulds with blowing needles, ejector rods are fitted in the blowing chamber as well as clamping jaws. They are driven forward as the mould opens and returned by coil springs as it closes.

Separation of the Pinch-off

Extrusion blow moulding processes with fully automatic parting of the pinch-off have been developed for the mass production of containers of all sizes and also for the manufacture of other blow moulded parts. The methods used to separate the pinch-off include pulling off and cutting off in the closed mould, squeezing and squaring off during demoulding, and the use of transfer and trimming devices after demoulding.

Separation of the Pinch-off by Pulling off and Cutting off in the Closed Mould

Figure 40 shows a possible method of separating the base and neck pinch-off from a bottle blow moulded with internal parison calibration. The base pinch-off is severed by a serrated or longitudinally grooved jaw which is advanced by a hydraulic or pneumatic control cylinder towards the parting line at right angles or obliquely to the welding edge. This principle can also be used to remove sidewall pinch-off providing it protrudes from the edge of the moulding and has cooled sufficiently to be torn off.

a blow moulded with internal parison calibration (shown on a three-cavity mould)
b cutting off the neck pinch-off
c pulling off the base pinch-off B and lifting off the neck pinch-off H

Figure 40: **Automatic Separation of Neck and Base Pinch-off from a Bottle**

Another method is to employ two opposed tearing bars inside or above the pinch-off pocket at right angles to the parting line. Here the pusher bar is moved by a control cylinder while the counter bar springs back to the starting position during demoulding. This principle can also be used for tearing off enclosed pinch-off such as results from handle openings projecting cleats, and carrying handholds. In this case stamping plates appropriate to the pinch-off should be provided. Another possibility is to remove the pinch-off by means of externally mounted hinged plates; these, too, should be serrated and designed to intermesh.

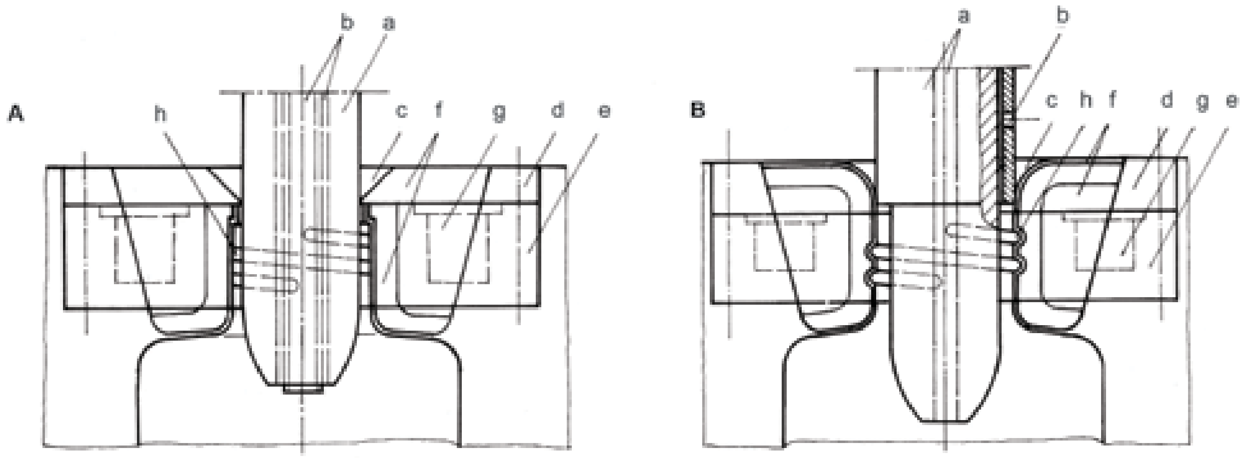
Finally, the base pinch-off can be removed by simultaneously lowering two base inserts or by lowering only one. With this method, however, the base of the moulding must be sufficiently cooled to prevent deformation, and must be supported around the edge or on one side. This method can also be used for removing pinch-off at the side of the neck with internal parison calibration.

Separation of the pinch-off during demoulding

The pinch-off can also be separated during demoulding by ejection plates and pins. The ejection pins are arranged opposite each other and are offset so that in the closed mould they are aligned with the pinch-off pocket and as the mould opens crimp the pinch-off. As a result of this applied stress the pinch-off is separated. This method can also be used to separate pinch-off at the side of the neck. The pinch-off is removed by the ejection pins while the neck is held by the calibration mandrel.

Design of Filling Neck, Pouring Neck and other Neck Connections

Internal calibration with a narrow mandrel as shown in Figure 41A gives an annular surface with a diametral seam on the inner circumference. In order to prevent the escape of secondary air in the region of the calibration mandrel even with thin walls, restrictor beading is provided in the pinch-off area around the mandrel. Moulding a bottle neck with a stepped mandrel as shown in Figure 41B gives a smooth annular surface with a seam on the outer circumference only. To ensure correct reproduction of the internal edge, venting through a 0.05 mm annular slit is recommended. In cases where accumulation of material is required to mould a neck as thick as possible from the parison wall thickness available or where it is necessary to form a collar, a compression method is used.

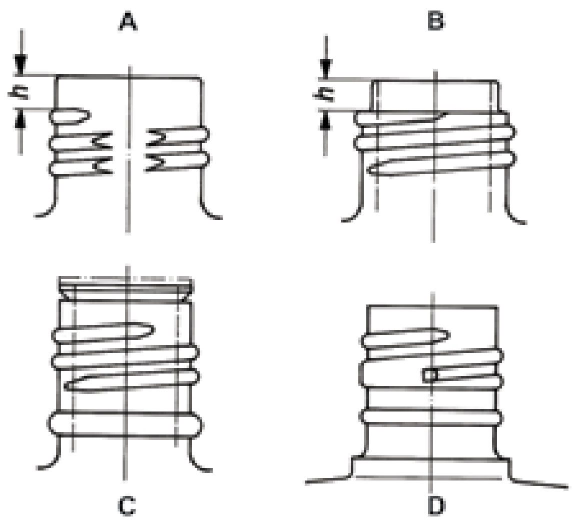


A Internal calibration of a bottle neck while blowing through the mandrel
- **a** interchangeable calibration mandrel
- **b** blow nozzle
- **c** annular pinch-off groove
- **d** hardened surface plate of the neck insert with cutting edge
- **e** lower threaded part of the neck insert
- **f** pinch-off pocket in the neck/shoulder region
- **g** neck cooling
- **h** threaded bottle neck which is reduced in o. d. at the neck top to ensure accurate calibration and prevent the escape of secondary air even with thin walls.

B Design for the calibration of a sealing surface which is free from flash
- **a** blow nozzle designed as calibration mandrel
- **b** cutting ring with narrow venting slit (0.05 mm) and vent holes
- **c** tulip-shaped pinch-off area
- **d** hardened surface plate of the neck insert
- **e** lower part of the neck insert with threads (h) which are interrupted in the parting line region
- **f** pinch-off pocket in the neck/shoulder region
- **g** neck cooling
- **h** threads which in A are interrupted along the parting line

Figure 41: Mould and Mandrel Design for the Calibration Method

With thin-walled, non-returnable containers, the neck top outer diameter can be reduced as shown in Figure 42B. This makes it possible to obtain a perfect seal – even with thin walls and a non-machined sealing edge – by internal calibration and the use of screw caps with conical sealing plugs. It also prevents escape of secondary air.



A thread which is interrupted in the parting line region; h = distance of the start of the thread from the neck edge
B bottle neck reduced in o. d. at the neck top for internal calibration of thin-walled, non-returnable bottles
C filler neck with moulded-on tamper-proof seal and collar with notched parting line (DGM 1853 118)
D design of thread for click-stop closure (prov. pat. DAS 1074995)

Figure 42: **Design of Thread and Neck for Bottles**

The neck section of the mould is usually designed, mainly for reasons of cooling, in two parts as an insert: the cover plate can be hardened to increase wear resistance. The neck insert should be fitted so that the join below the thread run out is not visible on the finished moulding when the cap is screwed on. The pinch-off area around the blowing mandrel can be conical, cup-shaped or tulip-shaped (Figure 41A, B).

The mould design for centrally and laterally inserted hollow needles is shown in Figure 39. By locating the blowing chamber at a sufficient height, it is possible to prevent side nipping of the parison in the area of the filling neck and to ensure uniform wall thickness of the neck top edge.

The transition to the top sealing surface or to the bottle shoulder should be rounded off. To prevent the occurrence of matt patches on the shoulder around the welding seams it may be necessary in some cases to provide a bevelled cutting edge on the mould cavity side. With a centrally positioned bottle neck, the shoulder of the bottle should be sloped or curved, depending on cross section, to counter the effects of stacking or compression loads. These measures prevent stress cracks or seam fracture due to the neck being pushed in, or distorted by sideways pressure. A pleasing contour can be obtained with flat high shoulders by rounding off the shoulder cross section as appropriate to suit the external diameter of the screw cap. With this design it is particularly important to ensure sufficient venting of the mould cavity in the neck region.

The peripheral and in some cases slightly outward sloping neck is particularly suitable for well vented, non-spill pouring. It is also an advantageous shape for stacking. With this design, tests must be carried out to determine whether from the point of view of the blowing method used, it would be better to build the outward slope into the mould itself or to incorporate a spreader device.

Threads for Screw Closures and Connections

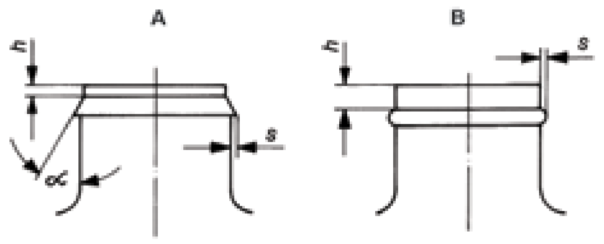
For screw closures and other screw joints, round threads and trapezoidal and buttress threads have proved successful. The latter should have well rounded edges, especially if the thread is blow moulded. In addition to these designs, closures, for example screw caps with seals for squeeze bottles, tamper-evident closures and other designs are also common.

Some dimensions and tolerances important in the neck design for screw closures with round threads and a conical seal are shown in Table 4.

Table 4: Neck design for screw closures

	A	B	C	D	E	F	G
Dimensions in mm	18	15.96	10.0	r1	10.5	1.1	3
	20	17.96	12.0	r1	10.5	1.1	3
	22	19.96	13.5	r1	10.5	1.1	3
	25	22.96	16.0	r1	10.5	1.1	3
	28	25.96	19.0	r1	10.5	1.1	3
Tolerances	+0.0	+0.0	+0.0	+0.0	+0.3	+0.1	
	0.5	-0.5	-0.5	-0.2	-0.0	-0.0	

Thread start and run out on blown mouldings can be correctly moulded only if they do not lie along the mould parting line. The thread start should be about 3 mm or more below the top of the neck (see Figure 42A). The run out on the screw cap can therefore be designed to accommodate the stresses that occur when the cap is over-tightened. In its final position the closure should not rest on the shoulder of the bottle as this could cause undue stressing of the neck leading to stress cracking and in addition could prevent a tight fit. For automatic filling and closure, thin-walled bottles sometimes require a reinforcing bead around the neck below the thread. The designer has to take the dimensions associated with this bead into account, as well as the already known tolerances. If there are lateral cut-offs on threads as is the case with internal calibration, the pitch can be interrupted – at a tangent to the thread core – in the region of the mould parting line. This prevents the formation of flash on the thread pitch, and trimming is made easier by the straight cut.



A design with conical torus, h = 1-3 mm, a = 30-45°, s = 1-2 mm

B design with annular torus, dimensions as for A

Figure 43: Pouring Neck with Click Stop for Snap Closure

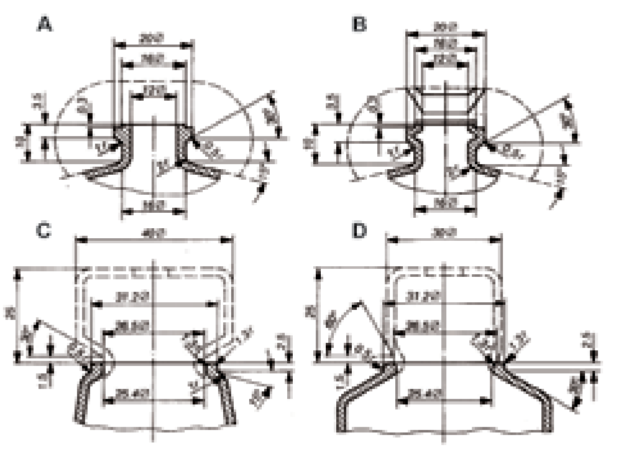
Snap Closures and Inserts

As well as screw closures, snap closures are also popular for plastic containers.

The snap joint beading around the bottle neck may be conical or round. Depending on the neck width and the flexibility of the snap closure, a bead height of 1-2 mm is used. To attach inserts for spraying or sprinkling, a circular groove or a bead must be provided inside the top of the neck. Since this necessitates the incorporation of a corresponding bead or groove on the calibration mandrel, the bead height should not exceed 0.5-0.75 mm. To ensure straightforward demoulding, it is essential not only for all transition areas to be slightly rounded, but also for blowing to be carried out through the stationary calibration mandrel and the mould to be open before the moulding is removed from the mandrel. By locating the inserts behind an outer diameter reduced conical collar above the thread, these difficulties can be overcome; a threaded design is also possible.

Flange and Clinch Closures

For aerosol sprays and bottles with the usual valves, the neck and shoulder should correspond in design to those of glass bottles or tin cans. Suitable designs are shown in Figure 44.



A internally calibrated glass-bottle type top
B externally calibrated glass-bottle type top
C top for 1 inch lift valve on slimline aerosol container
D top for 1 inch lift valve on aerosol shouldered container

Figure 44: Design Recommendations for the Top of an Aerosol Container

Wide-mouthed Containers

With wide-mouthed containers it is usually necessary to employ a "lost feedhead" blowing chamber and to trim off afterwards (see Figure 39). In this case it is worth considering whether a vertical, double mould with a single blowing chamber might not be more economic. The double mould could be designed for two containers of different size to compensate for variations in the wall thickness and diameter of the parison due to weight influences. Calibration is made possible with this arrangement by tapering the cross section of the top of the neck. Here, in addition to the normal extrusion of the parison with support air, it can be a technical advantage to pre-blow as the calibration mandrel is inserted. The tulip-shaped design of the neck insert also proves an advantage here since during insertion the blow mandrel does not cut off the parison until shortly before it reaches its final position. This neck design can however impair pouring.

Bottle Body and Side Walls, Volume

Since in parison extrusion the wall thickness can be controlled by die correction and programmed die adjustment, a wide choice of design is permitted for the body contour and the side walls. In this section therefore the discussion is confined to important design and processing factors. The correct design of side walls and cross section is particularly essential for shape-retaining non-returnable bottles, squeeze bottles and containers with contents subject to swelling, heavy duty containers, container liners and over pack containers where points to be considered include nonslip surface and stackability.

Grooves, Bands, Engravings

In the interests of drop and impact strength, rolling bands, as well as reinforcing or decorative bands running parallel along or around the container or crossing over each other should be as shallow and rounded in design as possible. They should also be at an appropriate distance from the rounded base or shoulder edge in order to provide the maximum resistance to compression loading and stress cracking. The same holds true for embossed lettering obtained by mould engraving and graduated scales to indicate volume; in the latter case, the vertical scale line should be omitted and the horizontal scale marks should not cross the parting line. The letter height should be selected for easy legibility of information, taking into account the colour and surface texture of the container. Engraving plates must have the same heat penetration characteristics as the rest of the mould wall, i.e. they must be capable of rapid cooling. If it is impossible to dispense with these design features on heavy duty containers, a particularly critical examination is required with regard to creep behaviour.[1]

Recommendations for the Correct Design of Side Walls and Cross Section

The number and position of handles on stackable containers should permit easy transport and loading. A shell-shaped handle on the base can help in this respect and at the same time permit easy emptying by tipping. It is also necessary to determine whether pallet dimensions can be maintained even when the side walls bulge as a result of hydrostatic pressure or the static pressure load from the contents.

1. In West Germany and other countries, spare fuel cans are legally required to submit to a design approval test which includes creep behaviour. Aerosol cans and bottles basically come under the regulations for pressure gas if the vapour pressure of the gas or mixture at 40°C exceeds 0.125 MPa and the container is larger than 220 cm^3.

The anti-slip security and shape retention of thin walled non-returnable bottles can be increased by waisting, by reinforcing bands, or by a groove or beading below the shoulder. Rippled side walls also help. A squat form is generally avoided by choosing a height: diameter or height: width ratio of >2: 1.

Resilience, too, is an important factor in the design of squeeze bottles and other squeeze containers. Stiffness and volume of contents must also be taken into account. Axially symmetrical shapes are suitable for flexible plastics such as LDPE. For stiffer plastics such as HDPE a rectangular-sided or oval cross section is preferred. The major/minor axes ratio or side ratio is generally 2:1. For powder contents, resilience is increased by giving the side walls a convex shape. From the point of view of creep behaviour, heavy duty containers should if possible be axially symmetrical in design. For this reason, weld seams in the body region are not desirable.

Deformation of the Side Walls Caused by Hydrostatic Pressure or Partial Pressure of the Contents and by Absorption and Swelling

Absorbing and swelling materials can cause indentation of the side walls of tightly sealed bottles due to changes in pressure and volume and to internal stress caused by swelling. This undesirable effect, sometimes referred to as ”container collapse”, also occurs on cooling after hot filling or closing under pressure, even with relatively small pressure differences of about 0.2 MPa. Experience has shown that this indentation is particularly pronounced on axially symmetrical bottles but less so on rectangular sided or oval containers. Other design points that help to counteract indentation are circumferential or diamond shaped reinforcing bands and gradations in cross section.

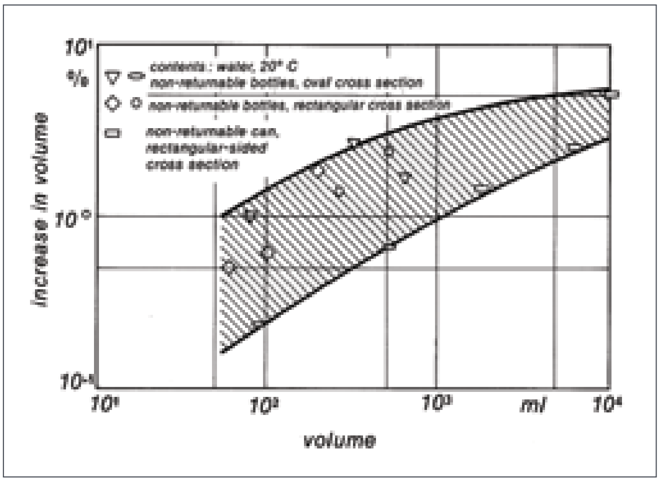


Figure 45: **Increase in Volume of Non-returnable Bottles and Cans Made of HDPE Caused by Hydrostatic Pressure**

The hydrostatic pressure of the contents causes the side walls in containers to bulge – especially those with rectangular or oval cross section. Depending on the flexibility, design, size and wall thickness, the increase in volume can be up to 5%. Figure 45 shows the measured increase plotted against the volume of contents for a number of geometrical shapes.

It is recommended that designers supplement this diagram by their own tests.

With square containers which have flat side walls, the amount of side wall bulging can be estimated from the approximate solution for a tightly clamped plate. If the height h and width b of the flat surface are known, then for a wall thickness s and contents density ρ in g/cm^3, and providing the height of the contents more or less corresponds to the plate height, the maximum sagging in cm is given by:

$$f \approx \Psi \frac{p \, . h \, . b^2}{s^3 \, . E_{BC}} \qquad (10)$$

where E_{BC}

is the bend creep modulus.

Volume

In designing the mould cavity volume V_F and the mould cavity dimensions for a specified contents volume V_G, it is essential to take into account not only the volume of the plastic $V_K = G_H \, . \, V$, the weight of the container G_H, the specific volume of the plastic V and the air volume V_L above the contents but also the change in volume due to shrinkage ↗V_S and the deformation of the side walls ↗V_D. The mould cavity volume is thus:

$$V_F = V_G + V. \, V_L + \Delta V_S \pm \Delta V_D \qquad (11)$$

Given the simplified assumption of a cylindrical container of uniform wall thickness and a shrinkage factor S’ (Table 6) which covers both radial and axial shrinkage, and ignoring changes in volume due to deformation, the following is obtained:

$$\frac{V_F - (G_H + G_H \, . \, V + V_L)}{V_F} = \frac{\Delta V_S}{V_F} = 1 - \left(1 - \frac{s^*}{100}\right)^3 \approx \frac{3s^*}{100} \quad (12)$$

If for the purpose of an approximate solution, it is assumed that

$$\Delta V_S / V_F \approx \Delta V_S / (V_G + G_H + V_L)$$

then by transformation and expansion – since in the volume range under consideration

$$\Delta V_D / V_G \approx \Delta V_D / (V_G + G_{H.}\ V + V_L)$$

then the following is obtained

$$VF \triangleq [V_G + G_H\ .\ V + V_L] \left[1 + \frac{3S^*}{100} \mp \frac{\Delta V_D}{100\ (V_G + G_H\ .\ V + V_L)}\right] \quad (13)$$

For a given volume of contents and air and specified weight, it is usually possible with formula 13 to arrive at a sufficiently accurate estimate of mould cavity volume if the values from Figure 45 and Table 5 are used.

Table 5: Specific Volume and Shrinkage of Blow Mouldable Polyethylene

Plastic	Specified volume V at 20°C (cm^3/g)	Shrinkage S* (%)
LDPE	1.09	1.2 to 2
HDPE	1.05	1.5 to 3

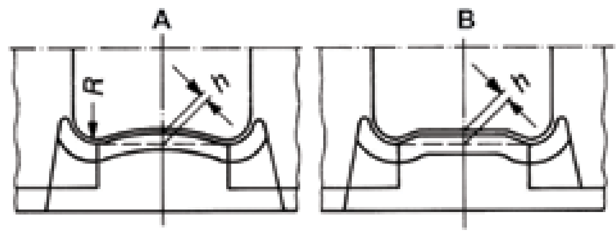
Container Base Design

To prevent rocking, blow moulded container bases must not be flat all over. The base generally has a rounded outer rigid rim and the centre is usually domed or recessed. Another measure to counter rocking is to taper the standing rim in the region of the mould parting line (material accumulation). Blow moulded base studs usually give rise to undesirable thin places. For thin-walled liners, a flat base design or one adapted to the supporting outer container is preferred because the hydrostatic pressure is borne by this.

The base rim is often given a stiffening edge, as shown in Figure 46. The points mentioned in the Corner and Rounding Edge section must be taken into account for thin-walled, non-returnable packs with optimum shock resistance. Depending on the standing area, the base may be lens-shaped, stepped or roof-shaped. Doming inwards (lens shape) is the best method for compensating internal stresses caused by shrinkage. The camber height of the undercut in the blow mould for a rigid base must be designed so that during demoulding the base seam is not stretched too much and the bottle shoulder is not damaged against the edges of the mould cavity. These points also apply to the base insert necessary for correct positioning of the printing on bottles. The best position from the point of view of blow moulding is shown in Figure 47.

In addition to the mould cavity dimensions and container design, the wall thickness and stiffness as well as the shrinkage of the moulding determine the amount of base doming permissible. For containers of normal capacity up to 5 litres, guide values for flexible plastics are 4-8 mm and for stiffer plastics 3-6 mm. The first group includes LDPE and the second HDPE.

For higher base doming, moulds in which the base insert drops when the mould is opened are required. For larger, thick-walled mouldings, base inserts can be used which are demoulded with the moulding, and then removed from it and replaced in the mould.



A convexo-concave base with rounded edges
B hip-roof shaped base for square and rectangular cross section with peripheral base edge h height of the undercut

Figure 46: Base Design for Bottles

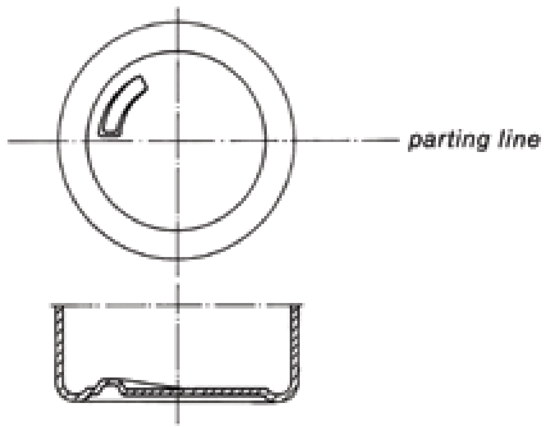


Figure 47: Technically Advantageous Location of the Base Insert for Correct Positioning of Printing on Bottles

Handles

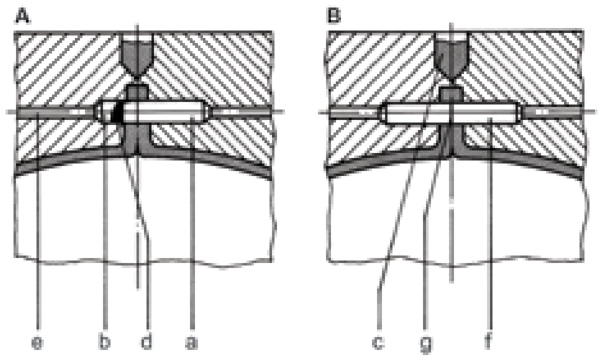
If moulded-on handles, cleats and handholds for carrying have to be formed from the parison they must lie in the mould parting line. If nipping is done around the circumference (for example between the handle and upper edge of the container) the recess along the edges must be sufficiently deep to allow complete mould closure without pressure on the pinch-off; otherwise there is a danger that cast moulds will fracture.

Shell-shaped handholds should if possible be perpendicular to the mould parting line. This generally helps to avoid mould release difficulties even without detachable inserts.

Eyelets, Fasteners and Integral Hinges

The most suitable mould design for eyelets and fastening straps in the mould parting line is shown in Figure 48. To avoid mould release difficulties with design A, punch bolts and blind holes should be kept as short as possible. The pinch-off can be severed or pulled off when the handle is inserted. With design B, if both bolts are fitted precisely, the pinch-off film can be pressed so thin that again it can be easily torn off when the handle is inserted. The same design principles apply to fastening strips.

Extrusion blow moulding can be used for the production of contour packs in which the two halves are joined by means of an integral hinge. So that the web between the two mould cavities can be cooled, it may be necessary to form a dihedral angle in the joining faces of the mould halves with the edge of the angle running along the hinge. The thickness of the hinge should be 0.1-0.3 mm depending on end use and the radius 1.5 mm.



A with punch bolts and blind holes **B** with two squeeze bolts
- **a** punch bolt
- **b** blind hole
- **c** pinch-off
- **d** pinch-off to be removed or torn off when the handle is inserted
- **e** duct for compressed air
- **f** squeeze bolt
- **g** pinch-off film to be torn off when the handle is inserted

Figure 48: Mould Design for Eyelets

Expansion Pieces and Bellows

Expansion pieces and bellows for technical applications are increasingly being blow moulded. With corrugated designs, the height of the corrugations should not be more than four times the pipe radius while the distance between the corrugations should be four times the pipe radius. With acute-angled designs, a height: distance ratio of up to 1.25 : 1 is recommended. The outer edges in particular should be rounded off to a radius of at least 1/10th of the corrugation height. To prevent rupture of the parison during blowing the edges over which the parison is passed must also be rounded off.

Moulds for Sealed Hollow Mouldings

There are certain types of hollow moulding such as floats which should if possible be sealed in the mould. For this purpose, blow moulds have been developed which by means of a ‘crowning’ technique weld over the puncture caused by insertion of the blow needle. In addition to the radially inserted blow needle which produces a nipple like projection around the puncture, it may be an advantage to use a needle which is inserted very obliquely (almost tangentially) from the side into the thickened wall in the region of the weld seam.

Inserts

Inserts made of plastic, rubber, metal or other material can either be press-fitted somewhere on the mould parting line, or be embedded at a preferred site on the moulding by blowing. In both cases the mould insert must be designed to ensure that the insert is held securely in the required position during mould closure or blowing and that mould release difficulties are prevented. Inserts which are to be press-fitted such as threaded bushings on floats, can frequently be fixed on the blowing mandrel or an auxiliary mandrel. The inserts can be prevented from twisting or pulling out by means of rimmed, profiled and/or conical designs as well as by cross sectional gradation. Inserts embedded by blowing can be located in mould cavity recesses or attached in the mould cavity by small pins which are later removed, or by suction or magnetic means. The usual method of anchoring the inserts is by undercuts.

The use of loose inserts in a mould enables undercuts to be demoulded. In this way it is sometimes possible to dispense with costly moulds. It is also possible to insert various engraving plates in the mould as required, thus making the mould more versatile.

INJECTION BLOW MOULDING; MACHINES AND MOULDS, PROCESSING

Basic Principles

Injection blow moulding, like extrusion blow moulding, is a two-stage process. The first stage consists in injection moulding an inflatable pre-form in a mould comprising a cavity and hollow core. The second stage involves blow moulding and cooling in a follow-on blow mould, Figure 49.

The pre-form is injection moulded in the plastic temperature range of the moulding material and blow moulded in the thermoelastic range; the hollow core used in the injection moulding stage serves as blow stick in the second stage.

Injection blow moulding has a number of advantages:

- Scrap-free production of container mouldings with seamless neck and base regions and high surface quality.
- High gauge accuracy of containers, i.e. mouth, body and length dimensions.
- Uniform wall thickness, i.e. no undesirable thickened areas or thin patches.
- Minimal weight and volume tolerance ranges.
- Containers stand well because there are no seam lines or pinch marks on the container base.
- Optimum transparency with amorphous plastics.
- Mouldings have improved mechanical properties due to the biaxial stretching which takes place when they are in the elastic state.

These advantages have to be weighed against limitations in regard to moulding design and the selection of moulding material. Materials for injection blow moulding are required to have an easier flow and higher thermal stability than in extrusion blow moulding.

With regard to design, it should be noted that in the case of mouldings with an asymmetrical opening position, additional openings, or blown handles cannot be produced by injection blow moulding. This also holds true for bottles with pronounced cross sections or longitudinal sections, for example rectangular cross sections with side ratio of a: b> 1: 2.5.

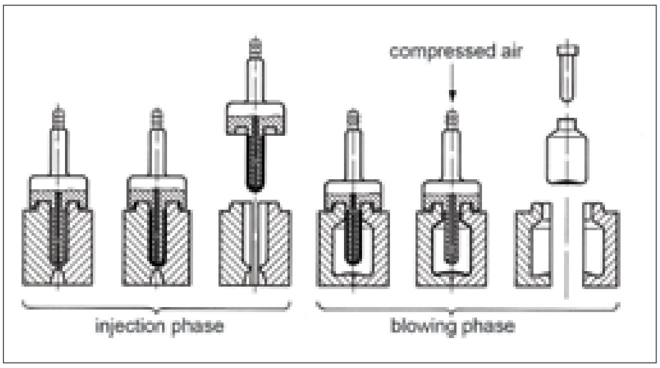


Figure 49a: Basic Principles of Injection Blow Moulding

Figure 49b: Collection of Injection Moulded "Pre-forms" Awaiting Blow Moulding into Containers

Machines and Moulds

For this two-stage process the individual equipment items required can be classified into two main groups:

- Purpose-built injection blow moulding machines (see figure 50).
- Injection blow moulds also suitable for use on conventional injection moulding machines (see Figure 51).

Another difference between the two groups is that to each conventional injection moulding unit can be assigned one or two blowing stations. Two blowing stations necessitate the use of a second blow mould which comes into operation in alternate cycles. The situation is different with purpose built injection blow moulding systems which in addition to an injection moulding station and blowing station also have a 'stripper' position. Although this means that another core set is required, it enables the overall cycle time of each 'station' to be reduced since control paths become somewhat shorter and the stripping operation runs concurrently with injection moulding and blowing.

Another important distinction between the two injection blow moulding systems lies in the way the pre-form is demoulded. In the injection moulding stage it is normal to use two-part moulds in which the parting line runs parallel to the core axis. But in contrast to this, it is also possible to 'withdraw' the core with the pre-form adhering to it from a one-piece mould block. The method of demoulding should be taken into account in designing the pre-form. This latter method has the advantage that a lower closing force can be used for the injection mould.

It is usually possible to choose freely between single and multiple injection blow moulding machines on the basis of container dimensions and the production rate required, irrespective of the method used to transfer the pre-form. The most important data in this selection are:

- Mould clamping surface
- Closing force of the injection mould
- Distance between core centres
- Mastication efficiency
- Capital and operating costs

To the question of whether to use a single or multiple machine, there is no standard answer. It depends on which type of machine is the most economic for the particular article to be produced. The most important requirement for all multiple machines is that they can be used also as single machines for development work.

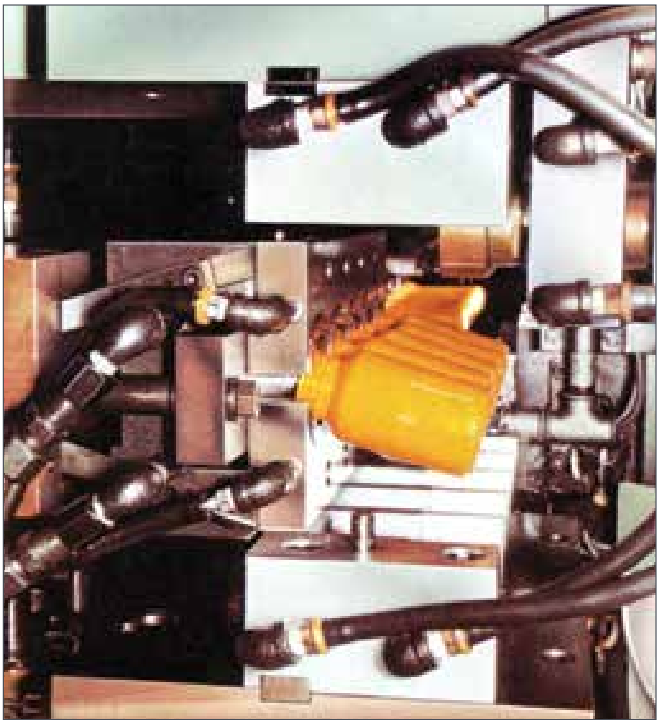


Figure 50: Mould Arrangement in Injection Blow Moulding

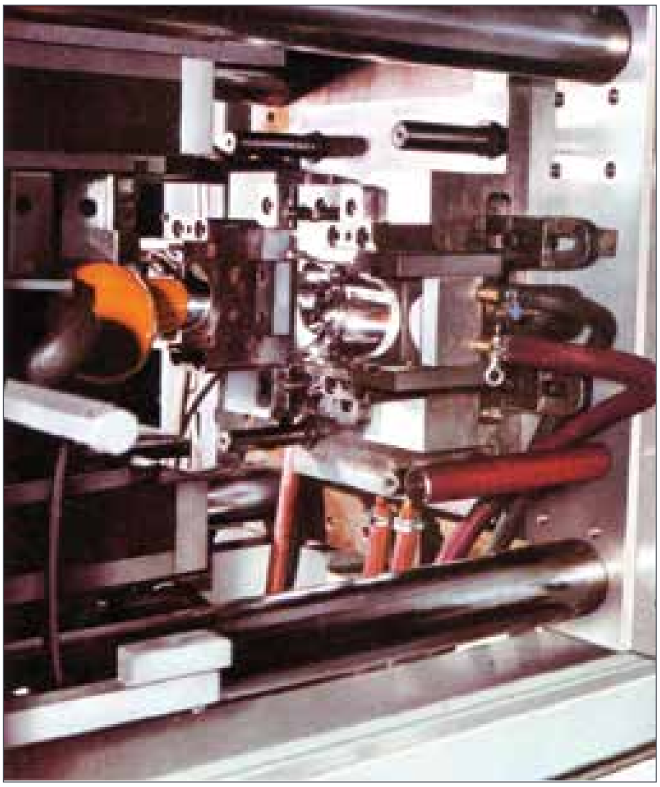


Figure 51: Injection Blow Mould Machine

Processing

In injection blow moulding, success depends primarily on the pre-form. The better the design work is thought out in advance, the less costly it will be in terms of both time and money for modifications during pre-production trials of the mould.

Design of the Pre-form

Before any consideration of design, the following question should be asked: Is the container concerned suitable for injection blow moulding? Certain limitations from the processing point of view have already been stated. In some cases, minor modifications in the design of the final article can make it eminently suitable for injection blow moulding.

Another essential point is to know for which injection blow moulding system the pre-form is being designed. The main consideration is whether a one-part or two-part injection mould is involved. It is also important to determine the mould closing force required for the projected pre-form area, as well as to match the stretch ratio to the flow properties of the moulding compound.

There are various principles which can be applied in the design of pre-forms for injection moulding in two-part mould cavities with the parting line parallel to the pre-form axis. The relative merits of these design principles are discussed below. In the USA, the preference is to operate with smooth cylindrical cores and to maintain a largely constant pre-form wall thickness. Although this method provides optimum conditions for cooling, the wall thickness distribution in the finished moulding is not ideal in many cases, depending on article design. Furthermore, cylindrical cores not only make it difficult to strip off the finished article, but usually also impede the removal of non-inflated pre-forms which are regularly encountered when running new moulds or when starting up production. This causes hold-ups since production cannot continue until the core has been extricated from the previous moulding.

In the USA, too, they are very keen on reducing the core diameter in the body region of the moulded container provided that the core cross section in the mouth region is not too small to start with (see Figure 52a). Besides a higher stretch ratio, this design usually provides a somewhat thicker pre-form wall and thus more favourable flow conditions and lower mould closing forces in injection moulding. On the other hand, cooling times are usually somewhat longer than with non-reduced cores.

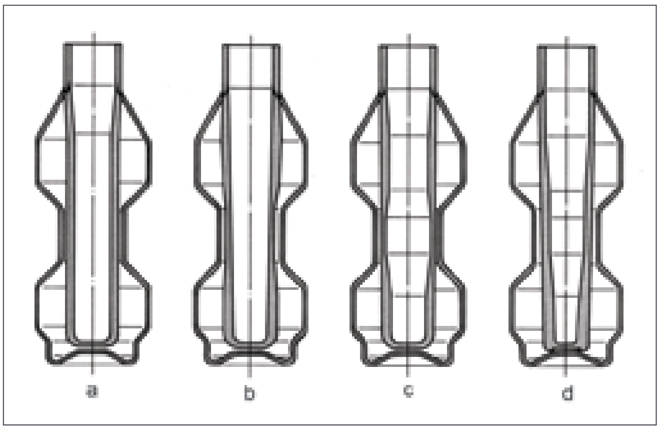


Figure 52: **Possible Designs for the Pre-form**

By way of contrast, smooth conical cores with a circular cross section and core taper of at least 0.5° have proved popular because they make production easier and more reliable. The conical design of this core produces variations in pre-form wall thickness which is usually magnified locally by particular features of article design and may occur in both transverse and longitudinal cross section (Figure 52b). Extreme examples of this are mouldings with a flat oval cross section or sharply conical longitudinal section. The limit value for a pre-form with oval cross section is

$$s_{max} : s_{min} \leftarrow 2 : 1$$

when related to the longitudinal cross section this ratio increases to

$$s_{max} : s_{min} \leftarrow 3 : 1$$

(see Figure 53). It should be noted that any alterations to the thickness of the pre-form wall must be made on the mould cavity side of the pre-form. If these alterations are carried out on the core side, it almost always happens that pre-forms in which local openings have been blown through, or pre-forms which have cooled down too much can no longer be stripped off because of undercuts (see Figure 52c).

Another possible pre-form design is with injection blow moulds in which the core is ‘withdrawn’ from the injection mould cavity which characteristically is a one-piece cavity. Here the pre-form must be provided with draft taper suitable for demoulding. In this case also the pre-form should be easy to remove from the core, a taper core is recommended (see Figure 52d).

Pre-forms with conical walls both inside and out are possible only if the core diameter in the mouth region is large enough, for example with wide-mouthed containers. If this is not the case then the design already described with a taper core and thickening on the mould cavity side (see Figure 52b) is chosen. Here the undercuts can be easily demoulded by means of two-part inserts operating under inclined sensor control. The closing force distribution is the same as for a one-piece cavity mould. Additionally, it should be noted that this method of demoulding allows the pre-form base to be shaped to the contours of the container, so that for example a highly concave base is possible.

The above points should be cleared up before commencing with the actual design of the pre-form.

As a preliminary step in calculating the dimensions of the pre-form, the article is first drawn to scale (10:1). In this drawing, the general requirements of plastic container design such as no sharp edges or square shoulders should be borne in mind. The scale has of necessity to be large because on this drawing the calculated pre-form dimensions (which often vary by only tenths of a millimetre) must later be clearly shown.

In the first calculation step a projected area comparison is made. The cross-sectional area of the container at a chosen point is calculated from the article diameter and required wall thickness. This is transformed into an area of equal size for which the core cross section is known. With the aid of the known core diameter, it is possible to calculate the outer diameter of the pre-form from the total cross-sectional area found. Since we are assuming a core with a constant taper of at least 0.5°, the core diameter at any point can be determined from the internal diameter of the container neck. It is preferable to divide up the length of the container into several cross sections, the number of which will depend on article design. The more changes there are in the contour of the container, the more sections will be required, and the closer together they will be. The starting point for this division is the top edge of the neck; the last section is in the base region.

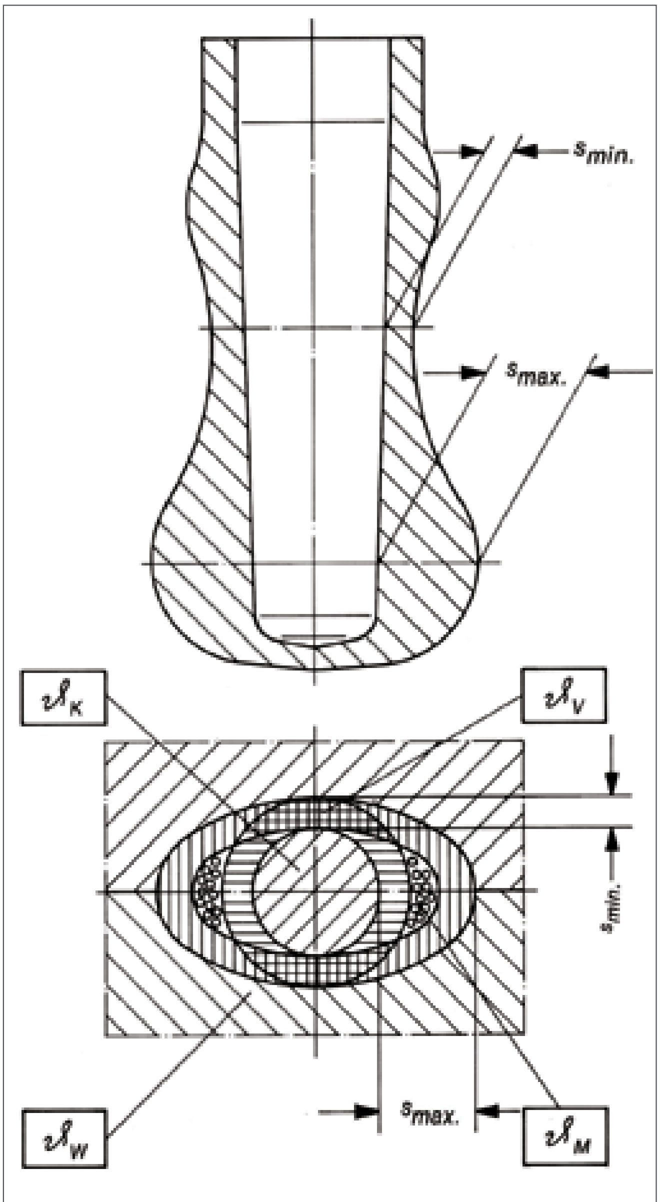


Figure 53: Wall Thickness Relationships on the Pre-form

In this way the individual values found can readily be checked against one another. These calculated values are entered on the drawing. The resulting pre-form is then tested against the relevant technical requirements and manufacturing feasibility. This might involve equalizing very slight differences or rounding off particularly sharp transitions. The most difficult region of the pre-form to design is the transition between the body and base, since the area comparison method cannot be used here. Instead, other mathematical relationships, which the technologist can check against empirical values, have to be applied.

After this correction, a volume comparison calculation is made. The volume of plastic required for the article is calculated from the container surface area and the specified wall thickness, and compared with the volume of the corrected pre-form. If there are large discrepancies in this comparison, the pre-form should be modified systematically and the volume calculation repeated. As soon as a pre-form is arrived at with a volume slightly less than or equal to the theoretical value, the calculation can be concluded.

It should be stressed that these volume calculations are based on the density of the particular plastic at 20°C. The difference in density is deliberately ignored (see Figure 54), i.e. the calculated pre-form turns out slightly too small and there is thus still room for modification after the first injection blow moulding trials.

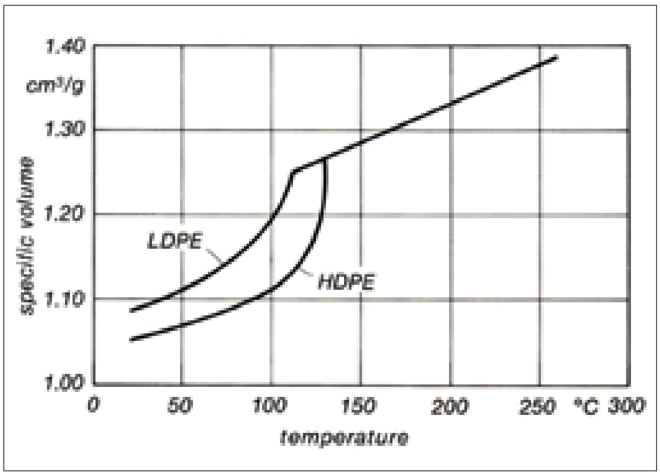


Figure 54: Specific Volume of HDPE and LDPE as a Function of Temperature

For the difference in density, the following equation holds true:

$$\frac{l_2}{l_1} = \sqrt[3]{\frac{V_2}{V_1}} \qquad (14)$$

l_1 length at room temperature (20°C)

l_2 length at melt temperature

V_1 specific volume at room temperature (20°C)

V_2 specific volume at melt temperature

For an article with a non-cylindrical shape, the volume comparison calculations are in principle no more difficult, just more extensive. In the first place, it is necessary to establish suitable mathematical formulae which enable the existing cross section to be calculated. Often, several overlapping calculations are required to determine as accurately as possible the size of the sectional area of a bottle with square, rectangular, elliptical or oval cross section. Furthermore, with non-cylindrical container cross sections, the ratio between the smallest and largest axis is of importance. The pre-form cross-sectional area is designed to match the article cross section. Since these calculations, particularly for non-cylindrical articles, require a relatively large amount of time, it is advisable to carry them out on a computer.

Injection Moulding the Pre-form

In injection blow moulding, the pre-form, and the pre-form mould are of great importance. The polyethylene melt is injected into the mould (which is normally at a controlled temperature above 100°C), and is then cooled down to its particular thermoelastic temperature range.

For the further processing of the pre-form, i.e. blowing, not only its design but, above all, temperature conditions are decisive factors. It is particularly important to equalize temperature variations between regions close to and remote from the gating and those due to differences in wall thickness in the longitudinal and transverse cross sections. The purpose of this is to allow optimum biaxial stretching of the pre-form to produce the container. This can be accomplished successfully if the core and more importantly, the mould, are temperature-controlled by means of three independently regulated circuits (neck, body, base). It should however be noted that only when the core diameter is greater than 15 mm can cooling channels capable of providing effective temperature control be accommodated in the core cross section (see Figure 55).

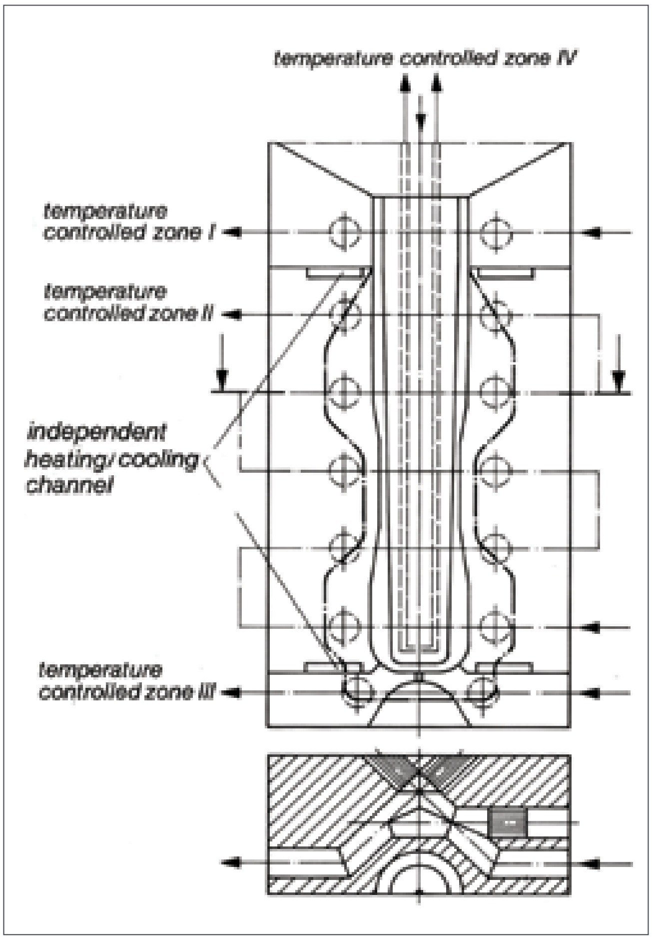


Figure 55: Possible Arrangements for Temperature Control of the Injection Mould Cavity

Reliable temperature control of the different zones of the injection mould can be provided only by a system of circulating oil or water. The system must be capable of supplying and removing heat. Cartridge heaters however provide heating only. This means that an almost autothermal heat balance is set up, which cannot be adequately controlled. Again, in view of the required uniform temperature control around the entire cross-sectional areas, only temperature control channels or chambers which completely surround the pre-form ensure reliable operation. This applies particularly when partially crystalline plastics with their relatively narrow stretching range are being processed. As already mentioned, direct temperature control of cores with diameters < 15 mm is not possible. In such cases with L/D ratios up to about 5:1, a core ‘flushing’ or airflow system of temperature control is used. With longer cores, an autothermal heat balance is set up and this can create processing problems.

Cores with diameters > 15 mm can be provided with a direct temperature control system although this is not always required. For example with L/D ratios up to 5:1, a core diameter <50 mm and a fairly uniform pre-form wall thickness, it is not absolutely necessary to have a separate core temperature control system when processing HDPE and LDPE. The deciding factor here is whether with a thick-walled pre-form and small core, enough heat can be supplied, and heat which has to be dissipated fully removed by conduction, radiation, and convection, to provide a core temperature distribution suitable for stretching or conversely whether with a thin walled pre-form and large core, enough heat can be supplied to achieve this purpose.

On this point, it should be noted that the required temperature distribution in the injection mould can only be achieved and maintained if the individual temperature control circuits do not overlap excessively and there is not a constant heat from the mould, base and mounting plates.

Incorrect temperature setting is indicated when, for example, the pre-form is locally over-stretched or bursts during blowing. In extreme cases the pre-form may even stick to the overheated core or in the mould cavity. If the neck region is too cold, the pre-form is not freely released from the core in this zone with the result that a toroidal thickening is formed inside the bottle at the point transition from the neck to the shoulder.

Not least among the factors which influence correct temperature control is the wall thickness distribution chosen. Problems arise if the ratio between the lowest and highest wall thickness is too great.

The temperatures set for the core (ϑ_K) and the different mould zones (ϑ_w) should preferably correspond to the required pre-form stretching temperature (ϑ_v). This means that the melt temperature (ϑ_m) must adapt itself to these set values while the pre-form is in the mould. In no circumstances, however, is it permissible to shorten the residence time of the pre-form in the mould by selecting core and mould temperatures far below the stretching temperature. If the edges of the pre-form are not properly temperature-controlled, problems arise in blowing (see Figure 56). Minor deviations from the required temperature may occur in the gating region or where there are large differences in wall thickness.

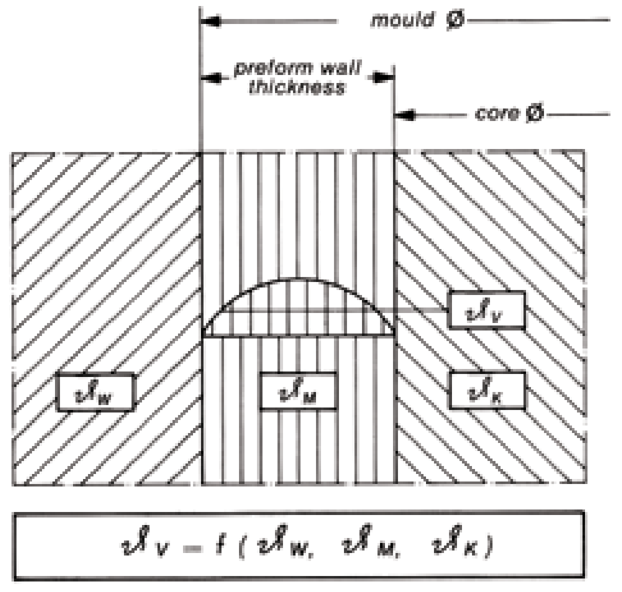


Figure 56: Ideal Temperature Conditions in the Injection Mould Cavity

The most advantageous stretching temperature for the pre-form depends on the moulding material used and the blow-up ratio employed. This temperature can be determined experimentally by producing containers with various temperature settings and pre-forming times and assessing their quality. The criteria used are drop strength, compression and bursting strength as well as appearance (transparency, surface finish).

In this way, the optimum stretching conditions are established and thus from the temperature curve for the pre-form, its pre-forming time and hence the cycle time can be predicted (see Figure 57).

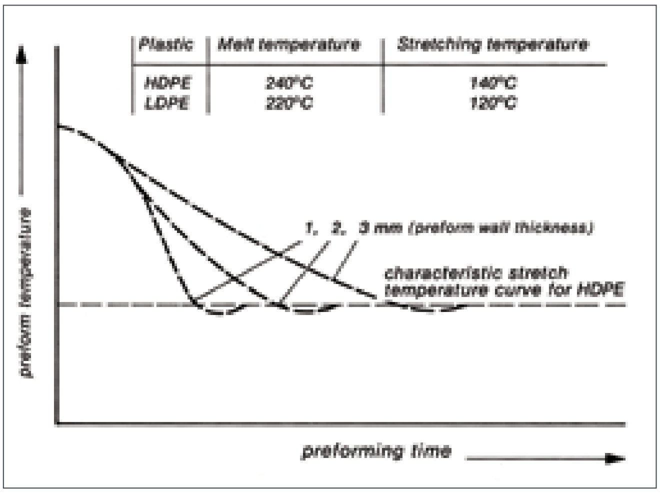


Figure 57: Temperature Curves for Injection Moulded Pre-forms Based on Optimum Stretching Temperatures for Polyethylene

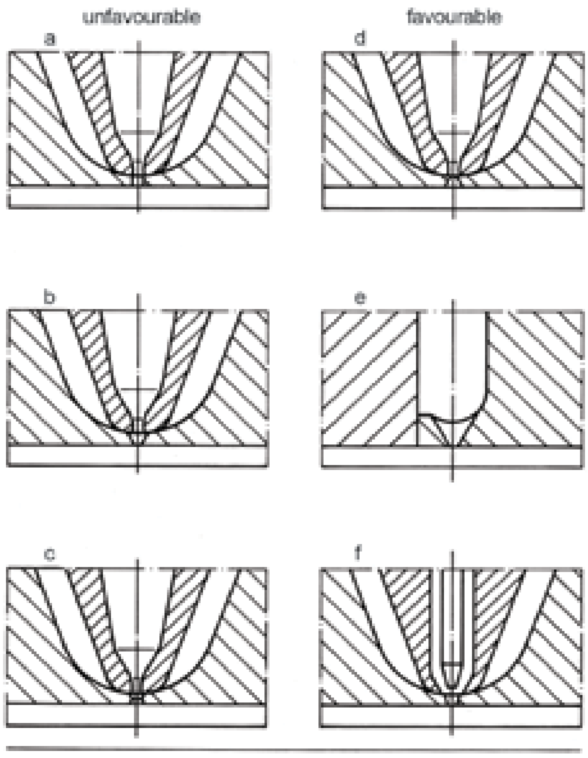
An important feature of injection blow moulding is the absence of waste in container production. This demands that in every case pin-point gating is used. The central positioning of the gating, too, is essential for optimum flow conditions. Furthermore, the design of the restricted gating determines how easily the sprue snaps off when the pre-form is demoulded. Special difficulties may arise here because, in contrast to conventional injection moulding, the pre-forms are in the thermoelastic temperature range or even higher. Fibrillation, holes due to sprues being ripped off in gating areas or laterally displaced pre-form bases are the result of incorrect temperature settings or unsatisfactory gating design (see Table 6).

Table 6: Injection Moulding Conditions for HDPE

Plastic	Injection pressure (N/mm^2)	Injection rate	Gate diameter with open nozzle* mm
HDPE	30–40	high	1.0–1.8

* The gate dimensions vary according to the pre-form dimensions

The sprue mark on the finished article should be as unobtrusive as possible (see Figure 58).



a cylindrical
b identical cone
c double cone
d opposed cone
e tunnel gate
f needle valve nozzle

Figure 58: Different Gating Designs

It should be noted, too, that follow-up pressure is used in the injection moulding stage of injection blow-moulding. The amount of pressure and hold-on time depends on the size of the gating and the type of plastic.

The main point which should always be remembered is that serviceable containers can be obtained only from visually perfect pre-forms, that is pre-forms which are complete and free from folds.

Hot runner moulds, sometimes used in conjunction with needle valve nozzles, have proved an effective means of overcoming problems in injection moulding and demoulding the pre-form.

Another characteristic of injection blow moulding becomes clear from a comparison between the surface quality of injection moulded and extruded pre-forms. When materials sensitive to shear are processed, the pre-form surface sometimes exhibits an undesirable ‘curtaining’ effect which may be due to injection conditions, the restricted gating design, the type of nozzle of the flow profile dictated by wall thickness distribution. The quality can usually be improved by altering one of these process variables.

Blowing the Pre-form

In the second process stage (blowing the pre-form to the final container) the core of the injection mould assumes the function of a blowing mandrel. For this purpose the core is provided with an air channel in addition to the temperature control channels. This air channel terminates in an annular gap which is opened and closed by means of a handle control also located in the core.

The annular gap may be open or closed in its normal position. However, it is important for it to be closed either when the core returns to the injection position or at the very latest by the pressure of the incoming melt during the injection stage. The opening of the annular gap during blowing may be similarly pre-controlled or alternatively, the incoming stream of blowing air can act upon a specially provided spring.

There is no set position on the core for the air outlet. This is however determined by a number of process variables. A reliable means of finding the most suitable position, and of checking pre-form design and temperature control, is by a study of the blowing process.

What is meant by this study is how pre-form deformation behaves as a function of blow-up time. The period considered here is from the start of blowing until stretching of the pre-form ceases, and does not include cooling time. It is advisable to increase the blow-up time by a constant interval (e.g. 0.5, 0.75, 1.0 sec etc.) and to blow several pre-forms on each setting.

Experience shows that irrespective of the position of the air outlet, the whole pre-form is initially lifted slightly from the core. At the same time, the air streaming into the pre-form seeks the most suitable point to commence stretching. This is either the thinnest or the hottest section of the pre-form, i.e. the region with the least resistance to stretching.

If the blown pre-forms (containers) obtained from the blowing test are now laid side by side, it will be seen that with correctly designed and temperature-controlled pre-forms, the extra stretching which takes place with lengthening blow-up time may occur in a different pre-form zone each time the interval is increased (see Figure 59). The explanation may well be local increase in strength brought about by the stretching. Apparently more new zones are stretched in this way all the time. These remarks show that as far as stretching of the pre-form is concerned it is of minor importance whether the air outlet is located directly below the pre-form neck, at the base of the pre-form or somewhere in between.

Figure 59: Blowing Investigation (coffee container with lid)

On the other hand, inflation in the body region with a spring-controlled blowing valve may lead to difficulties when the cross-sectional area of the core acts as a plunger and air pressure building up in the container closes the annular gap. This possibility exists particularly with increase in core size. When this happens, the fully inflated container can no longer be vented and bursts as the mould opens.

Mention should be made also of peripheral defects caused by the annular gap and known as “hair lines”, which may appear in the body region of transparent bottles. If these are unacceptable, it is advisable to locate the air outlet at the base of the pre-form.

There are two possible methods of stripping the moulded container from the core. It can be forced off along the entire length of the core by a stripper rake or ejector ring in the neck region. On the other hand, with slightly tapered cores, it is sufficient just to loosen the article somewhat in the neck region and then blow it off the core.

Since the air used for ejection comes from the same annular gap as the blowing air, with horizontal core axes the air outlet should not be located directly below the neck region of the container. It can happen that on being loosened, the moulded container is pushed above the annular gap, and the air provided for ejection blows uselessly into space.

The blow-up pressure should as far as possible be between 0.7 and 1.2 MPa to ensure a good surface finish on the container. Depending on article design and the moulding material used, it may be an advantage to commence blowing with a short preliminary blow at low pressure. When core dimensions allow, blowing should operate on the 'flushing' system, i.e. cold air is continuously blown into the container and the heated air passed out through an additional channel. With this system, the blowing cycle can be shortened and containers are more intensively cooled and so less susceptible to deformation.

What the maximum possible blow-up ratios (container diameter: pre-form diameter) for the various moulding materials are, cannot at present be stated accurately, as the necessary limit tests have yet to be carried out. However, blow-up ratios of 4:1 have caused no problems with the leading materials.

The blow mould should be capable of intensive cooling to the maximum extent. This is best achieved by providing cooling chambers or channels in the mould, which surround the moulding as completely as possible at a short distance from it. Mould cavities made of copper/beryllium alloys have proved suitable because of their good heat penetration properties.

General Notes on Processing

In injection blow moulding, the total cycle time comprises the cycle times of the injection and inflation stages plus the plant-related delay times. Almost all known patents for this process are based on a unit consisting of two cores, a mould cavity for injection moulding the pre-form and at least one blow mould. Thus both functions of injection and blowing can be performed at the same time. This means that the shot sequence is usually half the total cycle time, i.e. after each shot a finished article is demoulded. The shot sequence time and total cycle time are not the same.

Thus productivity is calculated as follows:

Thus it will be seen that in injection blow moulding calculations, it is the shot sequence time and not the total cycle time which is included.

The following periods are recorded:

- Pre-form residence time in injection mould; this includes the injection operation, follow-up pressure hold-on time and cooling time
- Container residence time in blow mould; this includes blowing and cooling the article (under internal pressure) as well as venting (release of internal pressure).

Plant-related delay times occur twice in the complete cycle during the operations of opening, pre-form transfer, article ejection and closing. As already indicated, pre-form residence time and container residence time are usually chosen to be of equal length. If this is not possible, e.g. when the wall thickness of the container differs only slightly from that of the pre-form, i.e. when only little stretching is required, it is possible to overcome the problem during the injection cycle by slowing down injection and reducing the cooling time. In this case, therefore, the shot sequence time adapts itself to the time required for the blow moulding cycle.

It can sometimes be an advantage as far as pre-form stretching is concerned to loosen the pre-form slowly from the core at the start of blowing. This enables a short low-pressure pre-inflation to be carried out before the actual blowing operation commences.

One of the basic rules in injection moulding applies equally to injection blow moulding - and concerns plastication time:

The screw speed during plastication should be only as high as is necessary to utilize fully the maximum possible plastication time. Figure 60 shows shot sequence time as a function of pre-form wall thickness.

After the pre-form has been injection moulded, it has to be brought from the thermoplastic to the thermoelastic state. This operation known as 'conditioning', along with blowing time, is one of the most important process variables determining shot sequence time. The factors which influence conditioning time are the thermal conductivity and enthalpy of the plastic used, as well as pre-form wall thickness. Since there are thickness variations in the pre-form wall corresponding to the moulded container, it is worth stressing here again the need for intensive cooling of thick-walled regions of the pre-form.

QENOS BLOW MOULDING GRADES

At Qenos, a range of blow moulding grades is produced at the Altona and Botany sites using various polymer technologies. All blow moulding grades produced at Qenos come under the *Alkatane* HDPE family of resins and are used in a variety of end applications (see Table 7).

CHEMICAL RESISTANCE

Although polyethylene resins are used in a large range of end applications, careful consideration needs to be made of the choice of polymer that will meet the demands of the finished product and the environment(s) that it will be exposed to (e.g. oils, fats, alkalis, acids and temperature, etc.). To make the best resin selection, customers are advised to discuss their specific end product requirements with their Qenos Technical Representative.

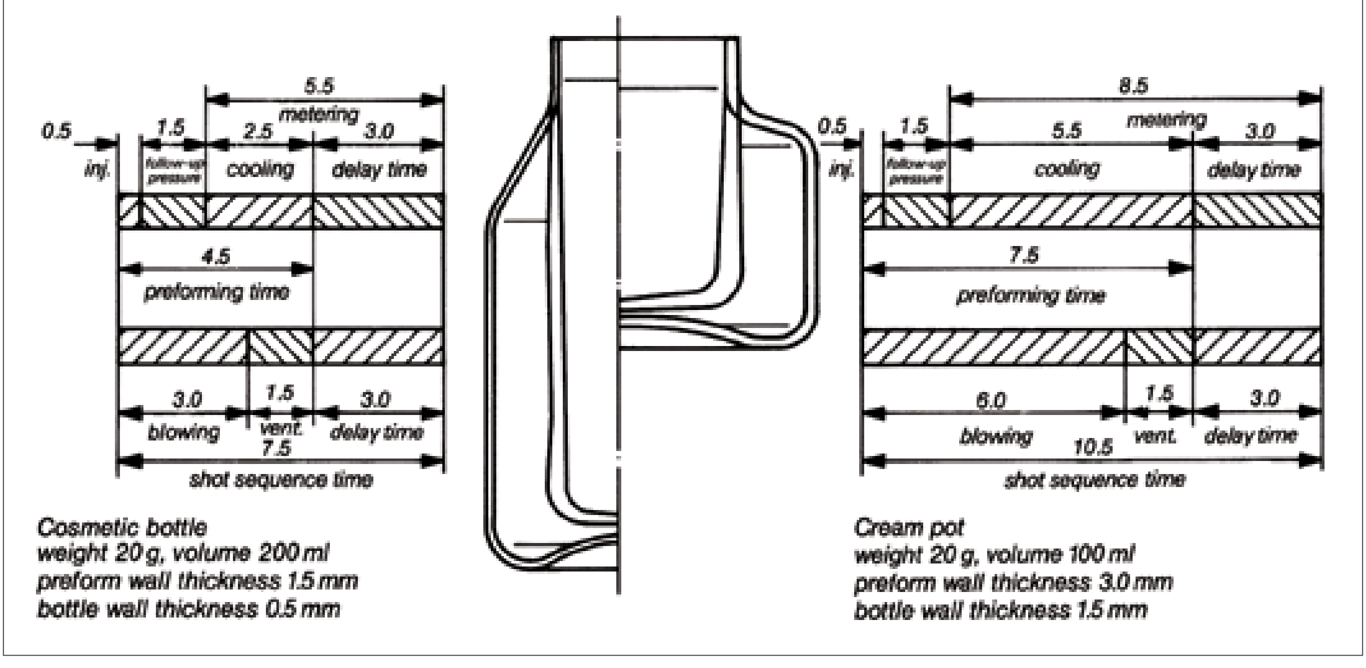


Figure 60: Shot Sequence Time as a Function of Pre-form Wall Thickness at Constant Article Weight

Table 7: Qenos *Alkatane* HDPE Blow Moulding Grades

Grade	Melt Index	Density	Applications
HD0840	0.06	0.953	Large part mouldings, especially blow moulded self-supporting drums and tanks (25 to 220 litres)
HD1155	0.07	0.953	Large part mouldings, including 25 litre to 220 litre tanks and drums
GM7655	0.09	0.954	Blow moulded containers including household and industrial chemical (HIC). Suitable for larger part mouldings
GF7660	0.30	0.959	Household and industrial chemical (HIC) containers, including detergent and pharmaceutical bottles
GE4760	0.60	0.964	Blow moulded water, dairy and fruit juice bottles
HD5148	0.83	0.962	High speed dairy packaging applications and other thin walled bottles, where ESCR is not a requirement such as milk, cream, fruit juice and cordial

APPENDIX 1 – BLOW MOULDING TROUBLESHOOTING GUIDE

Problem/Issue	Causes	Potential Solutions/Actions
Bottle Blow-outs	Contamination	Check for contamination in resin and regrind.
	Moisture	Check resin for presence of moisture.
	Bridging in extruder feed section	Increase rear barrel zone temperature slightly to prevent voids forming in the melt.
	Damaged moulds	Repair mould edges and pinch-offs to prevent holes forming along the seam.
	Fill pressure too low (applicable to reciprocating screw blow moudling machines)	To prevent air entrapment, increase fill pressure until drooling occurs at dies, then reduce pressure a little until drooling just stops.
	Mould closing speed too fast	Reduce mould closing speed to prevent formation of weak welds at the seams which may split when the bottle is trimmed and/or use clamp pause.
	Pinch-off too sharp or too hot	Increase pinch-off land width so that it does not cut parison.
		Increase cooling in pinch-off area.
Bottle Volume	Bottle weight incorrect	Check bottle weight every hour and maintain to target.
	Cycle time	Faster cycle times may increase parison and bottle temperatures and result in greater shrinkage.
	High pressure blow psi setting	Should be at recommended setting to insure good contact of parison with the mould surface and consistent cooling.
	Poor parison/mould contact	Clean mould vents
		Increase high pressure blow psi setting.
	Extruder profile temperature	A higher stock temperature will result in higher parison and bottle temperatures and result in greater shrinkage.
	Mould temperature	A higher mould coolant temperature will result in a higher bottle temperature and greater shrinkage.
	Storage temperature	Higher ambient bottle storage temperatures and longer storage times will result in greater shrinkage.
	Annealing conditions	Higher annealing temperatures and slower belt speeds will result in greater shrinkage.
(Too low or too high)	Mould volume incorrect	Resize mould.
	Volume inserts	Install or remove volume inserts.
Bubbles	Moisture in resin	Reduce cooling in feed throat if condensation is occurring here.
		Check for moisture in resin and ensure resin handling system is water tight.
	Bridging in extruder feed throat	Increase rear barrel zone temperature slightly.
	Fill pressure too low (applicable to reciprocating screw blow moudling machines)	To prevent air entrapment, increase fill pressure until drooling occurs at dies, then reduce pressure a little until drooling just stops.
	Worn screw and/or barrel	Screw and/or barrel may need to be replaced.
Contamination	Dirty regrind	Keep contaminants out of regrind; isolate regrind.
	Hopper magnets fully loaded	Clean hopper magnets regularly.
	Dust	Install filters on air intakes and clean regularly.
	Contaminated resin	Check for dirt, dust or other contamination in the resin.

Problem/Issue	Causes	Potential Solutions/Actions
Die Lines	Contamination or degraded resin	Lower mandrel and purge, or if contamination is adhered, remove tooling and clean. Check for foreign matter in virgin resin and in regrind.
	Low melt temperature	Check heaters and controllers, adjust so that stock temperature is in the recommended range.
	Damaged die or mandrel	Replace tooling if scratches or nicks are present.
Indented Parting Line	Blow air pressure too low	Increase blow air pressure.
	Air entrapment	Clean mould vents.
	Moulds not closing completely	Increase clamp pressure
		Reduce blow air pressure
		Check mould alignment or damage that may prevent moulds closing
		Clean mould faces
		Increase preblow cushion time.
	Mould temperature too high	Check mould cooling, especially around parting line
		Reduce mould temperature.
	Melt temperature too high	Reduce feed zone temperature
		Reduce die tip temperature.
Neck Finish	Incorrect bottle weight	Underweight bottles can result in improper shearing and overweight can cause neck finish trimming issues.
	Blow pin alignment or damage	Align blow pin centrally and at the correct elevation or replace if damaged.
	Damaged shear steels	Replace shear steels.
	Damaged pinch-off lands in thread area	Replace pinch-off lands.
	Moulds misaligned	Check and replace mould pins and bushings.
Parison Swing or Hooking	Incorrect die adjustment	Centre the die and ensure parison bolts are tightened.
	Off-centre pressure ring	Centre the pressure ring.
	Die temperature variation	Check head and manifold heaters and controllers, ensure die tip heaters are turned off after startup.
(parison swing at start-up is normal)	Air currents	Shield parisons from air draughts.
	Dirty die/mandrel	Clean the die gap.
Poor Weld at Pinch-off/ Weak Seams	Melt temperature too low	Increase melt temperature.
	Melt temperature too high	Reduce melt temperature.
	Mould close speed too fast	Reduce mould close speed; introduce a clamp pause.
	Mould temperature too high	Reduce mould temperature.
	Pinch lands damaged	Refurbish or replace pinch lands.
	Moulds not closing completely	Check mould alignment or damage that may prevent moulds closing
		Clean mould faces.
	Flash volume too large or too small	Reduce or increase flash volume.
	Excessive preblow or high pressure air too high coming on too early	Reduce preblow air and/or increase blow delay time.

Problem/Issue	Causes	Potential Solutions/Actions
Rough Surface on Bottle	Moisture condensation on moulds	Dry the mould cavities or reduce humidity in moulding room.
	Blow air pressure too low	Increase blow air pressure
		Check for leakage around neck rings, shear steel and blow pins.
		Inspect pneumatic system including air regulator, valves and air filter.
	Inadequate mould venting	Inspect and clean or repair mould vents.
	Melt temperature too low	Increase melt temperature.
Variable Parison Lengths	Bottle weight	Ensure weights are adjusted to target. If all bottle weights are varying, check shot pressure and accumulator precharge.
	Choke adjustment	Tail lengths can be changed by adjusting the chokes.
	Extruder screw rpm	Output is controlled by the screw rpm. Increase speed if tails too short and vice versa.
	Barrel and/or screw wear (over-riding temperatures)	Replace barrel and/or screw.
	Virgin/regrind ratio and consistency	Ensure consistent blending of virgin and regrind resin.
	Surging	Check for resin melting in barrel throat and ensure proper cooling.
	Incorrect temperature profile	Check heaters and controllers, adjust so that stock temperature is in the recommended range.
	Uneven head temperatures	Check temperatures, heaters and controllers.
	Incorrect tension in V-belts	Tighten or replace V-belts.
	Dirty hydraulic oil filter	Replace oil filter.
(varying tail lengths at start-up is normal)	Worn seals, excessive oil by-pass in shot cylinder	Replace shot cylinder seals.
	Worn thrust bearing centering bushing	Replace the centering bushing.
Webbed Handles	High melt temperature	Reduce melt temperature to increase parison swell.
	Preblow air pressure too low	Increase preblow air pressure, increase preblow time.
	Parisons hooking	Adjust die to straighten parison.
	Air currents	Shield parisons from air draughts.
	Mandrel sleeve incorrectly positioned	Adjust sleeve to the full up position.
	Mould/head alignment incorrect	Realign mould to catch the handle.
	Low shot pressure	Check the Manitrol valve for proper setting.
		Check the shot cylinder for leaks around seals and rings.
		Check hydraulic pump for worn parts.
		Check for low charge in nitrogen accumulator – if charge is lost, check for broken or leaking nitrogen bag.
	Pneumatics issue	Check that the air lubricator is dispensing the correct amount of oil
		Check that the preblow air regulator diaphragm is not ruptured or has a dirty seat
		Ensure that the Ross valve is clean.
		Check for dirt or faulty electrical connection in high/low pressure selector valve spool.

Disclaimer
The proposed solutions in this guide are based on conditions that are typically encountered in the manufacture of products from polyethylene. Other variables or constraints may impact the ability of the user to apply these solutions. Qenos also refers the user to the disclaimer at the beginning of this document.

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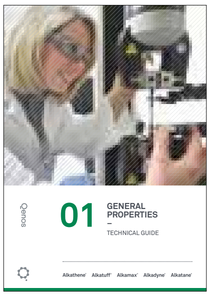
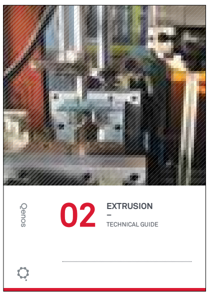
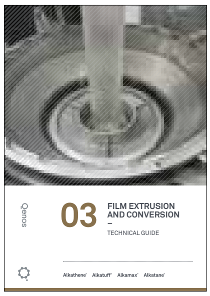
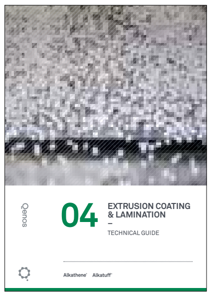
Issued July 2015.

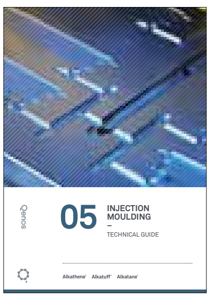
Polyethylene Technical Guide Series

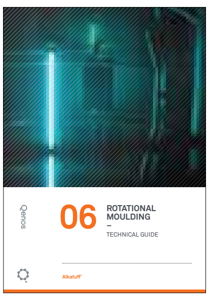


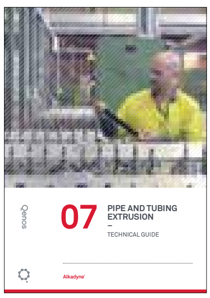












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