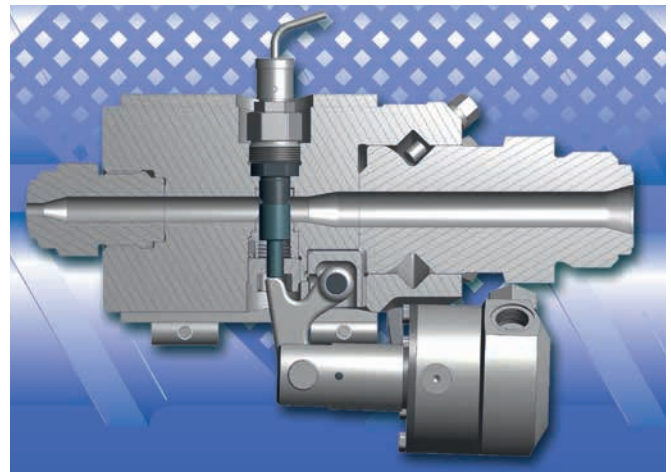
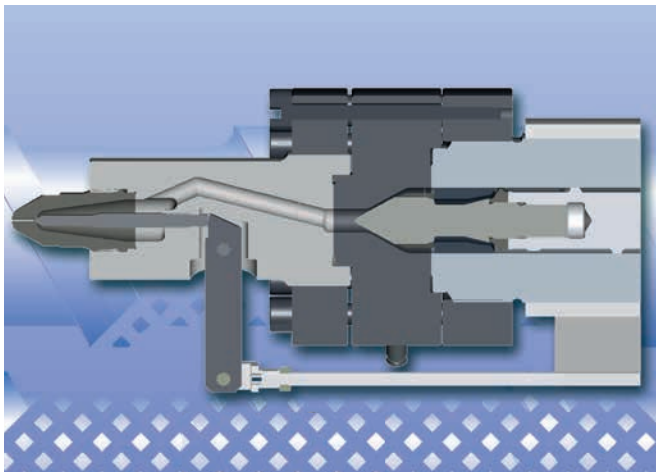


# Injection molding of high-quality molded parts

## Production equipment / machinery



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## 1 Machinery

In order to select the right size of machine and the correct equipment it is necessary to know:

- the material and type
- the shot weight or volume
- the mold mounting dimensions
- the requisite locking force
- any special conditions for attaining the specified quality.

Since this brochure is not intended as a text book for up-and-coming injection molders, only those points which we feel to be particularly necessary for achieving a satisfactory result will be dealt with here. One of the important topics in this respect is the selection of the right screw size and geometry.

## 2 Screws

The most commonly used geometry for a standard screw today is shown in Figs. 1 and 2. It is characterized by a relatively long feed zone (50 to 60 %) and a not-too-short compression zone (25 to 20 %).

In the case of semi-crystalline materials, it is a good idea for screws with diameters in excess of 80 mm to have a reduced flight depth (Fig. 2). This is because of the greater amount of energy that is required for plastication (shear heating).

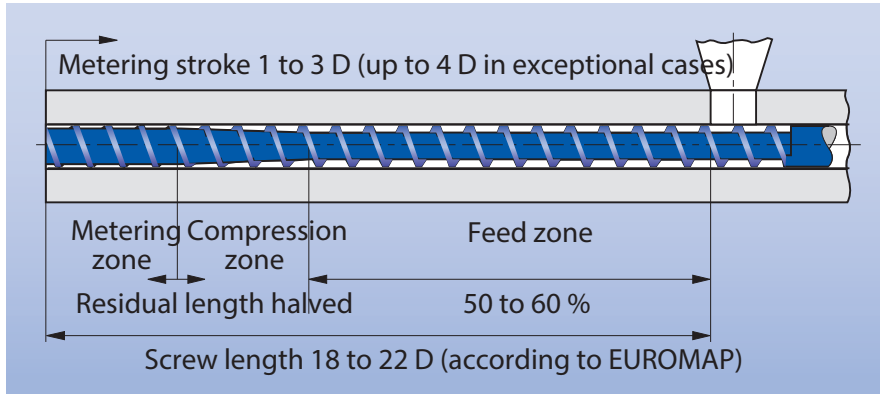


Fig. 1: Standard screw geometry

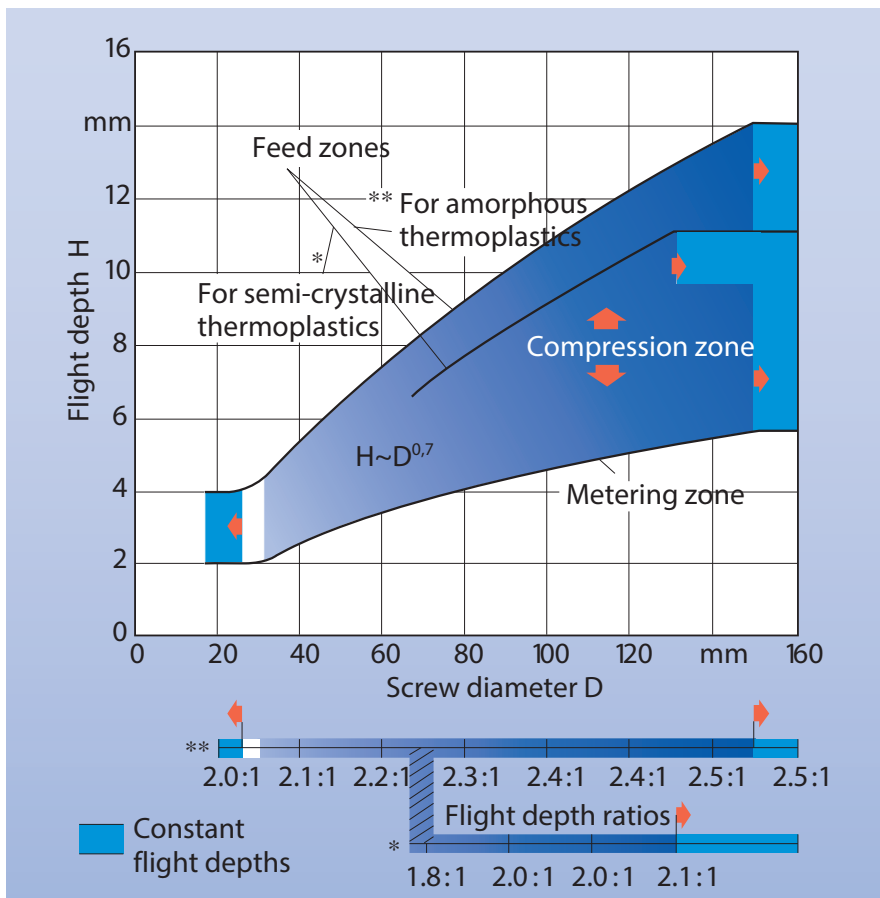


Fig. 2: Correlation between screw diameter and flight depth ratio

The use of a general-purpose screw demands a willingness to compromise. Molders who are reluctant to employ a special-purpose machine should refer to Table 1: Flight depths and flight depth ratios.

### Screw length and pitch

In view of the constant increase in the required plasticating rate in terms of both quantity and quality, the screw must be long enough to ensure homogeneous melting (approx. 20 D). It is not, however, possible to select a screw of any desired

length. The use of screws with an L/D ratio of more than 25 can result in damage to the material caused by long residence times.

When processing our thermoplastics Apec®, Bayblend®, Desmopan®, Makrolon® and Makroblend®, three-zone screws with an L/D ratio of between 20 : 1 and 23 : 1, a flight depth ratio of between 2 : 1 and 2.5 : 1 and a pitch of 1 D have proved suitable.

Screw diameter mm	Flight depths mm			Flight depth ratios	
	Metering section for semi-crystalline and amorphous thermoplastics	Feed section		Amorphous	Semi-crystalline
		Amorphous	Semi-crystalline		
25	2.0	4.0	4.0	2.0:1	2.0:1
30	2.1	4.3	4.3	2.0:1	2.0:1
35	2.3	4.8	4.8	2.1:1	2.1:1
40	2.6	5.4	5.4	2.1:1	2.1:1
50	3.0	6.5	6.5	2.2:1	2.2:1
60	3.4	7.4	7.4	2.2:1	2.2:1
70	3.7	8.4	6.8	2.3:1	1.8:1
80	4.0	9.1	7.6	2.3:1	1.9:1
90	4.2	10.0	8.4	2.4:1	2.0:1
100	4.6	10.8	9.1	2.4:1	2.0:1
110	4.8	11.5	9.8	2.4:1	2.0:1
120	5.0	12.0	10.4	2.4:1	2.1:1
130	5.2	12.8	11.0	2.5:1	2.1:1
140	5.4	13.4	11.0	2.5:1	2.0:1
150	5.6	14.0	11.0	2.5:1	2.0:1

Table 1: Flight depths and flight depth ratios of injection molding machine screws for processing amorphous and partially crystalline Covestro thermoplastics

In cases where the mixing effect of a standard screw is not sufficient (such as for coloring by the processor or for the processing of regrind), different special-purpose screw designs have proved successful. These are equipped with additional shearing and mixing elements in the metering zone (Fig. 3). They permit clearly improved mechanical and thermal homogenization of the melt without any drawbacks in terms of plasticating performance or other aspects. The improved thermal homogenization simultaneously reduces the development of local shrinkage differentials on the molded part. This is particularly important for precision components made of semi-crystalline materials, yet also reduces the tendency to warp in general. Work on optimizing these screws is not yet completed. Here too, the aim is for a standard screw that can be employed as a general-purpose screw as far as possible.

In the case of standard and special-purpose screws, the screw diameter is selected on the basis of the shot weight or shot volume that is required to fill the mold. To this end it is necessary to make allowance for both the metering stroke and the residence time.

Extensive experience has shown that the best metering stroke is between 1D and 3D (D = screw or cylinder diameter). In exceptional cases, it can be up to 4D. Deviations from this range can lead to defects in the molded part.

In the 1980s, machine manufacturers started to lengthen the metering stroke (> 4D) as a cheap way of increasing shot volume. This led to an increased occurrence of large-area air streaks. Air bubbles were also observed in isolated cases, which were not always visible on the surface as bulges. The big bubble in Fig. 5, however, developed under extremely unfavorable conditions.

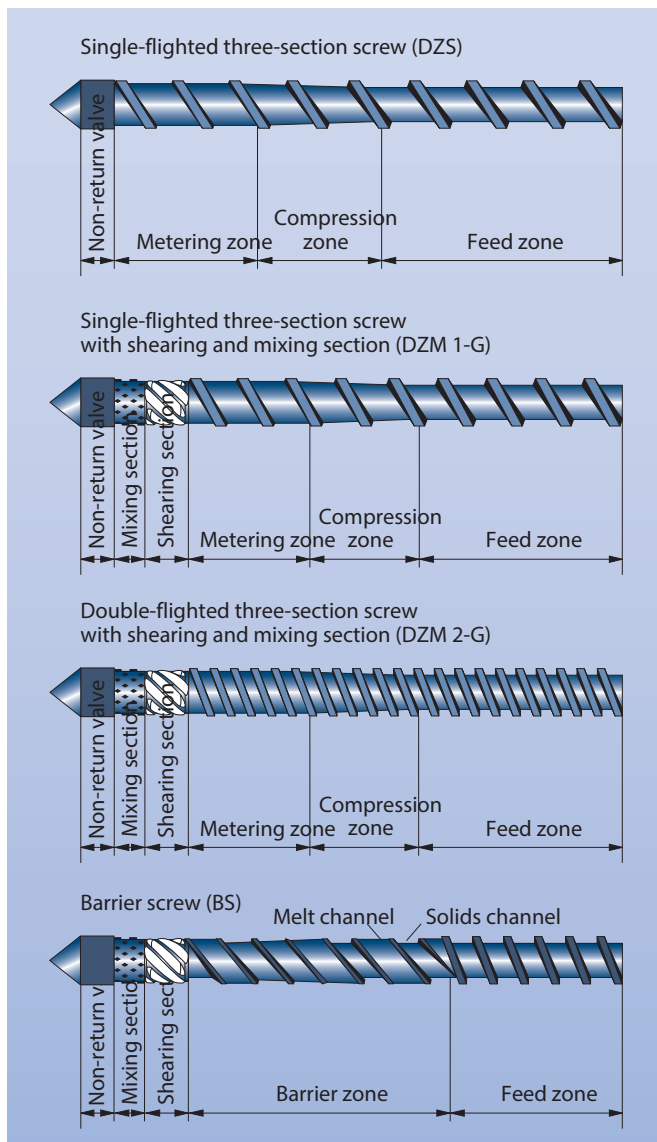


Fig. 3: Examples of special screws with shearing and mixing elements in the metering zone

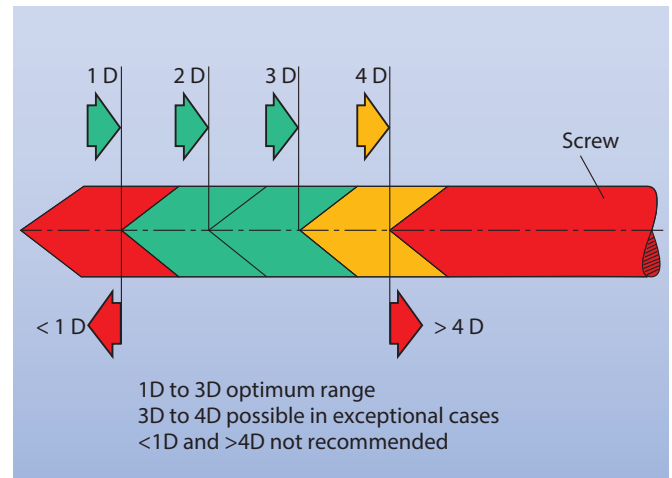


Fig. 4: Optimum and potential metering strokes for injection molding

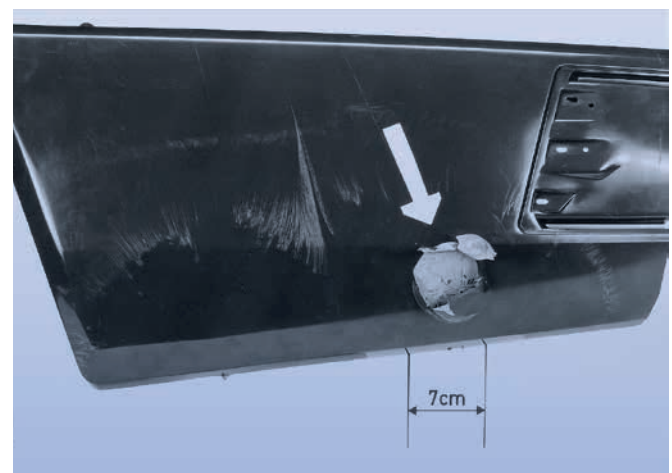


Fig. 5: Air streaks and an air bubble on a large injection molding due to an excessively long metering stroke

The cause is shown in the schematic diagram. By having the screw move back a long way, a zone containing entrapped air develops in the cylinder. This then causes the surface defects shown above to form in the molded part at a certain distance from the gate.

Conversely, with an excessively small metering stroke (generally  $< 1D$ ), there is a danger of material damage or a color change through an excessively long residence time.

The **residence time** can be determined empirically with the aid of an indicator (e.g. color concentrate). This can be calculated for known plasticizing units or established with the aid of nomograms. In practice, it is necessary to make allowance for the thermal sensitivity of the material being processed. The following time ranges apply for the mean permitted residence time:

- 4 to 6 min for (PC + ABS), (ABS+PA) and (PBT+PC) blends and FR grades
- 4 to 8 min for PC, PC-HT

These ranges commence at 4 minutes because experience has shown that (especially with semi-crystalline materials)

operating conditions with residence times of less than 4 minutes can produce an insufficiently compounded melt. The broader a material's residence time range, the larger its processing window.

Taking into account the optimum melt stroke range, the nomogram shown in Fig. 7 can be used to allocate the shot weight in question to the appropriate plasticating units and hence machine sizes. The converse allocation is, of course, also possible.

In **Example A** that is plotted on the nomogram, the potential shot weight range is being sought for an existing screw diameter of 25 mm. With low-density melts, this is 12 to 35 g and, with high-density melts (e.g. highly filled grades), between 20 and 66 g (corresponding to the change in shot weight as a function of density for an identical shot volume).

In **Example B**, the best screw diameter range for a shot weight of 2,500 g is to be determined. This is somewhere between 100 and 150 mm for the optimum metering stroke range. It shifts towards correspondingly smaller dimensions as the melt density increases.

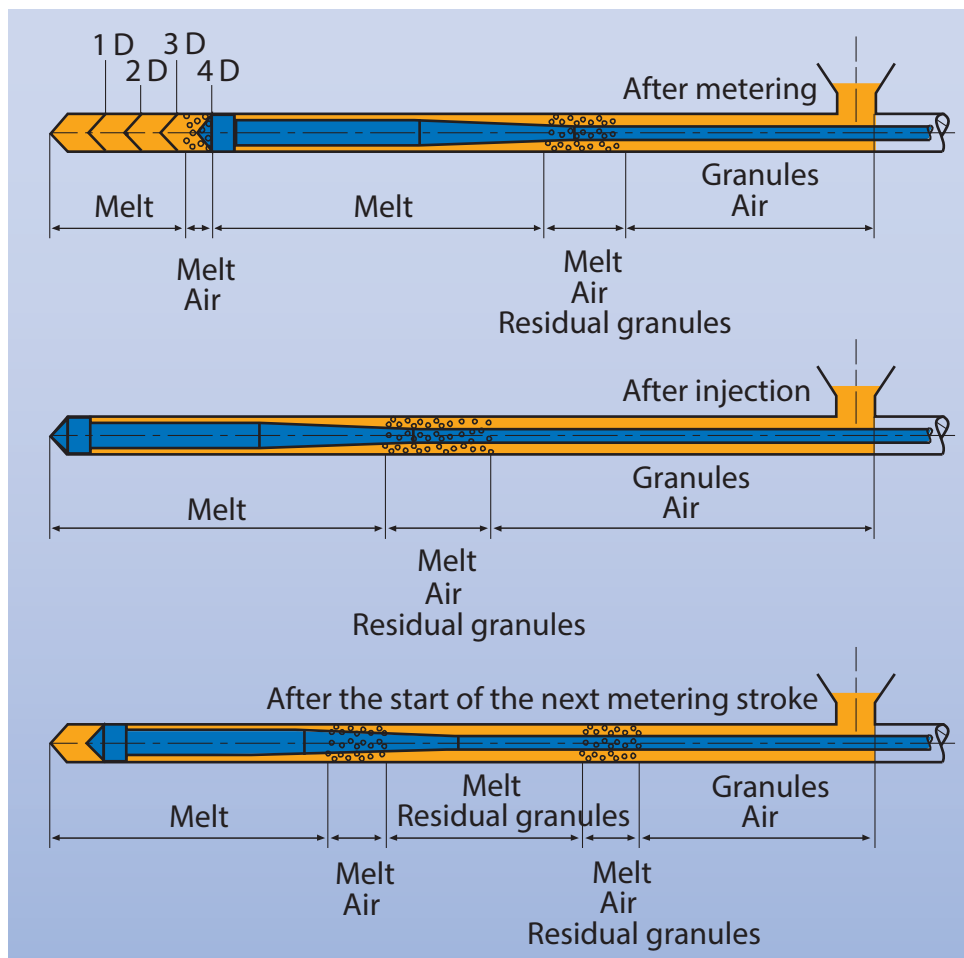


Fig. 6: Zones with entrapped air for a metering stroke of  $> 4D$

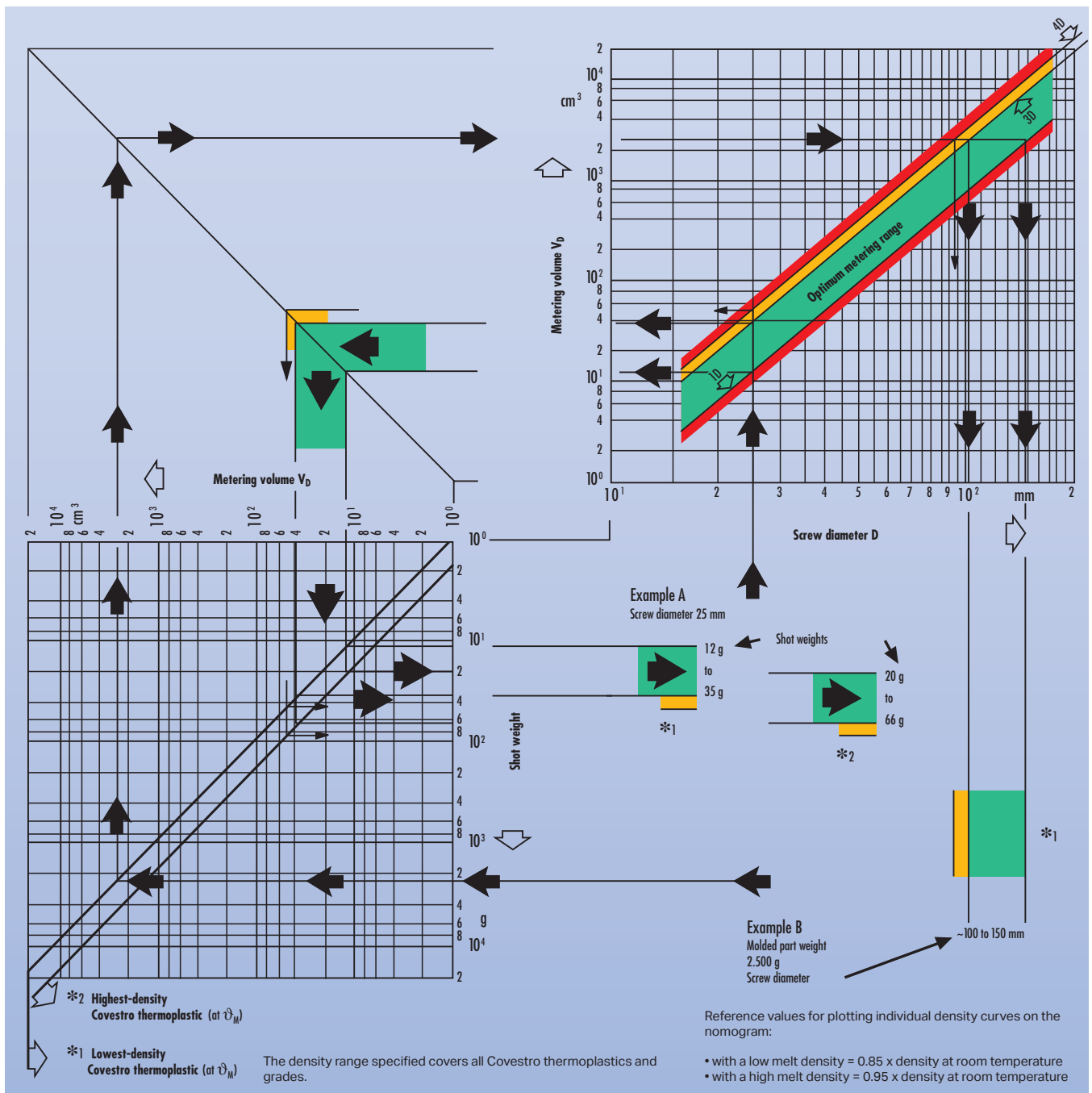


Fig. 7: Determination of screw diameter or shot weight with allowance for the metering stroke

### 3 Nozzles

Open nozzles are generally employed. Shut-off nozzles can be used for easy-flow materials, although these more readily lead to problems such as material degradation through shear, or extensive residence time in stagnant spots. Long color-change times will also be necessary with an unfavorable design.

Needle valve or cross-bolt shut-off nozzles are generally used with engineering thermoplastics. In the case of spring-loaded systems, the pressure required to open them and keep them open is no longer available as injection pressure.

As a result, the melt is briefly subjected to a high shear stress. Pneumatic and hydraulic opening systems do not suffer from these disadvantages.

With needle valve nozzles (Fig. 8) there is a danger that the needle may become clogged by intruding melt. Cross-bolt shut-off nozzles (Fig. 9) do not cause any substantial loss of pressure provided the runners are adequately dimensioned and ensure smooth and even flow. With cross-bolt shut-off nozzles special attention must be paid to the alignment of the runners (when open).

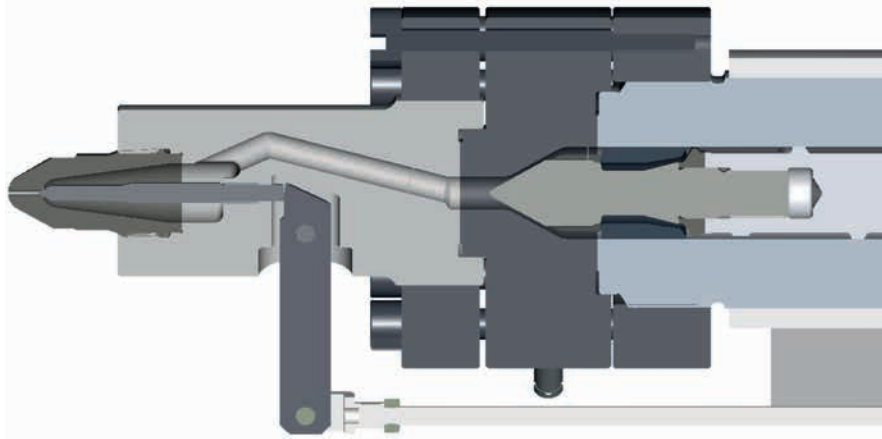


Fig. 8: Needle valve nozzles manufactured by KraussMaffei Technologies GmbH, Munich

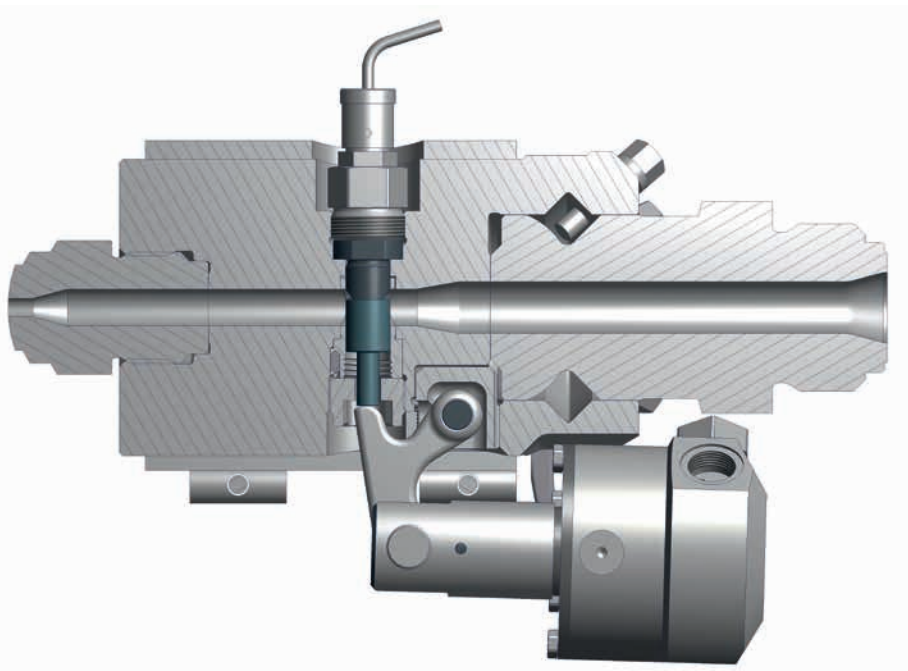


Fig. 9: A cross-bolt shut-off nozzle with pneumatic or hydraulic control manufactured by Herzog Systems AG, Flawil, Switzerland

**All nozzles should be heated and controlled separately.**

To ensure a good seal between the nozzle and the sprue bush, the nozzle radius should be 0.5 to 1 mm smaller than the radius of the contact surface on the sprue bush.

The nozzle aperture must also be adapted to the sprue bush and be 0.5 to 1 mm smaller than the gate diameter (see Fig. 10).

Care must also be taken to ensure an adequate alignment of the sprue-bush and nozzle apertures.

**4 Locking force/clamping force**

A sufficient clamping force is a further key criterion when selecting a machine. It is important for flash caused by mold opening to be avoided right from the outset. On large surface-hardened molds, in particular, the flash will press itself into the parting plane. Any subsequent flash which develops due to deformation of the parting edges can then only be eliminated again by re-machining the parting planes. This, in turn, is highly a complex and time-consuming task in the case of molded parts that have been designed to achieve the lowest possible wall thickness with a view to mold filling. Instead of this, the parts are frequently deflashed on an individual basis.

The minimum clamping force required can be worked out by multiplying the area of the molded part that is projected onto the parting plane by the mean filling pressure prevailing in the mold.

Recommendations (for the sprue gate):

- nozzle radius 0.5 to 1.0 mm smaller than the sprue-bush radius
- aperture at the nozzle tip 0.5 to 1.0 mm smaller than the smallest aperture of the sprue bush with which it is in contact (avoidance of rivet-head formation)

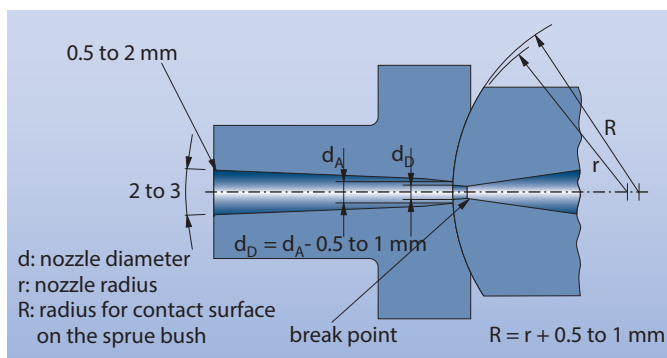


Fig. 10: The nozzle in contact with the sprue bush

**a) Estimation method**

The actual clamping force required can be greater than the minimum clamping force established with the aid of the formulae on the right.

Allowance must also be made for additional parameters, such as

- the rigidity of the machine and the mold
- the permitted breathing of the mold
- the processing parameters
- the molding compound
- the design of the molded part.

The empirical values for estimating the clamping force set out below (Table 1) can thus only be regarded as a guide.

Clamping force  $\geq$  mold opening force [kN]

$$= \frac{\text{projected surface [cm}^2\text{]} \times \text{mean cavity pressure [bar]}}{100}$$

Projected surface = sum of all the surfaces subject to pressure projected onto the plane of the clamping platen (see example in Fig. 11)

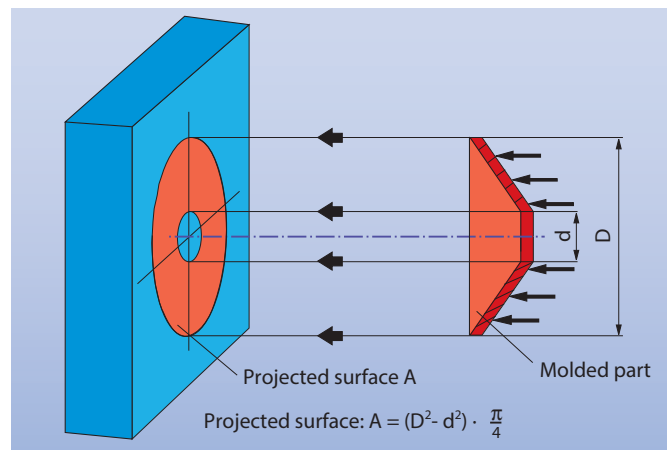


Fig. 11: Truncated-cone-shaped disc as an example of the surface projected onto the parting plane, forcing open the mold

Apec®	PC-HT	300 bis 500 bar
Bayblend®	(PC+ABS)	250 bis 400 bar
Desmopan®	TPU	300 bis 700 bar*
Makrolon®	PC	300 bis 500 bar
Makroblend®	PC/PBT, PC/PET	250 bis 400 bar

\* For material grades with very good flow behavior, it may be necessary to use the higher pressures in order to prevent flash formation.

Table 2: Mean cavity pressures (opening pressures) for the mathematical determination of the clamping force



## b) From rheological calculations

When rheological calculations are used for the mold filling process, the pressure profile over the filling path is obtained as a function of the material, the processing parameters and the molded part geometry. This, together with the projected dimensions of the molded part, will permit the requisite clamping force to be calculated more precisely.

A number of programs, however, calculate the filling pressure requirement in such a way that the filling pressure is at precisely 0 bar at the end of the flow path. In practice, it is necessary to select a higher pressure both for setting the switchover point during injection molding (pressure measurement point close to the gate) and for calculating the clamping force. The increase in pressure is based on the residual pressure that is needed at the end of the flow path (see graph, Fig. 12).

With long flow paths, it may be necessary to have a high initial holding pressure surge (graded holding pressure). This is propagated over the entire molded part with losses and with a time lag and must be taken into account when specifying the clamping force.

The latest computer programs for simulating mold filling (3D FEA) also make allowance for the holding pressure profile, establishing the overall opening force, among other things, as a basis for selecting the minimum clamping force.

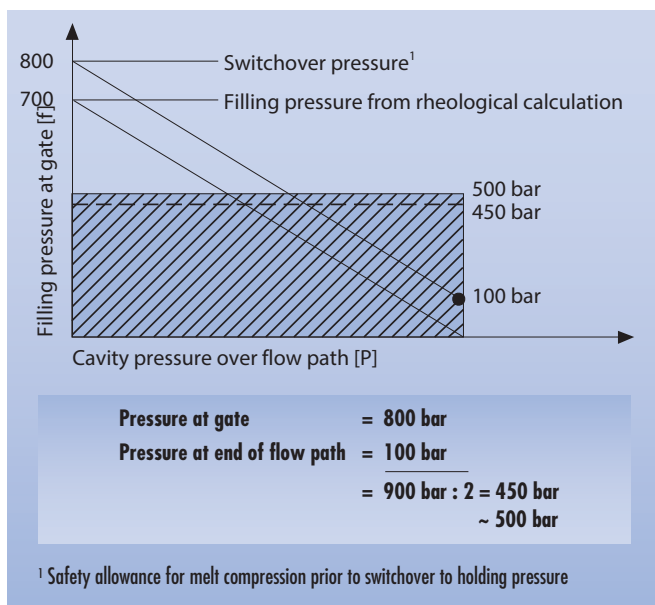


Fig. 12: Determination of the mean cavity pressure (opening pressure) for wall thicknesses of up to approx. 3 mm

## 5 Temperature control units

The cavity wall temperature has a key influence on the filling process and the properties of the molded part. Correct mold cooling is thus one of the key quality-assuring measures.

Apart from an appropriate heating/cooling channel system in the mold, selecting the correct temperature control unit is also important.

One key requirement for the rapid attainment and reliable control of the mold temperature is a **sufficient heating and cooling capacity** for the temperature control units employed. The diagram (Fig. 13) contains guide values for a heating capacity which is dependent on the mold size and the mold temperature.

A further requirement is that the pumps on the temperature control unit should have a sufficient conveying capacity (with a mass flow rate of 10 to 15 l/min for the heating/cooling medium). It should be borne in mind here that a flow resistance can rapidly build up as a function of the length and cross-section of the heating/cooling channel and the number of flow deflections. The pump may not then be able to supply the requisite pressure (Fig. 14).

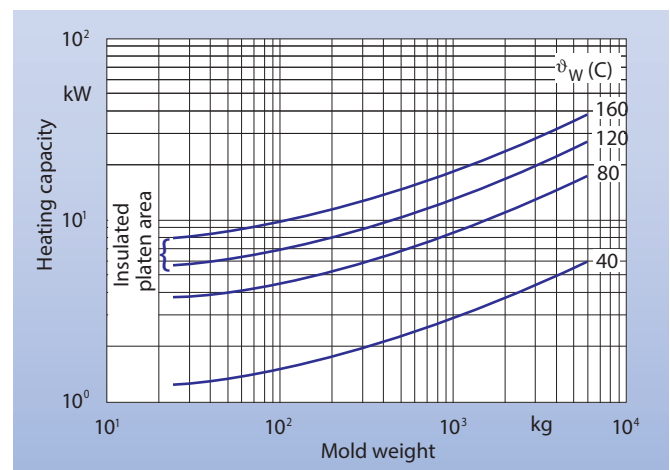


Fig. 13: Guide values for the requisite heating capacity f (mold weight and qW)

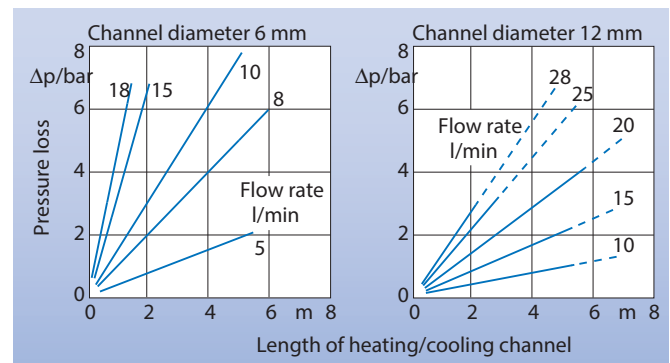


Fig. 14: Pressure loss as a function of the heating/cooling channel geometry and the flow rate

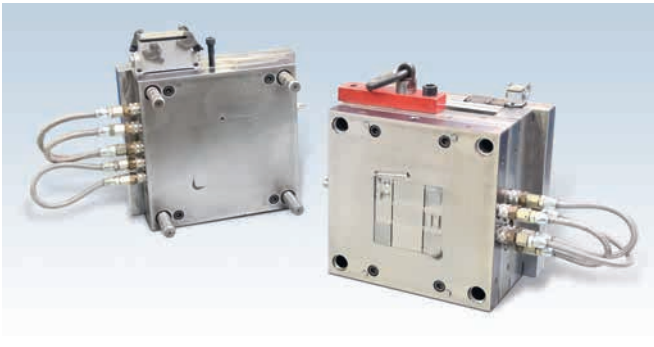


Fig. 15: Mold with heating/cooling circuits connected up via external hose sections

This can be remedied by using more than one heating/cooling unit and thus having a separate temperature control for the two halves of the mold, for example. It may also be necessary to further **divide up the heating/cooling channels** into sections. These modifications can be performed on molds that are already in use if the heating/cooling circuits are series-connected via hose or pipe connections on the outside, as is frequently the case with large molds (Fig. 15).

At times, it will be necessary to employ specially constructed, separate circuits to counter warpage effects through having a temperature control suitably tailored to the local heat levels prevailing within the cavity.

An **excessively high temperature differential** between the inflow and outflow of the heating/cooling medium indicates that the flow rate is too low. For standard quality requirements, the differential should be  $\leq 4 \text{ K}$  and for precision parts  $\leq 1 \text{ K}$ .

A **further selection criterion** for a serviceable heating/cooling unit is a sufficiently accurate form of **temperature control**. The medium input temperature should be as constant as possible, and the control fluctuations kept to a minimum. Excessive control fluctuations can generally be avoided by changing the controller characteristics, correctly positioning the temperature sensor and ensuring that there are sufficient heating/cooling medium reserves in the system.

The introduction of heat via the hot melt can make the mean equilibrium temperature that develops up to 30 K higher than the temperature of the heating/cooling medium (Fig. 16). This actual temperature can be recorded by means of a temperature sensor in the mold and reduced to the setpoint temperature through a **corresponding correction to the medium input temperature**.

The saw-tooth-like fluctuations in the cavity wall temperature follow the same rhythm as the cycle time. They develop through the short-term heating that results from the hot melt coming into contact with the cavity wall. The level of the temperature increase is determined by the temperature differential between the melt and the mold and through the rate of heat dissipation from the mold cavity.

Any change in the curve profile for the cavity wall temperature with a steady cycle time, melt temperature and medium input temperature indicates a changed flow rate for the heating/cooling medium (pump characteristics of a different heating/cooling unit or furring up of the heating/cooling channels when water is used as the heating/cooling medium).

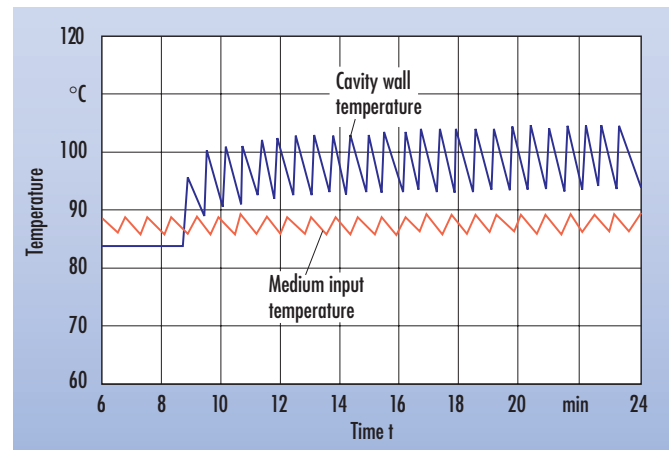


Fig. 16: Mold and medium input temperature profiles over time

**Typical value**

These values are typical values only. Unless explicitly agreed in written form, they do not constitute a binding material specification or warranted values. Values may be affected by the design of the mold/die, the processing conditions and coloring/pigmentation of the product. Unless specified to the contrary, the property values given have been established on standardized test specimens at room temperature.

The manner in which you use and the purpose to which you put and utilize our products, technical assistance and information (whether verbal, written or by way of production evaluations), including any suggested formulations and recommendations, are beyond our control. Therefore, it is imperative that you test our products, technical assistance, information and recommendations to determine to your own satisfaction whether our products, technical assistance and information are suitable for your intended uses and applications. This application-specific analysis must at least include testing to determine suitability from a technical as well as health, safety, and environmental standpoint. Such testing has not necessarily been done by Covestro.

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With respect to health, safety and environment precautions, the relevant Material Safety Data Sheets (MSDS) and product labels must be observed prior to working with our products.



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