

Hot Runners in Injection Moulds

Daniel Frenkler and Henryk Zawistowski
English Translation by Robert Walkden

RAPRA
TECHNOLOGY LTD.

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Preface

The technology of hot runners in injection moulds for plastics is becoming more and more widely used, and this has been accompanied by an increase in the range of hot runner systems available. This development has meant that in manufacturing practice, the user of hot runner moulds is faced with the problem of how to make an objective comparison between the systems on offer from the technical information at his disposal – company catalogues and brochures. The large range of hot runner systems on the market and the complex link between their design and the result obtained in practice means that many designers and users have difficulty in making the best choice. Besides economic and technical considerations, this choice must also take into account the specific properties of the plastics. An understanding of the physical processes taking place in the mould during injection forms a basis for informed building and optimum selection of the hot runner system, and for its subsequent operation. This is an aspect to which the book gives special attention.

In the meagre selection of works on the subject of the design of injection moulds, comparatively little space is devoted to hot runner systems. There is only one book exclusively addressing this subject, and that was published in 1960 [E. Moslo, *Runnerless Moulding*, Reinhold Publishing Corporation, 1960].

The aim of this manual is to fill that gap. It introduces a logical division of hot runner systems, illustrates the design of nozzles, manifolds and other system components, discusses the principles of selection, building, installation and use, analyses the causes of faults and suggests ways of eliminating them, and presents examples of applications. In researching this book, we made use of information that is available in the technical literature and that was provided by hot runner system manufacturers and users. With our own experience to guide us, we have tried to be objective without making evaluations of individual systems produced by specific companies.

Writing a book takes a certain time, and the rapid development of hot runners has meant that by the time the book was ready for publication, some nozzle types had already been replaced by later versions. The book cannot, however, be a substitute for a company's catalogue, and the very latest illustrations are not essential for explanatory purposes.

We would like to thank all those who have assisted us, and especially the manufacturers of standard hot runner systems who made their graphic material available to us. Readers

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will find a list of these manufacturers in Appendix 1. Special thanks also to Robert Walkden who performed the difficult task of translation from the Polish, and to the staff of Rapra Technology, particularly Claire Griffiths, Steve Barnfield, Sandra Hall and Frances Powers, who all worked on the editorial aspects of the English translation. Thanks also to Clive Broadbent of Fast Heat International (UK) Ltd., who kindly proof read the final version of this book.

Daniel Frenkler, Henryk Zawistowski

Nynashämn, (Sweden), Warsaw, (Poland), July 2000

Note: all the measurements in the figures are in mm.

Introduction

Hot runners (referred to from here on as HR) constitute a technique that has been used in thermoplastics injection moulds for over 30 years now. There are some 60 manufacturers in the market supplying their own HR systems. Use of HR is constantly increasing, and it is estimated that HR technology is currently used in every fourth mould made in Europe, and in every sixth made in the United States, with forecasts showing a further increase in use with similar proportions being maintained (Figure A). The basic HR principle was patented in the USA as long ago as 1940 [1]. Despite the time that has passed since then, the technique has not altered, and today's HR developments differ little from the idea that lies behind the prototype (Figure B). One of the first HR moulds in Poland was designed from reports in the trade literature (BASF) and manufactured at the PLASTIC company in 1965 (Figure C). The technique developed slowly at first, and interest was limited, especially as hot runner systems were designed and built on an individual basis at that time. It was not until the oil crisis of 1973 that the economic conditions combined to favour rapid development of HR. When raw material prices were rising from week to week, processors were forced into radical material cost reductions. One way of achieving this was through use of HR systems, which eliminated waste in sprue form. Manufacturers of HR nozzles, and later of full HR systems, appeared in the market. The sudden rise in demand for HR

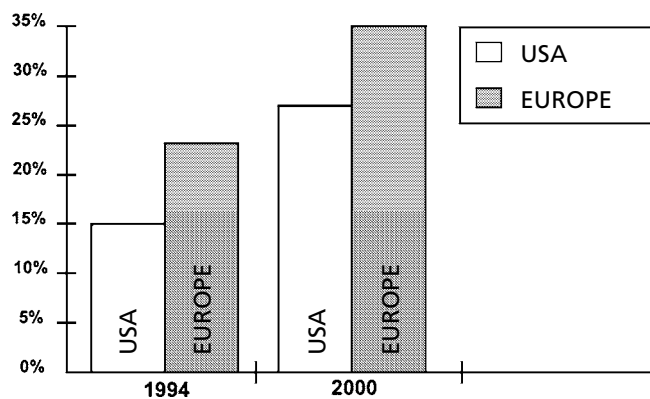


Figure A Percentage use of HR in injection moulds
(data from EWIKON Heißkanalsysteme)

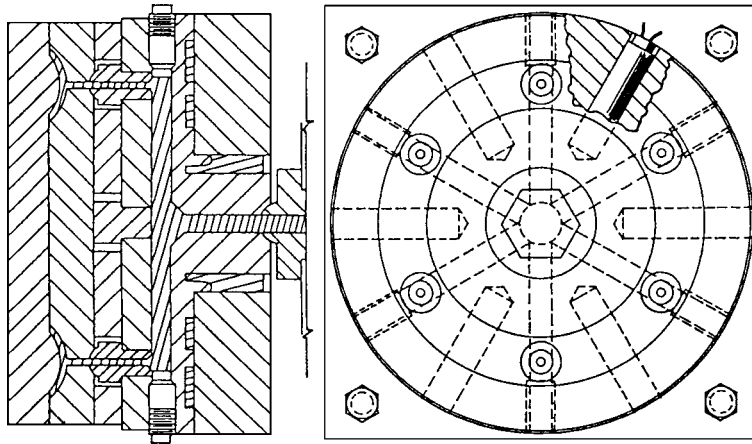


Figure B HR mould designed, built and patented by E.R. Knowles (USA) in 1940 [1]

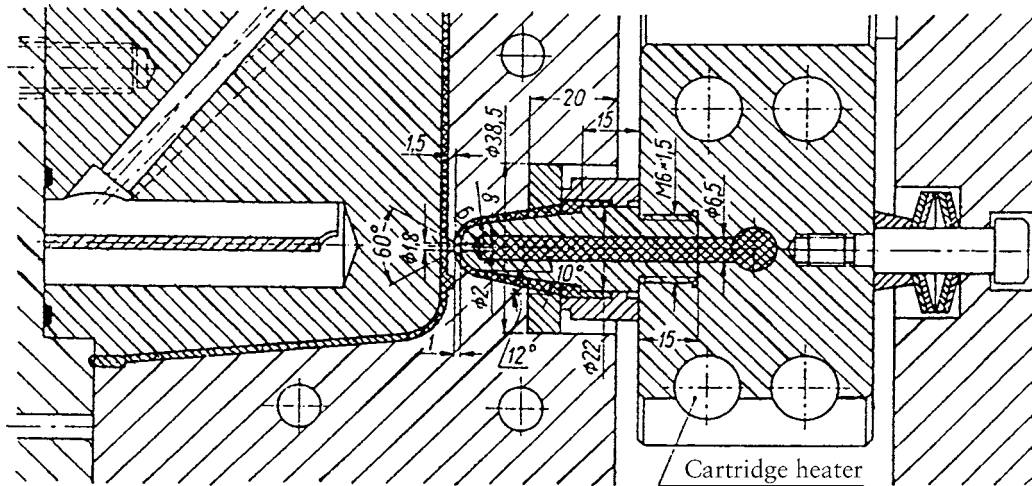


Figure C HR mould design for a PE box
(PLASTIC, Warsaw, designed by Henryk Zawistowski, 1965)

systems did, however, have a negative effect - manufacturers had not the time to upgrade systems; HR nozzles were vulnerable to blockage, not properly adapted to the properties of the plastic, temperature controllers lacked sensitivity, and there was no such thing as an automatic heating start function. This caused disillusionment with HR technology and a fall in demand. The period of stagnation, however, brought about an increase in outlay on technical and quality development, with the result that HR systems of the last decade may now be regarded as technically mature developments. There is such a large range of HR systems on the market nowadays that efficient systems can be selected for most applications and virtually all thermoplastics. The wide variety of designs is partly a consequence of the continuous development of HR technology, but also arises from the patent situation, which restricts the freedom of dissemination of optimal designs.

Sensibly applied HR technology has a number of advantages. Chief among these are reductions in raw material consumption and easier automation of the injection process. In many cases greater production output is achieved by shortening the injection cycle, or other technical benefits are attained. The design of some types of moulds has been simplified. Injection of certain products, particularly of large size, would be difficult or downright impossible without HR technology. It was only the introduction of HR moulds that made the production of cheap disposable items a possibility. HR technology enables production costs in large series to be reduced. One fundamental pre-condition, however, is correct selection of the HR system; if this is not done, the effect may be the reverse of that desired. The negative attitude of some processors to HR technology may owe its origins to bad experiences caused by arbitrary nozzle selection, choice of cheap nozzles at the expense of durability and optimum functioning, use of home-made nozzles, unskilled operation, lack of qualifications and especially lack of familiarity with the physical processes taking place during plastics processing, lack of a suitably drawn up cost balance, and also by the lower capabilities of early HR systems. HR system manufacturers are aware of this, and attribute considerable significance at the present time to informing the user of the importance of choosing the right HR system and running it properly, and they take an active part in finding the best solution, often actually taking upon themselves the responsibility for system selection.

There is no such thing as an HR system that would be ideal for all materials and all types of product. Thermoplastics have a very wide range of rheological and thermal properties. This means that a specific HR system that is right for a particular thermoplastic or group of thermoplastics will function less well, or not at all, for another group of such plastics. The operation of the system further depends on such factors as the shot volume and injection speed, the flow length, the shape of the mould cavity and the need to change the colour of the plastic. There are certain restrictions applicable to thermally sensitive plastics and plastics vulnerable to shear, and to plastics with flame-retardant additives, fillers and reinforcing agents.

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Warning! An HR system is individually selected for each specific instance: a particular moulding, a particular plastic and particular production conditions!

HR technology may be employed for special injection methods, like in-mould, i.e., lamination of inserts made of film and textile liners, injection of foam plastics, multi-component injection, inert-gas-assisted injection, etc.

It should be remembered, however, that no system is better than its own weakest link. The best nozzle will let you down if it is controlled by a primitive ON/OFF regulator that does not keep the temperature within the required range, or by a regulator without the SOFT START function, which will substantially shorten the life of the heaters.

Another limitation to the operation of the system may be a badly-designed mould e.g., without zonal temperature regulation, or contaminated raw material, and so on.

A further condition for proper operation of an HR system is reproducibility of injection parameters, attainable in principle only with an automatic mould operating cycle. To achieve the desired profitability of production, it is essential to employ skilled technical staff, since proper handling has a very considerable impact on the functioning of an HR mould. A lack of skill may be the weakest link in the production process.

References

1. E. Moslo, *Runnerless Moulding*, Reinhold Publishing Corporation, New York, 1960.

1 Types of Hot Runner Systems

Hot runners (HR) have become the predominant delivery system for thermoplastics in injection mould designed primarily for large-series production and for the manufacture of products with long flow paths. Despite the substantial cost of moulds with hot runners, which may sometimes be greater than the cost of an injection moulding machine, they enable increases in productivity and decreases in raw material costs to be made so that the investment in them not only pays for itself, but is often a precondition for being in the market at all (audio and video cassettes, packaging, knobs, polyethylene terephthalate (PET) bottle preforms, syringes and other disposable items, and so on). However, in moulds for short- and medium-series production, cold runner gating systems (referred to from here on as CR) with sprue removal continue to dominate for economic reasons. Design and economic circumstances, especially in the production of small mouldings, often necessitate the use of mixed systems (HR and CR). A general breakdown of gating systems is shown in **Figure 1.1**.

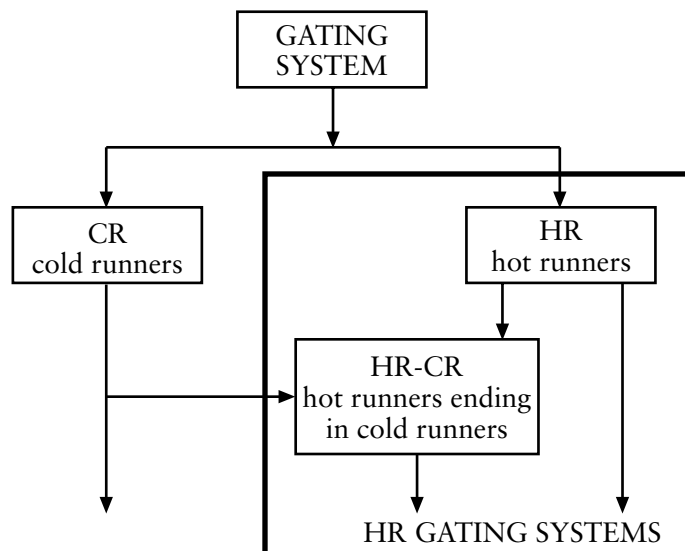


Figure 1.1 Types of gating system in injection moulds for thermoplastics [1]
(Reproduced with permission from Plastech, Warsaw, Poland.)

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A provisional breakdown of HR methods may be based on two fundamental criteria (**Figure 1.2**): the material delivery method and the heating method.

This division of the subject will make the understanding of HR technology easier.

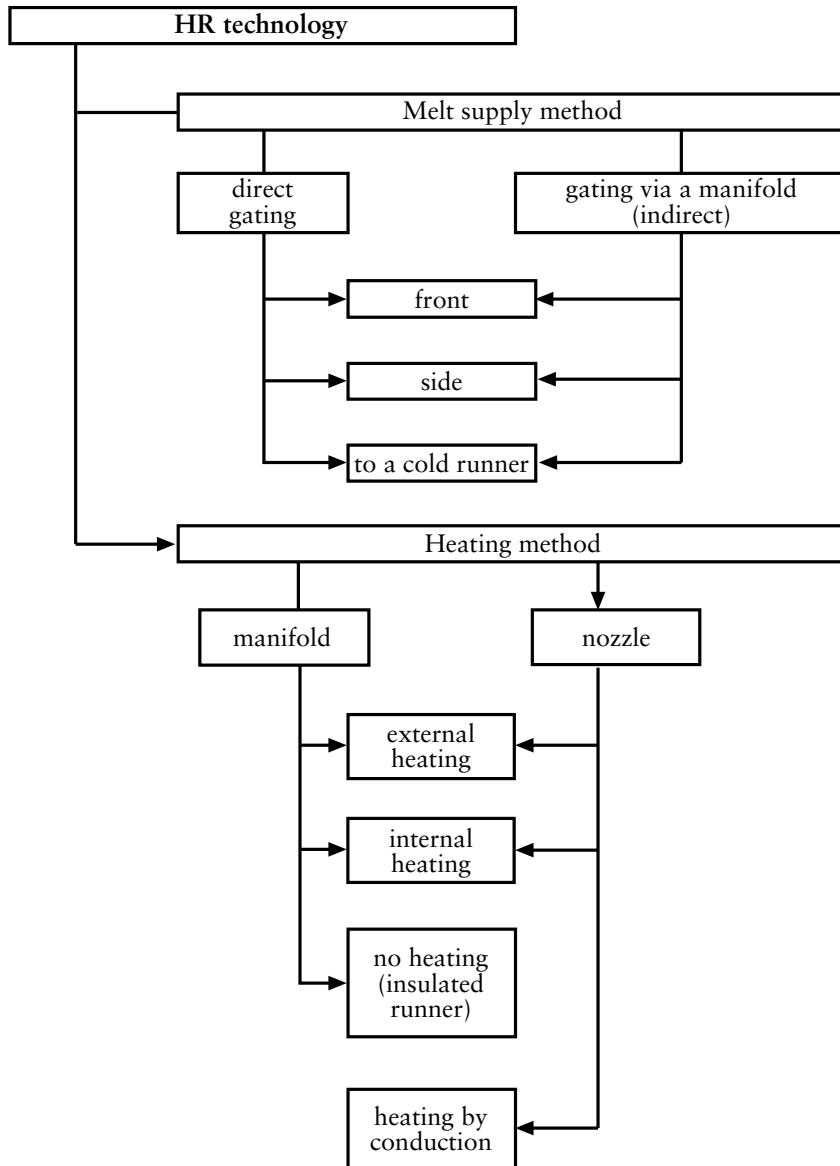


Figure 1.2 Types of HR system

1.1 Melt supply methods

On the basis of a breakdown that has appeared previously in the specialist literature [2], we have adopted a classification system for HR that relates to the method of plastic delivery - direct gating and gating via a distribution system (indirect gating). A view of the basic applications of HR in which this classification principle is applied is shown in Figures 1.3 and 1.4.

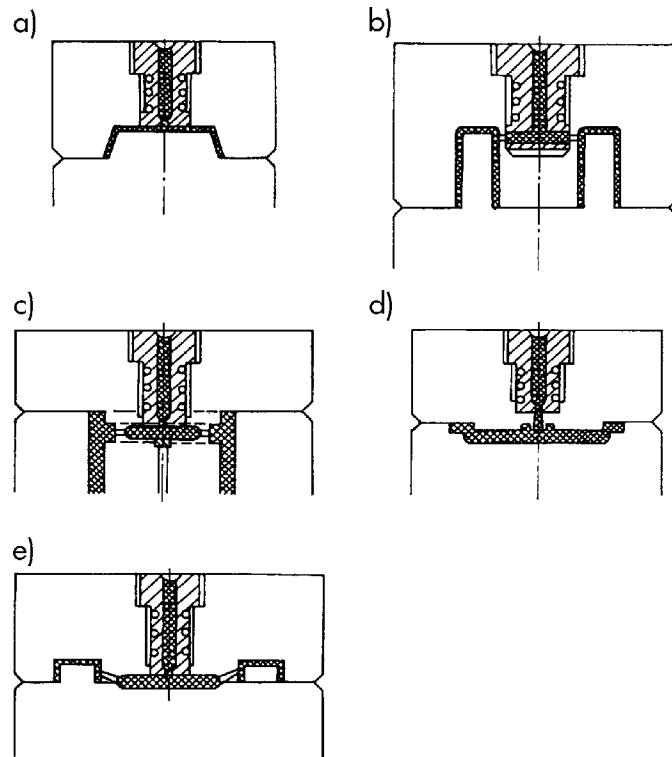


Figure 1.3 Direct gating

a - front; b - side in multi-cavity mould; c, d - to a cold runner, in single-cavity mould;
e - to a cold runner, in multi-cavity mould

Direct front gating. The simplest HR system is created through replacement of the CR system sprue bushing (Figure 1.3a) by a heated nozzle, also known as a hot sprue bushing. Then we get a waste-free pinpoint gate, instead of either a sprue which requires cutting off, or a pinpoint sprue (with cold preliminary chamber similar to a 3-plate feed) with scrap sprues discharged towards the injection cylinder. This system has particular advantages in

the case of large moulds because of the large distance between the injection cylinder nozzle and the mould cavity, since a long sprue can have such a large diameter that there has to be a lengthening of the cycle, and sinks or voids appear at the bottom of the moulding. It might be added that under certain conditions this cold point sprue within the preliminary chamber does not solidify (plastic with wide temperature window, e.g., polyethylene (PE), and a short injection cycle), and may function as an insulated channel. The hot nozzle, however, enables temperature control to be practised, as a result of which this dependence of the injection process on the type of plastic and the cycle time is eliminated.

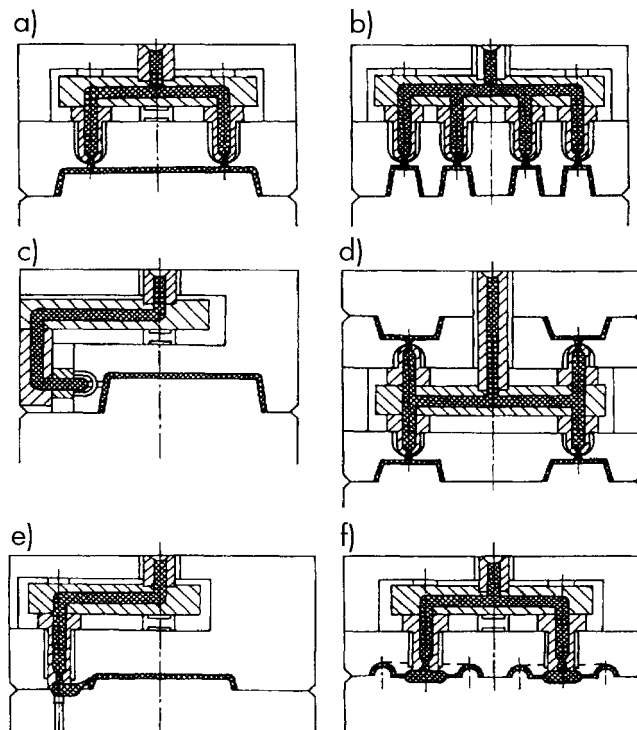


Figure 1.4 Gating via a distribution system (indirect)

- a - front, multi-point, in single-cavity mould; b - front, in multi-cavity mould;
c - side, in single-cavity mould; d - front, in stack mould;
e - to a cold runner, in single-cavity mould; f - to a cold runner, in multi-cavity mould

Direct side gating replaces cold tunnel gating (Figure 1.3b). Its advantage is that a single nozzle delivers plastic to several cavities, but its application is restricted to certain product shapes.

Direct gating to a cold runner in single-cavity mould. Where there is a central aperture in the moulding, the plastic may be delivered via HR nozzles, then via CR with a normal or tunnel gate (Figure 1.3c). Injection via an aperture (not necessarily central) is also used when it is not possible to locate the sprue on the outside surface for aesthetic reasons. A complex cavity design or process considerations sometimes prevent the nozzle being brought right into the cavity; this problem may be solved by using injection in a sprue (Figure 1.3d).

Direct gating to a cold runner in a multi-cavity mould. In this design, the CR is only partially replaced by an HR system. A simple open HR nozzle eliminates the sprue (Figure 1.3e), thus shortening the required mould opening path and making it easier to separate the sprue protrusion from the moulding on the transporter belt. This method is used when the production volume or product shape does not justify the use of HR nozzles for each cavity.

Front multi-point gating via a distribution system (indirect). For large products, or where the ratio of the flow path to the wall thickness reaches a large value, to reduce pressure losses during filling (or to reduce wall thickness), and also to give better pressure transfer during the holding phase (Figure 1.4a), multi-point gating should be used. An HR system has in this instance enabled moulds with two parting lines with CR to be eliminated, which has simplified the mould design, done away with sprue waste recirculation, shortened the cycle time and enabled mould operation to be automated. This system has also allowed injection moulding of products limited in size only by the technical capacity of the injection moulding machines (injection volume and pressure and clamping force).

Front gating via a distribution system (indirect) in multi-cavity mould. The most profitable introduction of HR systems has turned out to be for injection moulding of products requiring a central gate position (Figure 1.4b). Consequently this design is being increasingly used. As in the previous case, the HR system enables moulds with two parting lines with CR to be eliminated.

Side gating via a distribution system (indirect). This type of gating is only used in special cases because of technical restrictions and the relatively high cost of a special HR distribution system (Figure 1.4c).

Front gating via a distribution system (indirect) in a stack mould. The HR system has made it possible for stack moulds to be developed (Figure 1.4d), with two, even three parting lines.

Gating via a distribution system (indirect) to a cold runner in a single-cavity mould. For aesthetic reasons, or because of a complex cavity design, in some products one cannot position a sprue on the front surface of the moulding. Sometimes it is possible to invert the

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product in the mould and inject onto the inside surface; but this way of doing things has the disadvantage that the ejection system also requires inversion, i.e., locating in the fixed half of the mould, which means lengthening the gating. Consequently a design is more often used in which the plastic is fed in from the side of the cavity via an HR distribution system and an open nozzle, then via a cold runner ending in a gate, e.g., a tunnel or edge gate (**Figure 1.4e**). This method is again used for larger products, where side injection has to be applied to obtain the set orientation of the structure and to avoid stress concentrations and the risk of warping.

A better way of doing this is just to use an injection moulding machine with an off-line cylinder or with a cylinder feeding the plastic in the mould parting line.

Gating via a distribution system (indirect) to a cold runner in a multi-cavity mould.

The distributor and open nozzles do away with a substantial part of the protruding sprue (**Figure 1.4f**). This method is used when there is a large number of cavities for small products, when for economic reasons one HR nozzle feeds several cavities, and also when the specific design of the mouldings, e.g., gear wheels, or the mould design, e.g., slides, make it impossible to run the channels in at the parting line.

Use of mixed CR and HR systems has the advantage (leaving economic considerations aside) of simplifying the problem of temperature control in the HR nozzle gate area, and additionally enables the 'cold plug' from the injection moulding machine nozzle to be halted.

Example. Using as an example an 8-cavity mould (**Figure 1.5**), various gating designs are shown:

- a) conventional gating with CR and tunnel gate;
- b) sprue replaced by HR open nozzle, which facilitates sprue removal from mould and sorting. In this example, the sprue and runner scrap is reduced by approximately 40%, and the cycle time is reduced by approximately 10%;
- c) an HR distribution system together with two HR open nozzles has been introduced, thus eliminating the primary runner. The sprue and runner scrap is reduced by approximately 60-70% in comparison with the primary design;
- d) each cavity is fed directly by an HR nozzle. Elimination of the CR allows the injection temperature to be reduced and the cycle time to be further shortened, because central gating enables the wall of the moulding to be made thinner. Waste recycling is not necessary, so this saves on the associated investment in additional equipment, but the cost of the mould is relatively high and manufacturing profitability is probably only attained with a manufacturing series of over one million pieces.

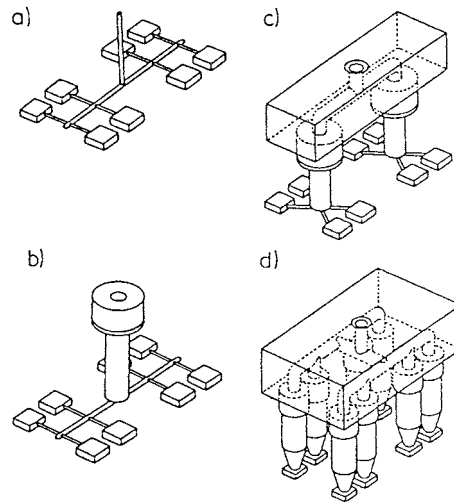


Figure 1.5 Gating system variants in 8-cavity mould

a - CR; b, c - HR-CR; d - HR

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1.2 Methods of heating

The purpose of an HR system is to feed plasticised material into the cavity of a mould in a similar state to that in which it left the injection moulding machine nozzle. In this system, the temperature of the plastic must be held at a constant level (isothermal system) along the entire flow path by supplying heat in a quantity sufficient to cover heat losses (**Figure 1.6**). At the same time there must be compensation in the HR system for the rise in temperature caused by the friction heat arising as the plastic flows through the channels, and especially the gates. Different methods of supplying heat to the distributor channels and nozzles give rise to technically differing system operating conditions.

The HR systems that are on the market may be divided into two groups:

- systems with internal heating (**Figure 1.7a**).
- the more common type of system with external heating (**Figure 1.7b**);

Since an HR system essentially comprises two functional parts, the distributor with sprue bushing and the nozzles; mixed systems can also be found, i.e., a distributor with external heating or nozzles with internal heating.

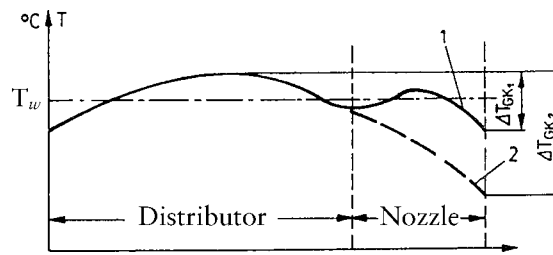


Figure 1.6 Curve of temperature variations in the flow path in an HR system

1 - with heated nozzle; 2 - with conducting nozzle; T_w - injection temperature;
 ΔT_{GK1} - temperature fluctuations of plastic at nozzle with independent heating;
 ΔT_{GK2} - temperature fluctuations of plastic at nozzle heated by heat from distributor

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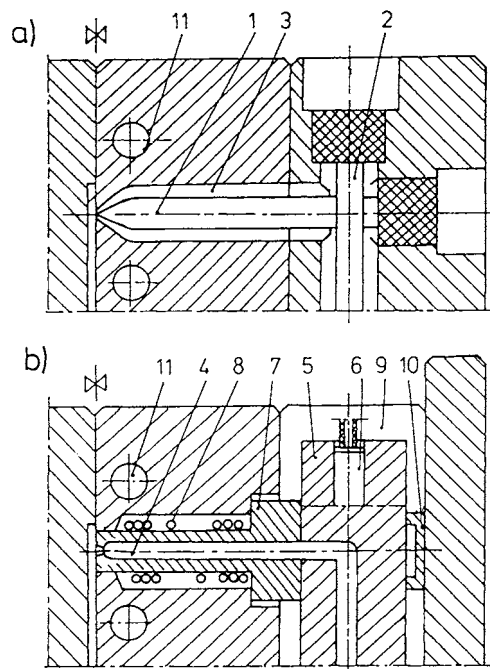


Figure 1.7 Comparison of HR systems

a - with internal heating; b - with external heating; 1 - torpedo; 2 - pipe with heater;
 3, 4 - flow channels; 5 - distributor; 6, 8 - heaters; 7 - nozzle; 9 - insulation space;
 10 - pressure pad; 11 - cooling circulation channels

An HR system without heating (insulated) is rarely encountered nowadays; although sometimes a combination of an unheated channel with a heated torpedo is found.

Heating by conduction only occurs as part of a system, e.g., in the form of a heat-conducting nozzle.

The design and manufacture of HR systems by an individual should, because of the degree of risk, be restricted to exceptional cases, e.g., distributors of atypical geometry, or where there is no chance of ordering them from an HR manufacturer. An individual should very definitely not design and manufacture HR nozzles, because the savings achieved are illusory. The most common consequences of an unverified design are a high hazard level, production stoppages, leaks, low product quality and an extended cycle time. A modern nozzle is a complex mechanical/thermal system designed on the basis of many years' experience.

The plastic flow characteristic varies depending on the heating method.

In a channel with external heating (**Figure 1.8a**) we have the simplest flow model. The melt in the channel flows in laminar fashion at a very low flow rate next to the channel wall, and at the maximum rate in the centre of the channel. The differentiation in flow rates causes shear stresses in the melt. The greatest increase in flow rate, i.e., the greatest shear velocity, is attained by the melt near to the channel wall. However, there are relatively low shear stresses along the hot channel wall - lower than with flow along a cold wall - with a uniform flow in the channel centre.

In a channel with internal heating (**Figure 1.8b**), the heater is in the centre of the channel, which imposes an annular channel cross-section. The flow characteristic is more complicated, as a frozen layer of plastic lies up against the cold outside wall of the channel, and this has an insulating effect. Besides this, in the case of amorphous plastics there is a layer of plastic in a highly-elastic state between the frozen and fluid layers; the temperature of this layer is a little lower than the processing temperature. As a result of periodic transport of the plastic (injection process), fluctuations throughout the channel occur in the thickness of the fluid layer and the frozen layer, and the progress of the highly-elastic layer is slow. The real active channel cross-section is no more than one-quarter to one-half of the total channel cross-section. During flow, relatively high shear stresses occur both along the inside hot wall of the channel and along the external layer of frozen plastic.

In an insulated channel (**Figure 1.8c**) there is a flow like that in CR, but with the difference that there is a thick frozen layer of plastic on the wall of a channel of very large diameter, and this serves to insulate the fluid core. Its thickness depends on the state of thermal equilibrium between the cold wall of the channel and the hot melt

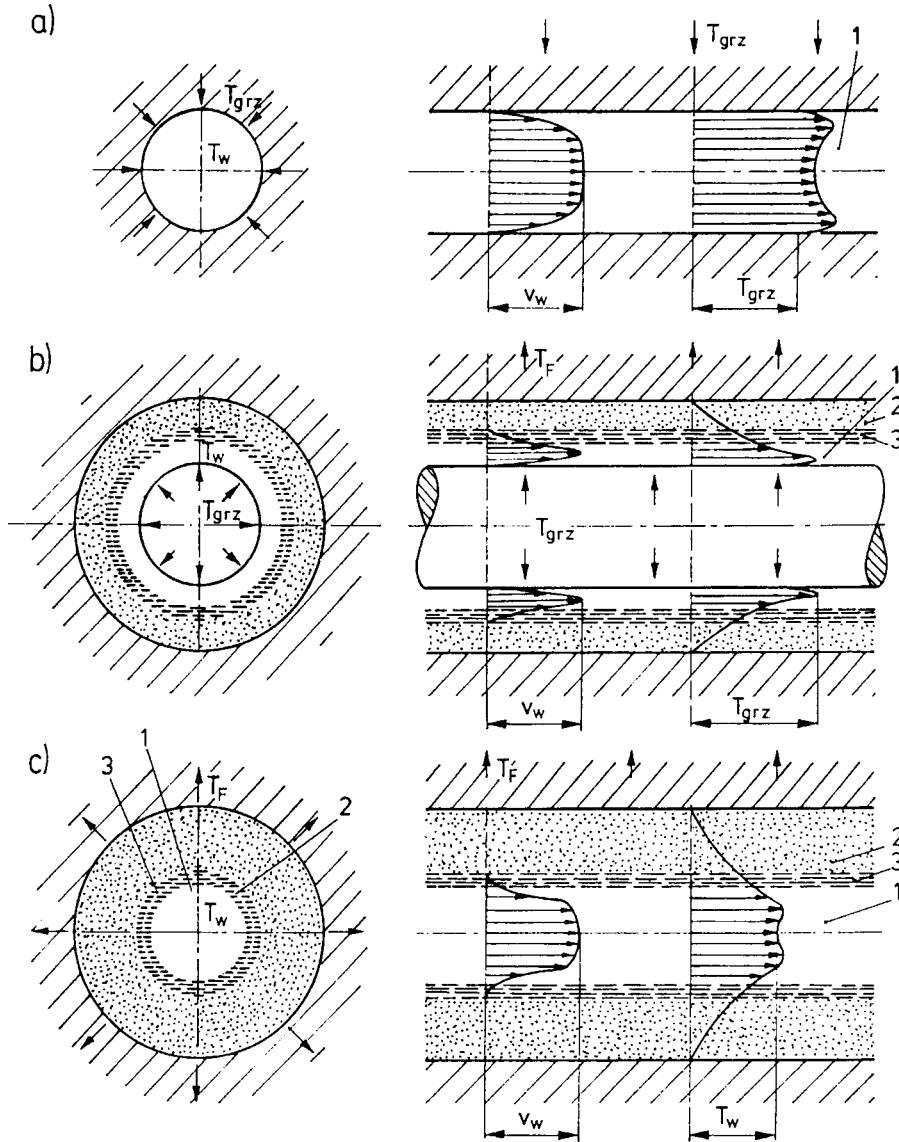


Figure 1.8 Melt flow rate and temperature distribution in channel cross-section

a - channel with external heating; b - channel with internal heating;
c - insulated channel; 1 - fluid plastic; 2 - frozen layer; 3 - highly-elastic layer
(amorphous plastic)

T_{grz} - heater temperature; T_F - mould temperature; T_w - plastic (injection) temperature;
 V_w - injection velocity

being pushed through the channel, and fluctuates during each injection cycle. The longer the cycle time, the thicker the insulating layer, and consequently also the smaller the working diameter of the channel. At each stoppage, the frozen contents of the channel have to be removed.

In an HR system with external heating the flow channels are located in a heated distributor in the form of a plate suspended inside the mould (**Figure 1.7b**). Electric heaters, usually in the form of cartridges or heating pipes with bends, are located outside the channels. The distributor is thermally insulated from the rest of the mould by an air gap and sometimes insulating screens, and rests on shaped washers with limited heat conduction. There are also distributors on the market that are designed differently. Round channels without dead spaces allow an optimum flow of plastic and make it easy to change plastics or colour. The pressure drop in the channel during injection is constant; it may be calculated and then brought to equilibrium on filling of the mould cavities.

One drawback to this system is the large heat losses and the penetration of heat to the mould plates, which is a reason for designing additional cooling channels. There is a need for compensation for the thermal expansion of the distributor and for the introduction of extra design features to make the system leakproof.

HR nozzles operating with an externally-heated distributor may be fitted with external or internal heating. In simple applications, short nozzles without heating are still in use, i.e., nozzles conducting heat from the distributor.

The whole HR system is divided into temperature control zones; temperature measurement and control are carried out with the aid of automatic regulators separated from the mould.

An HR system with external heating is a traditional system, but is more costly and creates a greater risk of disruptions to production than a system with internal heating.

In an HR system with internal heating large-diameter flow channels are located in the distributor or more usually in the mould plate itself (**Figure 1.7a**). In the channel axis there is normally a pipe with a cartridge heater. Because the external wall of the channel is cold, the outside layer of plastic freezes and forms an insulating layer. This gives a substantially lower electricity consumption (by some 50%), and there are no problems with heat insulation or thermal expansion of the distributor. The outside frozen layer of plastic functions at the same time as an excellent seal for the system. The HR temperature essentially has no bearing on the thermal balance of the mould.

With internal heating, the external temperature of the distributor plate also depends on the mould temperature. This dependence is shown in the graph in **Figure 1.9**. Thus with an

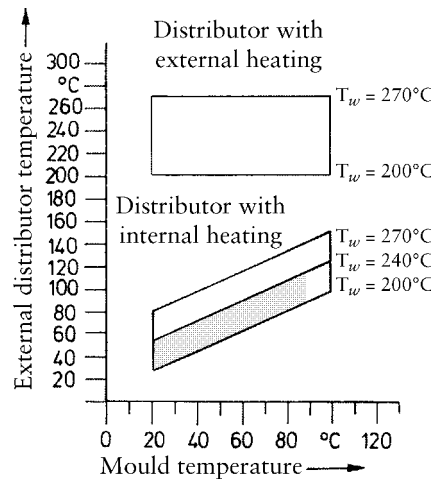


Figure 1.9 External temperature of distributor with external and internal heating depending on mould temperature and plastic temperature T_w (for distributors with medium heating power of 2 W/cm^3) [3]

(Reproduced with permission from P. Braun, *Kunststoffe*, 1997, 87, 9, 1184.
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injection temperature of around 240°C and a mould temperature of 40°C , the distributor temperature will be approximately 70°C . Under the same heat conditions, an externally-heated distributor plate will have a surface temperature only a little lower than 240°C .

A drawback to this system is the large volume of the channels, which prolongs the thermal loading time for the plastic. Another drawback is the large pressure drop in the channel and the pressure variations during injection resulting from the fluctuations in the thickness of the fluid layer of plastic. For technical and design reasons it is difficult to achieve rheological balance of the flow in the system. Relatively high shear stresses occur in the melt. The unmoving layer of plastic and the dead space to be found in the system make it difficult to process heat-sensitive plastics or to change the colour. The system is recommended above all for easily-processed plastics such as polystyrene (PS), PE or polypropylene (PP), but injection of engineering plastics is also possible.

To facilitate colour changes, designs with an openable distributor are used, which makes it easy to clean the channels after removal of the mould from the injection machine.

HR nozzles operating with an internally-heated distributor also have internal heating. It is difficult to install shut-off nozzles in this system.

The cost of the above system is 20-25% lower than that of a system with external heating. It also provides a guaranteed low probability of production disruptions, and is easier to service.

The distributors in the two systems are usually heated by a supply of 220/230 V, (many EEC countries have raised their rated mains voltage to 230 V) but some systems operate at 5 V. Nozzles, on the other hand, are usually heated by a 220/230, 24 or 5 V supply. At 5 V and 24 V, special bar or tubular (high-supply) heaters are used, which assists miniaturisation and provides more uniform heating and more precise temperature control. This type of heating is known as low voltage heating, and the heaters as low voltage heaters.

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Hot Runners in Injection Moulds

2 Conditions for use of Hot Runners

Use of an HR system always requires a detailed technical and cost feasibility study. The starting point, however, is a set of general technical information on the structural principles of HR moulds, and their advantages and limitations - especially where conditions of use are concerned. The use of HR must arise out of rational needs, and must not be, for example, a manifestation of a designer's ambition, or a symbolic exercise in modern manufacturing methods.

2.1 Technical advantages and limitations of using HR

Alongside the undoubted advantages of HR technology, there are also limitations to its use.

Information on the limitations of HR systems may be of particular assistance when making an objective assessment of whether to install one.

Technical benefits from using HR are:

- Simplification of the design of certain types of mould. Use of CR moulds with an extra parting line (moulds known as three-plate moulds or with a so-called intermediate plate) (see **Figure 2.5a**) have major restrictions. The functioning of such moulds is difficult to automate because of the sprue removal aspect, and because of the tendency for the sprue to get stuck between the mould plates. The heavy moving plate of the mould can be a cause of rapid wear to the plate guide system. The same could be said of its drives and mechanical travel limiters. Besides this, the opening and closing time for a mould of this type is always longer than for moulds with a single parting line. The proportion of the sprue in the overall injection mass in three-plate moulds is also greater.
- Eliminating the fall in melt temperature which occurs in a cold runner, has enabled the use of a longer flow path in the cavity. This is of significance in the case of partially-crystalline plastics, which feature a narrow temperature window that prevents compensation of the temperature drop in the CR by raising the injection temperature.
- The plastic flowing into the cavity is at a controlled temperature (assuming precision temperature regulation in the HR system).

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- The lower pressure loss in the HR means a higher cavity fill pressure is available.
- In moulds for large products, there is greater freedom to select the optimum location for the injection points, which leads to a more uniform filling, with a smaller loss of temperature and pressure in the mould cavity. Engineering mouldings show less differential shrinkage and lower internal stresses.
- A reduction in the injection pressure required to fill the cavity, which enables the required injection moulding machine locking force to be reduced.
- The potential to regulate the holding time by controlling the time for which the gate is live or by mechanically closing it. The reproducibility of self-cooling conditions for a plastic under pressure, and thus also of moulding shrinkage, are thus improved. Holding pressure loss is also less than for CR, since the gating runner has a larger operating cross-section which does not diminish through the formation of an insulating layer.
- HR make it possible to design moulds of, for example, the modular type for thin-walled packings, bottle preforms, and so forth, and also moulds for sequential moulding, moulds for in-mould decoration and lamination, and so on.
- The potential for further development of stack moulds and for design of moulds with gating via a long core.

Limitations of the use of HR:

- An HR system must be selected for a particular application and plastic. A change of colour of the plastic may be difficult and time-consuming if this has not been allowed for in the design (this is also true of systems with internal heating). A change in the type of plastic may be difficult or even impossible if, for example, nozzles of a different type have to be used for the new plastic.
- There is an increased risk of damage to thermally sensitive plastics, which, following plasticisation in the injection cylinder, must also feature resistance to over heating in the HR system. The 'dead space' that occurs in some systems causes stagnation and the risk of breakdown of the plastic. The pros and cons should always be weighed up when an HR system is being considered for use with polyvinyl chloride (PVC), high temperature plastics and for plastics with additives that reduce flammability. The thermal loading on the plastic may be considerable, especially during breaks in operation.
- The system is vulnerable to mechanical contamination of the raw material, which may cause gate blockage. This is countered by locating an additional filter in the injection nozzle or sprue bushing.

- A certain amount of experience is required to avoid gate stringing or drooling of some plastics from the nozzle.
- The distribution and number of small cavities is limited by the nozzle diameter.
- The use of an HR system has a substantial bearing on increased mould height, which may not exceed an admissible value for the given injection moulding machine.
- One condition of proper functioning of an HR system is the automatic operation of mould and injection machine, as far as possible without between-shifts or maintenance stoppages.
- Mould operations may run into problems if trained staff are not available. Start-up of the HR system, change of plastic, stopping and, if necessary, cleaning of hot runners cannot be done without some knowledge and observance of certain principles. For the same reason, repairs and maintenance should be carried out by trained staff only. Damage to moulds caused by unskilled servicing generally leads to serious financial losses.
- A considerable expansion of the scope of maintenance is required.

2.2 Initial grounds for introduction of an HR system

The large financial outlay associated with production of HR moulds makes it advisable to perform a feasibility study (**Figure 2.1**) similar to that undergone when buying an injection moulding machine [1]. This gives the information necessary to decide whether it makes sense under the given circumstances to apply HR technology to manufacture a given product.

As may be seen, the analysis includes not only measurable economic aspects, but also in many cases non-measurable considerations of a technical, organisational and quality nature. Performance of an analysis that takes into account the specific nature of the product in question builds on the general lists of advantages and drawbacks to HR use that was discussed in Section 2.1. In specific sections the study may be made in a general way, as an estimation, or even with detailed calculations (see Section 2.3).

Content of a benefit analysis

Savings on materials and labour. A determination is made of the reduction in production costs resulting from the elimination or diminution of waste in the form of sprues and runners.

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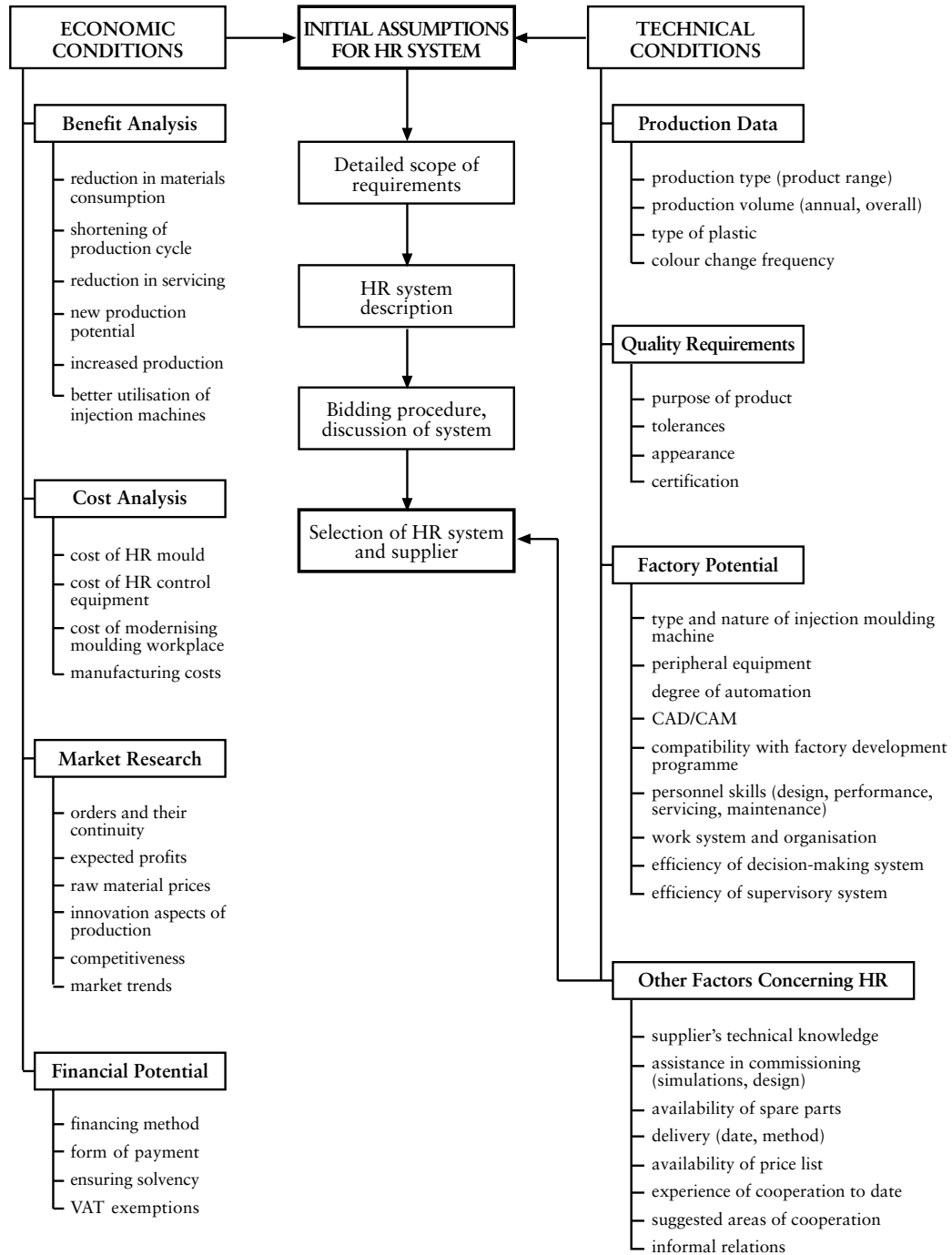


Figure 2.1 Feasibility study for the introduction of an HR system

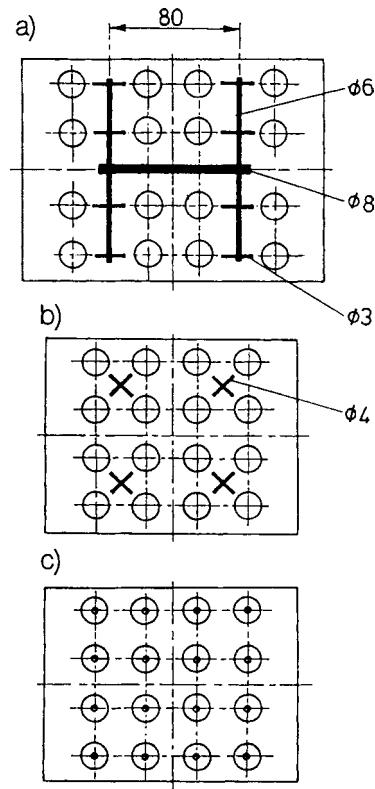


Figure 2.2 Comparison of waste arisings in mould

a - cold runner - 25 cm^3 (approximately 17 t/y); b - HR system ending in cold runner - 5 cm^3 (approximately 3.5 t/y); c - HR system - 0 cm^3
 ϕ - diameter

This means:

- Reduction in raw materials consumption;
- Reduction of finishing work on mouldings (sprue removal);
- Curtailment of the waste recycling process (sorting, milling, drying, storage), leading in turn to a reduction in the number of regrinding machines, and savings on labour, energy consumption and production area required.

Example. In a typical 16-cavity mould (**Figure 2.2**) the quantity of waste for three types of gating will be compared. In layout (a), with cold runners throughout, the volume of sprue is some 25 cm^3 ; in a type (b) mould with a simple HR system with four nozzles and

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a short CR, the volume of sprue has diminished to 5 cm³; while in a type (c) mould with a full HR system with sixteen nozzles, sprues and runners have been completely eliminated. Assuming a cycle time of 30 s, a type (a) mould will produce around 3 kg of waste per hour. In the course of a year, working a single shift, this will mean 48 weeks x 120 h x 3 kg = 17,280 kg. Thus one injection moulding machine will produce 17 tonnes of waste, which needs sorting, regrinding, possibly storing and then returning into production. A type (b) mould will give only 20% of this waste with a HR system of moderate cost, and this makes it competitive for medium production runs. A type (c) mould is expensive, but will pay for itself with production runs of suitable volume.

Increasing production through shortening of the cooling time and machine times and automation of work:

- A shortening of the cycle time is possible in two cases: when the cold sprue is considerably thicker than the moulding and governs the cooling time; and when the availability of greater pressure and injection speed enable wall thickness (e.g., of packaging items) to be reduced. Generally speaking, a fall in the cost of production of thin-walled mouldings may be expected. Where the mouldings are small and the share of sprue large, we may expect a further shortening of the cycle through a reduction in injection time and plasticisation time of what may sometimes be a several times smaller mass of plastic;
- Automatic and waste-free operation of HR moulds enables production to be continuous, even during holidays. In this respect the set comprising injection moulding machine, mould with HR and peripheral equipment may become a Flexible Work Centre (FWC).

Simplified production. After sprues and runners are eliminated, automatic separators or manual sorting to separate them from the mouldings are no longer required, which makes the automation of work easier.

Improved utilisation of injection moulding machines. Use of moulds with HR makes it possible to:

- Increase the available shot volume through sprue elimination (it should be remembered, however, that the compressibility of the melt in HR demands an increase in the available shot volume by around 20% of the HR volume);
- Reduce the required injection and holding pressure;
- Reduce the required locking force;
- Shorten individual phases of the operating cycle;

- Reduce energy consumption.

This not uncommonly leads to the selection of a smaller injection moulding machine and a reduction in machine costs.

New production potential. HR technology particularly enables the injection method to be employed to produce large-sized pieces. Examples of products where HR technology underpins the manufacture are, transport boxes, automobile bumpers and street waste bins. The restriction on their manufacture has been the length of the flow path and the associated problem of filling the mould cavity.

Analysis of outlay

This analysis includes investment costs and production costs directly and indirectly linked to the introduction of moulds with HR or HR and CR. The following costs must be accounted for:

- Purchasing moulds with HR;
- Control equipment - temperature regulators;
- Upgrading of the machinery stock, which most frequently means purchase of injection moulding machines;
- Equipment to automate work or raise the efficiency of automatic operations, for example, robots for rapid removal and management of travel of falling mouldings, to apply labels and so on;
- Equipment to monitor the ejection of mouldings;
- Process equipment underpinning the operation of the HR system; circulation thermostats and magnetic grids (see Section 3.4), special nozzles;
- Manufacture;
- Maintenance of operations (replacement of damaged heaters, seals, and so forth);
- Staff training.

The outlay expended should, however, be related to the production volume (see Section 2.2) and the results of market research.

Market research

Professional market research, even in cases where orders are already in place, will allow rapid adaptation to current prices, the implementation of a flexible financial policy and a reduction in the degree of risk of undertaking manufacture. Specialists in this area look at the degree of innovation in the manufacture, competitiveness and trends in market development. Work in this field is covered by confidentiality clauses, just as company's achievements in design, processes employed, equipment, and so on, should be.

Production data

The next factors that must be considered in deciding not only whether to use HR, but also in the subsequent choice of the optimum system, are:

- Definition of the detailed range, for example use of thin-walled pots with precise orders of magnitude;
- Production quantity - monthly, annually, overall;
- Type of plastic and introduction of additives to determine its processing conditions;
- Frequency of colour changes in relation to supply batches.

Quality requirements

HR technology enables control of plastic pressures and temperatures to be enhanced, these being parameters that have an impact in shaping the internal and external quality properties (see Section 3.2).

In view of the compulsory need to automate operations, cycle time repetition conditions are created. This leads to a rise in what is known as machine capacity, C_m , and in process capacity, C_p , and this process may be under statistical control [2]. This in turn is one of the conditions of quality production as required by the set of national standards EN ISO 9000-1 [3].

Factory potential

The factory potentials specified in Figure 2.1 may be taken as arguments *for* or *against* the use of HR. Technical development, though, is bringing about a situation where HR

technology is increasingly competitive, particularly for the economics of manufacturing mass-production items, and also as regards the quality of technical products.

Analysis of world trends shows that the most important factor in providing the conditions for use of HR is increasing employee skills.

When decisions are being taken about the use of HR and also subsequently, when the best system is being selected, the experience of HR system manufacturers should be utilised. Considerable assistance may be obtained from them in mould design and simulation of filling.

The initial principles put forward enable the requirements to be made specific, and then the optimum HR system to be selected for the production process in question (see Section 7).

Only now should the procedure of seeking offers and discussions to verify the system be commenced. Final choice of a supplier also depends on some other factors (see **Figure 2.1** - Other factors concerning HR).

2.3 Comparative cost analysis

Cost analysis of the production of HR moulds is just one aspect of determining whether use of HR technology is appropriate.

In the case of products where use of HR is a condition of their manufacture, cost analysis is aimed at establishing whether it would be profitable to take up their production in competition with other manufacturing technologies. In such cases, cost analysis must include all outlay on commencement of manufacture.

In most cases of modernisation of the manufacturing process, the manufacturer is faced with a choice between an HR mould and a conventional CR mould, and this is where a cost analysis will show which of these choices is the more profitable, depending on the production volume envisaged. When the difference in costs is insignificant, the factors listed among the advantages and drawbacks of HR systems may become crucial to the choice. Experience to date has shown that profitability based solely on material savings (complete elimination of cold sprue in multi-cavity moulds) is achieved only where production volumes are relatively large. The reason for this is the expense of HR systems (one moulding point in a multi-cavity mould costs an average of £750-1000). HR technology should therefore be used in the first instance for products where material and time savings may be achieved. There is, for example, a group of products manufactured in multi-cavity moulds which require front gating, for example, preforms, bottle-tops,

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aerosol caps and cups. Because of production volumes, they are nowadays manufactured exclusively by HR systems, which allow a very large number of cavities to be used (up to 96), as well as short cycle times and full automation of operations. It would be quite impossible to manufacture these using CR gating given such numbers. However, for a small-series production of moulded parts requiring this type of gating, CR is still used, with three-plate moulds, despite their undoubted drawbacks.

To compare the costs of moulds with different types of gating, a simplified analysis based on the following data may be made:

- A - price of raw material, £/kg
- B - annual production volume, pieces/year
- C - mould depreciation period, i.e., manufacturing period, year
- D - weight of moulded part, kg
- E - number of cavities
- F - machine cost, £/h (includes depreciation over approximately 10 years and running costs - energy, water)
- G - personnel cost, £/h (includes wages, national insurance, social costs)
- H - price of mould, £
- I - cycle time, s
- J - weight of sprue, kg
- K - value of secondary raw material (cost of recycling waste approximately 30% of raw material price), £/kg
- L - cost of mould maintenance (generally 5% of mould price), %/year
- M - interest on mould price (currently approximately 20%), %/year

Three basic cost components need to be calculated for the mould types considered:

1. *Cost of plastic* in the case of

no sprue recycling:

$$K_m = A \cdot D \cdot 1000 + \frac{(A - K) \cdot J}{E} \cdot 1000, \text{ £/1000 pieces} \quad (2.1)$$

sprue recycling:

$$K_m = A \cdot D \cdot 1000 + \frac{K \cdot J}{E} \cdot 1000, \text{ £/1000 pieces} \quad (2.1a)$$

The cost of waste recycling K is lowest if the waste is recycled directly at the injection machine, i.e., through a mill (slow-speed granulator) and returned to the charging hopper. In addition, the quantity of original raw material consumed is essentially reduced. With this waste recycling system, raw material savings from use of an HR system are small. Quality requirements may, however, limit or preclude waste recycling to certain products, e.g., food or pharmaceutical packaging, and products for medical use, for example, syringes, dialysers and so on.

2. Cost of manufacture

$$K_w = \frac{(F + G) \cdot I \cdot 1000}{3600 \cdot E}, \text{ £/1000 pieces} \quad (2.2)$$

3. Cost of mould

$$K_f = \frac{H}{B} \cdot \left(\frac{1}{C} + \frac{L + M}{100} \right) \cdot 1000, \text{ £/1000 pieces} \quad (2.3)$$

from which the production cost is:

$$K_p = K_m + K_w + K_f, \text{ £/1000 pieces} \quad (2.4)$$

Example. Cost comparisons are made for an eight-cavity mould for boxes and lids (**Figure 1.5**) in four gating options:

- with CR
- with HR nozzle and CR in parting line
- with two nozzles and manifold as HR and short CR
- with full HR system (manifold and eight nozzles).

These products may be moulded either from the front or from the side.

Three possible planned production volumes are considered: 1,500,000, 3,000,000 or 6,000,000 pieces over a 3-year period.

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Table 2.1 Cost Comparisons of Using Different Moulds							
				type (a) mould	type (b) mould	type (c) mould	type (d) mould
A	Raw material price	£/kg		0.50			
B	Production volume	pieces/y	option 1	500,000			
			option 2	1,000,000			
			option 3	2,000,000			
C	Mould depreciation period	years		3			
D	Weight of moulded part	kg		0.005			
E	No. of cavities			8			
F	Machine cost	£/h		1.66			
G	Personnel cost	£/h		0.83	0.75	0.66	0.33
H	Mould price	£		3,279	3,607	4,667	6,833
I	Cycle time	s		20	18	17	16
J	Sprue/shot weight	kg		0.009	0.0075	0.002	0
K	Secondary raw material value	£/kg		0.16			
L	Mould maintenance cost	%/y		5			
M	Mould price interest	%/y		20			
K _m	Material cost	£/1000		2.83	2.77	2.55	2.46
K _w	Manufacturing cost	£/1000		1.71	1.49	1.36	1.10
K _f	Mould cost	£/1000	option 1	3.83	4.22	5.36	7.85
			option 2	1.92	2.11	2.68	3.93
			option 3	0.95	1.05	1.34	1.96
K _p	Production cost	£/piece	option 1	8.37	8.47	9.27	11.41
			option 2	6.46	6.36	6.58	7.49
			option 3	5.50	5.31	5.24	5.52
	Cost reduction	%	option 1		-	-	-
			option 2		1.5	-	-
			option 3		3.4	4.7	-

The following assumptions are made for the calculation:

- the personnel costs with HR mould production are lower, since their automation is easier
- HR control equipment depreciation is incorporated into the machine cost
- waste recycling is not applicable to this production.

The costs are shown in **Table 2.1**.

Discussion of costs:

- Option 1 (total production volume 1,500,000 pieces) no justification for use of HR;
- Option 2 (production volume 3,000,000 pieces) use of type (b) mould will provide a 1.5% cost reduction (in comparison with the cost of type (a) mould);
- Option 3 at a production volume of 6,000,000 the following cost reductions would be achieved: 3.4% for a type (b) mould, 4.7% for a type (c) mould, while with a type (d) mould, because of the high cost of a full HR system there will be a 0.4% rise in cost. An assessment should however be made of whether technical, organisational or quality advantages might justify use of a type (d) mould.

Production costs are shown graphically in **Figure 2.3**.

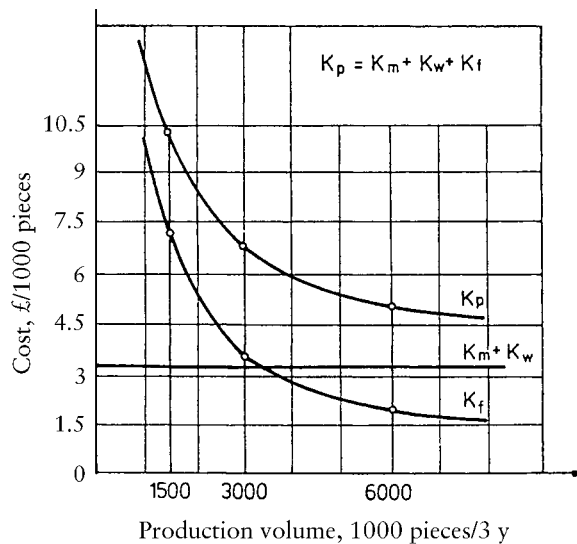


Figure 2.3 Production cost K_p using injection moulding method and its components in relation to production volume - for a type (d) mould from the calculation example

Hot Runners in Injection Moulds

The materials cost and the manufacturing cost per 1000 pieces are independent of the production volume, but the mould cost is dependent on it. The sum of these costs makes up the production cost in the form of curve K_p which is asymptotic to the straight line of fixed costs $K_m + K_w$. It is typical of a cost curve that to begin with the production cost falls very rapidly (at low production volume), while in the final phase, with high production volume, this fall becomes only gradual.

For a rough assessment a simplified calculation of the threshold number of cycles, designated as glc , i.e., production volume/number of cavities, above which it pays to invest in a mould with an HR system is used. The formula does not include the reduction in personnel (cost G) or the rise in mould cost (maintenance cost L and interest M), and the result is approximate.

The threshold number of cycles is:

$$glc = \frac{\Delta H}{\Delta J \cdot (A - K) + \Delta I \cdot (F + G) / 3600} \quad (2.5)$$

where (see also **Table 2.1**):

ΔH - difference in mould cost

ΔJ - savings in material, kg

ΔI - savings in cycle time, s

This dependence is presented in **Figure 2.4**.

For a type (b) mould from the example:

$$\Delta H = £328, \Delta J = (0.009 - 0.0075) \cdot (0.49 - 0.16) = £0.0005/\text{cycle}$$

$$\Delta I = (20 - 18) \cdot 15/3600 = 0.0014 \text{ £/cycle, so the total saving} = 0.0018 \text{ £/cycle}$$

$$glc = 2000/0.113 = 177,000 \text{ cycles, which corresponds to } 1,400,000 \text{ pieces,} \\ \text{or to } 885 \text{ h of operation.}$$

Figure 2.5 shows examples of conventional mould designs which have been converted using more up-to-date HR systems.

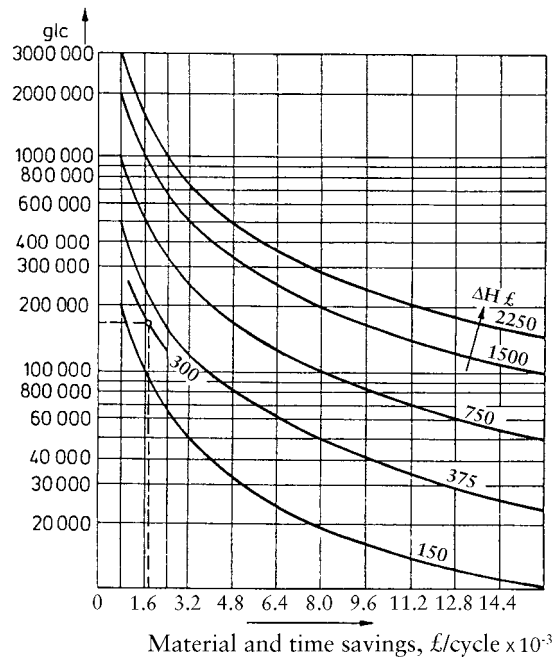


Figure 2.4 The threshold number of cycles (adapted from a graph by Günther) for the use of an HR system depends on the savings on materials and labour and on the difference in the mould cost ΔH (glc : threshold number of cycles)

A type (a) mould of three-plate design with heated sprue bushing is converted using an HR manifold and nozzles with side gating. The cycle time has been reduced by 35%, and the production cost has fallen by 43%.

A type (b) mould has been converted by replacing the cold sprue bushing with an HR shut-off nozzle. The cycle time has been reduced by 8%, and the production cost has fallen by 18%.

Cost analysis, regardless of which calculation method is used, is usually the last and decisive part of a feasibility study.

Also subject to economic decisions, however, are cases where the costs of substituting one technology for another are being compared, for example, manufacture of vehicle mudguards from sheet metal or from plastic, or use of separate glued-on internal liners in the boot or in-mould laminated parts. One component of the analysis may therefore be a reduction in installation or even operating costs, as well as non-measurable benefits arising from a reduction in vehicle weight or an increase in product attractiveness.

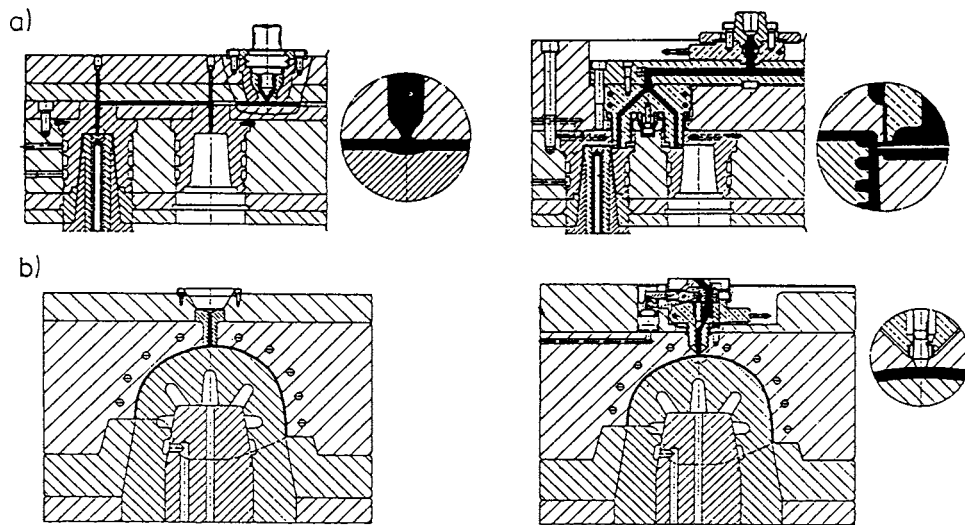


Figure 2.5 Examples of mould designs and the savings which can be achieved through the use of HR system

a - 35% time reduction, 43% lower costs; b - 8% and 18%, respectively

(Reproduced with permission from Mold-Masters, 1977.)

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3 Links with Technology

Many problems of a process nature are linked to use of an HR system, such as the influence of the properties of a plastic on the design of the HR, the influence of the system on the quality features of the product and the demands made of the mould and injection moulding machine.

The HR system determines the design of the mould, and has a further impact on the selection of machine and process equipment. In modern technology, the establishment of a FWC starts with the mould design. If the fundamental process conditions are not taken into account, there can be no question either of correct selection of an HR system or of its proper utilisation.

3.1 Impact of properties of plastics on HR system design

3.1.1 General impact of composition and structure of plastics

When plastics are in a state that indicates they are ready for processing, they are a mixture of a number of constituents:

- *a polymer*, which may be an ordinary polymer, e.g., PS, polycarbonate (PC), polymethyl methacrylate (PMMA), a copolymer, e.g., styrene-acrylonitrile copolymer (SAN), ethylene-vinyl acetate copolymer (EVA), a polymer blend, e.g., styrene-butadiene copolymer (SB), acrylonitrile-butadiene-styrene (ABS), a graft polymer, e.g., methyl methacrylate-butadiene-styrene (MBS) or an alloy, e.g., PC/ABS, ABS/polyamide (PA), polybutylene terephthalate/polycarbonate (PBT)/PC).
- *additives* to alter the processing or end use properties, such as thermal stabilisers, antioxidants, lubricants, UV stabilisers, foaming agents, flame retardants, plasticisers and so on.
- *fillers*, such as chalk, talc, long and short glass fibres, mineral and carbon fibres, glass beads and so on.
- *dyes and pigments*.

The thermal and rheological properties of plastics have the greatest impact on HR system design, and quite often they actually govern the potential for its use. The thermal and rheological characteristics of polymers control their processability, which is in turn dependent

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on the chemical structure, the molecular mass, the shape and elasticity of the molecules and the structural make-up. Even within a single family of thermoplastics, considerable differences may be seen between the processing properties, despite a similar structure.

High density polyethylene (HDPE) plastics, for example, feature a high level of crystallinity (70-90%), whereas the crystallinity of low density polyethylene (LDPE) lies between 20 and 60%. PE of a normal molecular mass (50,000-300,000) has a low level of viscosity, whereas PE with a very large molecular mass (5,000,000, Hostalen GUR) usually has such a high level of viscosity that it may only be processed using a pressing method.

In the case of alloys, their processability depends on the percentages of each of the polymers. The additives mentioned also alter the characteristics of the polymer, and often constrict or shift the range of processing temperatures, which may require a modification of the HR system; they may additionally have a mechanical or chemical action on individual components of the system.

For this reason the correct selection of an HR system frequently demands an expanded plastic specification, particularly as each manufacturer employs his own compositions and types of additives, has his own designations and places greater emphasis on the advantages during application than on the difficulties and restrictions encountered during processing.

Molecular structure

Polymers are composed of long chains of molecules, known as macromolecules (also called 'large-molecule plastic', a term which is still used sometimes). In thermoplastics, these chains may have a linear or branched structure. The measurement used for the length of the chain of polymer molecules is the average molecular mass $\bar{M}$. The greater the value of $\bar{M}$, the greater the mechanical strength of the polymer, but also the higher its viscosity. The breakdown of polymer chains with multiple recycling of waste causes a wide scatter of $\bar{M}$, and thus also differences in the use and processing properties.

Plastics with different viscosity ranges are allocated to specific processing processes. A single plastic may be offered by manufacturers in numerous varieties with differing viscosity values depending on the intended use and processing process (see **Figure 3.1**). Within injection technology it may, for example, be necessary to select one of a dozen or so varieties of the same type of plastic (with differing viscosity), then model the flow or make calculations for the manifold solely on the basis of data supplied by the manufacturer for the given version of the material.

Structure of thermoplastics

In their liquid state, plastics always have an amorphous, i.e., formless structure, with liquid crystal polymer (LCP) as an exception. During cooling (depending on the plastic) the structure becomes established, or a crystalline structure is created (see **Figure 3.2**).

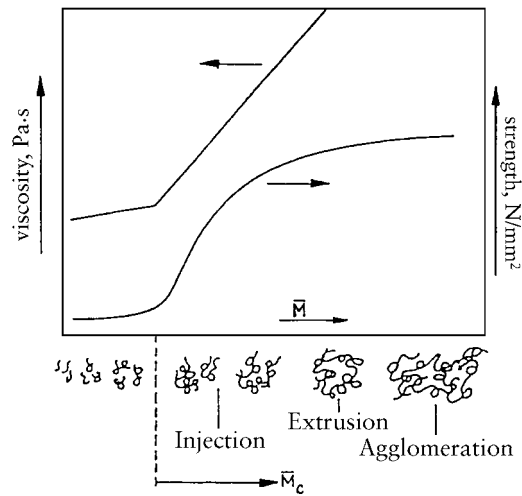


Figure 3.1 Graph of viscosity and strength of plastic against average molecular weight [1]
 $\bar{M}_c$ - value governing processing

(Reproduced with permission from G. Erhard, *Konstruieren mit Kunststoffen*, Carl Hanser Verlag, Munich, 1993. © 1993, Carl Hanser Verlag.)

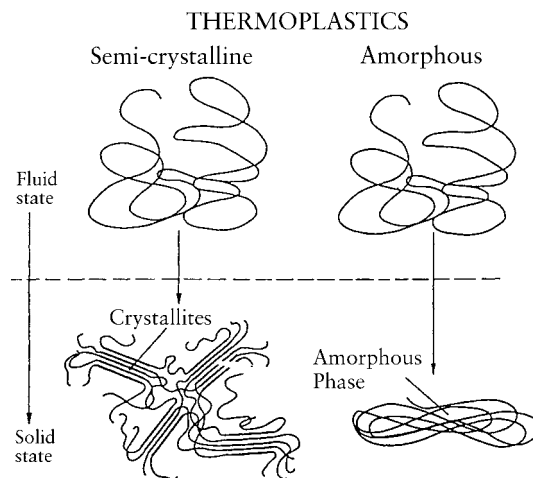


Figure 3.2 Shaping of the structure of thermoplastics

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Thermoplastics are divided into two main groups:

- *plastics with amorphous structure*, where the macromolecules have retained their tumbled, 'felt-like' form - this group of plastics includes, for example, PS and its derivatives, PMMA, cellulose acetate (CA), polyphenylene oxide (PPO), PVC, PC, aromatic PA (APA), sulphone plastics (polysulphone (PSU), polyether sulphone (PES)) and fluoroplastics;
- *plastics with a semi-crystalline structure*, where molecular chain fragments lying alongside one another have created crystallites surrounded by an amorphous structure. In this group of plastics, low-crystalline plastics like LDPE, PA or EVA, are differentiated from high-crystalline plastics like HDPE, polyoxymethylene acetal copolymer (POM), PPS, PET and PBT.

The optimum degree of crystallinity that is characteristic of a particular plastic (defined in percentage terms) may only be attained through slow cooling of the moulded part in the mould cavity. This means that heated and thermostatically-controlled moulds have to be used. Although this lengthens the cycle time, it is a basic pre-condition for the manufacture of quality products with stabilised dimensions and good mechanical and use properties.

In the extreme case of very rapid cooling, it may even be that a crystalline structure is not allowed to form in certain plastics. This fact is utilised in injection moulding of PET bottle preforms to make the material, which is essentially a crystalline plastic, translucent.

Two factors that are governed by the structure type of the plastic are the temperature window and the mould temperature, especially in the vicinity of the gate, and this means that the structure has a fundamental impact on the HR system design and selection, and particularly on the nozzle design and the heating method. It also has such a far-reaching impact on the mould temperature regulation system, i.e., the number and method of linking of heating/cooling medium circulation zones, that moulds for amorphous plastics are of an essentially different design to moulds intended for injection of semi-crystalline plastics.

A general comparison of some of the processing properties of amorphous and semi-crystalline plastics is given in **Table 3.1**.

Table 3.1 Comparison of processing properties of amorphous and semi-crystalline plastics	
Amorphous plastics	Semi-crystalline plastics
Broad range of processing temperatures	Strictly defined temperature window
Gradual variations in viscosity during heating and cooling	Sudden transition to liquid state and back, rapid setting when crystallisation temperature is passed
Lower enthalpy (required amount of heat removal during cooling)	High enthalpy
Lower moulded part removal temperatures required to prevent deformation	High moulding removal temperatures possible
Possible use of low mould temperatures for economic reasons	High mould temperatures to achieve proper crystallisation
Raised mould temperatures reduce internal stresses - thermostatic control recommended for technical products	Thermostatic control of moulds essential in quality product manufacture
Small shrinkage in volume during setting, enabling holding time and pressure to be reduced	Large shrinkage in volume during crystallisation and setting requires consistent high holding pressure and long gate open time
Small primary and secondary shrinkage of set moulding	Large primary and secondary shrinkage of mouldings
Durability of moulded parts depends on frozen internal stresses	Moulded part properties depend on degree of crystallisation

3.1.2 Temperature window

Thermoplastics (with the exception of elastomers) are utilised in a vitreous state in the range between the brittle point and the glass transition temperature (T_g) sometimes referred to as the softening point. The way this happens and the associated viscosity change are explained in **Figure 3.3**.

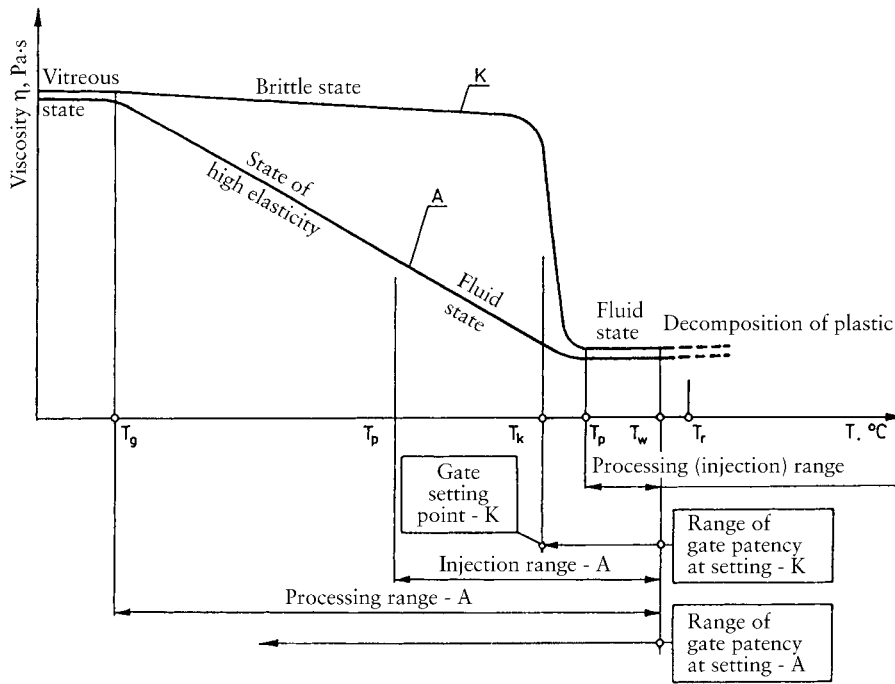


Figure 3.3 Change in state of plastic depending on temperature and characteristic temperature ranges

A - amorphous plastic; K - semi-crystalline plastic; T_g - glass transition temperature;
 T_k - crystallisation temperature during cooling; T_w - injection temperature;
 T_r - decomposition temperature; T_p - flow temperature
 (melting of crystallites - for a semi-crystalline plastic $T_p \approx T_k$)

An amorphous plastic (curve A) softens at a higher temperature than the T_g , with its viscosity continuously diminishing. The state of the plastic at temperatures above T_g is known as the high elasticity state, and in this state the plastic may be bent or vacuum-formed. When the not precisely defined flow temperature, T_p , is reached, the plastic may be extruded or injected (injection temperature, T_w). Further heating of the plastic causes its thermal destruction (breakdown temperature, T_r). The flow and setting temperature are not strictly defined for amorphous plastics.

For a semi-crystalline plastic (curve K), while the amorphous phase in it will gradually soften at temperatures above the T_g , thus slightly increasing the elasticity of the plastic. It is only when increased energy reaches the molecules and when the temperature, T_k , is

passed that rapid melting of the crystalline phase and a steep fall in viscosity take place. The plastic then becomes liquid, passes the temperature T_p , and at temperature T_w , may be injected. When semi-crystalline plastics are cooled, when the temperature, T_p , is passed rapid crystallisation sets in, with a very steep rise in viscosity, preventing plastic flow.

To make it easier to evaluate the processing properties of plastics, **Table 3.2** shows the average processing and glass transition/melt temperatures and the mould temperatures for certain plastics. The plastics are listed in descending order of the difference ΔT between the processing temperature (by various methods) and the glass transition temperature (for amorphous plastics $\Delta T = T_w - T_g$) or melting temperature (for semi-crystalline plastics $\Delta T = T_w - T_p$).

For amorphous plastics, where this window is very wide and also includes, for example, thermoforming, the sprue in an HR nozzle gate solidifies slowly, and at temperatures lower than T_p , it does not form a plug hard enough to block the gate. The value of ΔT should therefore be taken as no more than an approximate window of openness of an HR gate for amorphous plastics.

In the case of semi-crystalline plastics, the temperature window within which a plastic is liquid is strictly limited by sudden crystallisation and setting of the plastic, and thus the ΔT window more precisely defines the thermal window for HR gate patency (the temperature range at which a melt can flow through a gate) for these plastics - solidification takes place immediately the temperature T_k is exceeded.

Table 3.2 shows that for the majority of amorphous plastics, ΔT is over 100 °C, e.g., for ABS, $\Delta T = 250 - 110 = 140$ °C. A rapid fall in temperature is needed here to stop up the gate, i.e., intensive cooling of the gate zone on the mould side and restriction of the heat flow from the nozzle heating zone side. This enables the cycle time to be shortened. For most semi-crystalline plastics, $\Delta T < 60$ °C, e.g., for PA 66, $\Delta T = 285 - 255 = 30$ °C. If premature solidification is to be avoided, they require a high gate temperature to be maintained.

In the middle of the table is a group of semi-crystalline and amorphous plastics with a temperature window of $\Delta T = 60 - 100$ °C, e.g., for PC $\Delta T = 300 - 220 = 80$ °C, and for PP $\Delta T = 90$ °C. These plastics require a raised gate temperature.

In view of the speed with which the plastic solidifies in the gate, from now on quick-setting crystalline plastics (such as POM or PA 6), will be distinguished from slow-setting plastics (such as PE or PP).

Table 3.2 is an overview; the injection moulding temperature windows recommended in practice are given in **Table 3.3**.

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	Plastic	Temperature, T (°C)			Temperature window, DT (°C)				Characterisation of gate zone	Fluidity of Plastic					
		(of) injection	(of) gas transition	(of) mould	25°	60°	100°	180°		low	medium	high			
AMORPHOUS	PPO	300	120	80					'COLD'						
	PEI	370	215	100											
	PMMA	245	100	70											
	ABS	250	110	75											
	ASA	245	105	75											
	SAN	255	115	80											
	PS	225	100	45											
	SB	225	100	70											
	PES	350	230	150											
	PSU	315	200	150											
	PVC	195	100	35											
	PC	300	220	90											
	CAB	215	140	55											
	TPU	210	150	35											
SEMI-CRYSTALLINE			(of) crystallisation						INCREASED TEMPERATURE						
	PE	250	140	25											
	PP	255	165	35											
	LCP	400	330	175											
	PA 11	230	175	60					'HOT'						
	PA 12	230	175	60											
	FEP	340	290	150											
	PET	285	245	140											
	PBT	265	225	60											
	PPS	330	290	110											
	PEEK	370	334	160											
	PA 610	250	215	90											
	PA 6	250	220	90											
	PA 66	285	255	90											
	POM	200	181	100											

Table 3.3 Temperature windows used in HR technology [2]

(Reproduced with kind permission from Arburg.)

Plastic		Temperature (°C)		
Name	Symbol	Nozzle*	Mould	State change
AMORPHOUS				Solidification
Polystyrene	PS	160-230	20-60	90
High-impact polystyrene	HIPS (SB)	160-250	20-60	85
Styrene/acrylonitrile copolymer	SAN	200-260	40-80	100
Styrene/acrylonitrile/butadiene copolymer	ABS	180-260	40-85	105
Hard polyvinyl chloride	hard PVC	160-180	20-60	80
Soft polyvinyl chloride	soft PVC	150-170	20-40	55...75
Cellulose acetate	CA	185-225	30-60	100
Cellulose acetate butyrate	CAB	160-190	30-60	125
Cellulose propionate	CP	160-190	30-60	125
Polymethyl methacrylate	PMMA	220-250	60-110	105
Polyphenylene ether (Polyphenylene oxide)	PPE (PPO) mod	245-290	70-120	120...130
Polycarbonate	PC	290-320	60-120	150
Polyaromatic	PAR	350-390	120-150	190
Polysulphone	PSU	320-390	100...160	200
Polyether sulphone	PES	340-390	120-200	260
Polyether imide	PEI	340-425	100-175	220...230
Polyamide imide	PAI	340-360	160-210	275
Amorphous polyamide	PA amorph	260-300	70-100	150...160
SEMI-CRYSTALLINE				crystallisation, melting
Low-density polyethylene	LDPE	210-250	20-40	105...115
High-density polyethylene	HDPE	250-300	20-60	125...140
Polypropylene	PP	220-290	20-60	158...168
Polyamide 4.6	PA 4.6	210-330	60-150	295
Polyamide 6	PA 6	230-260	40-100	215...225
Polyamide 6.6	PA 6.6	270-295	50-120	250...265
Polyamide 6.10	PA 6.10	220-260	40-100	210...225
Polyamide 11	PA 11	200-250	40-100	180...190
Polyamide 12	PA 12	200-250	40-100	175...185

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Table 3.3 Temperature windows used in HR technology [2] <i>Continued</i> (Reproduced with kind permission from Arburg.)				
Plastic		Temperature (°C)		
Name	Symbol	Nozzle*	Mould	State change
SEMI-CRYSTALLINE <i>Continued</i>				crystallisation, melting
Polyoxymethylene acetal copolymer	POM	185-215	80-120	165...175
Polyethylene terephthalate	PET	260-280	50-140	255...258
Polybutylene terephthalate	PBT	230-270	40-80	220...225
Polyphenylene sulphide	PPS	300-360	20-200	280...288
Perfluoroalkylvinylether copolymer	PFA	350-420		300...310
Fluorinated ethylene propylene	FEP	340-370	150-200	285...295
Ethylene/tetrafluoro/ethylene copolymer	ETFE	315-365	80-120	270
Polyvinylidene fluoride	PVDF	220-300	70-90	171
Polyether ketone	PEK	400-430	150-180	365
Liquid crystal polymers	LCP	280-450	30-160	270...380
THERMOPLASTIC RUBBERS				
Polyamide thermoplastic elastomer	TPE-A	200-260	20-50	
Ester thermoplastic elastomer	TPE-E	200-250	20-50	
Styrenic thermoplastic elastomer	TPE-S	180-240	20-50	
Urethane thermoplastic elastomers	TPE-U	190-240	20-40	
Olefinic thermoplastic elastomers	TPE-O	110-180	15-40	
*Injection machine nozzle temperature = HR nozzle temp.				

The characterisation of plastics given in Table 3.3 provides the following recommendations for HR technology:

- for amorphous plastics
 - gate solidification requires use of low gate zone temperature; this is achieved by using a nozzle with the gate made in the mould material, and by additional intensive cooling of the gate zone; the nozzle tip has a larger contact area with the mould and does not require special insulation.
 - use of a nozzle with a gate introduced into the mould cavity may cause deformation of the surface of the setting part, if it touches a nozzle face that is too hot.

- greater temperature fluctuations are permissible throughout the HR system (except when using PVC and CA).
- for semi-crystalline plastics
 - to keep the gate free during the holding phase and to prevent rapid solidification in the gate, a high gate zone temperature is required; this is achieved by using a nozzle with in-body gate, i.e., a nozzle introduced into the mould cavity, and an additional nozzle tip insulation zone.
 - keeping the temperature window narrow (POM, PA) requires use of HR nozzles that conduct heat well, with a specially-designed heating system, plus a multi-zone precision manifold temperature control system.
 - it must be remembered that in some gates a cold plug occurs, which might be injected into the cavity together with the plastic.

As may be seen, the two groups of plastics require different HR system selection criteria to be applied, particularly where nozzles and heating systems are concerned.

Thermoplastic elastomers, with their specific mechanical properties, constitute a special group of plastics processed by an injection method. The application temperature lies above the glass transition temperature, and solidification of the plastic takes place gradually. This causes problems with the sprue breaking off and the creation of a plug in the gate. The low level of hardness and the ultimate high elongation require the use of a different gate geometry. The following general recommendations are for thermoplastic elastomers:

- use of gates of very small diameter with a sharp edge (without a cylindrical section) to enable the sprue to be broken away;
- use of shut-off nozzles to prevent the appearance of a 'crater' at the point where the sprue is broken off;
- use of side gates causing shearing rather than fracture.

3.1.3 Properties of plastics in a liquid state

In both the solid and the liquid (molten) state, plastics have properties that differ from those of other materials. The way in which these differences are addressed when designing moulds, and also HR systems, and subsequently when running the process, is what governs product quality. The following material properties must therefore be appreciated:

- in a liquid state, plastics are compressible;

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- the viscosity of plastics depends not only on the processing temperature, but also on the shear stresses, which in turn depend on the flow velocity gradient;
- during flow, the phenomenon of tension and orientation of the molecules occurs;
- molten plastics have a very limited thermal resistance time (just a few minutes, in some cases), and their molecules are easily destroyed through mechanical action (shear) or chemically (oxidation);
- in both the solid and liquid states, plastics are poor heat conductors;
- during high-velocity flow, sedimentation (separation of components) may occur, and even coagulation (formation of filler or pigment pellets).

Compressibility of plastics in the liquid state

The action of pressure on a plastic produces compression of it, and thus a diminution in specific volume through packing of the molecules. This means that, in contrast to typical fluids, plastics are compressible.

This phenomenon is illustrated by the PVT (pressure - specific volume - temperature) curves plotted for individual plastics (see **Figure 3.4**). The PVT graphs for an amorphous plastic (PS) and a semi-crystalline plastic (HDPE) show the ideal setting process for a plastic in a mould after filling at 80 MPa pressure.

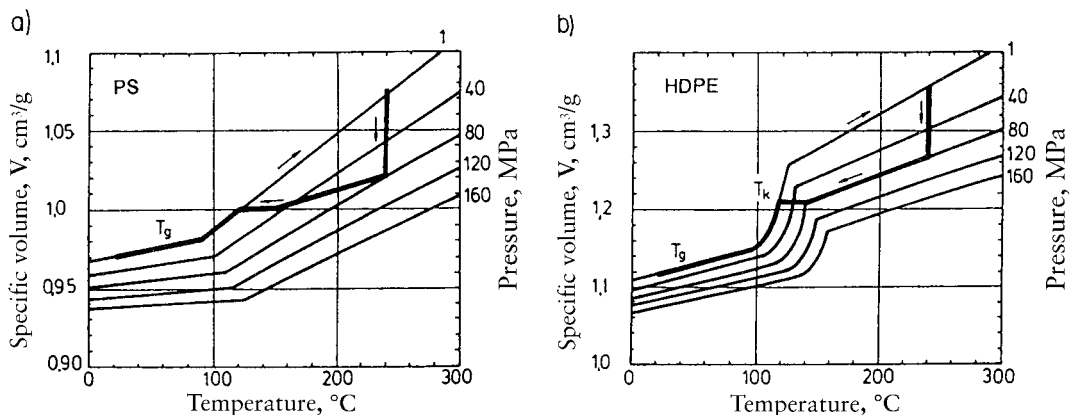


Figure 3.4 Sample PVT (pressure - specific volume - temperature) diagrams

a - for amorphous plastic; b - for semi-crystalline plastic; T_k - temperature of crystallisation of plastic in mould; T_g - glass transition temperature

Following injection of the plastic into the cavity (at a constant temperature, T_w) its specific volume has diminished, and the compressed plastic is subject to further isobaric cooling at the holding pressure. The measure of compression of the plastic is the increase in its density.

One adverse effect of the compression that occurs in the plastic in the manifold channels and HR nozzles is the potential for drooling through the sprue bushing and gate aperture following retraction of the injection machine nozzle. In both cases this may interfere with the processing process, cause damage to the mould (gate stringing) and affect product quality.

Variations in volume shrinkage in the liquid state

Shrinkage is caused by contraction of plastic. When the plastic cools, there is a diminution in the mobility of the molecules, and thermal contraction is associated with a diminution in the distance between molecules.

For plastics with a subsequent semi-crystalline structure, e.g., HDPE in **Figure 3.4b**, the plastic should set under constant pressure (isobaric procedure) down to the crystallisation temperature T_k . Release of the heat of crystallisation causes a retardation of the temperature drop, while at the same time there is a rapid fall in specific volume. There is a partial arrangement of molecules into ordered structures called crystallites.

Volume shrinkage of a plastic in the mould cavity is 5-7% for amorphous plastics, but can reach 25% for semi-crystalline plastics.

Volume losses are compensated as cooling proceeds by plastic flowing into the cavity under the holding pressure, until the gate is closed or becomes solidified. When the flow of plastic ceases, shrinkage losses are compensated for by expansion of the plastic (compressed by the holding pressure). The need to make up for such large losses, sometimes amounting to a quarter of the shot volume, means that greater gate diameters are used for HR nozzles for semi-crystalline plastics, as compared to amorphous plastics.

If the gate is closed too soon, volume losses cannot be compensated for, particularly at the end of the flow path; the end result being voids and sinks. A similar effect results from too short a holding time or a low holding pressure. Too late a closure (solidification) of the gate enables the holding pressure to act for too long, giving excessive compression of the melt, especially in the gating area. The risk of cavity overloading only arises with amorphous plastics. This may cause the moulded item to crack, in the gate vicinity in the first instance, and spontaneously during use. With semi-crystalline plastics this risk does not occur because of the considerable volume shrinkage.

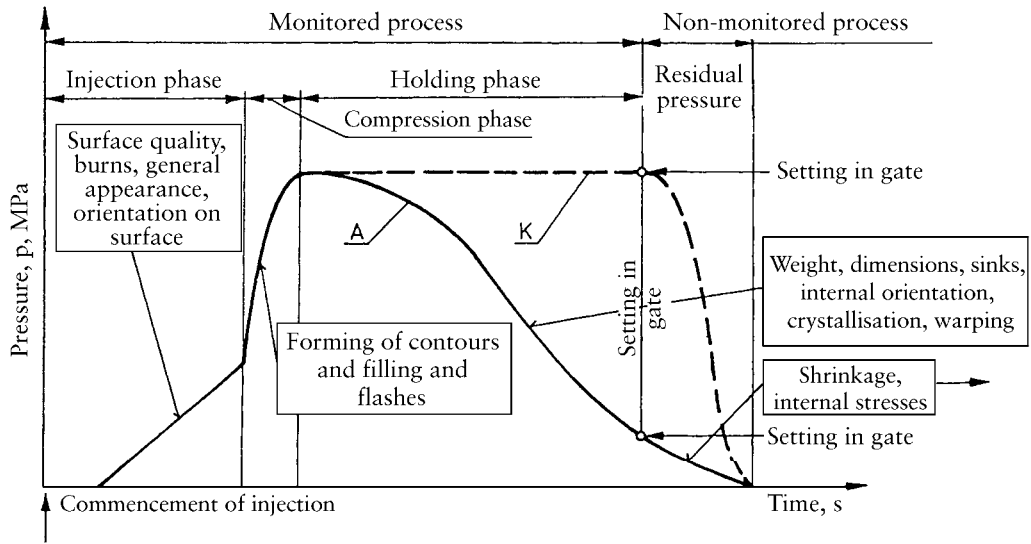


Figure 3.5 Curve of changes in pressure in mould cavity and shaping of quality features

A - curve for amorphous plastics; K - curve for semi-crystalline plastics

Thus differences arise from the shrinkage compensation process and the degree of compression in setting the holding pressure curve, for injection of these two types of plastic.

For example, for PS it is recommended that the plastic sets in the mould cavity at a diminishing holding pressure in a controlled (programmed) way (see **Figure 3.5**). In this case the gate gradually loses patency in relation to the fall in pressure as well as temperature.

Fluidity of plastic

The fluidity of a plastic is defined as the viscosity value during the flow.

Between the layers of a melt (see **Figure 3.6**) flowing at differing velocities, shear stresses, τ , occur.

$$\tau = \eta \frac{dv}{dy}, \text{ Pa} \quad (3.1)$$

where η is the 'apparent' viscosity of the plastic, Pa.s

$dv/dy = \dot{\gamma}$ is the flow velocity gradient in the melt, known as the shear rate, s^{-1} .

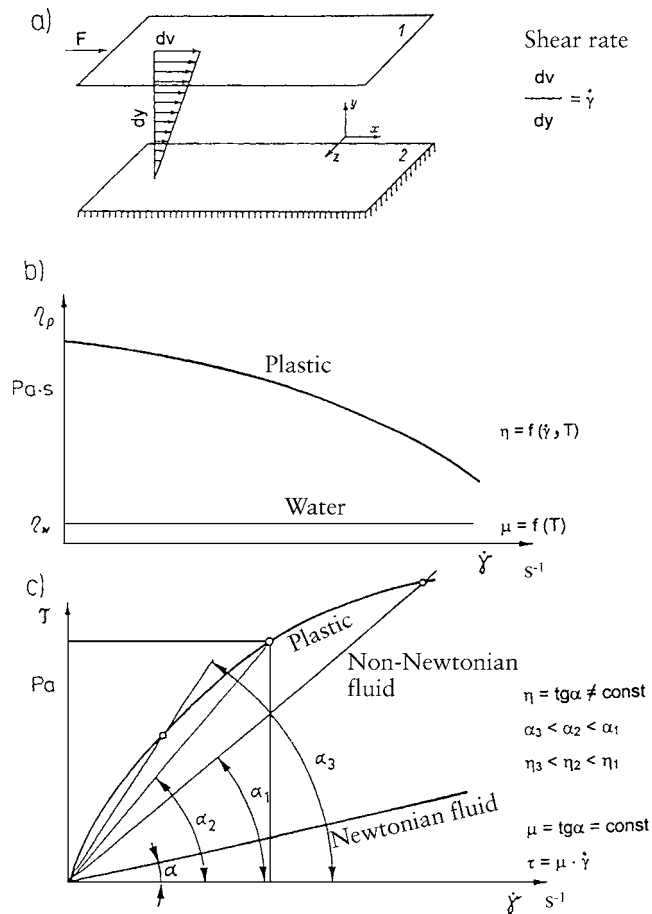


Figure 3.6 Rheological properties of plastics

a - viscosity dependences between layers of flowing melt
1 - layer of melt; 2 - layer of melt or runner wall;

b - comparison of curve of changes in viscosity of plastic, η , and viscosity of Newtonian fluid, μ , as a function of shear rate (double logarithmic scale)
(f = shear force);

c - shear stress, τ , as a function of shear rate

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Transformation of Equation (3.1) gives us

$$\eta = \tau / \dot{\gamma} = \tan \alpha$$

This dependence is illustrated in **Figure 3.6c**.

The viscosity of so-called Newtonian fluids, (water, oil, etc.), depends solely on temperature. From **Figure 3.6c** it can be seen that for such fluids, $\tan \alpha = \text{constant}$ and the viscosity is determined in this case as $\mu = f(T)$ (see **Figure 3.6b**).

The dissimilarity between the behaviour of different plastics in flow means that they belong to the group of pseudoplastic non-Newtonian fluids and their viscosity depends not only on temperature, but also on the shear velocity, thus $\eta = f(T, \dot{\gamma})$.

As can be seen from **Figure 3.6b**, the viscosity of plastics, i.e., $\tan \alpha$, diminishes as the shear velocity, $\dot{\gamma}$, rises. In practice this means that the greater the flow velocity of the plastic in the mould (this is governed by the injection velocity and pressure), the more fluid the plastic.

Graphs of the viscosity variations in plastics obtained in a laboratory using a capillary rheometer (see **Figure 3.7**) serve as a basis for calculation of pressure losses and for computer programmes modelling the flow of the plastic in question in the mould. Analysis of these flow curves shows that with the injection of, for example, ABS, the viscosity may vary by more than ten times, depending on the injection velocity used, whereas the viscosity of PC and PA 6 varies only slightly within a certain range of values of $\dot{\gamma}$.

In the literature an index of plastic viscosity called melt flow index (MFI) is used; this is measured for a single, very low shear rate (comparable with the rate during the extrusion process), and additionally at various measurement pressures. Thus MFI values are only of use to make a provisional decision on whether a plastic is suitable for a given conversion process when the plastic is being purchased, and cannot be used in calculations.

The viscosity variation curves for plastics shown in **Figure 3.7** have been plotted for several temperatures. The actual impact of temperature on viscosity variations is better illustrated by the graphs in **Figure 3.8**.

One heat source is the heating of the injection cylinder and HR system and internal friction caused by shear stresses during softening of the plastic and during flow through the distributor channels of the mould.

For purposes of comparison, the diagram shown in **Figure 3.9** may be used for HR system selection; however, it only covers standard versions of the given plastic.

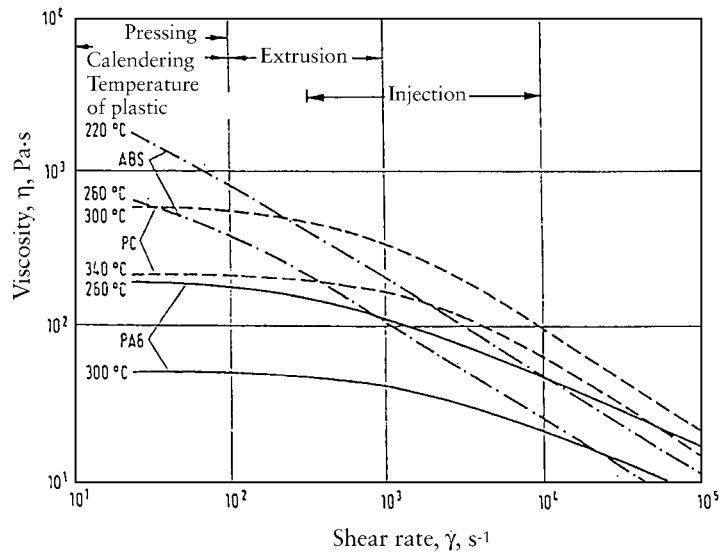


Figure 3.7 Graph of viscosity of plastics as a function of shear rate for different injection temperatures [3]

(Reproduced with permission from H. Saechtling, *Kunststoffe Tascherbuch*, 26th Ausgabe, 1995, p.78. © 1995, Carl Hanser Verlag.)

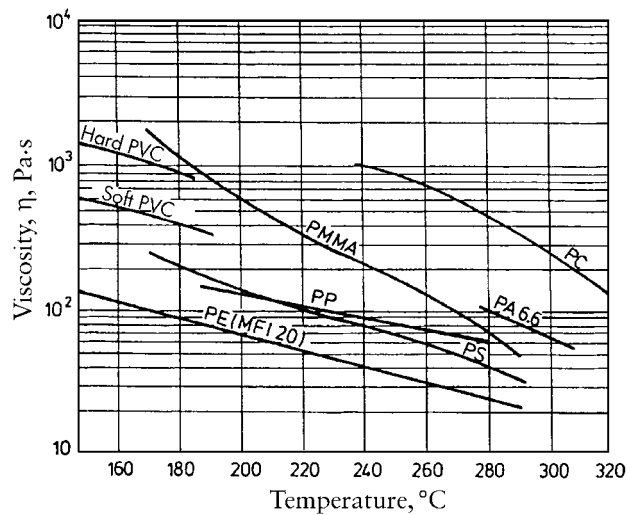


Figure 3.8 Curves of viscosity variations as a function of plastic temperature at a constant shear rate of 1000 s⁻¹

(Reproduced with permission from ICI.)

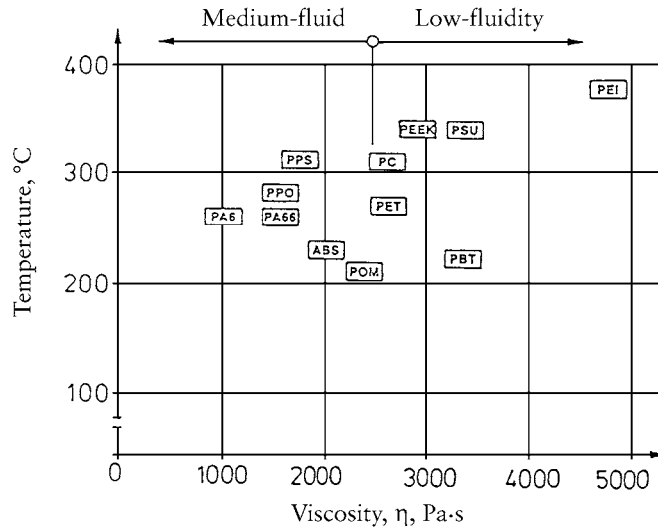


Figure 3.9 Comparison of viscosity of certain engineering plastics at shear rate of 1000 s^{-1}

(Reproduced with permission from D-M-E Europa. © D-M-E. Europa)

A flow of plastic under high pressure has a different flow velocity distribution to that of a flow of Newtonian fluids (see **Figure 3.10**). The greatest rise in velocity occurs at the runner wall, while the flow velocity in the centre of the channel is more or less stable. The greatest shear stresses in the plastic thus occur at the runner wall, while in the centre of the runner the shear and friction effect is negligible. Consequently in the cross-section of the distributor channel there is an uneven plastic temperature distribution, and it is only in the centre of the stream that it possesses the desired injection temperature, T_w (**Figure 3.10**).

It should also be remembered that close to the runner wall there may be slippage in the plastic layer at a velocity of v_p [4]. This depends on the type of plastic, the addition of lubricants, the flow velocity, the smoothness and the runner wall temperature. With HR, this is a theoretically desirable phenomenon, as it prevents overheating of the plastic layer next to the wall. It has not, however, been fully studied, and there is no certainty that it occurs in all instances.

The plastic temperature rise resulting from internal friction in the distributor channels and nozzle does not normally exceed 5°C for LDPE, HDPE, PP, PS or polyurethane (PU), but it can easily exceed 15°C for PVC, PMMA or POM of high viscosity, which is enough to trigger degradation of the plastic.

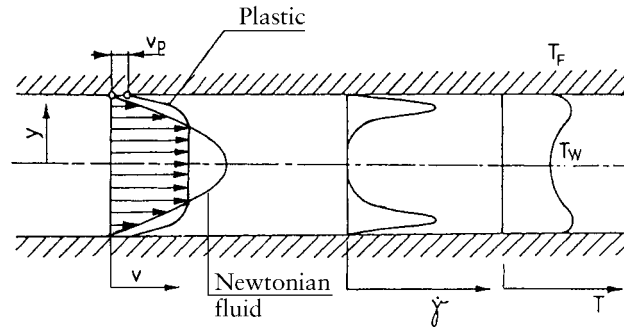


Figure 3.10 Distribution of velocity, shear rate and melt temperature T in channel cross-section or mould cavity

v_p - velocity of plastic slippage; v - velocity; y - radius

The creation of additional heat friction also depends on the runner geometry and on variations in their direction and diameter.

With a plastic flow through a gate while the cavity is being filled, however, there is such a steep increase in flow velocity and shear stresses that a short-term temperature jump occurs, with a sudden increase in the fluidity of the plastic just as it flows into the cavity.

[Research by PSG Plastic Service has shown that because of friction of the plastic, the temperature of the material of the gate itself may, in extreme cases, reach as much as 600 °C.] By utilising this phenomenon one can, as with a CR system (and with a well-chosen gate diameter) reduce the adjustable plastic injection temperature to a minimum, while a rise in temperature may be confined to the gate by increasing the injection velocity.

Like the runner dimensions, the viscosity of the plastic influences the magnitude of pressure losses in an HR system, and thus has a bearing on the permissible runner length. When HR nozzles are being selected a permissible pressure loss of up to 25 MPa or thereabouts is often adopted. The total pressure loss in an HR system, meanwhile, should not exceed 60 MPa (see Section 7.2).

It should also be borne in mind that a fall in pressure, Dp , during flow through a runner while injection is occurring is accompanied by a rise in plastic temperature in line with the general equation [5]:

$$\Delta T_w = \frac{\Delta p}{c_p \cdot \rho}$$

where c_p is the specific heat, kJ/kg °C; ρ is the density, g/cm³.

For PS injection, for example, it is 5 °C/10 MPa (**Figure 3.11**).

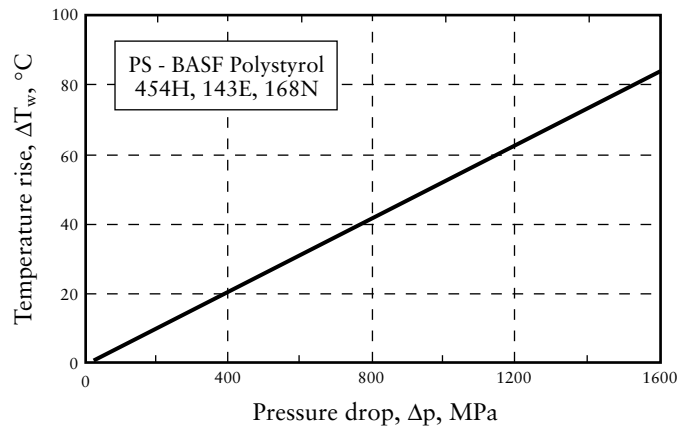


Figure 3.11 Rise in temperature of plastic (polystyrene) in runner as a result of drop in pressure Δp [6]

The potential for mould cavity filling by various plastics is shown in **Table 3.4**. The flow paths in the table were calculated for a pressure drop of 75 MPa, which is often taken as a limit.

Table 3.4 Flow paths depending on moulded part wall thickness with mean pressure drop in cavity of $\Delta p = 75$ MPa (from STRACK Normalien)					
Plastic			Flow path (mm) for moulded part wall thickness		
Symbol	Type	Manufacturer	1 mm	2 mm	3 mm
PP	Hostalen PP 1080F	Elenac SA	170	550	1100
PP+GF 40	Hostalen PPN7190TV40	Elenac SA	120	370	700
CAB	Cellidor S200-22	Bayer	80	250	475
TPU	Desmopan 460	Bayer	35*	100*	200*
PA 6	Ultramid B3S	BASF AG	84	325	720
PA 6 + GF 30	Ultramid B3WG6	BASF AG	85	300	570
PA 6.6	Ultramid A3K	BASF AG	86	340	790
PA 6.6 + GF 30	Ultramid A3WG6	BASF AG	71	280	620
PA 6.12 + GF	Zytel 77G-43L	DuPont Engineering Polymers, Europe	84	290	590

Table 3.4 Continued					
Plastic			Flow path (mm) for moulded part wall thickness		
Symbol	Type	Manufacturer	1 mm	2 mm	3 mm
PET + GF	Rynite FR 530	DuPont Engineering Polymers, Europe	60	200	400
LDPE	Lupolen 1800S	Elenac SA	230	760	1530
HDPE	Hostalen GC 7260	Elenac SA	115	370	800
SB	Polystyrol 475K	BASF AG	140	420	800
PS	Polystyrol 143E	BASF AG	165	520	990
ABS	Novodur PL-AT	Bayer	85	270	510
ABS + GF	Novodur PHGV17	Bayer	52	162	310
PC/ABS	Bayblend T65MN	Bayer	51	180	370
SAN	Luran 358N	BASF AG	105	330	630
PBT	Pocan B1505	Bayer	22**	80**	200**
PBT + GF 35	Pocan B3235	Bayer	35	140	285
PC	Makrolon 2405	Bayer	62	222	475
PC + GF 30	Makrolon 8030	Bayer	38	140	290
PPO	Noryl SE1	General Electric Plastics	60	190	365
PPO + GF	Noryl GFN3 SE1	General Electric Plastics	45	140	260
POM	Delrin 500	DuPont Engineering Polymers, Europe	85	280	560
POM	Delrin 100	DuPont Engineering Polymers, Europe	36	122	240
PPS + GF	Ryton R4	Phillips Petroleum	87	310	620
PSU	Polysulfon P1700	Union Carbide Chemical Company	42	145	280
PEI	Ultem 1000	General Electric Plastics	34	120	245
* Δp 34-36 MPa; ** Δp 57-63.5 MPa.					

Shear resistance

Every plastic manifests a limited shear resistance, determined as the permissible shear rate; exceeding this value causes mechanical destruction and tearing of molecules of the plastic as a result of excessive internal friction, which has a bearing on the mechanical, electrical or thermal properties of the moulded part. The plastics with the greatest shear resistance are those of low viscosity, e.g., readily fluid versions of PP and PE, PA, etc. Low shear resistance is a feature of plastics like PP (of a high viscosity), PC, PSU and PPS. PVC, CA, CAB, EVA, POM and fluoroplastics have a particularly low shear resistance.

Meanwhile a long runner or gate with too small a diameter may cause the permissible shear rate to be exceeded and the structure of the polymer or additives to be damaged; it may also cause breakdown of the alloys or local separation of mineral fillers or pigments. The permissible shear velocity for a given plastic therefore governs not only the minimum gate diameter required to fill the mould during the injection phase (see **Figure 7.4**), but also selection of the nozzle itself.

Data provided by Mold Flow show that the following values of shear rate, $\dot{\gamma}$ occur in individual sections of the flow path:

in the cavity	$\dot{\gamma} = 100\text{-}5,000 \text{ s}^{-1}$
in the runners	$\dot{\gamma} = 1,000\text{-}20,000 \text{ s}^{-1}$
in the gate	$\dot{\gamma} = 10,000\text{-}100,000 \text{ s}^{-1}$

Example. A calculation of shear velocities occurring in gates with a circular and annular cross-section [7] for a moulded part 100 x 100 x 2 mm in size with an injection time of 1 s, was made:

a) **Point gate** (circular cross-section):

flow rate, Q , (cm^3/s)	20	20	20	20	20
gate aperture radius, r , (mm)	4	3	2	1	0.5
shear rate, $\dot{\gamma}$, (s^{-1})	398	443	3,183	25,465	203,718

b) **Annular gate:**

flow rate, Q , (cm^3/s)	20	20	20	20	20
external radius, r_a , (mm)	4	4	2	2	2
internal radius, r_i , (mm)	2	1	1	0.50	0.25
shear rate, $\dot{\gamma}$, (s^{-1})	1,061	566	8,488	4,527	3,696

As may be seen, even minor changes in dimensions with small point gates cause a massive rise in shear rate. True, it is short-lived, and has been mentioned, it has a positive effect in instantly reducing the viscosity of the plastic immediately before the filling of the cavity, but at the same time the temperature rises and there is a risk that the material will suffer major degradation. In addition, if the fluidity is increased too much, an uncontrolled turbulent flow may occur. This phenomenon comes about especially in narrow gates, and leaves its mark on the moulded part in the shape of serious surface defects in the gating area, flaking, etc.

More detailed information concerning permissible instantaneous and long-term shear rate values may be requested from the manufacturer of the plastic in question, together with a graph of viscosity $\eta = f(\dot{\gamma}, T)$.

Orientation of molecules and fillers in a fluid plastic

While a plastic is flowing, the shear stresses that occur in it cause tension in the polymer molecules which arranges them in the direction of flow. This is one of the characteristic properties of plastics in a fluid state.

At the point when the plastic solidifies, the orientation is fixed permanently (becomes frozen) - see Section 3.2.1. Because of the structure of the molecules, PS, SB, SAN, ABS, PA, POM, HDPE and PP undergo particularly strong orientation, while that found in PMMA, CA, PC, PVC, PC and LDPE is much weaker.

While flow is taking place, the fibre fillers in the plastic also undergo orientation. Orientation causes anisotropy in almost all properties of a plastic in a moulded part, and of shrinkage too (see Section 3.2.2). The effect of it may be compared to growth rings in wood or directionally-laid reinforcement in concrete structures.

Thermal resistance of plastics in fluid state

In processing practice, the resistance of the plastic to the action of heat governs the admissible time for which the plastic may remain in the injection machine cylinder and the HR of the mould.

Heat-sensitive plastics include PVC, POM, PBT, PET, CA, CAB, CP, polyfluoroolefins, PPA, polyether ether ketone (PEEK) (at processing temperature) and all plastics with flame retardants; while thermally stable plastics include PE, PP, PMMA, PC, PS and others.

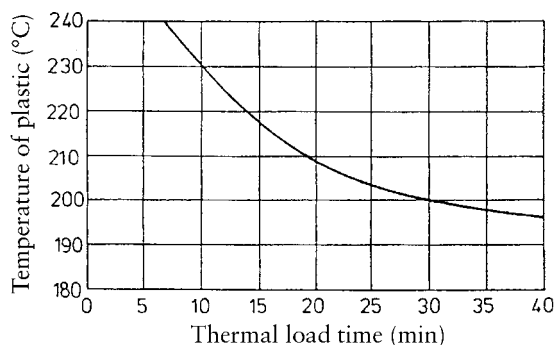


Figure 3.12 Admissible residence time for POM (Hostaform) in injection moulding machine cylinder

(Reproduced with permission from Hoechst AG. © Hoechst AG.)

The time spent by heat-sensitive plastics in the cylinder and HR is 5-10 minutes, but may be as much as 30-60 minutes for thermally stable plastics. The graph shown in **Figure 3.12** shows that this time depends to a large extent on the temperature.

When the temperature is dropped to 160 °C, PC may spend as long as 24 hours in the cylinder. Degradation of solid PVC or POM takes place while the cylinder is still cooling after the injection machine has been turned off, and consequently it is recommended that these plastics be pushed through by another plastic, ideally LDPE. This is also true of PC and some plastics of the high temperature group, though for different reasons (adhesion to metal). The narrow temperature window of PA 66, PA 4.6, PPA, PBT and PET is restricted still more by the addition of fibres or glass beads because their thermal conductivity is substantially higher than that of the main material [8].

Multiple re-use of recycled granules makes for a continuous presence of an increasing amount of degraded molecules, and means that visible defects may occur much earlier in moulded parts, e.g., brittleness or emission of gases during processing.

Besides thermal degradation of molecules, there is also degradation resulting from oxidation arising through contact between molten plastic and oxygen in the air. PA plastics are particularly sensitive to this. An air bubble may get into the HR following removal of the injection nozzle, or into the injection cylinder as a result of decompression.

Foaming agents essentially break down at set temperatures while still in the injection cylinder, which requires the use of special design principles for the HR system and the way the hot runners operate within the machine.

Additives put into plastics to reduce their flammability have a very limited thermal resistance threshold. The same is also true of many dyes and pigments of organic origin.

Processing of thermally sensitive plastics thus places additional requirements on a HR system:

- restriction of the ratio of HR volume to shot volume to shorten the time spent by the plastic in the runners. This may be done in cases where the total volume of the cavities is less than the capacity of the distributor channels;
- division of the system into a greater number of temperature regulation zones to reduce the difference in temperatures in the system, and use of heaters with a temperature variation characteristic that is as close to a straight line as possible;
- avoidance of systems with plastic deposition, i.e., distributors with internal heating, torpedoes and nozzles with a large insulating chamber;
- maintenance of leakproof in the sprue bushing/injector nozzle system.

3.1.4 Interaction between plastics in fluid state and HR components

- ***Chemical interaction.*** Decomposition products of molten plastics may have a corrosive effect on the mould, and particularly on HR components. PVC has a strong corrosive action at the processing temperature because of the release of hydrogen chloride and the formation of hydrochloric acid. Overheating of POM and PET releases formaldehyde and acetic aldehyde, respectively. Fluid plastics of the fluorine group, like PFA, FEP, polyvinylidene fluoride (PVDF) or ethylene-tetrafluoroethylene copolymer (ETFE) are highly corrosive, as in these conditions fluorine readily enters into a chemical bond with iron. Too high a temperature may be the cause of decomposition of flame retardants (antipyrenes) and of halogen release, as compounds of bromine, fluorine, etc. Stainless steels or protective coatings then need to be used. Copper alloys are especially vulnerable to corrosion.

The reverse action also occurs, e.g., entry of PP into a chemical reaction with copper alloys, and hence with copper/beryllium. This reaction may cause the surface of a copper/beryllium component to become corroded [9], with the moulded parts being contaminated by alloy molecules. At the same time macromolecules of plastic are damaged through the catalytic action of copper on molten PP. Copper/beryllium nozzles for injection of PP should have a nickel or silicon carbide coating.

- **Mechanical interaction.** Glass fibre (GF), mineral fillers for plastics and some inorganic pigments like titanium dioxide (TiO_2 ; titanium white) and chromium oxide (Cr_2O_3 ; chrome green) cause abrasive damage to all injection machine components coming into contact with the plastic, especially the screw and its non-return valve, and also to the HR, chiefly the ends of the nozzle tips, the gates, the valve pins and so on. A particularly strong abrasive effect is brought about with PA 66 and GF. Research has shown that it is 7 times greater than that found with PES and GF. With these plastics, special abrasion-resistant nozzle types and replaceable inserts, tips and gate apertures, should be used.

3.2 Impact of HR on product quality

An HR system is on the one hand an extension of the injection machine nozzle, while on the other it is a mould runner system. Compared to CR systems (see Section 2.1) it substantially enlarges the scope of process interaction, especially by reducing pressure losses and by enabling gate closure to be thermally or mechanically controlled. Depending on the heating method, however, this is achieved at the cost of introducing an extra heat source into the mould, which may give rise to local structural flaws.

3.2.1 Shaping of internal features of product in mould

From commencement of injection through to removal of the product from the mould, changes are taking place continuously in the plastic as the process parameters impact upon it.

The laminar nature of the flow and the cooling procedure, in which different layers of the plastic cool at differing rates, giving varying properties, make it difficult to analyse these phenomena. In the mould, the supermolecular structure is shaped. This comprises the frozen state of orientation and the fixed amorphous structure or created crystalline structure. They alter the given (nominal) properties of the plastic and cause the occurrence of various viscoelastic strains, which are made manifest in the moulded part as changes to the shape and internal stress state.

The involvement of an HR system may assist, but may also locally hinder, the process of formation of these internal features.

Laminar structure of moulded part

One particular feature of injection-moulded parts is the laminar nature of their structure (from the aspect of their properties), which arises both out of the flow method and the way they are cooled.

When the plastic is flowing into the mould, the so-called fountain effect makes the plastic at the leading edge of the stream turn outwards and create a rapidly-setting surface layer. This layer has a double role: it is both a slip layer and an insulation layer, protecting the increasingly slow-moving core from premature solidification.

Product property optimisation depends on achieving the maximum possible homogenisation of the properties of the surface layer and the core layer, which always sets more slowly. This means that one condition for the manufacture of quality products is use of higher-temperature moulds, because this slows down the cooling of the surface layer and reduces its thickness.

The insulation effect of the surface layer is utilised in HR distributors with internal heating (see Section 4.2.2).

State of orientation of molecules in a moulded part

Each injection-moulded part has its own characteristic state of orientation.

The strongest orientation occurs in the rapidly solidifying surface layer of a part. In the fluid core, however, this orientation is small because of the low shear stresses. This is why thin-walled products are the most highly oriented. Anisotropy of properties is so great in this case that, for example, disposable beakers made of PS crack lengthwise under very small pressures. Thick-walled parts feature small anisotropy and more even shrinkage.

Shape changes that are a result of orientation are permanent in nature. They will only disappear if the part is heated to the softening temperature.

A plastic becomes oriented while it is still flowing through the distributor channels and nozzles. No information is available concerning the transfer of this state to the mould cavity. With frontal entry of the plastic via the HR nozzle there is a radial arrangement of molecules, and the directional shrinkage that occurs after setting is typical: it is less across the flow than along it. One consequence of this is a surplus of material at the periphery and a tendency for folding and warping to occur. When fibre fillers are used, the opposite effect, central swelling, may occur.

The place where the molecules begin to be distributed radially (the point sprue) is the weakest place in the part, and this is the place where stress fractures are most likely to appear.

Orientation is most commonly, though not always, an adverse phenomenon. It cannot be prevented, but its homogeneity may be influenced by so programming the injection velocity that the leading edge of the stream of plastic flows at the same velocity regardless

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of the cavity cross-section. To avoid major viscosity variations, use of larger gate cross-sections is preferable, and ideally nozzles closed with a valve pin.

As with CR, the orientation direction in the part may be influenced by selecting the injection point location. This is why one of the criteria for selection of the HR nozzle location, and thus also the distributor geometry, in moulds for large products of complex configuration is (apart from rheological conditions) the condition of minimisation of shrinkage deformation. This clearly requires computer modelling with a warpage analysis programme to be used.

Shaping the structure of a moulded part

While a plastic is solidifying, structural changes occur that have an influence on the subsequent use properties and shrinkage of the product [10]. These changes do not occur immediately, but over a shorter or longer period, which may continue after removal from the mould. This period depends on the rate of cooling, and thus on the mould cavity wall temperature and the wall thickness of the moulded part.

- Before attaining a vitreous state, amorphous plastics pass through a state of high elasticity. Slowing down the cooling of the surface layer helps the molecules to get closer together.
- Slowing down the cooling of a semi-crystalline plastic enables optimum crystallisation to be more rapidly achieved in the surface layer of the product.

The higher the cavity wall temperature, the closer the properties and the volume shrinkage of the surface layer come to those which occur with the naturally slower cooling of the core layer, and thus the less difference there is between them.

The presence of HR in a mould hinders the equal heat removal from the two sides of the part. With external heating of the distributor there is always a need to create an effective thermal barrier and to increase the intensity of the process of heat removal from the cavity on the gating side. A poorly-designed mould, no thermostatic control and badly-connected or contaminated coolant circulation channels cause an unwanted heat flow from distributor to cavity, an increase in shrinkage of the layers on the warmer side of the cavity and warping of the part. Here too the critical location is the gating zone, if the front of the nozzle is a part of the cavity. Besides such typical surface flaws as partial local melting, an excessive increase in crystallites may also occur there, causing a reduction in part strength. It is therefore sometimes a good idea to remove the nozzle from the part by introducing a short cold runner.

Internal stresses

Thermal contraction of a plastic and the changes in supermolecular structure described result in viscoelastic deformation in the molecules. While the moulded part is still in the mould, contraction may only take place freely in the wall thickness direction, which results in its surface coming away from one of the walls of the impression (usually the cavity). So while the part is in the mould, full reverse deformation is not possible, and a non-equilibrium state of internal stresses arises in the part.

Instantaneous elastic strain and delayed viscous strain arise in the part only when it is released from the mould; there is a change in the shape of the product, with equilibrium and relaxation of internal stresses.

Because there is a considerable difference in the degree of shrinkage, especially in the moulded part cross-section, and its configuration, e.g., ribbing - may hinder full deformation and attainment of an equilibrium state through change in shape (warping), a certain state of tensile and compressive stress will always occur in a part. This consequently depends on the shape of the product and on the material properties influencing the rigidity of the product.

Slow structural changes are still occurring when the product begins to be used: there is re-crystallisation and a moving together of the molecules until the state of equilibrium characteristic of the given material is attained. Post-moulding shrinkage levels out at this stage and there is relaxation of the stresses associated with these changes.

The state of stress and shape changes resulting from orientation remain unaltered.

3.2.2 Shrinkage of moulded parts

Total shrinkage of a moulded part comprises the following phenomena, which occur simultaneously:

- *linear shrinkage* which is unvarying over time, and is a consequence of orientation. It causes differences in dimensions depending on the direction of flow and the degree of orientation.
- *volume shrinkage*, caused by contraction of the plastic during cooling and by the structural changes during this period that have been described. This causes differences in dimensions depending on the cooling time and the pressure in the cavity.

Only volume shrinkage undergoes changes in time. From the use aspect, shrinkage of a part relates to linear dimensions and is given as a percentage.

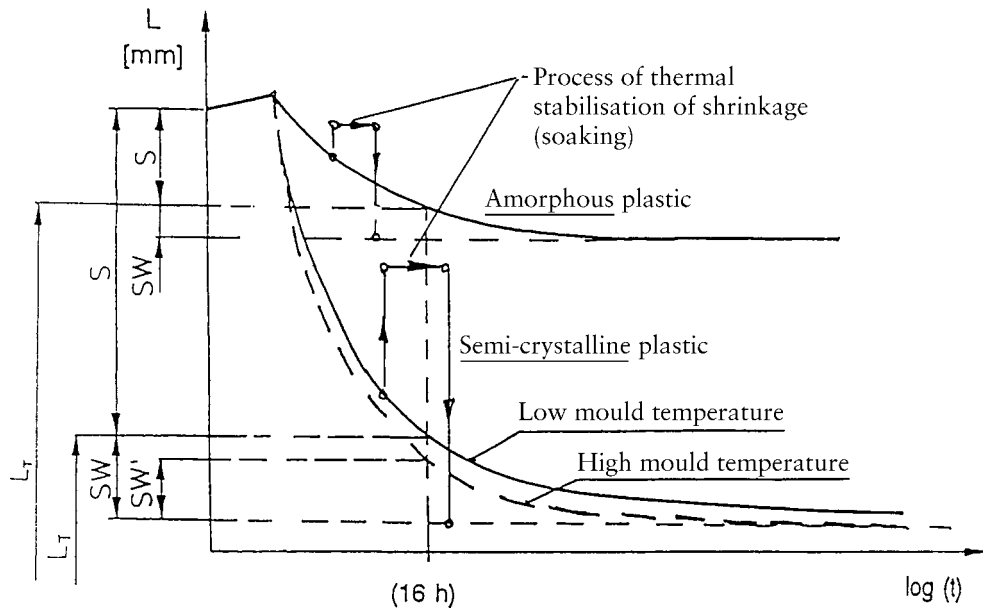


Figure 3.13 Curve of variation in moulded part dimensions as a result of shrinkage S - mould shrinkage (16 h); SW - post-mould shrinkage (up to 500 h); L_T - technical size

As the main strain in a moulded part arises during the first 16 hours, it is taken that *shrinkage*, as it is known in the literature and in standards (another name for it is mould shrinkage), governs the changes in dimensions which take place during this period. What follows is a process known as *post-moulding shrinkage*, which is not monitored (see **Figure 3.13**).

Assuming, as an approximation, that the sum of mould and post-mould shrinkage is a constant, we should always strive towards mould (controlled) shrinkage forming the greatest possible part of the sum.

In multi-cavity moulds, attainment of the same and reproducible shrinkage in all moulded parts is only possible with parameters for cavity filling, gate setting and plastic cooling that are identical for all the cavities. Preconditions for this are balancing of the flow in the HR distributor channels, maintenance of tight dimensional tolerances and gate geometry, and use of accurate heat regulation.

Table 3.5 shows the impact of various factors on the magnitude of shrinkage. It is easy to ascertain which of them depend generally on the mould design and gating system, and which may be influenced by utilisation of an HR system.

Table 3.5 Controlling shrinkage in injection-moulded products	
Increasing:	
Plastic temperature Removal temperature High mould temperature Injection time* Distance from gate	Shrinkage rises
Holding pressure* Holding time* Cycle time Injection pressure Plasticising pressure* Injection velocity	Shrinkage falls
* also increasing susceptibility to stress fracturing	

3.3 Mould requirements when an HR system is used

Use of HR systems is most commonly linked to long-series production. Modern moulds for such production feature:

- use of verified designs (which companies are unwilling to disclose);
- a design which makes use of standard components, ready-made drive mechanisms, mould bases, and particularly HR systems - this influences the quality of mould manufacture and substantially shortens mould manufacturing time;
- use of attested steels adapted to machining and process requirements;
- mould design taking into account the thermal conductivity of mould materials - this especially concerns the mould cores;
- use of modern heat treatment processes and protective coatings;
- mould design using CAD systems. The shapes of contemporary products increasingly require modelling in CAD-3D for the manufacture of electrodes or direct computer numerical control (CNC) machining of the moulding surfaces. Three-dimensional models are generally essential for computer modelling of flow in a cavity;

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- use of computer simulation to optimise the design of the gating system and cooling, shrinkage, stresses and warpage.

When ordering HR moulds, the toolmaker employed should always be one who has the appropriate equipment and experience for the job, both in providing the HR system specified, and in manufacturing moulds of the given type, e.g., moulds for medical products, packaging, precision parts, optical components, large containers, and so forth. References should always be checked and suitable warranties obtained.

The reliability and durability that are a feature of modern moulds are reflected in their price, which sometimes exceeds the price of the machine. It is already normal to expect moulds for large-scale production to last over 10 million cycles.

Use of an HR system in a mould greatly increases its cost and the operating and servicing requirements. The mould design should envisage that a separate HR thermal system is added to the conventional heat exchange system. Provision should therefore be made for the following:

- obligatory heat insulation of HR from mould cavity and other components of the mould and its surroundings;
- the action of the HR nozzle gating as a heat valve for the plastic flow, with the potential provided for control of patency of the gating using an identified temperature control zone, see **Figure 3.14** - zone II;
- obligatory thorough analysis for HR system selection, especially in relation to the type of plastic - there are no universal solutions here;

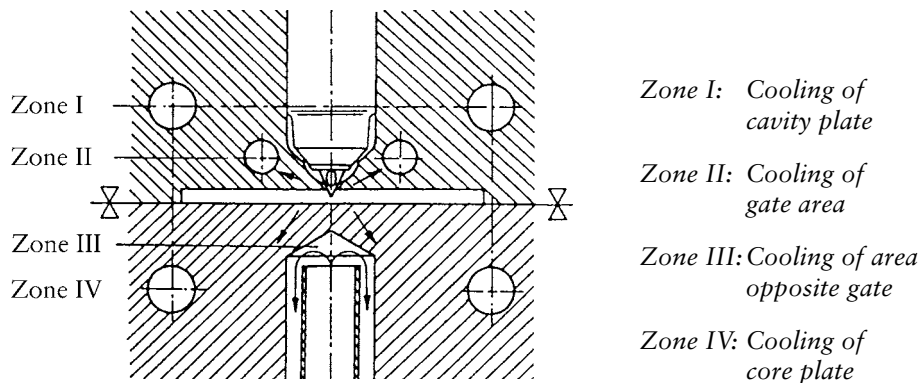


Figure 3.14 Mould temperature regulation in nozzle zone

- training of staff in operating and maintenance of moulds with HR;
- use of joint temperature control circuit connections to prevent wrong connections (connection blocks).

Considerable rigidity is required of the whole item, especially in the HR distributor area, and plates and screws must be used which are capable of withstanding thermal stresses.

3.4 Interaction between HR moulds and injection moulding machine

All injection moulding machines capable of operating in an automatic cycle are suitable for use with an HR system.

The following factors should be borne in mind when choosing an injection moulding machine:

- HR moulds generally require a greater available installation height;
- when establishing the machine shot volume, the compressibility of the plastic should be borne in mind where the channels are of large capacity;
- for depreciation of the HR mould and to reduce disruptions with multiple start-up, continuous operation of the injection moulding machine is recommended.

Modern injection moulding machines with HR moulds provide the potential for:

- including an HR temperature regulation system in the injection machine control system; for example, the nozzle temperature, as one of the injection parameters may, after determination of admissible deviations, be subordinated to Statistical Process Control (SPC) systems;
- use of extended supervision of the filling process: blocking of any of the gates or a heating failure will cause incomplete filling of the cavity. The effect will be a premature rise in injection pressure, a change in the pressure curve profile, disturbances to the hydraulic pressure (holding pressure) switching point or the occurrence of too high a residual cushion before the front of the screw. Each of these parameters may be limited by a tolerance field (**Figure 3.15**), transgressions of which are recorded and cause the machine to shut down.

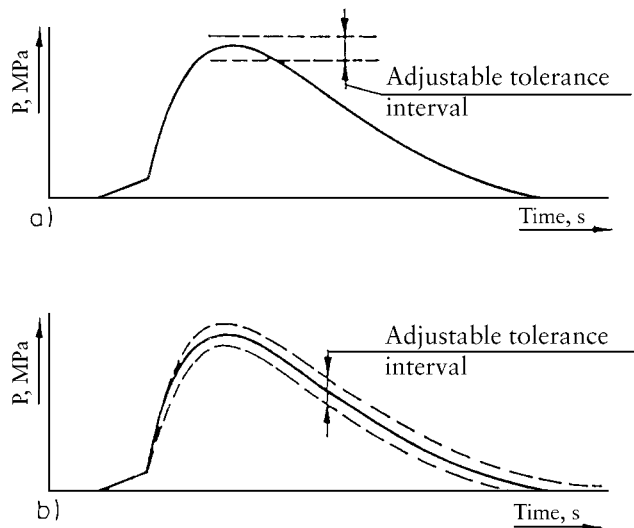


Figure 3.15 Supervision of pressure in mould
a - peak value monitoring; b - pressure variation curve monitoring

When selecting *integral and peripheral* equipment, it is essential to use:

- nozzles for distributor decompression and, depending on the requirement, nozzles with a filter or tip shut-off nozzles;
- a thermostat or water or oil thermostatic control system;
- a magnetic grid in a charging hopper.

The use of all *equipment guaranteeing* automatic mould operation is required, primarily robots, or even simple manipulators:

- putting mould inserts, labels, film, etc., into moulds;
- removing moulded parts or speeding up their removal;
- controlling removal of moulded parts; and equipment to reduce start-up time:
- heating the mould before it is put on the injection machine;
- reducing to a few minutes the time taken to place and fasten the mould and connect up water and air leads and also power connections and HR zone temperature control.

Servicing of the injection moulding machine - HR mould - ancillary equipment complex requires a high level of staff and supervisory skills. Introduction of a system of comparative computer monitoring of specified and actual times in the injection department gives very good results, even with old injection moulding machines. The effect of this is to improve quality and increase output by as much as 30% (Zelmer Poland). Simultaneous recording of breaks in operation also provides information on the continuity of functioning of the HR.

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4 Structure of a Hot Runner System

A HR system consists of the following functional zones (parts):

- *sprue bushing*, through which the melt is fed from the injection moulding machine cylinder to the distributor channels;
- *distributor*, which distributes the melt flow between the nozzles;
- *nozzle*, through which the melt is fed into the mould cavity or to an auxiliary cold runner;
- *a gate*, which may be a part of the nozzle or the mould.

The uses of the HR functional zones are defined in **Figure 4.1**.

In some applications the manifold may be dispensed with, and the HR system is confined to a single central nozzle.

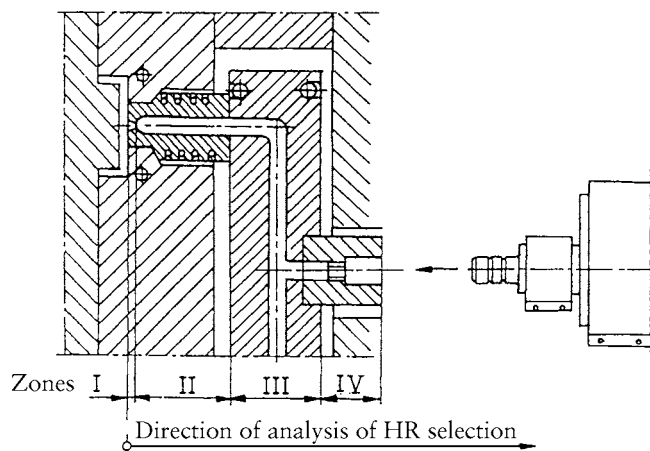


Figure 4.1 Four HR functional zones (see next page for explanation of zones)

Figure 4.1 continued. Four HR functional zones (table accompanying figure)				
Zone	I	II	III	IV
Name	Gate	Nozzle	Manifold	Sprue bushing
Function	- delivering melt to cavity - maintaining open passage while holding pressure is on - closing off flow	- melt supply to gate - maintaining constant temperature	- melt distribution - maintaining constant melt temperature - transferring melt pressure	- connecting to machine nozzle channel - sealing connection with nozzle - decompression if required - melt filtration if required
Parameters				
p	↓	↓	↓	↓
T	↑	constant	constant	constant
v	↑	constant	constant	constant

The task of an HR system is to feed the melt to the mould cavities in the state in which it leaves the injection machine cylinder, although it is not able to adjust the homogeneity of the melt. If an HR system is not correctly designed, selected or built, it may cause disruption to production and flaws in the items moulded.

HR systems have the following requirements:

- uniform temperature distribution on the flow path. This means a heating system that compensates for heat losses, an insulation system and a precision temperature control system able to compensate for thermal inertia in the heating.
- minimum possible falls in pressure and low shear rate, while at the same time keeping the time spent by the melt in the runners short. This requires a careful choice of runners and gates (diameter and length).
- potential to control gate patency as a thermal valve
opening - blowing out melt plug
closure - freezing of melt plug
or mechanical closure linked to control of the injection machine.
- maintaining a flow balance, i.e., ensuring simultaneous filling of all cavities.
- leakproofness of system.
- in some cases, ease of colour change.
- durability, particularly of heaters.

- ease of installation in mould.
- ease of cleaning and replacement of worn components.

Note. Full thermal balance and correct functioning of the HR system may only be achieved through automatic operation of mould and injection moulding machine, thermostatic control of the mould and the use of plastic material with no mechanical impurities.

Recommendations. It should be stressed that the recommendations for, and limitations to the use of HR systems that follow, are for information only. The vast assortment of plastics available on the market with all their different properties and production parameters, coupled with the variety of HR system designs, means that in individual cases HR nozzles and systems which ought not to be recommended in principle have nevertheless been successfully employed. As an example, systems with internal heating have numerous adherents, despite their known limitations in use, and these adherents manage to cope with the problems of changing colour and with injection of melts that are susceptible to thermal degradation. This is greatly facilitated by experience on the part of staff in running the process. Besides this, the assessment of the results may be subjective, if there are no special demands for product quality, or care taken to keep the cycle time short or do away with breaks in production.

4.1 HR nozzles

The HR nozzle is the end of an HR system, and comprises a heated channel, terminating in a gate, which feeds the melt to the mould cavity or to a cold auxiliary channel. An HR nozzle may also be the sole part of an HR system, as a central nozzle. In many applications, and for various reasons, the gate is not a part of the nozzle, and is made in the mould.

A nozzle without a gate has a partial body, and ends in a channel leading to the gate, or ends with a tip introduced into the gate. There is also a simplified version of the body-less nozzle known as a torpedo.

The nozzle is a crucial part of the HR system, and must meet many high requirements. Besides the general requirements made of an HR system, nozzles have to provide the following:

- unvarying melt temperature in the runner to prevent any variation in flow properties of melt: uncontrolled freezing of the melt at the nozzle end (or at both ends of a central nozzle), or overheating in the middle of the nozzle. The temperature characteristic should be close to rectilinear.
- heat insulation between the hot nozzle and the cooler mould, since a raised cavity temperature will cause a longer cooling time or local strain in the moulded item (internal stresses).

Hot Runners in Injection Moulds

- ‘clean’ and reproducible separation of the moulded item from the melt in the gate area. The gate, which may be part of the cavity or the nozzle, is a critical part of an HR system. There should not be any drooling or stringing of the melt at the gate, but at the same time this can be difficult to avoid.
- maintenance of leakproofness between nozzle and manifold, and also leakproofness of the nozzle seating in the mould plate.
- ease of operation: cleaning, dismantling, replacement of damaged components, and so on.
- universality of design, i.e., the potential to adapt the nozzle to the shape of the moulding, the properties of the plastic, the appearance and height of the sprue, etc.

Both these requirements and the various installation possibilities that arise in practice have made for the presence of a wide range of nozzles on the market. A detailed and ordered breakdown of nozzles using various criteria is shown in **Figure 4.2**.

Type of heating. Nozzles have external or internal heating, or both types at once. There are also heat-conducting nozzles. These are short nozzles made of a copper alloy warmed by the heat from the HR manifold.

Some designs are of a mixed type, where the front part of the nozzle is made of a material with a high thermal conductivity (copper/beryllium alloy, sintered molybdenum) and is not heated.

One condition for the functioning of a nozzle is that it be thermally insulated from the mould. The best insulation is provided by an air gap. In nozzles with an in-mould gate, this gap may be filled with melt for design reasons (to prevent contact between the nozzle tip and the mould), and is then known as an *insulation chamber*. Another solution is to seal off and insulate the nozzle tip using a titanium alloy ring of low thermal conductivity. The nozzle flange may be insulated by a ceramic washer, but above all the contact area with the mould is kept to the minimum dictated by strength considerations.

Function. Central nozzles and manifold nozzles differ only in that the former are designed to interact directly with the injection machine nozzle. Both a central and a manifold nozzle may be in the form of a hot sprue bushing leaving a small sprue and intended mainly for gating to a cold runner.

Type of sprue. The basic division of nozzles, by type of sprue, is as follows:

- open nozzles, leaving a short point sprue, and in some applications only a vestige where the sprue breaks off (**Figure 4.3a**). Also in this group are somewhat simpler open nozzles (also known as hot sprue bushings) which leave a short rod sprue (**Figure 4.3b**);
- nozzles with tip, which leave behind a very short annular sprue (**Figures 4.3c and 4.3d**);

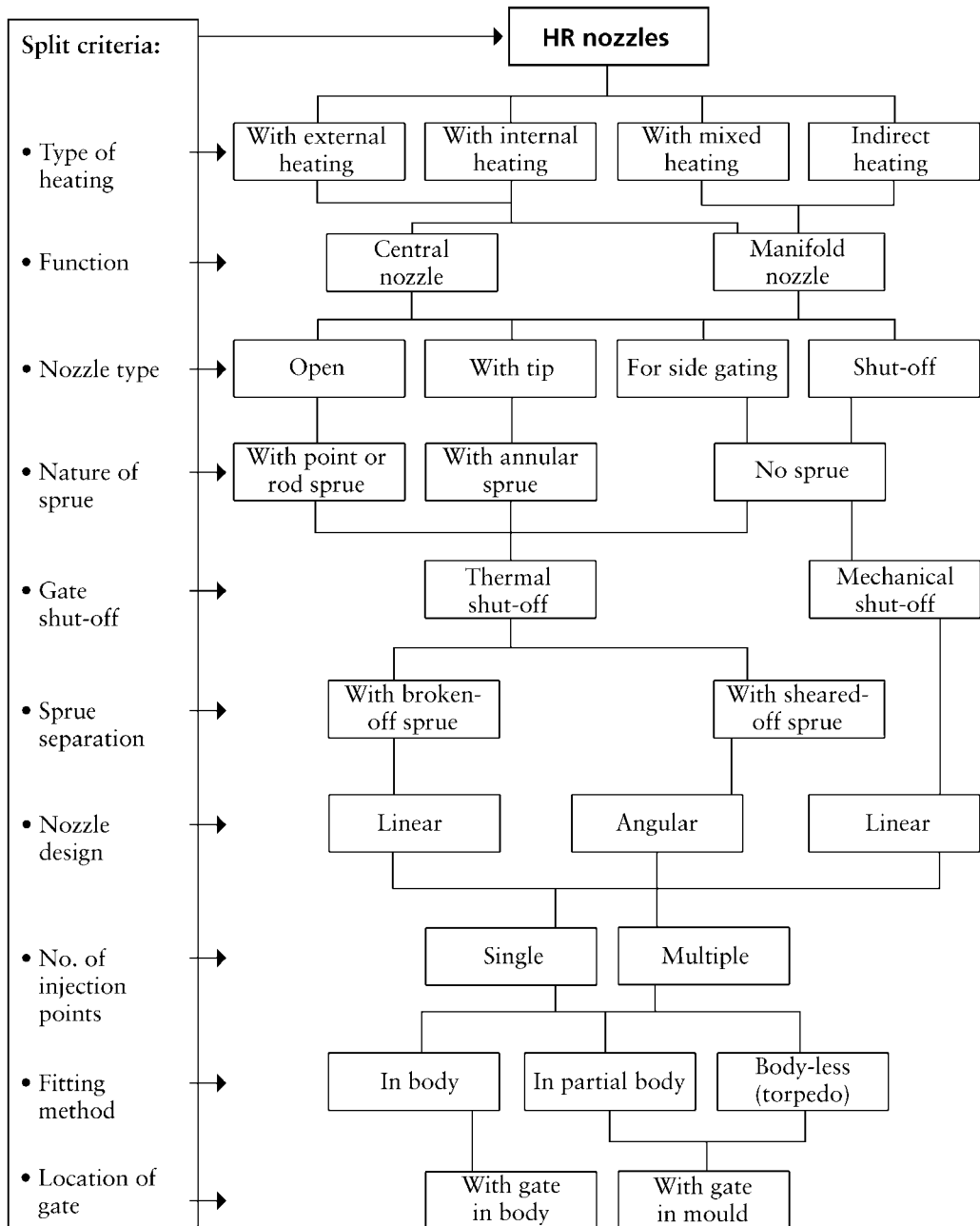


Figure 4.2 Criteria for classification of HR nozzles

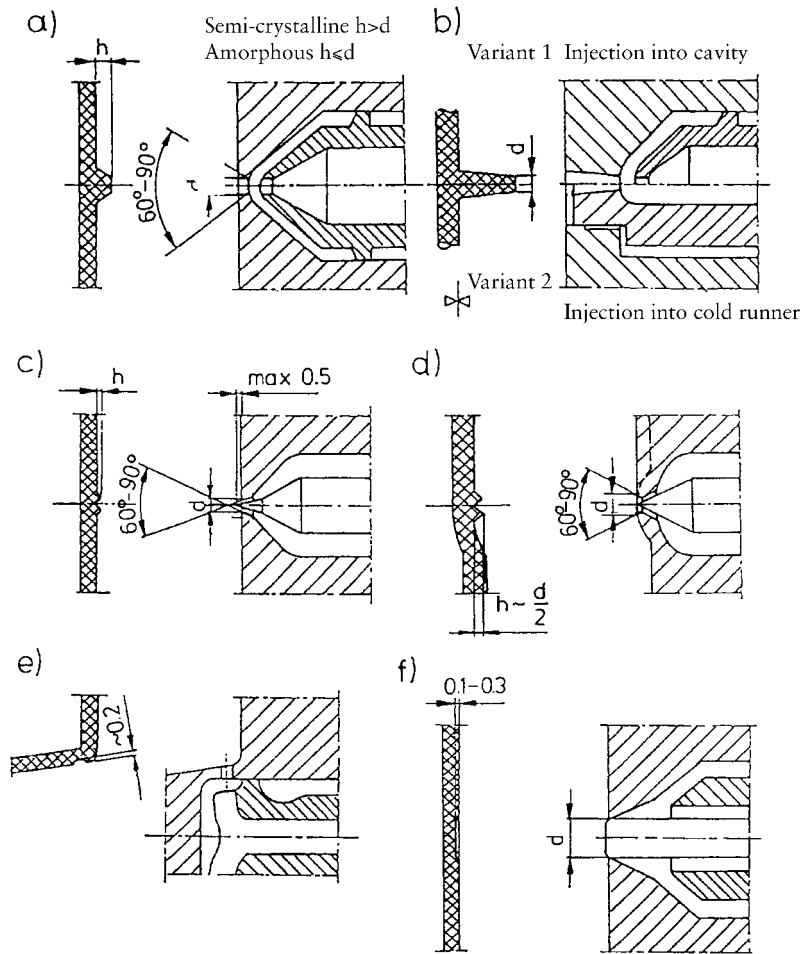


Figure 4.3 Basic types of nozzle and sprue

- a - open nozzle - point (conical) sprue, broken away; b - open nozzle - rod sprue, broken away; c - tip nozzle - annular sprue, broken away, 'cosmetic' type; d - tip nozzle - annular sprue, 'technical' type; e - side gating nozzle - point sprue, sheared off; f - shut-off nozzle - no sprue

- shut-off nozzles, which leave only a mark from the valve pin (Figure 4.3f);
- nozzles to side gating (edge nozzles), which are open or tip-type, but, because of the side positioning of the gate, leave only a vestige where the sprue is sheared off (as with CR tunnel gates) (Figure 4.3e).

Table 4.1 Pressure losses and temperature rise in manifold channels [1] (situation in CR also given for purposes of comparison)									
Plastic	Processing conditions		Filling time t _w , s	Δp, MPa			ΔT, °C		
	Temperature			HR	HR	CR	HR	HR	CR
	Inject. T _w , °C	Mould T _p , °C		D _k = 6 mm	D _k = 8 mm	D _k = 6 mm	D _k = 6 mm	D _k = 8 mm	D _k = 6 mm
PS	240	20	1.0	203	127	272	+12	+7	+14
			3.0	158	98	221	+9	+6	+9
POM	210	80	1.0	210	88	291	+6	+2	+17
			3.0	99	41	144	+3	+1	+1
PC	300	80	1.0	481	227	623	+28	+13	+33
			3.0	248	101	359	+14	+6	+12
D _k - Channel diameter									

Gate closure and sprue removal. Gates may be thermally closed, i.e., self-freezing or mechanically closed using a pin. Sprues are removed by breaking them off, in the case of open and tip-type nozzles, or by shearing (for side gating nozzles).

Nozzle design. Two basic types of nozzle may be identified:

- in-line nozzles - with runner outlet parallel to nozzle axis;
- angle nozzles - with runner outlet perpendicular to nozzle outlet. These are nozzles for side gating.

Number of injection points. Besides single nozzles, there are also multi-point nozzles, with two to six or more injection points. These are mainly tip nozzles and side gating nozzles, but there are also open and shut-off nozzles. The use of multi-point nozzles enables the cost of a HR system to be reduced by bringing down the number of nozzles and possibly doing away with the manifold.

Type of body and placing of gate. There are a number of different types of nozzle:

- full-body nozzles, i.e., nozzles with gate running right into the mould cavity (mainly for semi-crystalline plastics). The end face of the nozzle forms part of the cavity;
- partial-body nozzles, i.e., nozzles running into an insulating chamber created in the mould and terminating in a gate (mainly for amorphous plastics);
- body-less nozzles, i.e., torpedoes (mainly for easily-processed plastics, such as PP or PE, and plastics not requiring frequent colour changes).

Materials used to make nozzles. The main features required of materials used for nozzles are a high level of mechanical strength and a high thermal conductivity (Figure 4.4), and in some applications they must also be highly abrasion-resistant and have special resistance to chemicals.

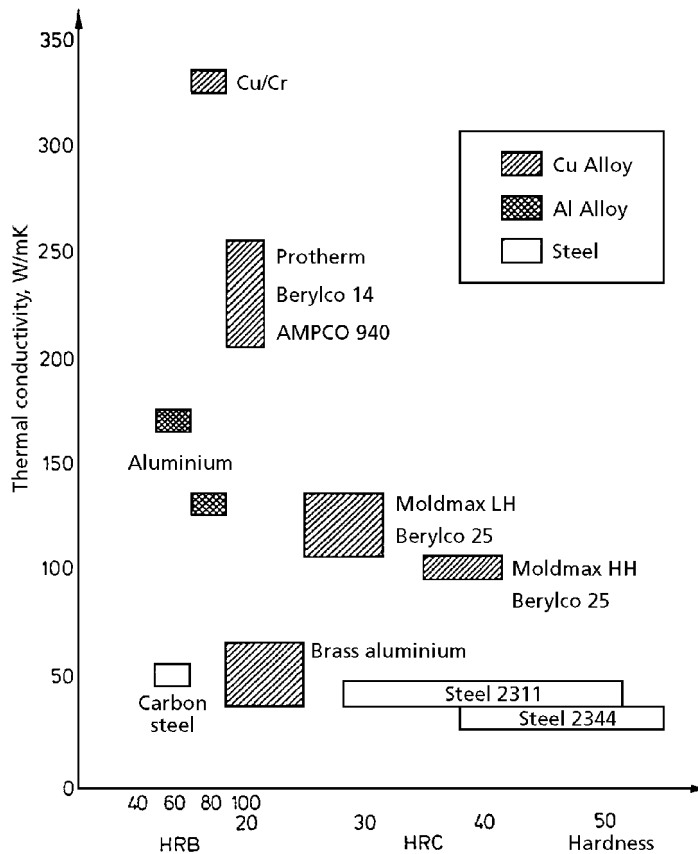


Figure 4.4 Thermal conductivity and hardness of materials used to make HR systems [2]

(Reproduced with permission from Guzzini Engineering)

The following standard materials are used:

- Hot-work tool steel: DIN 1.2343 steel (hardness approximately 44 on the Rockwell C Hardness Scale (HRC), thermal conductivity around 25 W/mK) for nozzle casings and bodies;
- High-speed steels with high abrasion resistance;
- Stainless steels resistant to the action of fluorine, bromine and other decomposition products;
- Sintered molybdenum (thermal conductivity around 115 W/mK) for nozzle casings and tips in applications up to 360 °C (**Figure 4.5b**), and for melts with an abrasive action (five times greater durability than that of copper/beryllium alloys). After ion treatment (thermo-implantation) the durability of molybdenum sinters is increased by many times. Molybdenum sinters are brittle in places where there is a notch, e.g., the thermocouple groove;
- Sintered tungsten carbide with a high abrasion resistance and good thermal conductivity, for nozzle tips and pin guides;
- Copper/beryllium alloys (thermal conductivity 200 W/mK) and copper/cobalt/beryllium alloys (225 W/mK) for nozzle casings and tips in applications up to around 280 °C (see **Figure 4.5a**) (because of the mechanical strength of the alloy, which rapidly falls when the temperature rises). Treatment involving an overlayer of silicon carbide increases injection abrasion resistance with, for example, PA and GF. Nickel coating eliminates the influence of copper on the melt (electroless nickel plating);
- Copper alloys (thermal conductivity up to 350 W/mK) and aluminium alloys for heating jackets with embedded or wound heater element;
- Titanium nitride coatings for nozzle tips, which give increased abrasion resistance;
- Titanium alloys (thermal conductivity around 7 W/mK) for sealing rings and insulating bushings for nozzle tips;
- Sintered ceramics (thermal conductivity below 2 W/mK) for nozzle and manifold spacer pads.

It should be borne in mind that the choice of a material with a high thermal conductivity necessarily brings with it a loss of hardness (**Figure 4.4**) and strength.

The thermal properties of selected materials are shown in **Table 4.2**.

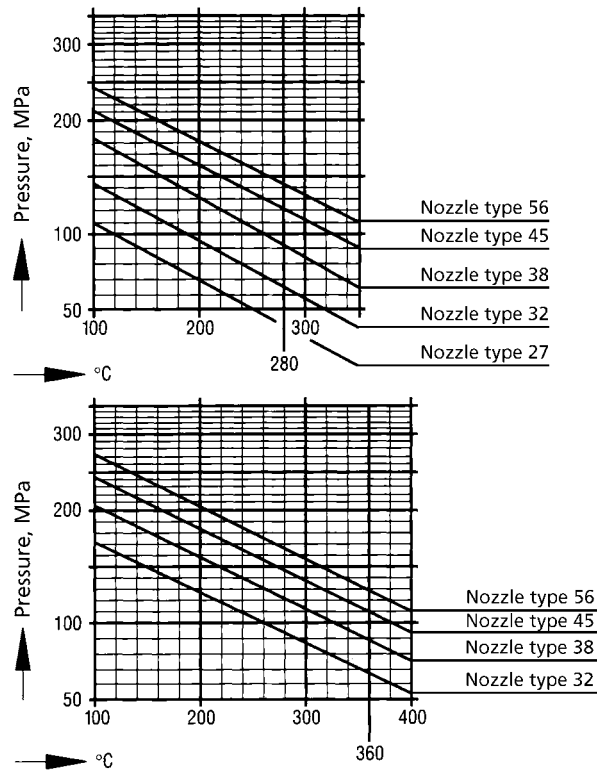


Figure 4.5 Fall in admissible injection pressure with rise in temperature for nozzles
a - made of copper beryllium; b - made of molybdenum alloys

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Warning. Machining of copper/beryllium alloys requires certain precautions to be taken to prevent chronic beryllium poisoning. This concerns machining methods during the performance of which dusts or fumes are generated, such as dry grinding, polishing, electromachining, welding and heat treatment at over 400 °C. Air extractors are needed to prevent inhalation of dust or vapours, and in some cases even respiratory masks.

Table 4.2 Thermal properties of materials used in HR systems			
Material	Coefficient of thermal expansion	Thermal conductivity	Specific heat
	α ($10^{-6}/K$)	λ (W/mK)	c (kJ/kg K)
Technical Cu	18.5	~350	0.39
CuCoBe (Hasco)	17	225	0.42
CuBe (ELMET HA)	17	209	
Al alloys	23	130-170	
CuAl		50	
Mo sinter (TZM)		115	
Steels:			
DIN 1.2311	11 (20-100 °C)	34	0.48
	13.4 (20-300 °C)		0.46
DIN 1.2767	12-13	30	0.48
DIN 1.2343	12	26	0.48
DIN 1.2083	11	21	0.46
DIN 1.1730	11	52	
Sintered steels	~10	~5	
Heat-conducting cement		13	
Ti alloy (TiAl 6V4)		7	
Ceramic sinters	9	<2	
Insulating plate (laminate)		0.2	1.0
Comparative materials:			
Air		0.04	
Water		0.6	
Glass		0.7	
Asbestos board		0.18	
Silver		410	
CuCrZr		322	
Copper		395	
Aluminium		200-230	
Plastics:			
PMMA	70	0.19	1.46
PP	110	0.2	1.67
POM	80-90	0.23	1.25
LDPE	160-180	0.35	2.09-2.3
PA6, PA6.6	70-100	0.3	1.67-2.1
PC, PBT	60	0.2	1.17
PS	40-80	0.15	1.25-1.67

4.1.1 Gates

The gate is the termination of a flow channel, and is a critical functional zone in an HR system. It governs the functioning of the nozzle, regardless of whether it is located in the nozzle or inside the actual mould cavity. The gate plays the part of a thermal or mechanical valve. Gate control concerns both melt flow control and gate closure (open time).

Thermal closure of a gate (self-solidifying) occurs in open, tip and edge nozzles (**Figure 4.3**). The cooling action of the mould brings about gate closure. Because the melt flow stops, there is a rapid temperature drop in the gate. During removal of the moulded item, the sprue is broken off (in a side nozzle it is sheared off), and a short plug of plastic is left in the gate. Detachment of the plug should take place in the narrowest cross-section of the gate taper (**Figure 4.6a**). The consistency, shape and size of the plug have a bearing on the efficacy of thermal closure of the nozzle and on the potential for re-opening it:

- with amorphous plastics, the plug is ductile and readily pushed out, especially in the central section (**Figure 4.6a**);
- with quick-freezing semi-crystalline plastics there is a sudden phase change, and a hard plug will form with only a slight fall in temperature. The ejection potential depends on the plug thickness. One condition for a plug to act as a valve is melt decompression in the HR system. If this is not present, there is a risk of the plug being forced out by the residual pressure of the melt in the manifold, with uncontrolled drooling (**Figure 4.6h**). When the system is functioning normally, the plug is forced out by the pressure rise during the next injection.

Too low a temperature in the front section of the nozzle causes blocking of the gate (**Figure 4.6b**), that is long-term plugging of the nozzle duct, requiring the machine to be stopped. It sometimes happens that a completely frozen sprue firmly stuck in the gate is torn away at the wall of the moulded item (**Figure 4.6c**). At the next injection it is forced into the mould cavity. With amorphous plastics, it may be melted by the melt stream, but with semi-crystalline engineering plastics, especially various types of PA, POM, PBT and so on, a very visible flaw appears in the shape of a lump of plastic sticking out of the product wall. Some manufacturers of these plastics (DuPont) consequently advise using short flow channels where possible in multi-cavity moulds with open nozzles [3]. Then the cold plug enters either a sprue catch well (undercut recess) opposite the gate, or a well at the end of a main channel termination.

If the gate temperature is too high, the sprue may break off too high up and the plug will be perforated. There will then be gate stringing from the inside of the nozzle. Alongside uncontrolled drooling, this is the main defect of open nozzles, and is very

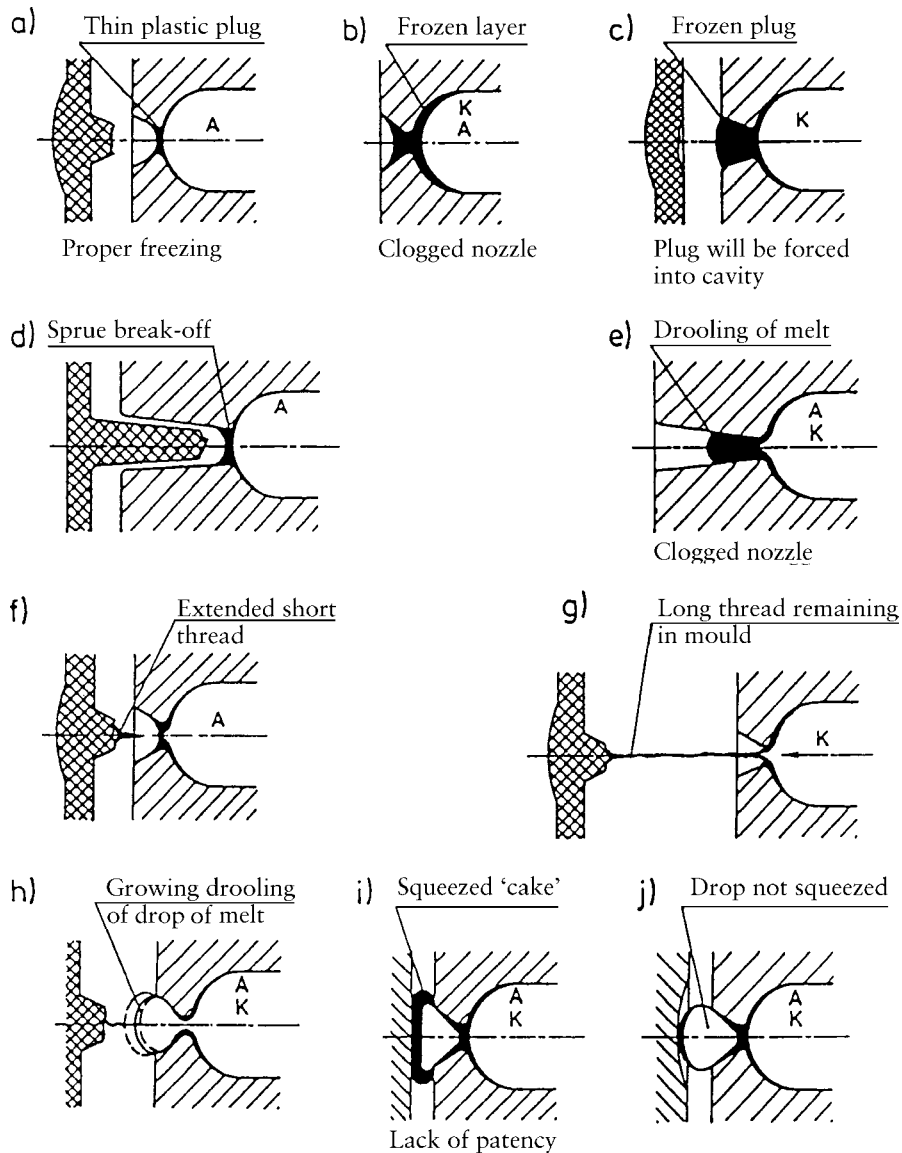


Figure 4.6 Thermal closure of gate in open nozzles

A - amorphous plastics; K - crystalline plastics; a - frozen gate protecting against uncontrolled drooling of melt; b - clogging of nozzle by thick layer of melt; c - broken-off sprue remaining in gate; d - proper sprue break-off in elongated gate; e - frozen drop of melt clogging gate; f, g - gate stringing; h - drooling of drop of melt when moulding has been removed; i - effect of squeezing of drop and blockage of gate; j - avoidance of drop squeezing by making recess in mould core.

difficult to eliminate. This phenomenon depends on the configuration and size of the gate, the properties of the plastic and the temperature. A short thread that breaks away (**Figure 4.6f**) is no more than a cosmetic flaw, and is easily eliminated. A long, trailing thread of melt rapidly damages the mould parting surface, even if the latter is very hard. Use of a tip gate (**Figure 4.8c**) reduces the risk of drooling, especially if there is the potential to regulate the tip temperature. Gate drooling is a particular feature of PA, PP, PP/EPDM, HDPE, PET and PS, PC, and even sometimes ABS. Control of gate closure requires an interaction between nozzle heating control and cooling of the gate zone. The difficulties associated with temperature control for an open gate may be reduced by lengthening the gate, i.e., moving the critical point of the gate further away from the surface of the moulded item (**Figure 4.3b** and **Figure 4.6d**). This option is sometimes utilised in the case of quick-setting crystalline plastics (it is also used to reduce the stress concentration), with injection into places that are difficult of access and, frequently, with injection into a cold runner. Even an extended gate may become clogged if drops of melt from a nozzle that is too hot run into it (**Figure 4.6e**).

Drooling from the nozzle (**Figure 4.6h**) may cause problems with cavity filling. A drop of melt that is squashed when the mould is closed create a 'cake' that blocks the gate. The recommendation is to make a small lenticular recess in the core opposite the gate, particularly for the production of thin-walled products. This confers the following advantages:

- it facilitates a uniform spread of the melt ('propagation');
- it makes it difficult for the gate to be blocked by cakes of melt (**Figure 4.6f**);
- it reduces internal stresses in the moulded item around the gate, because thickening enables partial relaxation of them;
- it facilitates even filling of the cavities in a multi-cavity mould;
- it makes the moulded item stronger in the vicinity of the gate.

This analysis shows the necessity of applying different principles to the design of HR systems depending on the type of plastic. Strong gate cooling is essential for amorphous plastics, but slow-setting crystalline plastics (PE, PP) also require it (see **Table 3.2**).

In view of the gradually diminishing fluidity of amorphous plastics during cooling (see **Figure 3.3**), the design of the gate zone and cooling circuit should ensure that a large temperature drop occurs so that the gate is frozen before the mould is opened, and so that the sprue breaks away properly. Cooling is effected via channels drilled

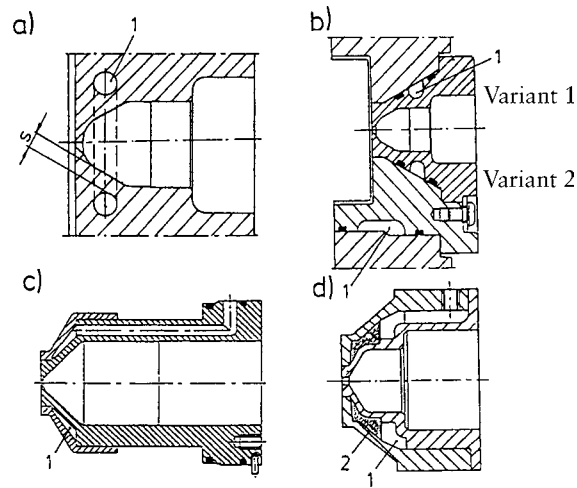


Figure 4.7 Individual cooling of gate zone

1 - cooling channel; 2 - copper insert;

a - via channels drilled in plate; ($s = 4-8$ depending on nozzle size);

b - cooling of insert of mould with central nozzle

(Reproduced with permission from Husky Injection Moulding Systems);

c - cooling of nozzle body

(Reproduced with permission from PSG Plastic Group);

d - cooling of body of nozzle with copper conducting insert

(Reproduced with permission from Unitemp SA).

around the gate, or made in a replaceable insert (Figure 4.7). The insert provides better cooling, and also the potential for replacement in the event of wear on the gate. Gate cooling should be via a special zone to allow temperature regulation that is independent of the mould cavity temperature. With a larger number of gates the zones should not be connected in series, since then the temperature of successive gates will rise.

For semi-crystalline plastics with a strictly-defined melting point, the gate zone design and its control must provide for a high gate temperature to be maintained with low tolerance of fluctuations in that temperature. This means better insulation of the gate zone from the mould cooling zone, and an increased potential for the heat flow to reach the gate. Accuracy of control ensuring smaller temperature fluctuations is greater if the nozzle thermocouple is located near to the gate. In full-body nozzles,

gate cooling is regulated by setting a suitable nozzle end abutment length, L_p (Figures 4.13 and 4.14). For quick-setting crystalline plastics (such as POM or PA 6), heat insulation of the gate is required, with the shortest possible abutment length. For slow-setting plastics (PE, PP) a certain cooling of the gate is needed, and a slightly greater abutment length should be provided.

There are also nozzle bodies with internal cooling (Figure 4.7c), which makes gate temperature control easier and enables them to be used with amorphous plastics.

As a result of internal heating, annular gates of tip nozzles are far less susceptible to clogging. When the melt is injected, a layer arises adjacent to the wall, but because of the hot tip it does not entirely stop up the gate. When amorphous plastics are injected, this layer forms a ductile plug in the vicinity of the tip (Figure 4.8a) which is easy to eject.

When semi-crystalline plastics are injected, a gap filled with fluid melt arises between the frozen layer and the tip, but because the melt flow ceases gradually, shear stresses are reduced and the melt viscosity rises. The tip end provides a constant flow of heat preventing freezing and clogging (Figure 4.8b). The slight protrusion of the tip end helps to control the stringing phenomenon (Figure 4.8c). The Spear System tip nozzle, in which the tip is a heating element with a controllable rapidly-varying temperature, is equipped with an effective thermal closure system (see Figure 4.23).

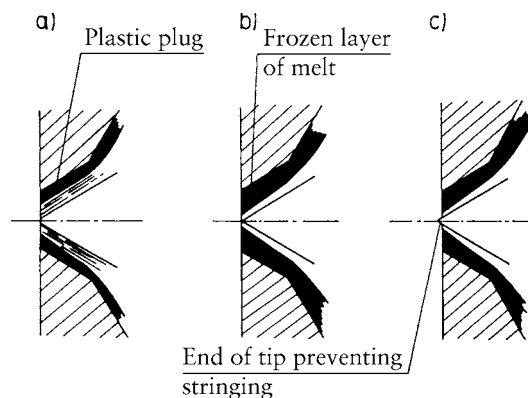


Figure 4.8 Thermal closure of gate in tip nozzles

a - closure by plastic plug with amorphous plastics; b - gate closure by choking of flow with semi-crystalline plastics; c - prevention of stringing by end of hot tip.

Mechanical closure of the gate takes place with the aid of a moveable pin (plunger) which is introduced into the gate aperture (**Figure 4.3f**). This design allows a large gate aperture to be used, and has numerous advantages, such as:

- easier cavity filling, especially with high-viscosity or shear-sensitive plastics;
- the potential to maintain a long holding phase, thus enabling an HR system to be used for thick-walled items;
- the precision control of length of holding phase (gate closure), regardless of gate zone heat balance, which improves dimensional accuracy of items;
- the potential to close the gate immediately after cavity filling under high pressure, which prevents withdrawal of melt and flaws in structure;
- the elimination of gate drooling and stringing;
- only a round vestige from the pin face remains on the moulded item;
- the potential to use special injection processes like structural foams or cascade moulding.

The gate size and configuration are based on the melt flow rate during injection (ease of filling) and the holding phase duration (shrinkage compensation); they are therefore governed by:

- the size and design of the product, and particularly its weight and thickness;
- the properties of the plastic, and especially its structure and viscosity;
- the type of gating and nozzle;
- aesthetic requirements.

The flow of melt from the nozzle through the gate to the mould cavity takes place at a very high shear rate, and consequently causes a pressure loss. On the other hand the high shear rate causes the generation of frictional heat and a fall in the melt velocity, which helps cavity filling. When establishing the gate size, the following problems need to be considered:

- an excessive pressure loss in too small a gate gives rise to problems with cavity filling (the pressure drop in an open gate may be restricted to around 1 MPa);
- too small a gate obliges the user to use a high nozzle temperature, which makes it harder to cool the gate zone, or else high pressure, which increases the level of internal stresses in the moulded item;
- excessive friction in the melt when the admissible shear rate is exceeded causes damage to the melt structure and a deterioration in the mechanical and optical properties (see Chapter 3.1). This condition governs the minimum gate diameter.

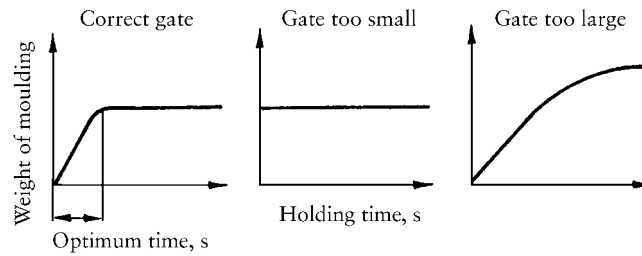


Figure 4.9 Weight method of determining gate patency time
(*Reproduced with permission from Mold-Masters.*)

In the case of engineering products, a gate should theoretically have the greatest diameter possible for the previously discussed reasons. Too large a gate, however, may cause a lengthening of the injection cycle, if its freezing (thermal closure) does not occur before the item cooling time elapses.

The gate freezing time may be determined using a weight test. In this test a series of items are moulded with an unvarying cycle time, but with an increasing holding time, and then they are weighed. Since the weight of the item cannot increase once the gate is frozen, the shortest holding time at which the item achieves its maximum weight is the equivalent of the gate freezing time (**Figure 4.9**).

The gate size sometimes requires optimisation following trial injections. The adjustment to the gate should be carried out in a way that does not alter its configuration. Special recommendations concerning adjustments to the gate of a tip nozzle are to be found in Chapter 4.1.3.

The configuration of gates incorporated into a mould cavity should conform to the recommendations of the nozzle supplier.

Aesthetic requirements. Open gates are most commonly used for products where there are no special aesthetic requirements. For products subject to high aesthetic requirements, less visible annular or shut-off gates are used. Where a vestige left by the gate on the front surface is unacceptable, edge gates are used, or a system linked to a cold tunnel gate.

The size of an annular gate is a compromise between rheological demands on the one hand and aesthetic requirements on the other. However, one should always consider the risk of inferior product quality as a result of reducing the gate size. In the case of disposable products or products for short-term use, a minor deterioration in the plastic properties may be tolerated, but for products for long-term use this may have adverse consequences.

A 'technical' gate of larger diameter (**Figures 4.3a and 4.3d**) has a conical reinforcement at the base, which ensures that it breaks away above the product surface without any risk of forming microscopic cracks on the surface.

A gate may be located in a spherical recess to prevent the sprue interfering with the functioning of the product or with manual gripping of the product. The height of the sprue depends on the configuration and size of the gate and on the properties of the plastic. It is usually higher, the less sensitive the plastic is to the effect of a notch (the more ductile it is).

A 'cosmetic' gate of smaller diameter (**Figure 4.3c**) with inverted cone has a sharp termination at the base, which ensures that it breaks away leaving the minimum vestige, and sometimes level with the product surface. This gate configuration works best with PE. A 'cosmetic' gate may also be located in a recess.

The appearance of the gate after break-off depends on the type of plastic. Plastics that are sensitive to the effect of a notch, in other words most amorphous plastics, and to some extent quick-setting crystalline plastics, manifest brittle fracturing. Plastics that are not notch-sensitive, namely most crystalline plastics, manifest ductile fracturing, while thermoplastic elastomers undergo delamination.

Some companies offer nozzles with replaceable gate inserts and tips. With a single standard body, it is possible not only to change the melt delivery system and the shape and type of gate, but also to do away with the witness ring left by the nozzle face (**Figure 4.10**).

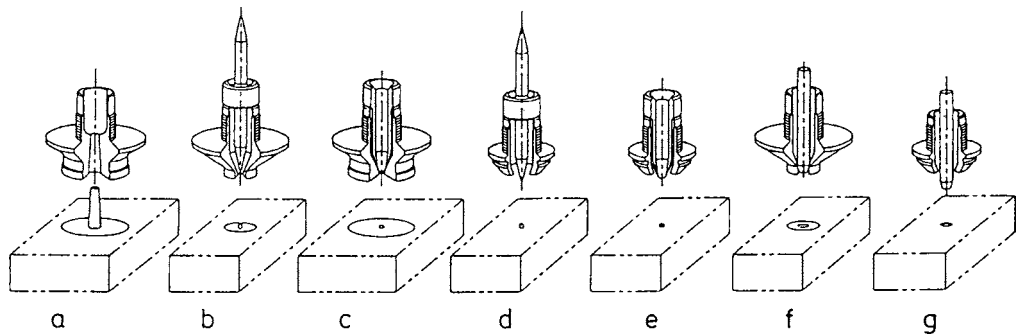


Figure 4.10 Replaceable gate inserts and tips with various types of sprue and body
a - open nozzle (rod sprue); c, e - open nozzle (point sprue); b, d - tip nozzle (annular sprue); f, g - shut-off nozzle (no sprue); a, b, c, f - in-body nozzles (nozzle face witness ring on moulding); d, e, g - partial-body nozzles

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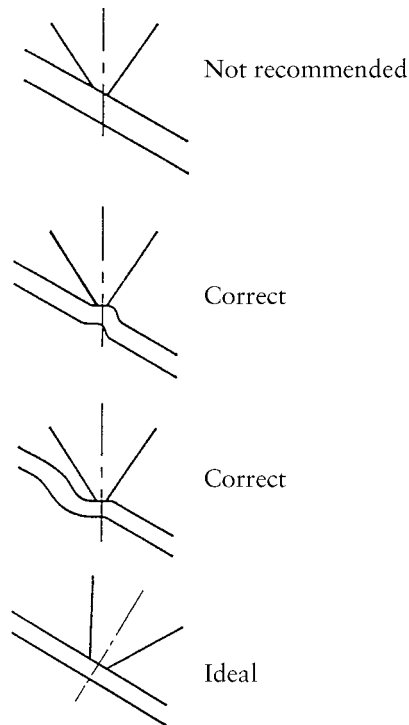
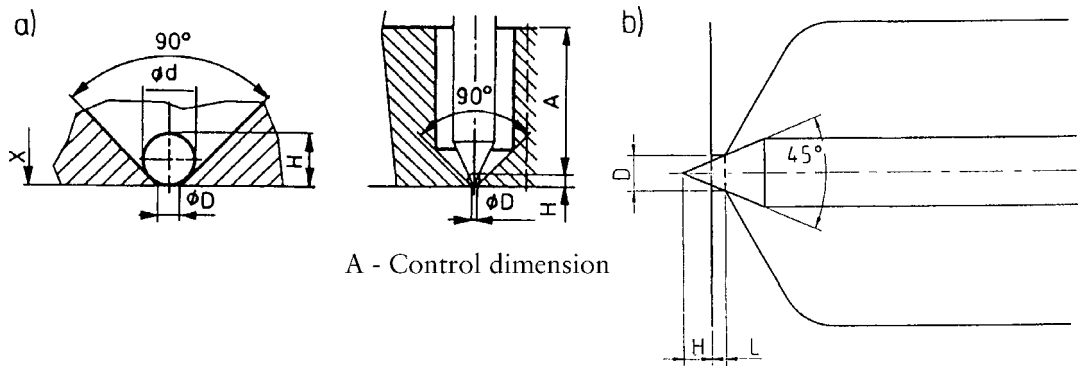


Figure 4.11 Modification of angled surface of moulded item with frontal moulding
(Reproduced with permission from Günther Heisskanaltechnik GmbH.)

Locating the gate, and particularly an annular gate, on an angled surface, causes uneven freezing of the gate and the formation of a much larger sprue. In such cases the shape of the moulded item may be modified as shown in **Figure 4.11**.

Gate manufacture. To achieve the optimum strength of the gate zone in the mould, use of ductile steel is recommended (hot work steels, e.g., DIN 12343), with a hardness of 48-50 HRC. Deep nitriding or chrome hardening should be avoided. Polishing and rounding of the insulating chamber are recommended to reduce internal stresses. Where gates are electromachined, the possibility of edge brittleness should be borne in mind.

Drilling or electromachining of taper gates, and also of taper insulating chambers, is facilitated by the introduction of depth measurement using a measurement ball. Auxiliary measurements are to be found in some companies' catalogues (**Figure 4.12a**). Length control of a manufactured gate is facilitated by a gauge plunger (**Figure 4.12b**), which is used both for cylindrical gates and for taper gates with a maximum angle of 45 degrees.



ϕD	H	ϕd
0.5	3.37	3
0.6	3.32	
0.7	3.27	
0.8	3.22	
0.9	3.17	
1.0	3.12	
1.1	3.07	
1.2	3.02	
1.3	2.97	
1.4	2.92	

ϕD	H	ϕd
1.5	2.87	3
1.6	2.82	
1.7	2.77	
1.8	2.72	
1.9	2.67	
2.0	2.62	
2.1	3.78	
2.2	3.73	4
2.3	3.68	

ϕD	H	ϕd
2.4	3.63	4
2.5	3.58	
2.6	3.53	
2.7	3.49	
2.8	3.43	
2.9	3.38	
3.0	3.33	

Figure 4.12 Ways of measuring gate and insulation chamber

- a - measurement of depth of insulation chamber L using ball giving required gate diameter (*Reproduced with permission from EWIKON Heißkanalsysteme*);
b - measurement of length of gate using gauge plunger. $L \approx 1.2 \cdot D - H$; ϕD : gate diameter;
 ϕd : measuring ball diameter

4.1.2 Open nozzles

Open nozzles leave behind a short point sprue on the surface of the product (or cold runner). A relatively large gate, normally some 1-4 mm, gives a good holding pressure and reduced stresses. Open nozzles are chiefly used for engineering articles where the vestige left by injection is less important, and for cold runner moulding (in a runner or short sprue). These nozzles are not suitable for gate-stringing plastics.

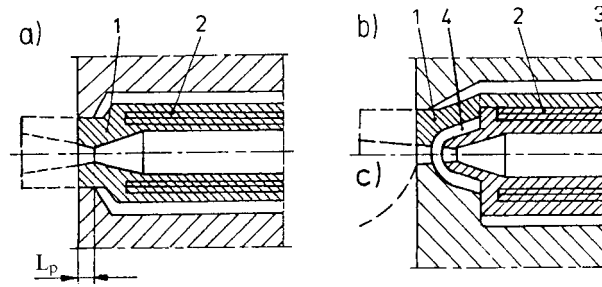


Figure 4.13 Structural principle of open nozzles

a - with direct gate; b, c - with insulation chamber in nozzle or in mould; 1 - body; 2 - heater; 3 - casing; 4 - insulation chamber; L_p - nozzle tip abutment length.

Open nozzles may be divided into two main types (**Figure 4.13**):

- nozzles with direct gate and full-body;
- nozzles with insulating chamber and full- or partial-body.

Nozzles with a direct gate and full body introduced into the mould cavity (**Figure 4.13a**) ensure a high gate temperature and prevent premature freezing. Thus they are most suitable for quick-setting crystalline plastics. The rate of heat removal from the gate zone depends on the abutment length of the nozzle tip in the mould aperture. The abutment length, L_p , depending on the plastic and the nozzle type, is most commonly taken as a maximum of 2 mm for quick-setting crystalline plastics (to insulate the nozzle from the mould), and around 3-4 mm for amorphous plastics (to cool the nozzle tip and freeze the sprue). The recommendations of the nozzle supplier should be observed, because each nozzle type has its own specific thermal characteristic.

During the processing of amorphous plastics and polyolefins, there is an additional risk of 'fusion' or deformation of the moulded item from the hot nozzle face.

Gate diameters may be increased according to need. The gate insert may be supplied with a surplus length, which enables it to be adjusted to a sloping or shaped mould surface.

In the case of open nozzles with an insulating chamber, the nozzle casing is separated from the gate by an insulation gap, which becomes filled with melt during the first injection. This insulation enables quite a large temperature difference to be maintained between nozzle channel and gate.

For open nozzles with an insulating chamber and a full body (Figure 4.13b), the nozzle face has a lower temperature, which causes the gate to cool a little more rapidly. This has resulted in these nozzles becoming fairly universal for both crystalline and amorphous plastics.

Open nozzles with an insulating chamber in the mould and a partial body (Figure 4.13c) enable the gate zone to be intensively cooled and to freeze rapidly. They are therefore most suitable for amorphous plastics, as well as for slow-setting crystalline plastics (PE, PP) and elastomers.

A partial-body nozzle does not leave a round witness ring from the nozzle face on the moulding, this is an essential condition of use for many products.

There are many design variants for open nozzles for specialist applications.

Open nozzles with direct gate are generally of simple design (Figure 4.14), and the melt is not left behind in them, so that they are best suited to heat sensitive plastics and to plastic colour changes.

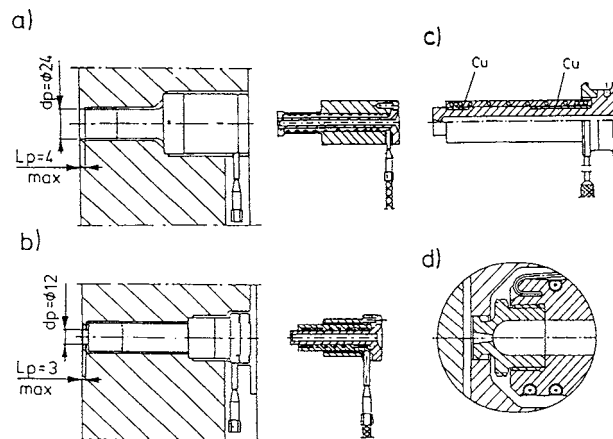


Figure 4.14 Examples of open nozzles with direct gate

a, b - nozzles with full and reduced abutment diameter (*Reproduced with permission from D-M-E Belgium*); c - nozzle with copper heat distribution bands (*Reproduced with permission from STRACK Normalien GmbH*); d - nozzle with replaceable gate insert. US Patent 5,346,388 [4] (*Reproduced with permission from Mold-Masters*).

d_p , L_p - abutment diameter and length, respectively

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Because of their ease of cleaning, they are recommended for waste processing. With open nozzles decompression should be used to prevent melt stringing or drooling.

Attention should be drawn to an important detail - the area of abutment of the nozzle to the mould in the gate zone:

- nozzle 4.14(a) features a large abutment (cooling) area and is fitted with a standard coil heater, making it possible to use this nozzle for slow-setting crystalline and amorphous plastics. Nozzle 4.14(c) has copper bands which improve temperature distribution;
- nozzle 4.14(b) meets the requirements for quick-setting crystalline plastics (such as PA, POM, PET) and plastics that do not flow readily (such as PC) because of a smaller abutment (insulation) area and the uniformity of heating by the heater embedded in a copper bushing.

Open nozzles with a direct gate located in a replaceable gate insert (**Figure 4.14d**) have the advantage that following abrasive wear on the gate, the gate insert may be replaced; one drawback, though, is the poorer heat supply to the gate, which means it has to be lengthened. To improve insulation (prevent melt freezing in nozzle channel), there is an insulating groove in the insert. The nozzle has an embedded heater with a thermocouple situated in the nozzle end.

Injection nozzles for gating on to a cold runner do not have to meet such high requirements and so cheaper nozzles of simplified design with a rod-type sprue, also known as hot sprue bushings, may be used for this purpose (**Figure 4.15a**).

These bushings are used both as central nozzles and as manifold nozzles, and are basically suitable for all types of plastic. The nozzle exit channel usually needs to be enlarged, depending on the application.

When installing these nozzles, it is essential to leave a gap of $\Delta L = 0.5$ mm (after heating) between the face of nozzle 4.15(c) and the surface of the moving half of the mould, which insulates the nozzle face from contact with the cold plate (this gap fills with melt during injection). In the case of crystalline plastics, an insulating groove is also included (b) to prevent clogging of the nozzle and to make sprue separation easier. Some manufacturers deploy extra heat insulation of the nozzle flange using a ceramic ring.

Figures 4.15c-g shows how nozzles are used in cold runner gating. Nozzle 4.15(c) is a point-gate nozzle, while nozzles (d)-(g) are of the sprue-gate type. The sprue length may be reduced by shortening the nozzle, but it should be remembered that a longer sprue helps in nozzle control.

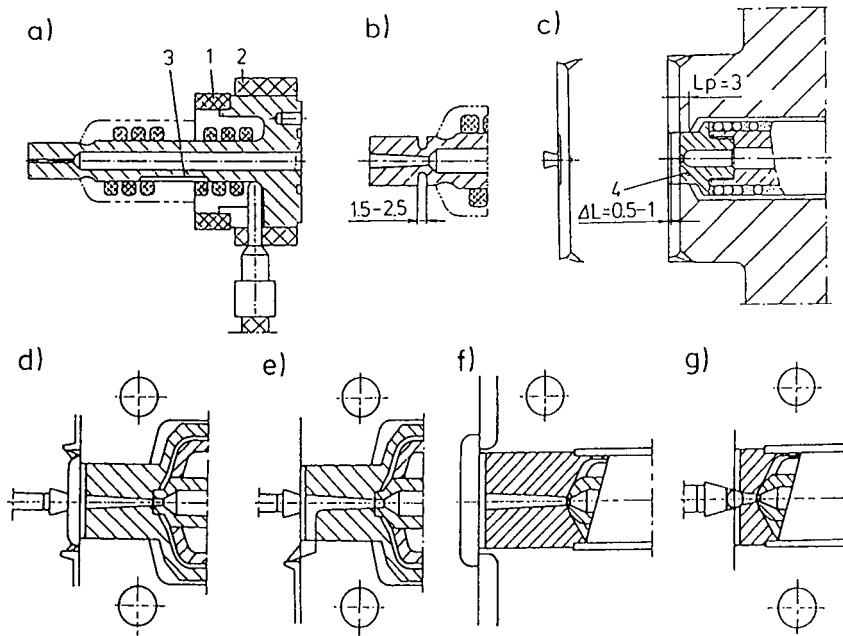


Figure 4.15 Open nozzles for injection into cold runner

- a - nozzle with rod sprue in standard version; 1 - ceramic insulation ring;
 2 - heater; 3 - thermocouple; b - version of nozzle a with insulating groove;
 (a & b Reproduced with permission from EOC Normalien); c - nozzle for injection
 into cold runner (Reproduced with permission from STRACK Normalien GmbH);
 4 - replaceable insert; d-g - nozzles for injection into cold sprue/runner
 (Reproduced with permission from Dynisco HotRunners)

For melts which cause stringing, there are open nozzles with a mini-torpedo (Husky) located at the entrance to the taper channel, i.e., at the point where the sprue is broken away.

Examples of use of nozzles with sprue gate are shown in **Figure 4.16**.

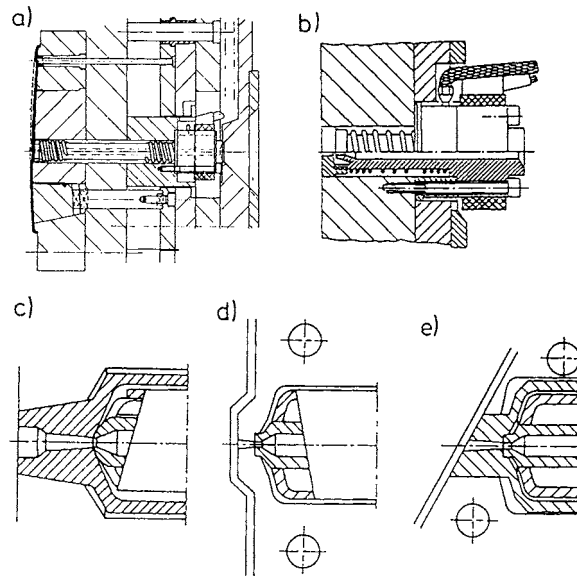


Figure 4.16 Examples of applications of open nozzles with rod sprue

- a - fragment of mould for hub cap (*Reproduced with permission from Kunststoffe German Plastics, 1995, 85, 6, 760, Figure 6. © 1995, Carl Hanser Verlag*);
b - nozzle used in mould a (*Reproduced with permission from PSG Plastic Group GmbH*);
c, d, e - nozzle applications (*Reproduced with permission from Dynisco HotRunners*)

In a mould for a hub cap 4.16(a) with injection from the inside, the appearance of the sprue is not significant, so it is possible to use a nozzle with sprue gate which is easy from the production aspect. The sprue is located in a replaceable insert, and the insulating chamber prevents nozzle clogging.

This design facilitates temperature control and such nozzles may be used with all types of plastic.

In example 4.16(c) the sprue is located on the stub of the moulding; in 4.16(d) it is in a recess in the moulding; and in 4.16(e) it is on an inclined surface.

Open nozzles with insulating chamber. The simplest and cheapest type of nozzle is the heat-conducting nozzle, made of copper/beryllium, heated by heat conducted from the manifold and located in a steel bushing terminating in a gate (**Figure 4.17a**). Extra insulation is provided by the air gap outside the bushing. This is a classic design subsequently used in moulds for small products made from plastics with a broad range

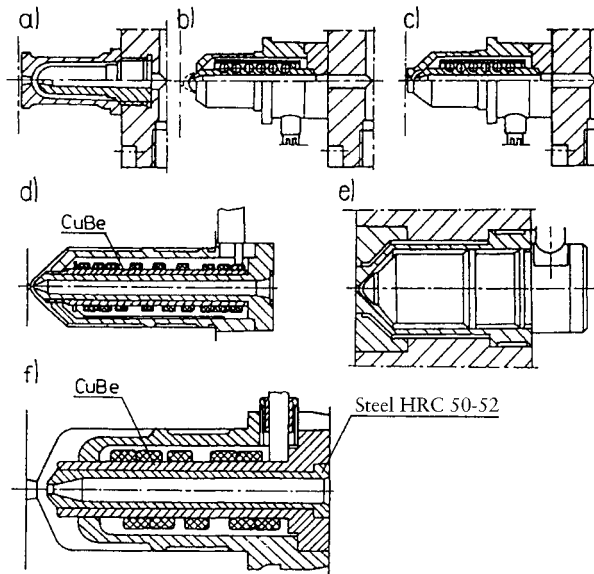


Figure 4.17 Examples of open nozzles with insulation chamber

- a - conducting nozzle made of copper beryllium 10; b, c - copper beryllium 10 heated partial- and full-body nozzles (*a, b & c Reproduced with permission from Hasco Normalien GmbH & Co.*); d, e - heated nozzle with steel casing and copper beryllium conducting bushing (alternatively, whole item made from molybdenum sinter (*Reproduced with permission from PSG Plastic Group. © PSG Plastic Group GmbH*); f - heated nozzle with copper beryllium casing and steel insert (*Reproduced with permission from Thermoplay s.r.l.*)

of processing temperatures (PS, PE). To maintain an adequate nozzle tip temperature, its length is restricted, e.g., for PE, a ratio of D:L = 1:3 is used.

Another type of design is the nozzle with copper/cobalt/beryllium alloy casing located inside a steel body bearing an external load (**Figures 4.17b and 4.17c**). In a nozzle used with reinforced plastics and plastics with an injection temperature of over 280 °C, the casing is made of molybdenum. The nozzle may have a full- or partial-body 4.17(b).

Another design has a nozzle in which casing and gate insert are in one piece, made of steel (**Figures 4.17d and 4.17e**). Between casing and heater there is a copper/beryllium jacket giving improved temperature levelling. In the nozzle used for the processing of reinforced plastics, the casing and jacket are a single component made of molybdenum. The nozzle may have a full or partial body, depending on its application. The design of

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nozzle 4.17(f) follows similar lines. A ring on the nozzle casing centres the nozzle and restricts the insulating chamber filled with melt.

Dwelling of melt in the insulating chamber, leading to its decomposition, is a problem that occurs in practice in large-series production of quick-setting semi-crystalline plastics which are at the same time thermally sensitive, such as POM. This residual material also makes it difficult to change colour or plastic. In practice one known solution to this problem is the preliminary filling of the insulating chamber with plastic material of a high level of heat resistance. PSG Plastic Group proposes the following procedure:

- injection of PA 66 under high injection and holding pressure;
- reduce temperature and purge nozzles three to four times, with readily-fluid material, e.g., LDPE;
- introduce the plastic material required and commence normal production.

Another solution is a mould design that enables the insulating chamber to be opened on the moulding machine and cleaned out (**Figure 10.1**).

The latest solution is to locate a small hood of high temperature plastic, e.g., PEEK or PEI, in the insulating chamber; this material retains its shape at temperatures of up to 250 °C. Ready-made hoods are available for PSG Plastic Group, Husky, D-M-E Belgium and Günther nozzles (**Figure 4.18**).

According to recent information [6], use of this sort of minimised hood has enabled hydraulic elbows to be moulded from PVC in a two-cavity mould with a nozzle made of molybdenum and injection in a cold runner.

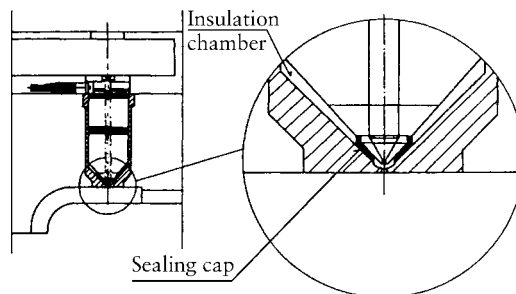


Figure 4.18 Seal to insulation chamber

(Reproduced with permission from PSG Plastic Group GmbH)

Replaceable gate inserts and tips increase the range of application of nozzles. Replaceable inserts enable the mould injection concept to be altered without the need to change the whole nozzle.

The majority of manufacturers, e.g., D-M-E Belgium, INCOE, Mold-Masters, PSG Plastic Group, supply nozzles with various types of replaceable inserts and tips, which makes it possible, for example, to replace an open gate with a tip gate without having to go the expense of changing the nozzle (see **Figure 4.10**). It also helps to optimise the gate used. Nozzles with replaceable gate inserts and tips are recommended for plastics with abrasive additives.

An example of such a nozzle is shown in **Figure 4.19a**. The in-cavity nozzle 4.19(b) has a replaceable bushing with gate and a replaceable tip.

The insulating chamber and the siting of the heater right up against the tip provide the high gate temperature essential for quick-setting crystalline plastics. The small size of the insulating chamber does not present problems when the colour is changed.

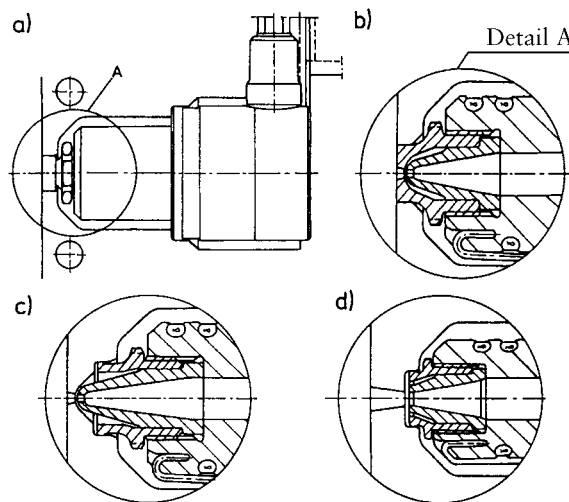


Figure 4.19 Examples of open nozzles with insulation chamber and replaceable gate inserts

a - nozzle installation; b - nozzle with replaceable inserts made of material with good thermal conductivity; c, d - nozzle with bimetallic inserts. (*Reproduced with permission from Mold-Masters; US Patent 5,299,928 [7]*)

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A nozzle introduced into the insulating chamber 4.19(c) and with the gate in the mould cavity is a modification of the previous nozzle, and at the same time an example of the use of bimetallic inserts. The seal bushing needed to create a small insulating chamber is made of a material with low thermal conductivity (titanium alloy) and insulates the tip, which is made of a material with high thermal conductivity. The gate is substantially cooler, and therefore the nozzle 4.19(c) may be used for amorphous and slow-setting crystalline plastics.

A nozzle introduced into the insulating chamber 4.19(d) and with a bimetallic insert and a sprue channel located in the mould cavity is designed for larger products with a longer cooling time, made from amorphous and slow-setting crystalline plastics.

4.1.3 Tip nozzles

Nozzles with a tip are increasingly being used because of the slightness of the vestige they leave on the product and their universality; they meet the requirements for use of both crystalline and amorphous plastics. Their characteristic feature is a hot tip introduced into the gate, which gives easier gate temperature control and simplifies the processing of quick-setting plastics. A relatively small gate - usually around 0.6-2.5 mm - combined with the tip leaves behind a very low ring vestige on the moulding surface. For very small products, 0.3 mm gates are sometimes used. The size of the vestige depends on the configuration and size of the gate, the properties of the plastic and also the cooling of the gate zone. The larger the gate diameter, the larger the vestige (**Figure 4.3**). The presence of the tip in the centre of the gate also helps to prevent gate stringing.

To achieve the effect of a notch when the gate breaks away, the edge of the tapered gate aperture should be sharp. For plastics that are sensitive to the effect of a notch, i.e., amorphous plastics (like PC, PMMA, PS) and quick-setting plastics (like PA, POM, PEEK), and also plastics with a high glass fibre content, there is a clean break (fracture) at the gate. In view of this it is possible to use a larger gate diameter (1-1.8 mm). For plastics that are not notch-sensitive (like PE, PP, TPE, soft PVC) and thermoplastic elastomers, clean gate breakaway does not occur. To obtain an equally aesthetic appearance, the gate diameter should be limited to 0.5-1 mm.

Use of tip nozzles is not recommended for shear-sensitive plastics (which include plastics with flame retardants or organic dyes), since the small annular gap in the gate may cause large shear stresses to arise, with a rise in temperature and degradation of the plastic or the additives in it.

Tip nozzles may be divided into three basic types (**Figure 4.20**):

- nozzles with heated torpedo, located in a deep flow/insulation chamber;

- nozzles with conducting tip (mini-torpedo) located in the central channel;
- nozzles with tip located in the insulating chamber. The central channel is linked to the chamber via several smaller holes.

Because of insufficient heat transfer, use of steel torpedoes and tips is not recommended for quick-setting crystalline plastics (apart from special products).

Nozzles with a heated torpedo (**Figure 4.20a**) are the oldest design, originally arising through improvements to the insulated channel system. The flow and thermal conditions match the HR system with internal heating described earlier. A torpedo located in a deep flow/insulating chamber is most commonly heated using a cartridge heater. The melt flows through an annular channel some 5-6 mm wide, and a frozen layer of melt is left behind on the outside surface of the channel (see Chapter 1.2). The advantage of these nozzles is their simple design and low price. The smaller diameter of the nozzles allows them to be located closer together in multi-cavity moulds, which in turn enables the number of cavities to be increased. A drawback is the problems associated with colour changes and processing of quick-setting crystalline plastics. These features limit the application of heated-torpedo nozzles largely to multi-cavity moulds (price) and smaller-sized products (small pitch) made from easily-processed plastics (chiefly PS, PE, PP).

The next type of nozzle is one with a heat-conducting tip (**Figure 4.20b**), also called a mini-torpedo, located inside the central channel. The tip is heated by the heat of the nozzle casing and the molten material. The insulating chamber is basically the termination of the channel and the melt does not get left behind in it. Colour can be changed rapidly.

In nozzles with a tip in the insulating chamber (**Figure 4.20c**), the tip is the termination of a bushing/casing with a centrally-positioned channel. The channel is linked to the

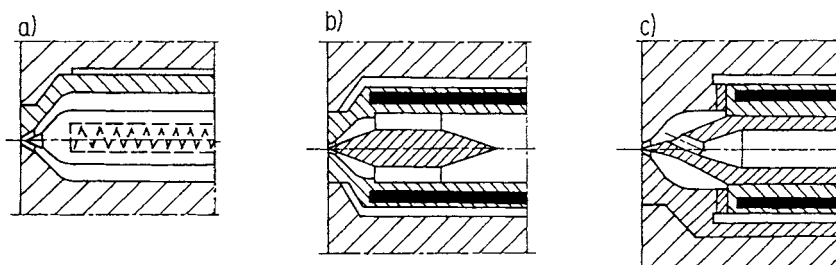


Figure 4.20 Structural principle of tip nozzles

- a - with heated torpedo; b - with conducting tip (torpedo) in runner;
c - with runner terminating in tip.

shallow insulating chamber by several slanting holes located in the tip taper. The tip is heated directly, or - if it is a replaceable part - indirectly.

Tip nozzles are equipped with a full body, a partial body, or - in the case of torpedoes - no body at all. The nozzle body facilitates the use of insulating gaps, and thus assists the processing of crystalline plastics and colour changes. Nozzles designed for injection of reinforced and filled plastics are supplied as a special product.

Nozzles with heated torpedo. The simplest kind of tip nozzle with torpedo (**Figure 4.21a**) is internally heated by a cartridge heater and attached directly to the manifold (mould plate) with internal heating. It thus serves at the same time to heat the feed channel in the manifold. The end of the nozzle is supported by three pins or short ribs in the bottom of the chamber. Sealing of the channel between the plates is provided by an external frozen layer of melt.

The tip nozzle with torpedo (**Figure 4.21b**) is equipped with a coil heater embedded in copper alloy inside the torpedo, ensuring optimum heat distribution. A thermocouple is located in the tip of the torpedo. The torpedo tip (4) in the shape of a wide cone with a large angle (to improve heat supply to the gate) has a broad insulating chamber, which (despite the tip being of steel) enables quick-setting plastic (like PBT or POM) and also not easy flowing plastics, like PC, to be processed. The torpedo tip (5) has the shape of a narrow cone (this restricts the heat supply to the gate) and a narrow insulating chamber, which is better suited to processing of slow-setting plastic (like PS). In view of its dimensions, this design may also be utilised in the event of restricted space in the gate zone. The shape of the gate entry has a similar impact to that of the torpedo tip shape. An entry of shape A in **Figure 4.21** is suited to plastics with a wide range of processing temperatures, while an entry of shape B in **Figure 4.21** gives better insulation of gate and tip and is suitable for plastics with a narrow range of processing temperatures (like PA or PBT). The insulating bushing (3) enables the thickness of the frozen layer of melt to be reduced, and it is recommended for use when colour changes are anticipated. The insert with gate (6) is used for filled and reinforced plastics.

Colour change problems are eliminated by the use of additional external heating of the bushing and insulating chamber (**Figure 4.22**). The additional bushing heating is switched on for a moment before commencing purging. This causes the frozen layer to melt partially and be purged, particularly in the gate zone. Following the colour change the external heating is switched off, and the residual thin layer is totally covered with new melt.

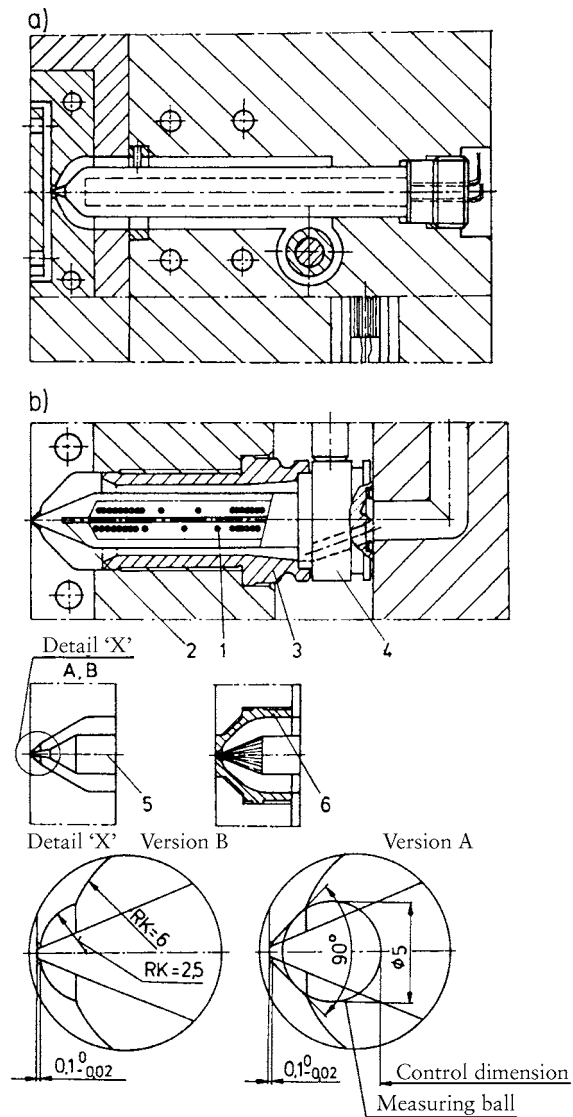


Figure 4.21 Examples of tip nozzles with heated torpedo

a - torpedo (Reproduced with permission from D-M-E Belgium); b - torpedo (Reproduced with permission from Dynisco Hot Runners); A, B - versions for different types of plastic;

A - with medium to broad range of processing temperatures, e.g., PP, PE, POM, PS, PC, PPU, ABS; B - with a narrow range of processing temperatures,

e.g., PA, PBT - glass-fibre-reinforced; 1 - coil heater, embedded; 2 - thermocouple; 3 - insulation bushing; 4, 5 - torpedoes with various tips; 6 - body with gate. (RK - Radius)

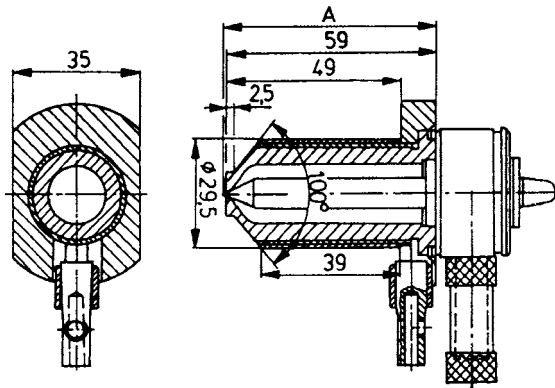


Figure 4.22 External heating of nozzle with torpedo, facilitating colour change
(Reproduced with permission from EWIKON Heißkanalsystem GmbH & Co. KG)

Nozzle with pulse-heated torpedo. This type of nozzle has made it possible to control the thermal closure of a gate. The nozzle (Figure 4.23a) is heated in two zones by a low-voltage current [8]. The torpedo is fitted with a 24V, 3A coil heater, while the tip is heated by an 8V, 12A current. Control of heating is based on regular heating of the tip synchronised with the injection process (c). Engagement of tip heating for about 3 seconds prior to commencement of injection causes a rise in tip temperature and melting of the plug of material in the gate. Switching off the heating (fully or partially) after the end of the holding phase causes rapid freezing of the gate as a result of cooling of the mould. The tip acts as a thermal valve with local temperature variation without any risk of overheating the melt in the nozzle.

This kind of nozzle may be used for most plastics, with the exception of plastics with flame retardants, PUR and elastomers.

Another example of nozzles with controlled thermal closure is the torpedo with low voltage heating (5V) (Figure 4.23d). An increase in heating power causes a rapid temperature rise at the torpedo end up to the processing temperature, and opening of the gate. A reduction in heating power causes rapid removal of heat from the torpedo end via the ribs that make contact with the torpedo body or with the mould plate, and closure of the gate.

Thermal closure effectively prevents gate stringing and reduces the vestige height. This system operates with a cycle of over 15 seconds.

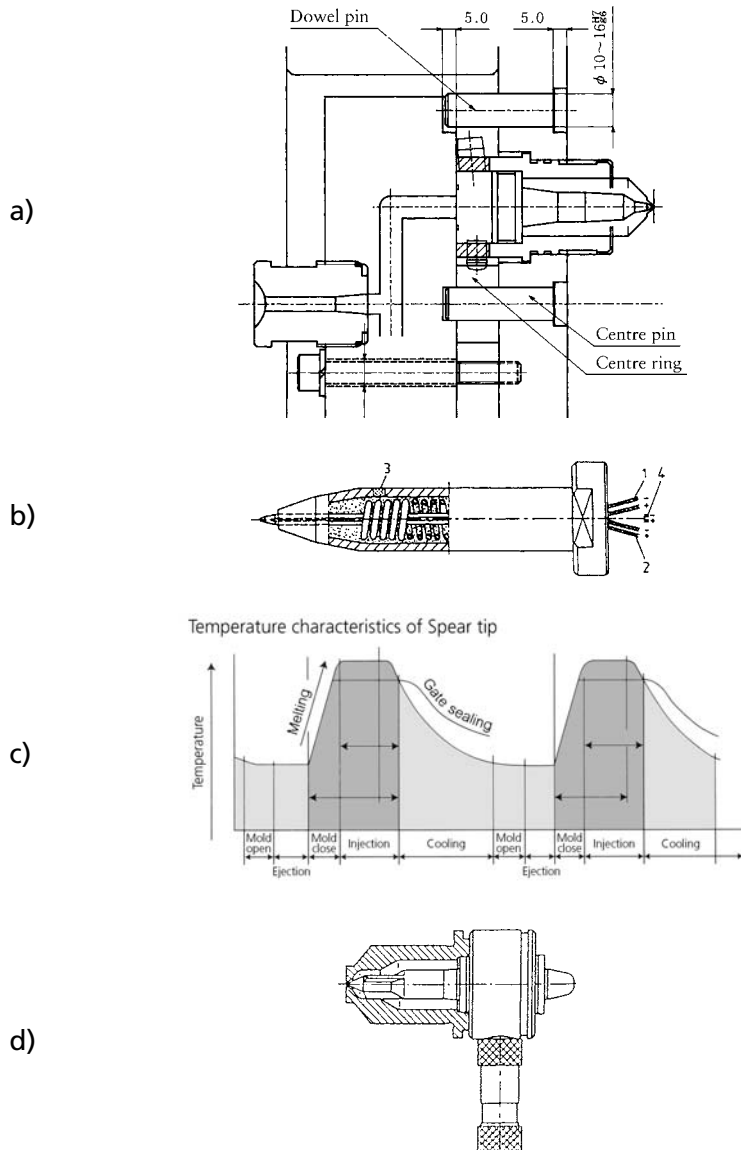


Figure 4.23 Nozzles with controlled thermal closure

a - torpedo installed in manifold (Spear System); b - torpedo structure; 1 - torpedo heating; 2 - periodic heating of tip; 3 - thermocouple; 4 - thermocouple leads; c - tip temperature control (*Reproduced with permission from Eastern Plastics Machinery Ltd.*); T_w - tip temperature on injection; T_f - melt flow temperature; T_z - tip temperature in frozen-off gate; t_c - cycle time; d - torpedo (*Reproduced with permission from EWI KON Heißkanalsystem GmbH & Co. KG*)

Nozzles with heat-conducting tip. Depending on their casing design, these nozzles feature various possibilities for attachment of the tip. The designs most commonly used are:

- long thin tip fastened to the rear part of the nozzle;
- short tip (mini-torpedo) fastened to the front part of the nozzle.

In a nozzle of simple design (**Figure 4.24a**), a long tip is attached at the end of the nozzle and supported by ribs. The nozzle flange is insulated from the mould by a ceramic ring.

In design 4.24(b), a short torpedo is part of a screw-in insulating bushing. A copper core inside the torpedo helps to feed heat to the gate. At the same time the steel jacket of the torpedo protects it from abrasion. This nozzle is suitable for all plastics.

A similar tip nozzle with mini-torpedo with helical channel 4.24(c) allows faster colour changes by forcing the melt stream in the insulating chamber to rotate.

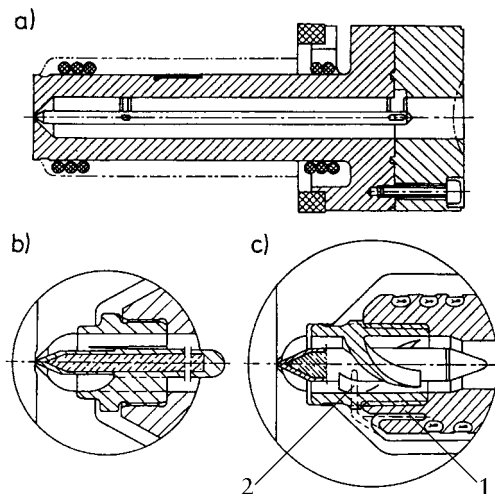


Figure 4.24 Examples of tip nozzles with conducting tip (torpedo)

a - with supported tip (Reproduced with permission from EOC);
b - with torpedo with copper core; c - with torpedo with copper core and helical runner (Reproduced with permission from Mold-Masters; US Patent 5,284,436 [9] and US Patent 5,318,434 [10]); 1 - nozzle thermocouple (control); 2 - torpedo thermocouple (readout only).

Nozzles with channel ending in a tip. Figure 4.25 a shows a nozzle with integral tip - the tip is part of the nozzle casing. The melt flows round the tip which is part of the casing via three parallel channels. The insulating chamber in the mould plate indicates that this nozzle is intended for amorphous plastics.

In the classic and most commonly encountered design (Figure 4.25b), the melt is fed by a central channel as close as possible to the termination of the tip, then flows through three holes lying at an angle to the insulating chamber, running round the actual tip end. Uniform heat distribution from heater to casing is ensured by the use of a copper/beryllium bushing.

In two designs (Figures 4.25c and 4.25d) the nozzle with insulating chamber in the body is fitted with a replaceable gate insert, with a length allowance which enables the nozzle to be adapted to the shape of the cavity. The nozzle tip is also replaceable - this makes it easier to change a worn tip or change the tip material, while the shape of the insulating chamber makes it easier to flush out.

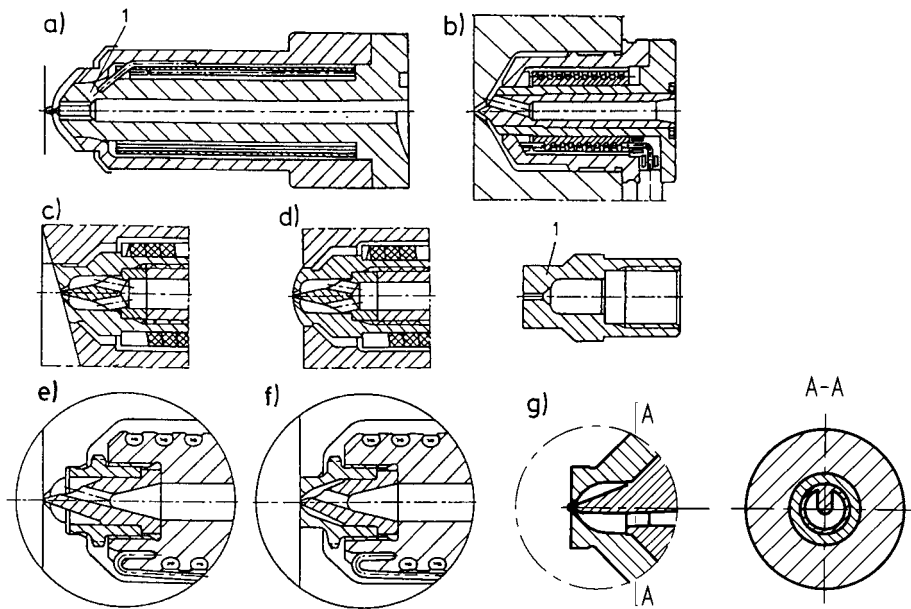


Figure 4.25 Examples of tip nozzles with tip-terminated channel

- a - nozzle with integral tip (Reproduced with permission from PSG Plastic Group GmbH); b - nozzle (Reproduced with permission from PSG Plastic Group GmbH); c, d - nozzle (Reproduced with permission from Jet Heisskanalsystem GmbH & Co. KG); 1 - tip (semi-finished product); e - nozzle with bimetallic tip; f - nozzle; (e & f Reproduced with permission from Mold-Masters); g - nozzle with tip in form of rib (Reproduced with permission from Hasco)

Bimetallic nozzle with replaceable tips: heat-conducting tip and insulating bushing (Figure 4.25e), also has a small insulating chamber making colour changes easier. Recommended for amorphous plastics with an injection temperature below 300 °C and polyolefins. Using a nozzle of this kind with bushing introduced directly into the mould cavity 4.25(f), a higher gate temperature may be provided; it is recommended for crystalline plastics with an injection temperature below 300 °C and, with some restrictions, for amorphous plastics.

Tip nozzles cause a separation of the melt stream past the tip in the channel, which then recombine after passing the tip, i.e., when it is already in the mould cavity. In some applications (including processing of ABS and thermoplastic elastomers, or where there are metallic or nacreous pigments), this causes perceptible join lines to appear on the surface of the moulding. To eliminate this flaw, a nozzle was designed with a tip which is a termination of a lateral rib and a U-shaped insulating chamber (Figure 4.25g). The fact that the nozzle is made from molybdenum enables quick-setting plastics to be processed (such as PA, POM, PBT) and plastics of the high temperature group.

Multiple tip nozzles have a single temperature control zone for all gates, which may restrict their use. Advantages are:

- smaller spacing between injection points than when individual nozzles are used;
- elimination or simplification of manifold design;
- lower price per injection point.

From the economic aspect, these nozzles have solved the problem of injection of very small products and precision products requiring the use of multiple gating, e.g., small gear wheels.

In a multi-tip nozzle (Figure 4.26a) the melt is delivered to each insulating chamber from a radial channel, and flows past small tips which may be made of various materials, depending on the material being processed. The tips are installed in a single heated copper/beryllium block.

In nozzles of type (b), the melt is supplied to the insulating chambers through holes in the tips (as in the design shown in Figure 4.25e). The purging distance for the residual melt is shorter.

Multiple tip nozzles may also be supplied as intermediate products with a termination in the form of a replaceable copper alloy head (intermediate product). This gives the user broad freedom of application in terms of the location and angling of the screw-in tips (Figure 4.27). The nozzle head is heated by conduction, and this means the nozzle should

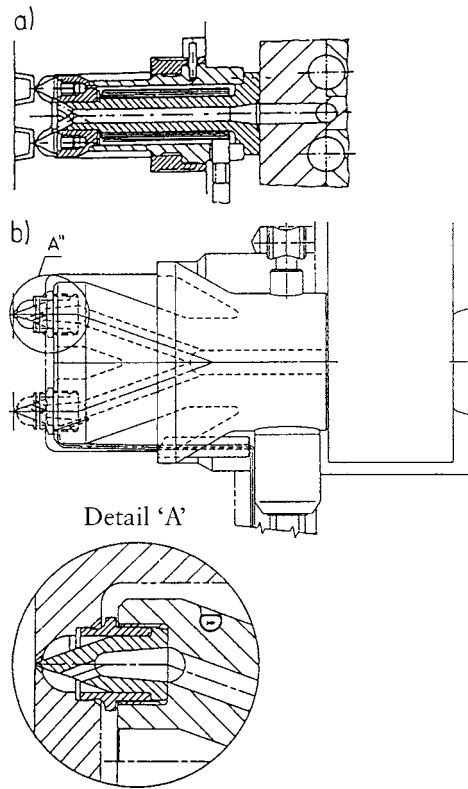


Figure 4.26 Examples of multi-tip nozzles

- a - nozzle (*Reproduced with permission from PSG Plastic Group*);
b - nozzle (*Reproduced with permission from Mold-Masters*)

be primarily used for easily-processed plastics; in the application example 4.27(b), a PC moulding may be successfully injected.

An example of an HR system with multiple tip nozzles is shown in **Figure 4.28**.

The design of the multiple nozzle with tips arranged in series (**Figure 4.29**) means that a set of such nozzles may be used in slide moulds, for example, or where a very small injection point spacing is required (in the manufacture of mouldings for microelectronics).

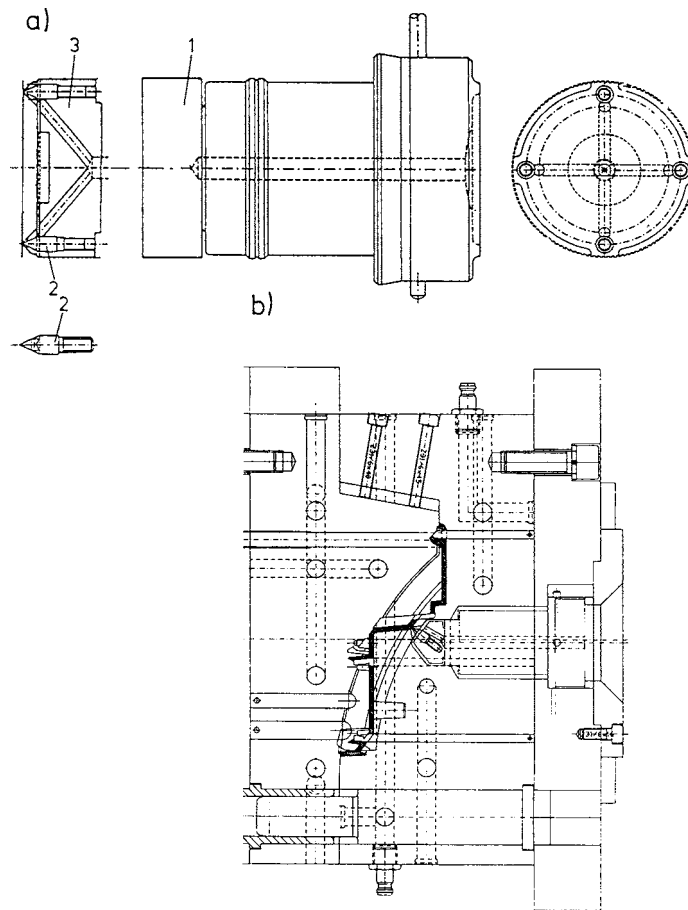


Figure 4.27 Multi-tip nozzle

a - semi-finished nozzle; 1 - head; 2 - tip; 3 - installation method (*Reproduced with permission from Roko. © Roko GmbH*); b - example of adaptation to angled injection (*Reproduced with permission from Stroja. © Stroja AB*)

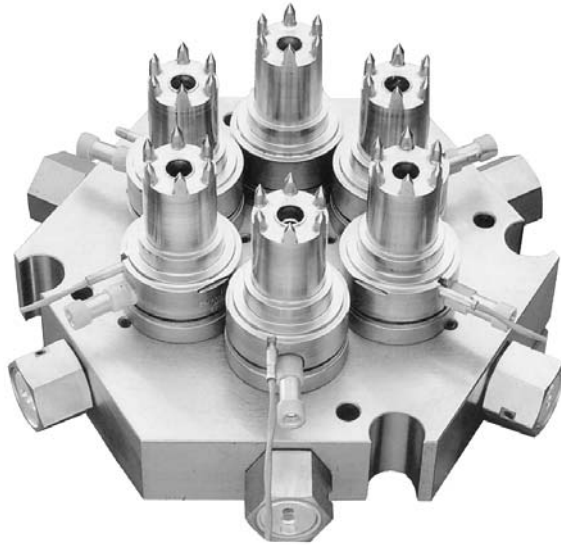


Figure 4.28 HR system with six-point tip nozzles for 36-cavity mould
(Reproduced with permission from Günther Heißkanaltechnik GmbH.
© Günther Heißkanaltechnik GmbH)

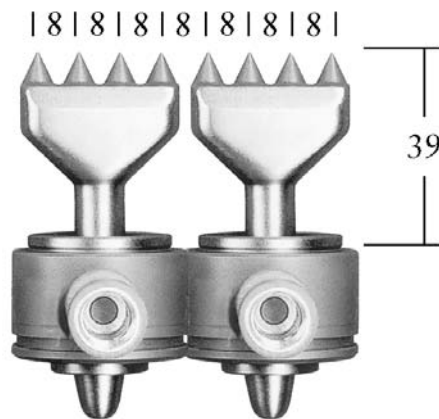


Figure 4.29 Set of four-point tip nozzles in comb layout with 8 mm pitch
(Reproduced with permission from EWIKON. © EWIKON Heißkanalsystem
GmbH & Co. KG)

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Use of multi-tip nozzles is, however, subject to numerous restrictions. The common insulating chamber gives rise to considerable forces associated with the effect of the melt pressure (Figure 4.30a).

A colour change may also cause problems, because the melt flows by a set route, the shortest, and the dead spots are substantially larger than in other designs (Figure 4.30b). When POM plastic in particular is being injected, use of several small but quite separate insulating chambers is recommended (Figure 4.30c).

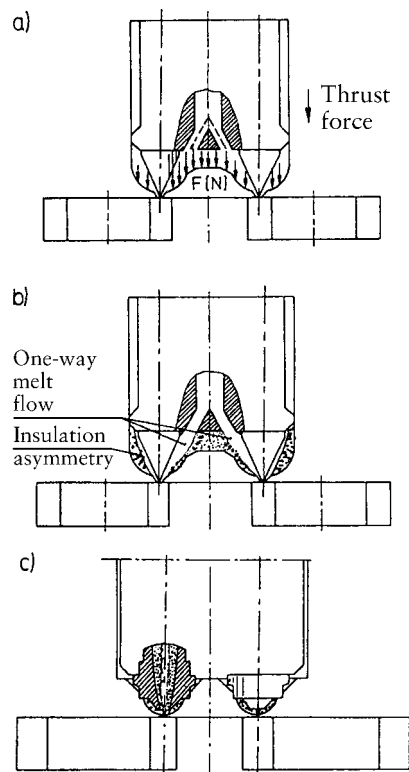


Figure 4.30 Analysis of multi-tip nozzle selection for moulding of small rollers out of POM [10]

a - forces acting on cavity plate with common insulation chamber (F = force, newtons); b - one-way melt flow in common insulation chamber; c - individual insulation chambers of multi-tip nozzle (*Reproduced with permission from Plastverarbeiter, 1997, 48, 4, 56, Figure 2. © 1997, Hüthig Verlag*)

Figure 4.31 shows the use of a tip nozzle with several points to mould a roller wheel of PA. To avoid the roller turning oval, the melt had to be delivered through multiple points.

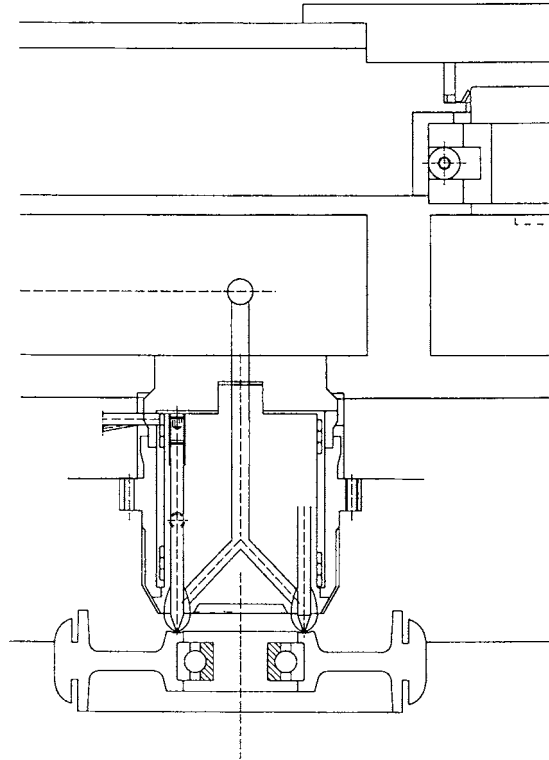


Figure 4.31 Application of 4-point tip nozzle for moulding of an idler roller from PA 66
(Reproduced with permission from EOC Normalien)

The position of the tip in the gate in full-body nozzles with bodies is set by the nozzle manufacturer, whereas in partial-body nozzles with a gate in the mould, the tip position depends on the precision of manufacture by the mould manufacturer. Nozzle manufacturers most commonly recommend siting the tip end (in a heated state) level with the cavity surface (**Figure 4.32a**).

The thermal expansion of the nozzle must therefore be taken into account (see Chapter 4.5). Withdrawing the tip inside the gate (b) causes a tall vestige to be left, while introducing

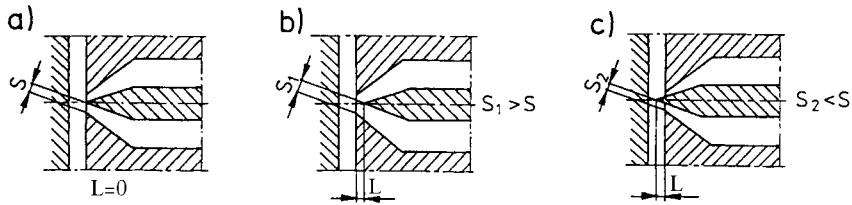


Figure 4.32 Tip position in gate

a - normal position; b - withdrawn tip; c - extended tip; S - annular gap;
L - tip positioning.

the tip into the cavity (c) causes throttling of the melt flow, with a risk of it burning, an ineffective holding phase and so on.

Gate adjustment. Adjustments to the diameter of a tip nozzle are always made on the insulating chamber side by increasing the entire taper (Figure 4.33).

An adjustment on the mould cavity side, based on making (or enlarging) a cylindrical hole, makes for only a slight enlargement of the gap, but the sprue height is increased.

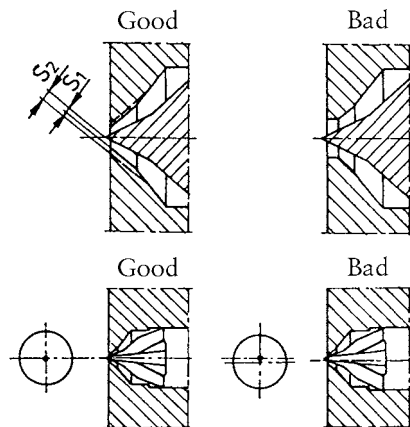
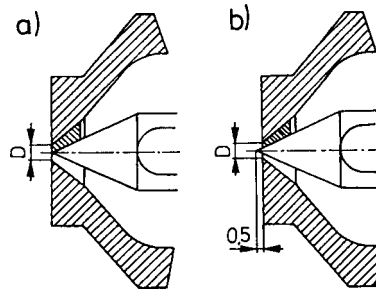


Figure 4.33 Optimisation of annular gate aperture

a - way of adjusting gate diameter; S_1 , S_2 - gap before and after adjustment;
b - coaxiality of gate and tip



Material	D gate diameter, mm	Pressure loss, MPa	
		nozzle a	nozzle b
PC (Makrolon 2800)	1.0	18.3	32.6
	1.8	6.3	8.7
PE (Lupolen 1810)	1.0	2.6	4.1
	1.8	1.3	1.7

Figure 4.34 Pressure losses in the annular gate [14]

(Reproduced with permission from *Plastverarbeiter*, 1988, 39, 9, 157, Figures 3 and 4.
© 1988, Hüthig Verlag)

A non-coaxial position of the tip in the gate causes throttling of the flow and a rise in the sprue height.

Pressure losses in the gate in tip nozzles are greater than for other nozzles because of the annular nature of the flow and the tendency towards minimisation of the gate size. It may be said, roughly speaking, that the pressure loss for PA 6 in a tip nozzle is around 40-50% greater than in an open nozzle of the same gate diameter [13].

Figure 4.34 shows the pressure losses for PE and PC depending on the gate diameter and tip position. The magnitude of these losses indicates the importance of correct selection and precision of manufacture of the gate.

4.1.4 Shut-off nozzles

Shut-off nozzles were developed with large-diameter gate designs in mind, and also with the idea of eliminating the undesirable vestige left by the sprue (see Chapter 4.1.1). In the nozzle, the gate is closed by a moving pin when the set holding time has elapsed. Control

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of nozzle closure makes reproducibility of an effective holding time, and thus of the degree of packing of the melt, possible, and this in turn provides an improvement in dimensional precision in the moulding. Because gate closure may be finished before solidification of the moulding, use of a shut-off nozzle often enables the cycle time to be reduced, in comparison with an open nozzle.

In contrast to other nozzles, a shut-off nozzle leaves no vestige, just a round mark from the pin. This is why it is used to manufacture products with high surface quality requirements.

One consequence of the relatively large gate diameter is a fall in pressure losses, together with a reduction in shear stress and friction heat, which cause damage to the molecular structure of the plastic. As a result, use of a shut-off nozzle enables materials with a low shear resistance or containing additives that are shear-sensitive to be more easily processed. Certain limitations may occur in the case of nozzles with a flow channel of zigzag shape. Generally speaking the products have better use properties, and this is particularly true of large products which require a very high injection speed to manufacture. The internal stresses in the moulding are lower than when a different type of nozzle is used, since a lower holding pressure may be employed. There is no risk of the melt drooling or stringing. The gate diameters employed are 1-6 mm; the diameter is normally twice the thickness of the moulding.

A shut-off nozzle is the only type of nozzle that allows HR to be used for injection moulding of structural foam, and for sequential and cascade moulding.

Closure. Nozzles with a tapered or cylindrical shut-off closure (**Figure 4.35**) are used:

- for tapered closure 4.35(a), the pin rests with its tapered end on the gate, causing a tight closure of it. The gate may not, however, be loaded with the full pin closure force, since fracture may occur, and the gate zone material may even be ripped out. Because of this, the pin length must be set precisely in a mould heated to operating temperature (with a preliminary pin holding force corresponding to a length excess of 0.02 mm in the forward position of the piston).
- Theoretically the pin may give poor gate closure during injection of plastics with a mineral filler, because too great a pin closure force may cause compaction of the filler at the contact surface. Manufacturers using this type of closure do not confirm that such cases occur;
- for cylindrical closure 4.35(b); the pin, with a cylindrical end, is introduced into the gate (which may be cylindrical or tapered) without applying any mechanical loading to it. Gradual abrasive wear on the gate aperture, however, gives rise to a more visible mark left by the gate.

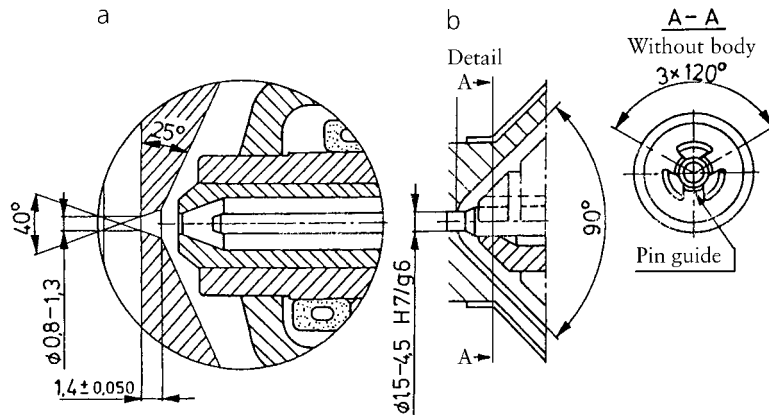


Figure 4.35 Ways of closing the nozzle

a - with a tapered closure (*Reproduced with permission from Thermoplay. © Thermoplay s.r.l.*); b - with a cylindrical pin H7/g6 - H7 is hole tolerance, g6 is shaft tolerance, (THERMOJECT-II). (*Reproduced with permission from PSG Plastic Group. © PSG Plastic Group GmbH*)

Despite mechanical gate shut-off, there is a problem with the melt freezing in the gate, just as with other types of nozzle.

The use of partial-body nozzles is therefore recommended (**Figure 4.36a**) to inject amorphous plastics, and full-body nozzles (**Figure 4.36b**) to inject semi-crystalline plastics. In the case of partial-body nozzles, the gate is located in the mould cavity, and is consequently relatively cold, so that premature freezing could occur during processing

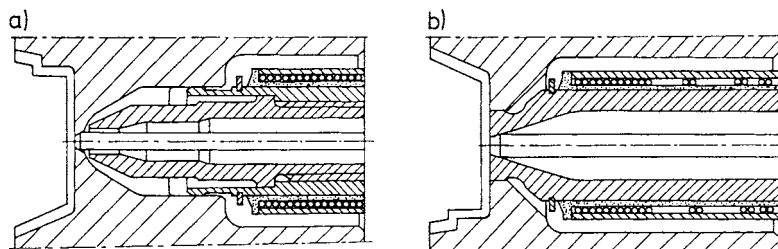


Figure 4.36 Comparison of design of partial-body (a) and full-body (b) and shut-off nozzles used depending on the plastic structure

(*Reproduced with permission from Husky Injection Moulding Systems. © Husky Injection Moulding Systems*)

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of crystalline plastics. This would make entry of the pin into the gate impossible, and a sprue would appear on the moulding surface. In the case of full-body nozzles, the nozzle face is hot, and when amorphous plastics are processed, creasing may occur, or even damage to the moulding surface contacting the nozzle.

In addition, specific requirements regarding cooling are made of shut-off nozzles:

- to prevent a matt impression, or even adhesion of the pin to the moulding, the face of the shut-off pin must be sufficiently cool. If a gate is located in a mould cavity, a shut-off pin is cooler;
- the fluidity of the melt in the insulating chamber, (i.e., the melt temperature) must be high enough to allow entry and retraction of the pin (closure and opening of the nozzle). This problem may occur when quick-setting crystalline plastics, e.g., POM, or not easily flowing plastics, e.g., PC, are injected, and when the cooling time is long.

The casing of a partial-body nozzle used for high temperature plastics should be made of a material with high thermal conductivity to prevent freezing of the plastic before the gate, e.g., when PC is being injected through a nozzle with a steel casing, the pin may become captured in the solidified melt.

The wide variety of designs for the front zone of the nozzle has arisen because of the need to adapt to different material properties and types of product. **Figure 4.37** shows different types of nozzle with replaceable inserts.

The full-body shut-off nozzle (a) is designed for the processing of quick-setting crystalline plastics, e.g., PA, PAEK, PEEK, POM, PPA, PPS and others. Proper heat supply to the gate prevents gate freezing before the holding time is completed, and facilitates the essential final compaction of the material.

Nozzle design 4.37(b) is intended for the processing of amorphous and slow-setting crystalline plastics. The pin has a cylindrical end and is guided in an insulating bushing. The helical shape of the guide ribbing enforces a rotation of the melt stream and gives easier flushing of the insulating bushing channel.

The nozzle design with a bimetallic insert 4.37(c) features an insulating chamber with a very thin melt insulating layer. An external titanium alloy bushing provides additional insulation improvement while at the same time giving very good cooling of the gate. The low mould temperature does not affect the nozzle temperature, and means that the nozzle may be used to process all amorphous plastics, including changes of colour, and to produce thin-walled mouldings with high-speed moulds.

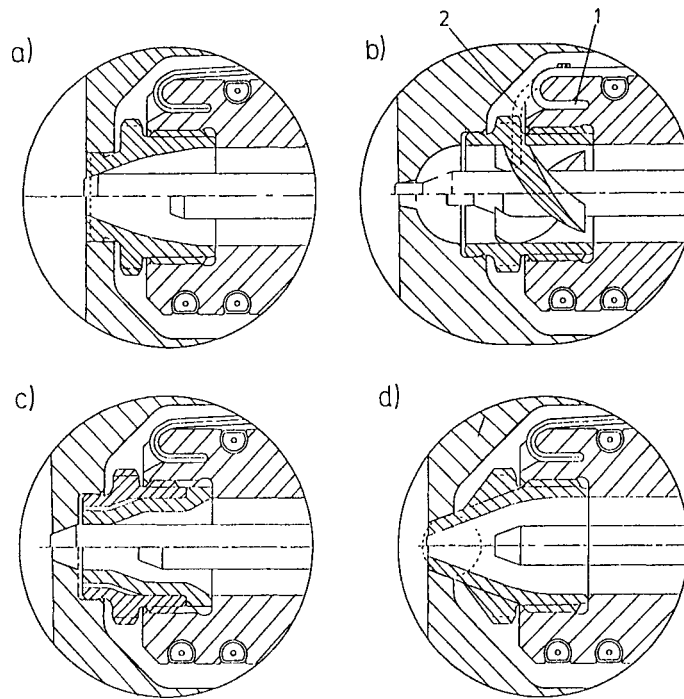


Figure 4.37 Design versions of a shut-off nozzle with replaceable inserts

a - with guiding insert; b - with cylindrical shut-off; c - with bimetallic insert; d - with insulating insert (*Reproduced with permission from Mold-Masters, US Patent 5,346,388 [4]*); 1 - nozzle (control) thermocouple; 2 - tip thermocouple (readout only).

In nozzle 4.37(d), the titanium insulating bushing introduced into the cavity means that the gate has a higher temperature. This nozzle is recommended for the processing of quick-setting crystalline plastics with frequent colour changes, and also for processing thick-walled mouldings requiring a long cycle time. Because of the ease with which a worn gate may be replaced, it is used to process reinforced and filled plastics.

Drives. The following shut-off pin drives are used:

- spring;
- pneumatic cylinder;
- hydraulic cylinder.

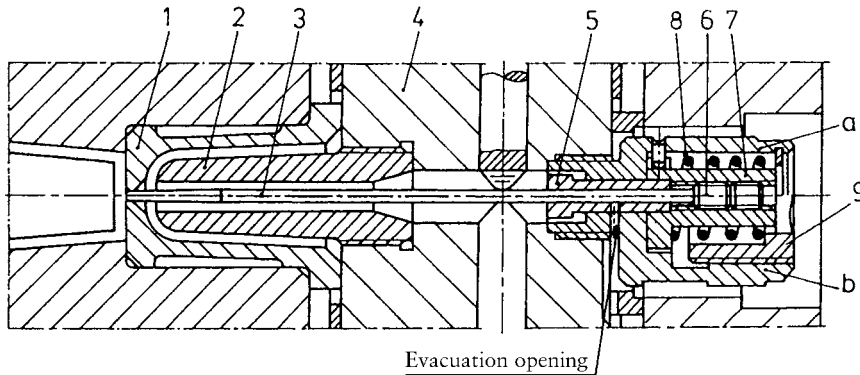


Figure 4.38 Spring drive to pin

a - without regulation; b - with closure force regulation; 1 - bushing with gate; 2 - copper beryllium guiding insert; 3 - shut-off pin; 4 - manifold; 5 - pin guide; 6 - pin position adjustment screw; 7 - pin body; 8 - spring; 9 - spring tension regulator bushing (*Reproduced with permission from Hasco Normalien. © HASCO Normalien Hasenclever GmbH & Co.*)

The type and implementation of the drive depends to a large extent on the siting of the nozzle. In a manifold nozzle, the cylinder or spring may be located behind the manifold, and may drive the pin directly. In a central nozzle the cylinder is normally located alongside the nozzle and drives the pin via a lever, a traverse or a gear system.

Spring drive. This is the simplest and cheapest drive (see **Figure 4.38**). The spring is used to close the nozzle, while opening takes place through the pressure of the melt in the injection phase.

The pin closure force is around 160 Pa, while opening takes place at a melt pressure of about 8 MPa. At a temperature of over 300 °C the spring force is liable to diminish. The body of the spring and pin guide are connected to the manifold, which renders the system independent of the effects of thermal expansion in the manifold.

The drawback to a spring-powered drive is indirect control. The gate is opened under pressure from the melt, which causes an ‘explosive’ mould filling, and is then closed as a result of a fall in the melt pressure in the channel. If the fall in pressure in the manifold channels in a multi-cavity mould is not uniform, there may not be simultaneous gate closure. Spring-driven nozzles are rarely used, but their low price makes them an interesting alternative for simpler technical applications.

Pneumatic and hydraulic drives provide independent control, but a greater amount of space is needed to install and cool the cylinder. In manifold nozzles the cylinder is usually set into the mould clamping plate, and in some designs it is made as part of the plate. The hydraulic cylinder temperature may not exceed 80-100 °C, so at high processing temperatures the clamping plate must be cooled. There are also systems with an extra plate accommodating a complete drive system, e.g., Mold-Masters systems.

The pneumatic drive is simpler than the hydraulic drive. Cylinder cooling is not usually needed, but the force generated by the cylinder is many times smaller. A pneumatic drive may be used primarily where low-viscosity materials are processed (processed at low pressure). One place it is used is in production halls for 'clean' products, where the presence of an oil mist in the air is unacceptable. The standard compressed air network (0.6 MPa) is used to power pneumatic drives.

When pneumatic cylinders are used, there is no risk of oil leakage along the shut-off pin to the manifold channel. Pneumatic drives may be used at higher temperatures than hydraulic drives.

Hydraulic drives. A special pump or else the injection moulding machine's own hydraulic system is used to power a hydraulic drive. The drive system comprises a pressure regulator (the pressures used are 2-8 MPa, depending on the manufacturer) and hydraulic manifolds. The injection machine control system is normally used to control the drive: the injection signal is used to open the nozzle and the end of holding phase signal to close the nozzle. Special time relays may also be used to provide control in a different sequence.

A manifold nozzle (see **Figure 4.39a**) is equipped with a hydraulic cylinder installed in the clamping plate and designed to operate at a maximum pressure of 5 MPa (closure force approximately 2,800 Pa). The pin runs in the manifold, giving the flow channel a rectilinear shape. One drawback, though, is the displacement of the pin away from the nozzle and cylinder axis (flexure) when there is a change in manifold temperature. The nozzle is closed by a cylindrical pin.

Manifold nozzle (b) has a large cylinder which may be driven either by compressed air at a minimum 0.6 MPa (closure force around 1 kN) or hydraulically at a maximum of 6 MPa (closure force around 10 kN). The pin is guided in the nozzle, so thermal expansion of the manifold does not affect the pin position. This design, though, leads to a zigzag flow channel. The nozzle is closed by a cylindrical pin in a tapered gate aperture.

Multi-point (2-4 point) shut-off nozzles have also appeared on the market, as both manifold and central nozzles. These nozzles may be used in multi-cavity moulds and for multi-point injection into a single cavity. The three-point manifold nozzle (see **Figures 4.40a and 4.40b**) is fitted with a single pneumatic/hydraulic cylinder driving pins set in a common mounting. In the design in **Figure 4.40c**, the pins of the four nozzles are driven by a similar single cylinder.

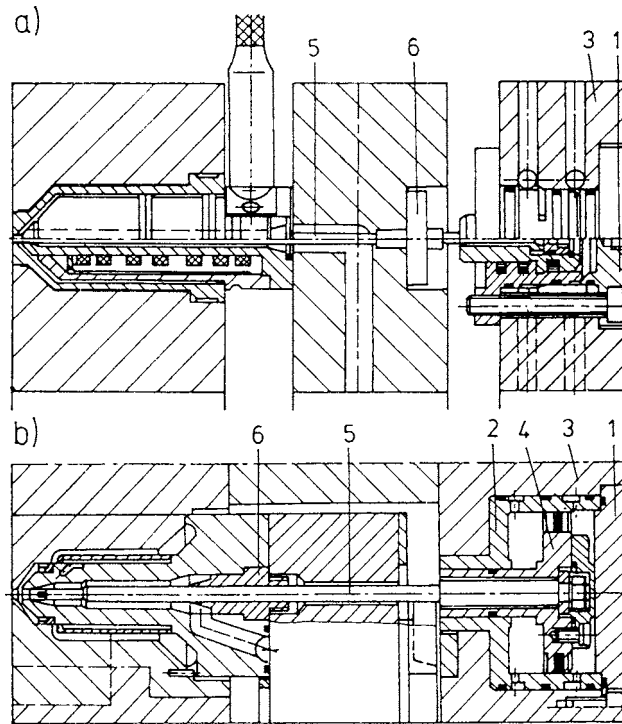


Figure 4.39 Manifold shut off nozzles

a - with hydraulic cylinder (nozzle is closed); b - with hydraulic-pneumatic cylinder (nozzle is open); 1, 2 - front and rear section of cylinder; 3 - clamping plate; 4 - piston; 5 - shut-off pin; 6 - pin guide (*Reproduced with permission from PSG Plastic Group.*

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Drive transmission designs (**Figure 4.41**) for central nozzles vary.

The nozzles (**Figure 4.41a**) is equipped with a centrally located cylinder with an annular piston, which may be driven by compressed air at a minimum of 0.6 MPa (closure force around 2 kN) or hydraulically at a maximum of 3 MPa (closure force around 10 kN). The drive is transmitted to the pin via a traverse cross beam. Because of its small length, this nozzle is also used in stack moulds.

In the case of the nozzle shown in **Figure 4.41b**, the hydraulic cylinder is installed with an articulation, and the drive is transmitted to the pin via a lever with a toothed segment and a rack.

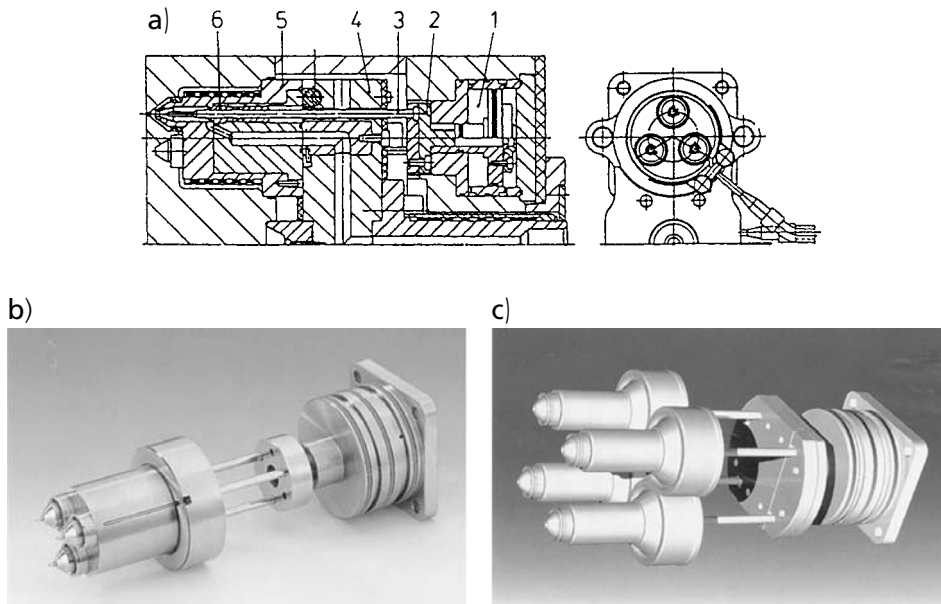


Figure 4.40 Three-point shut-off nozzle with pin drive by a common pneumatic cylinder

a - nozzle installation in manifold; b - nozzle with four injection points;
c - common cylinder for four separate nozzles; 1 - cylinder; 2 - pin mounting;
3 - shut-off pin; 4 - manifold; 5 - nozzle; 6 - pin guide

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Nozzles shown in **Figure 4.41c** are equipped with a 4 MPa hydraulic cylinder and a cylinder is a part of the mould plate. The drive is transmitted to the pin via an articulated lever.

The presence of a pin in the flow channel may cause join lines to appear on the moulding surface in some designs, like the tip in a tip nozzle. The greater the distance from pin end to gate during injection, the less the tendency for weld lines to appear. Some nozzles may operate with a cylinder with an extended opening travel. In the design shown in **Figure 4.42**, a side hydraulic cylinder is also used.

As in the previous case, the pin drive is transmitted by a lever, but the symmetrical channel eliminates a lateral force that could act on the pin and minimises abrasion by plastics with mineral fillers.

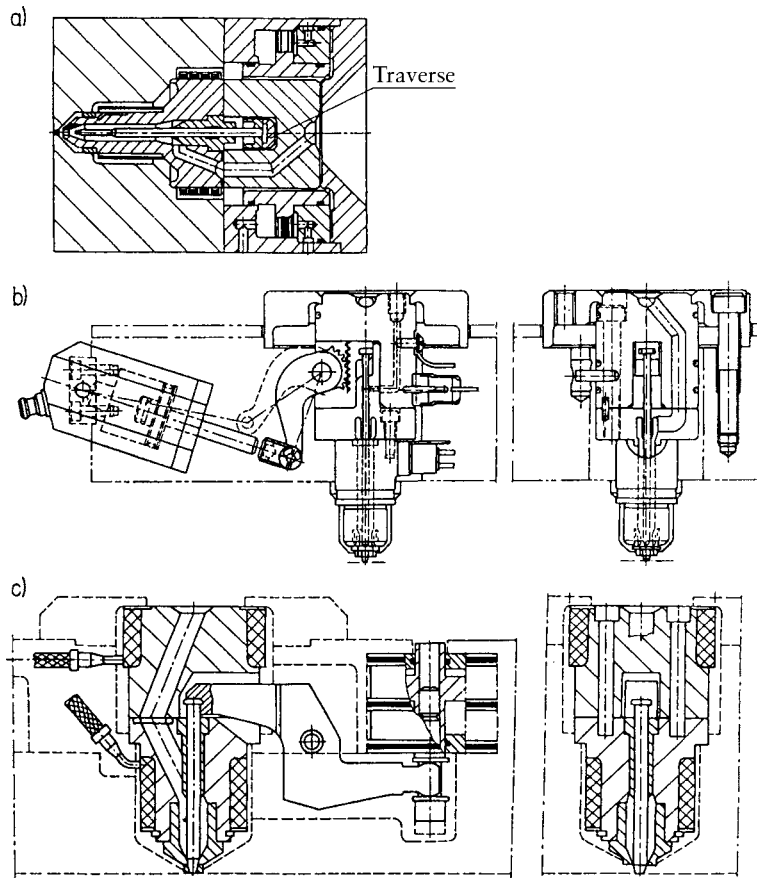


Figure 4.41 Central nozzles with pin drive transferred by

a - traverse (*Reproduced with permission from PSG Plastic Group.*

© PSG Plastic Group GmbH);

b - toothed lever (*Reproduced with permission from Mold-Masters;*

US patent 4,919,606 [15]);

c - lever.

(*Reproduced with permission from INCOE. © INCOE International*)

To avoid weld lines, nozzles have been developed with a pin situated at a slant and an integrated 0.8 MPa pneumatic cylinder (**Figure 4.43**).

The user should grind the pin end to fit it to the tapered aperture of the gate in the mould (grinding to take place together with the nozzle). During injection the pin is totally withdrawn from the flow channel, as a result of which the nozzle features the advantages

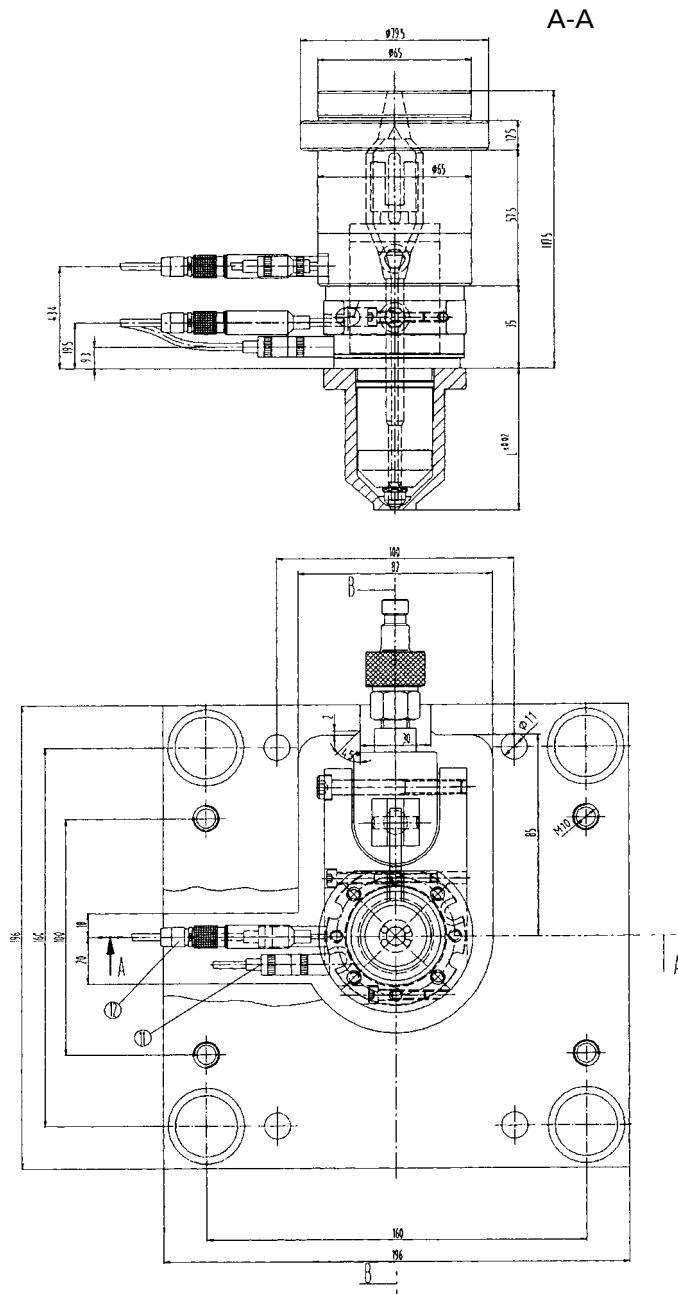


Figure 4.42 Central nozzle with pin drive via hydraulic cylinder lever
(Reproduced with permission from Günther Heißkanaltechnik GmbH.
© Günther Heißkanaltechnik GmbH)

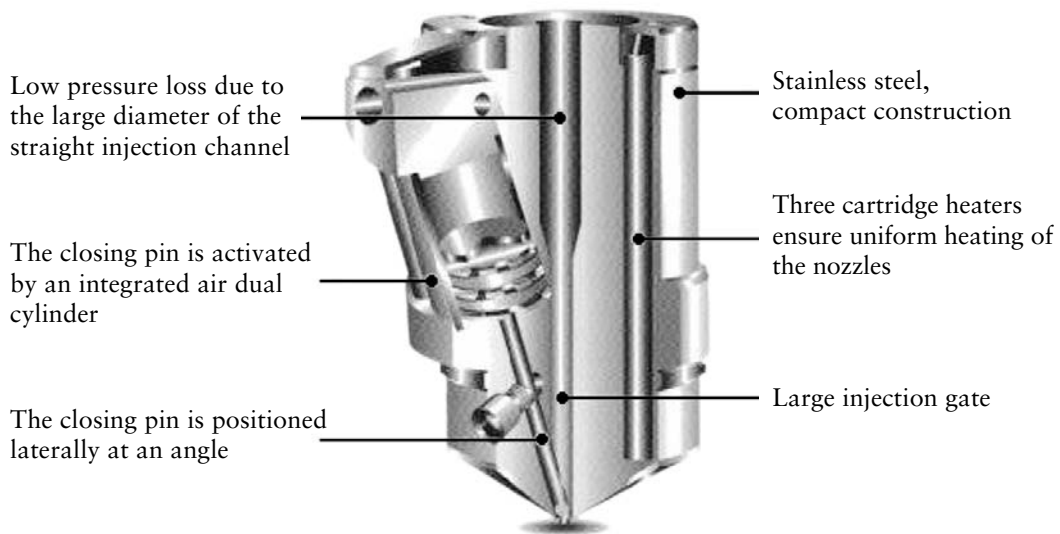


Figure 4.43 A straight injection channel shut-off nozzle
(Reproduced with permission from Guzzini Engineering)

of both a shut-off and an open nozzle. The use of this kind of nozzle is particularly recommended for injection of lenses and other optical products made of PMMA and PC.

In view of their compact design and relatively small installation height, this kind of nozzle may easily be used in stack moulds.

For moulds with injection points situated in a line, nozzles with a pin drive by a single hydraulic cylinder located at the side of the mould have been developed (see **Figure 4.44**).

The cylinder moves a rod with cams, and these in turn transmit movement to the pin holders. Inside the holder is a screw to adjust the initial tension of the pin. The cylinder operates at a pressure of up to 20 MPa and a temperature of up to 175 °C.

Figure 4.45 shows a mould for a battery housing with six-point injection. Shut-off nozzles are situated in a single row; their closure takes place hydraulically, while opening is driven by a set of springs. Instead of the standard sprue bushing (there was no place for it), a U-shaped gating block is used with a zigzag gating channel delivering the melt to an HR manifold. The manifold channel is deflected relative to the transverse axis of the mould. Mould filling balance is achieved through the use of sequential injection (see Chapter 8.1).

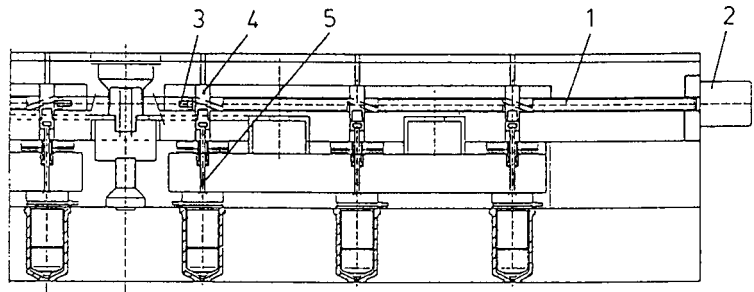


Figure 4.44 Manifold nozzles with pin drive via a set of cams travelling through a hydraulic cylinder

1 - rod with cam segments; 2 - cylinder; 3 - adjusting screw; 4 - cam; 5 - shut-off pin.

(Reproduced with permission from EOC Normalien)

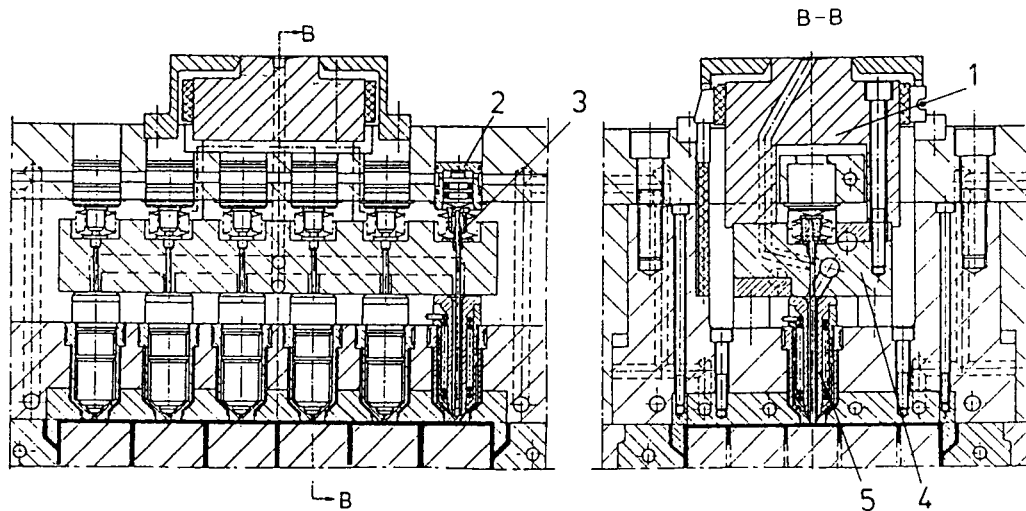


Figure 4.45 Mould for battery housing with six nozzles shut off hydraulically [16]

1 - gating block; 2 - hydraulic cylinder with one-way action; 3 - return spring;
4 - manifold; 5 - shut-off nozzle.

(Reproduced with permission from Kunststoffe German Plastics, 1985, 75, 12, 879, Figure 3. © 1985, Carl Hanser Verlag)

Pin guide. A shut-off pin may be guided and sealed in the manifold or nozzle, although in a piston it is installed with a clearance to allow for thermal expansion in the manifold. Practice has shown, however, that guiding the pin in the manifold creates a risk of fracture of a pin if it is captured in a piston, and increasingly nozzle designs have their own pin guide, with a zigzag flow channel as a consequence.

A pin guide with H7/g6 fit (hole tolerance/shaft tolerance) must on the one hand ensure that the pin can move, while on the other it must guarantee that melt cannot leak out. Providing a unilateral clearance for the pin of around 5 µm at an operating temperature in the order of 300 °C requires high-precision manufacture (lapping). Practice has meanwhile shown that some melt particles are only 2 µm in size. Manufacturers therefore use various anti-leak agents, such as, for example, transverse collector grooves, an evacuation hole to remove a leak from the transverse groove, silicone grease to seal the pin, etc.

The pin is brittle, as its hardness is around 54 HRC. To reduce the risk of pin fracture, in some designs soldering of the hard pin guiding section to the more ductile shut-off section is used. Lower pin hardness, however, reduces its abrasion resistance when material with a mineral filler is used. Some companies use pin with a titanium nitride or tungsten coating.

Shut-off nozzles are generally guaranteed against leakage up to 160 MPa, but only if a set temperature is not exceeded. At higher temperatures, the degraded polymer molecules get into the clearance gap and can cause pin seizure and immobilisation of the nozzle. Since the nozzle loses patency, incompetent operation may cause an increase in nozzle temperature and injection pressure, which may lead to instances of serious damage, or even ejection of the nozzle from the mould.

Mould filling control. An HR system with hydraulically or pneumatically closed nozzles has given rise to a new potential for controlling the mould filling process. These techniques are known as sequential and cascade moulding (see Chapter 8.1).

For injection of structural foams, use of a shut-off nozzle makes premature foaming impossible. A slight delay in nozzle opening facilitates ‘explosive’ filling of the whole cavity by a melt stream that is not foamed.

Restrictions on use. Alongside its advantages, use of shut-off nozzles is limited by the following factors:

- the use of hydraulic and pneumatic cylinders requires extra installation space and possibly extra cooling in the mould;
- use of a cylinder control system is required;
- skilled staff must be employed;

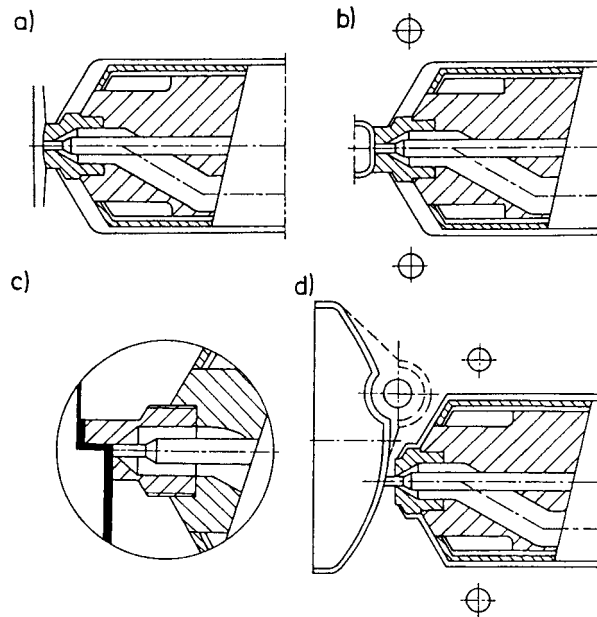


Figure 4.46 Examples of applications of shut-off nozzles
a, b, c - nozzles with shaped face; d - partial-body nozzle
(Reproduced with permission from Dynisco HotRunners)

- shut-off nozzles may not be used with an internally-heated manifold (EWIKON has resolved this problem by introducing external nozzle heating and heating of the manifold channel using two rods. This has created space for the shut-off pin);
- the high price of hydraulically or pneumatically closed nozzles.

Despite these restrictions, shut-off nozzles are increasingly used, particularly as controlled central nozzles. A few examples of their application are shown in **Figure 4.46**. The face of a full-body nozzle (**Figures 4.46a, b and c**) is shaped to match the cavity shape. In the case of a partial-body nozzle (**Figure 4.46d**), only the pin face needs machining.

4.1.5 Edge nozzles

Use of edge nozzles (nozzles for side gating) has made it possible to locate the gate on the side wall of the product. The vestige left by gate breakaway and the cavity filling characteristic are similar to those achieved with cold tunnel gating. The gate is situated opposite the core in

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order to break up the flow of melt and to break up the frozen plug from the gate. Gate location in the corner or on the convex wall of the product is recommended (see **Figure 4.47**) to ensure adequate mould wall strength and to remove heat from the gate zone.

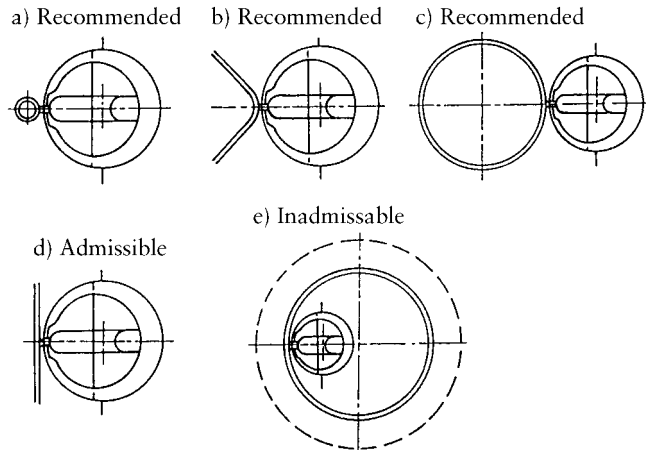


Figure 4.47 Principles for location of edge nozzles depending on shape of moulded item

a - for small-diameter moulding; b - into corner; c - for large-diameter moulding;
d - into straight wall; e - into moulding hole - weakening of cavity, incorrect heat removal.

(Reproduced with permission from Mold-Masters)

To achieve a 'clean' cut surface, particularly for thermoplastic elastomers, the gate taper angle should not exceed 15 degrees. The gate should not be located on thick parts of the moulding, since major shrinkage may draw melt out of the gate, causing a vestige on the moulding wall. The gate should not be located immediately behind a corner of the moulding for the same reason. The gate diameters used are 1-2.5 mm.

Edge nozzles are used both as central nozzles with one or more injection points, and as manifold nozzles, thus making it possible to design multi-cavity moulds with a reduced number of nozzles. Edge nozzles have enabled the economic problem underlying moulding of small products to be resolved, in much the same way as multi-tip nozzles did.

Edge nozzles may be divided into:

- open nozzles with insulating chamber;
- open contact nozzles;
- tip nozzles.

Open nozzles with insulating chamber. In the classic nozzle with insulating chamber located around the whole nozzle (see Figures 4.48a and 4.48b), the material left behind in the chamber is used for the thermal insulation of the nozzle from the mould.

Because of the relatively low gate temperature, good conditions were created for the injection of thermally-stable amorphous plastics with an injection temperature of less than 300 °C, and for injection of slow-setting crystalline plastics (like PE or PP). This type of nozzle is most commonly used to manufacture packaging featuring a short cycle time and where colour changes are infrequent. In both designs the melt flows via semicircular channels located in the nozzle face.

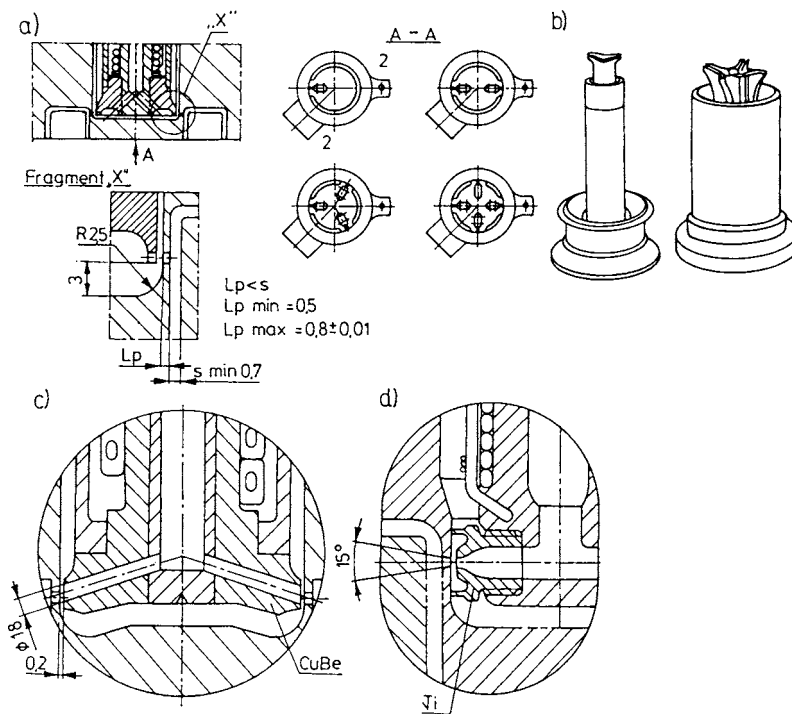


Figure 4.48 Edge nozzles with insulation chamber

a - nozzle with common chamber for all gates (*Reproduced with permission from PSG Plastic Group. © PSG Plastic Group GmbH*); b - two- and four-point nozzle - view (*Reproduced with permission from Husky Injection Moulding Systems. © Husky Injection Moulding Systems*); c - nozzle with common chamber for all gates and individual flow paths (*Reproduced with permission from Thermoplay. © Thermoplay s.r.l.*); d - nozzle with individual insulation chambers (*Reproduced with permission from Mold-Masters; US Patent 4,981,431 [17]*)

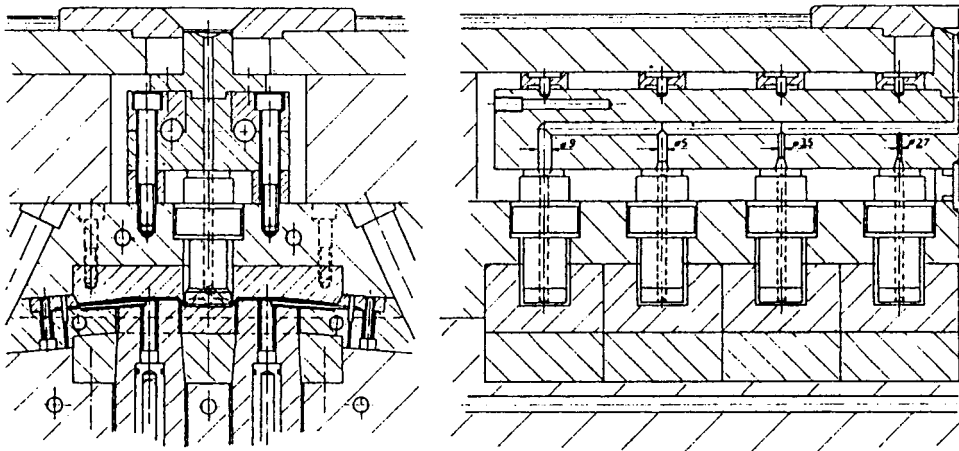


Figure 4.49 Application of open two-point edge nozzles in a 16-cavity mould for the production of aerosol caps [16] - rheologically balanced mould

(Reproduced with permission from Kunststoffe German Plastics, 1985, 75, 12, 878, Figure 4. © 1985, Carl Hanser Verlag)

When installing a central nozzle, the relatively large force ejecting the nozzle from the mould arising from the injection pressure should be considered.

In the case of a nozzle of type (**Figure 4.48c**), the flow channels are drilled in the front of the copper/beryllium nozzle and run to the gate via a gap around 0.2 mm wide, which improves melt delivery conditions.

The bushing which seals nozzles of type (**Figure 4.48d**) is contiguous with the mould wall. This design gives a higher gate temperature and is suited to processing of both amorphous and semi-crystalline plastics. Elimination of the large insulating chamber with its melt residue means that this nozzle may be used to process heat-sensitive materials and where there are frequent colour changes in amorphous plastics. Ejection of the nozzle from the mould by the melt pressure is prevented at the same time.

Figure 4.49 shows a 16-cavity mould with cavities lying in two rows, in which two-point open nozzles with an insulating chamber are employed. This design allows the number of nozzles to be halved. The manifold is rheologically balanced.

Open contact nozzles. In these nozzles, the nozzle face makes direct contact with the gate. At the point of contact, the gate has a high temperature (see **Figure 4.50a**).

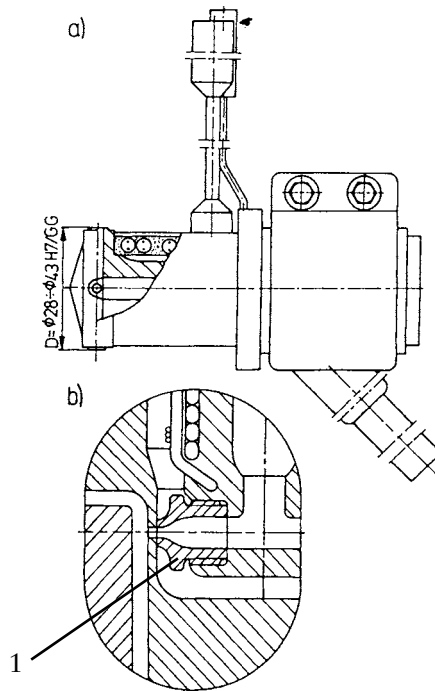


Figure 4.50 Open edge contact nozzles

a - four-point nozzle (*Reproduced with permission from Jetform. © Jet Heißkanal - System*);
 b - nozzle with sealing bushing; 1 - sealing bushing (*Reproduced with permission from Mold-Masters*)

The nozzle has a push fit in the mould aperture which is created by machining the diameter to a size depending on the temperature difference between the nozzle and the mould; sealing of the nozzle occurs at the operating temperature when the nozzle diameter swells as a result of thermal expansion. The nozzle with sealing bushing (see **Figure 4.50b**) is particularly recommended for processing of crystalline plastics, since the higher gate temperature prevents premature freezing.

Figure 4.51 shows an example of use of this kind of nozzle in a mould for shallow mouldings - the bottom of the nozzle insulating chamber is let into a recess in the core plate.

Tip nozzles. In recent years, tip nozzles for edge injection have also been designed. Because the tip is introduced into the gate, the length of the gate ceases to be a critical value, the cold plug in the nozzle is eliminated, and the mould wall has been thickened to 2-3 mm.

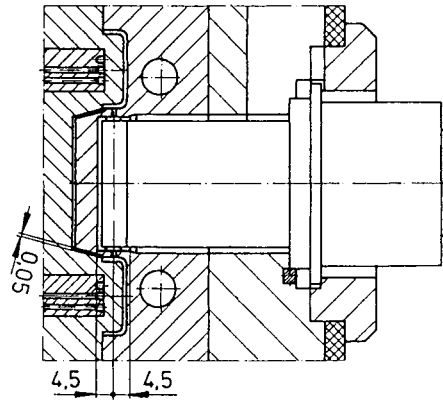


Figure 4.51 Example of application of edge contact nozzle for shallow mouldings in a two-cavity mould with central nozzle

(Reproduced with permission from Jetform. © Jet Heißkanal - System)

Use of a tip nozzle (see **Figure 4.52a**), however, necessitates the use of a split insulating chamber to make installation possible (introduction of tips into gates).

The halves of the chamber are clamped by keys. This nozzle is also suitable for processing PA, PBT and PC with glass fibre.

The design of nozzle (**Figure 4.52b**) features copper/beryllium tips that may be removed from the body, which means a special technique for installation in the mould and removal is needed. The tips (2) with auxiliary installation pins (4) should be located in the insulation chamber, and the nozzle body (1) is then placed on them. With the aid of nuts on the mandrels (4), the tips should be tightened up until they go into the grooves and onto the nozzle body pegs. Then the pin (4) should be unscrewed and the screws (3) introduced to replace it.

A system with internal heating (EWIKON) makes it possible to employ side gating with the aid of a manifold and standard tip nozzles located parallel to the parting line (see **Figure 4.53**).

This is possible because of the negligible thermal expansion of the system and the seal provided by the external layer of frozen melt in the channel. Mould assembly requires simultaneous insertion of manifold, nozzles and mould inserts.

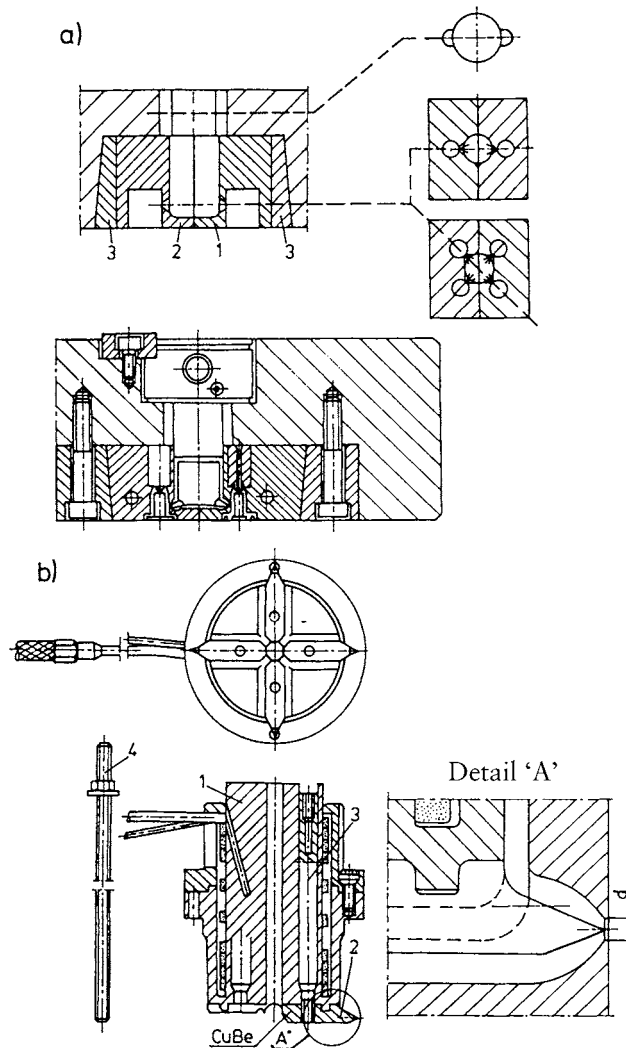


Figure 4.52 Edge tip nozzles

- a - nozzle with split insulation chamber in two- and four-cavity mould (*Reproduced with permission from Günther Heißkanaltechnik GmbH. © Günther Heißkanaltechnik GmbH*); 1, 2 - insulation chamber inserts; 3 - clamping keys;
 b - nozzle with tip inserts and method of installation in insulating chamber; 1 - nozzle; 2 - tip; 3 - clamping screw; 4 - setting screw
 (*Reproduced with permission from EOC Normalien*)

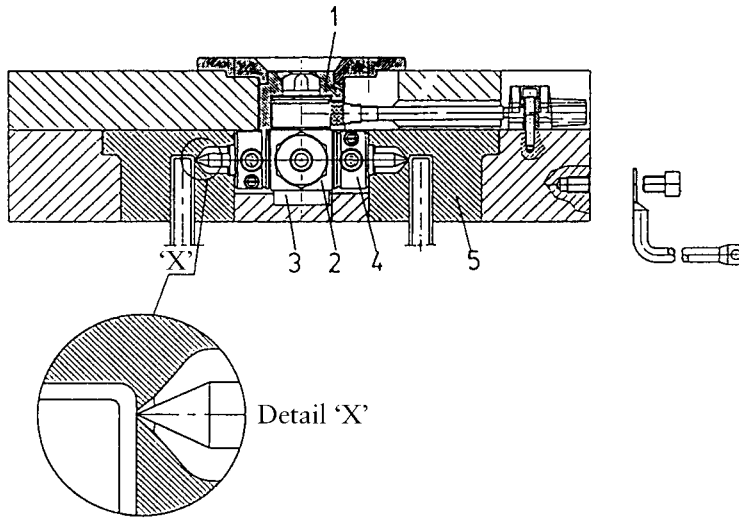


Figure 4.53 Edge gating effected using a manifold and tip nozzle located horizontally (parallel to the parting line)

1 - sprue bushing; 2 - manifold; 3 - manifold support; 4 - nozzle; 5 - mould insert
(Reproduced with permission from EWIKON. © EWIKON Heißkanalsystem GmbH & Co. KG)

4.1.6 Nozzle heating

Like manifold heating, nozzle heating may be divided into external, internal and mixed heating. In both types of heating, resistance coil or cartridge heating elements using 230 V AC or low voltage heaters operating on 5 V, 24 V or, less commonly, 15 V are employed.

The most common heaters are 230 V coil heaters, but some companies prefer low voltage heating, which has led to a miniaturisation of heating elements. Low voltage heaters give very even heating and allow precision temperature control.

One condition of maintenance of a constant melt temperature along the flow channel in the nozzle is excellent interaction between the heating system and the nozzle structure. This interaction is primarily governed by:

- the nature and siting of the heaters and their control;
- the nozzle design and selection of materials with suitable thermal conductivity;
- proper selection and installation of nozzles in the mould.

The way in which the above problem may be resolved is shown using successive modernisations of PSG Plastic Group nozzles as an example [17]. The problems associated with heating, heat losses and temperature distribution in the nozzles are discussed, and at the same time the complexity of the task of thermal optimisation of nozzles is made clear. Study of this example will assist the reader in evaluating the nozzles available on the market, and especially what are known as 'cheap' nozzles manufactured by the user himself.

Figure 4.54 shows three consecutive versions of a central nozzle (hot sprue bushing).

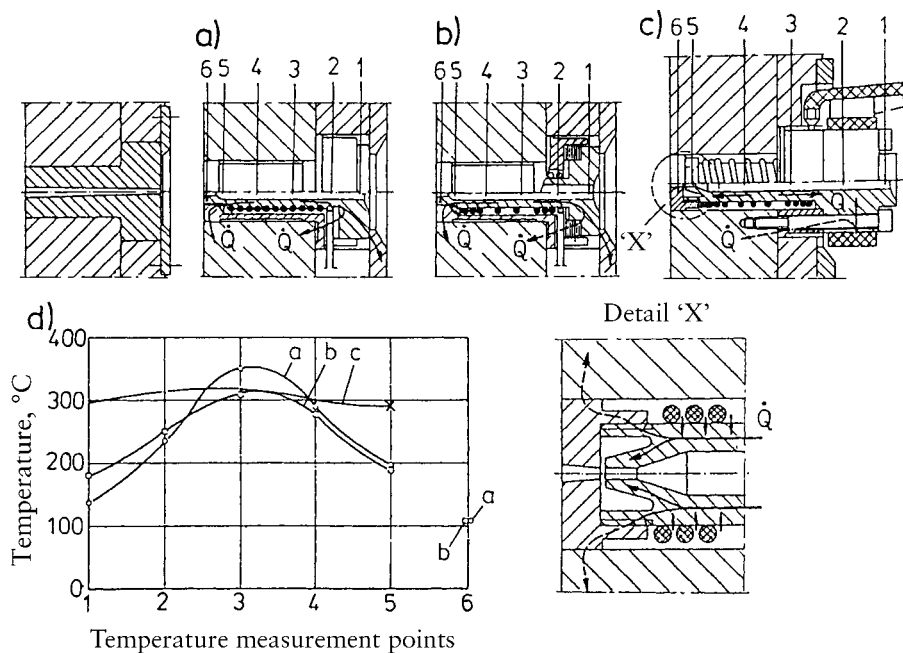


Figure 4.54 Successive stages of development of central nozzle [17]

a - first version of nozzle (hot sprue bushing), poor heat insulation from cold mould; $\Delta T @ 200\text{ }^{\circ}\text{C}$; b - second version of nozzle with improved heat insulation from mould and reduced heating in central zone; c - third version of nozzle with very good heat insulation and very good temperature distribution along melt flow path; detail 'X' - heat flow to mould; d - temperature distribution along flow path (measurement points 1-6) for nozzles a, b and c for a processing temperature of $300\text{ }^{\circ}\text{C}$ and a mould temperature of $30\text{ }^{\circ}\text{C}$.

(Reproduced with permission from R. Löhl, *Kunststoffe*, 1984, 74, 6, 312, Figure 3.
 © Carl Hanser Verlag)

The first nozzle version (**Figure 4.54a**) is a design with coil heater installed inside the split body with a thermocouple at the heater end face. The nozzle body is not insulated thermally from the nozzle casing and mould. The nozzle casing contacts the mould in five places, which causes large heat losses and a large temperature drop at both ends of the nozzle. At the set nozzle temperature of 300 °C and mould temperature of 30 °C, a temperature of 140 °C is attained at point 1, 350 °C at point 3 and 200 °C at point 5, and 100 °C at point 6, at the nozzle end face (see **Figure 4.54d**). The result of this uneven temperature distribution (difference in temperatures of over 200 °C) is frequent burning and decomposition of the melt in the central part of the nozzle, freezing of the melt in the gate zone and the rear section, and also adhesion of the moulding to a nozzle face that was too hot, or an extended cycle time because of slow cooling of the moulding in this zone.

The second version of the nozzle (**Figure 4.54b**) is a design with two improvements. The heater coil is elongated in the centre to reduce the relatively high temperature in the central part of the nozzle. In the rear section of the nozzle a ceramic ring is incorporated to provide thermal insulation from the cold mould. These adjustments led to a 30 °C rise in temperature in the rear section of the nozzle and a 40 °C fall in the central section, while in the unaltered front section of the nozzle no changes to the temperature curve are seen (see curve *b*) - the nozzle face temperature is still too high. The temperature differences are still too high for the processing of engineering plastics, though no problems occur with the processing of standard plastics (like PS or PE).

The third version of the nozzle (**Figure 4.54c**) is a design with highly significant improvements in the form of a gate insert with gate screwed onto the body. The screw joint acts as heat insulation, hence the heat losses via this route have been drastically reduced (temperature at point 5 - 290 °C). The insulation chamber between the nozzle body and the gate has the effect of reducing the nozzle face temperature to 80 °C. The rear section of the nozzle is supported on a tall spacer ring, fastened by screws to prevent a cooling action on the part of the register ring, and fitted with its own heater. The overall result of these procedures is a very even temperature distribution in the nozzle (see curve *c*) which has enabled engineering plastics, e.g., PA 66, PBT, PC, POM, PPO, PUR, etc., to be processed without difficulty.

Even higher demands, concerning the range of maintenance of a set temperature, are made of nozzles interacting with an HR manifold, since this is a precondition for achieving a cavity filling balance. **Figure 4.55** shows three successive manifold nozzle modernisation versions, again developed by PSG Plastic Group [28].

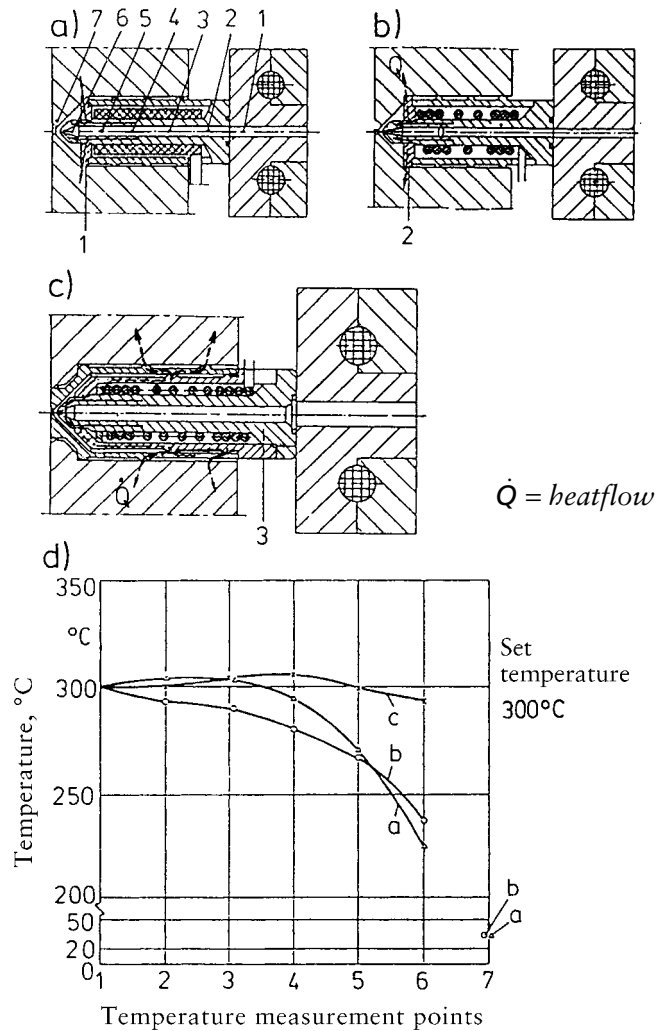


Figure 4.55 Successive stages of modernisation of manifold nozzle [18]

a - first version of manifold nozzle, poor heat insulation from cold mould;
 1 - steel support ring; b - second version of nozzle with improved heat insulation from mould and reduced heating in central zone; 2 - titanium support ring; c - third version of nozzle with good heat insulation, reduced heating in central zone and good temperature distribution; 3 - copper cobalt beryllium nozzle casing; d - temperature distribution along melt flow path for nozzles a, b and c (measurement points 1-7). For a processing temperature of 300 °C and mould temperature of 30 °C.

(Reproduced with permission from R. Löhl, *Kunststoffe*, 1984, 74, 6, 312, Figures 7, 8, 9 and 10. © 1984, Carl Hanser Verlag)

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The first nozzle version 4.55(a) is a design with a copper/beryllium alloy body to provide even heat distribution. The nozzle is heated by a band heater with a thermocouple located in the end face of the heater. The rear section of the nozzle, which is heated from the HR manifold, maintained the set temperature. The front section of the casing is supported on a chromium/molybdenum alloy steel ring, which means that part of the heat flux flowing to the nozzle exit is dispersed through these rings into the mould. As a result of this, along the flow path 4.55(d) temperature differences of around 80 °C have been seen, which have made it impossible to process engineering plastics.

The second version of the nozzle 4.55(b) is a design with two improvements. The heater coil is elongated in the centre to cause a more even temperature distribution. To improve insulation, the support ring is made of titanium alloy, but these changes have not made a lot of difference.

The third version of the nozzle 4.55(c) is a significantly improved design. Because the support ring caused a fall in temperature of about 60 °C at the nozzle exit (at point 6), it has been replaced by an internal jacket supported in the central part of the nozzle, where the nozzle is at its highest temperature. The result is a temperature difference along the flow path of barely 10 °C, which has made it possible to process engineering plastics. The thermocouple is separated from the heater by locating it in the ring in front of the heater. Thus more accurate temperature measurement is achieved. The temperature characteristic should be independent of the temperature level.

Coil heaters. 230 V heaters are usually made in the form of tubular coil heaters with a round, rectangular or oblate cross-section. The winding extends along the central part of the nozzle (known as logarithmic winding), since minor heat losses occur here, and so the nozzle needs only slight heating. Coil heaters are otherwise heating elements with a so-called 40-20-40 heating profile, defining the percentage power applied to the nozzle length (see Chapter 5).

One practical problem is locating the heater in the nozzle so that it provides an even heat transfer over the whole length of the nozzle with as rectilinear a temperature curve as possible. The most commonly encountered ways of locating heaters in a nozzle are:

- fitted directly over the casing (such as D-M-E Belgium, Thermoject - see **Figure 4.56a**) and additionally tightened after heating (Husky);
- shrink-fitted (after heating to a temperature of 450 °C - STRACK);
- embedded in a copper alloy bushing fitted onto the casing (such as INCOE) or embedded in copper inside the casing (such as Eurotool, Mold-Masters, Unitemp);

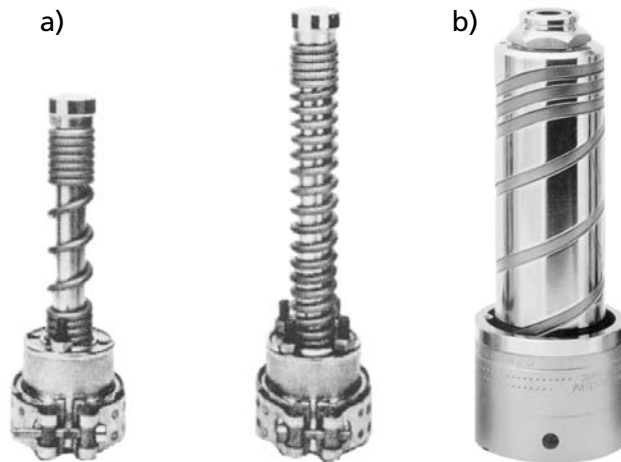


Figure 4.56 Nozzle heating by wound tubular heater

a - without (reflector) sheet with surface winding (*Reproduced with permission from Thermojet. © Thermojet*); b - with double winding soldered in groove (*Reproduced with permission from Mold-Masters; US Patent 4,557,685 [19], US Patent 4,583,284 [20] and US Patent 5,282,735 [21]*)

- wound in a helical groove on the casing (such as Hasco) and additionally soldered (such as Mold-Masters - see Figure 4.56b).

Coil heaters fitted onto the casing usually have external insulation in the form of a jacket of polished or nickel-plated steel sheet which reflects thermal radiation. Coil or band heaters fastened to the nozzle flange are similarly insulated by reflective band clips.

Embedded heaters feature greater durability and the potential for more precise temperature control. Push-on heaters are easily replaced if damaged. Press-on heaters may be removed by machining. Heating of such heaters using a gas torch may easily lead to tempering and loss of hardness in the nozzle.

Cartridge heaters used to heat torpedoes may be inserted into the torpedo body (D-M-E Belgium) or embedded in copper (Mold-Masters).

Heat pipes. In an attempt to even out the temperature along the flow channel, Dynisco HotRunners fits its nozzles with heat pipes (see Figure 4.57).

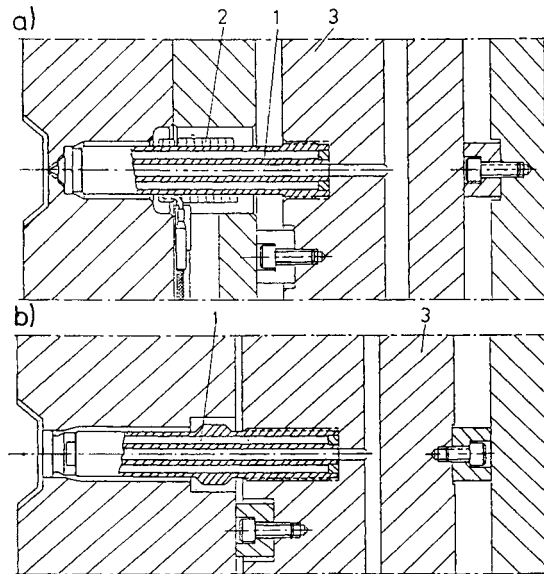


Figure 4.57 Nozzles with heat pipes

a - nozzle with coil heater; b - heat-conducting nozzle; 1 - heat pipe; 2 - heater; 3 - manifold (*Reproduced with permission from Dynisco HotRunners*)

Heat pipes are created in the nozzle casing, while the nozzle is heated by a band heater or just by the heat from the manifold (in the case of certain manifold nozzles). This method helps in the processing of plastics with a narrow processing temperature range (including PVC).

Low voltage heaters. Figure 4.58 shows two types of nozzle with low voltage heating: using external and internal heating. The heating element for nozzles with external heating is a steel tube introduced into the nozzle casing (see Figure 4.58a).

The heating element is fed with a 5 V current of up to 125 A. The power lead runs to the heater tube, while the return lead runs to the nozzle body.

The heating element for nozzles with internal heating is a torpedo fastened inside the channel (see Figure 4.58b). A torpedo comprises an iron alloy core encased in a steel jacket. The cylindrical surface of the core is insulated by a ceramic layer, as a result of which there is a current flow from the lead (4) through the core to the end of the torpedo and back via the jacket to the body. The heating element is powered by a 5 V, 100 A current. Temperature regulation takes place by altering the current strength.

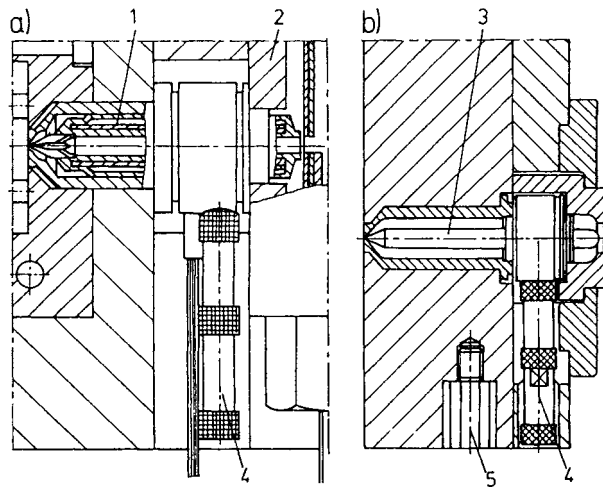


Figure 4.58 Examples of low voltage-heated nozzles

a - nozzle with external heating (*Reproduced with permission from Günther Heißkanaltechnik GmbH*); b - nozzle with internal heating (*Reproduced with permission from EWIKON Heißkanalsysteme*)

1 - heating tube; 2- manifold; 3 - heating torpedo; 4 - power lead; 5 - mass lead.

The advantages of low voltage heating of nozzles are: rectilinear temperature characteristic, small heat losses to the mould, small chamber diameter, rapid and uniform heating including tip, safety of servicing. One major benefit is the low energy consumption. According to EWIKON, 600 W power is sufficient to heat a nozzle 800 mm long with a 5 V current, whereas a 230 V heater requires 2,300 W.

Low voltage heating is particularly recommended for the injection of very small mouldings in multi-cavity moulds - for two reasons:

- a very small nozzle pitch is possible (from 11.5 mm);
- the constant temperature with rectilinear characteristic in the nozzle (and manifold) enables mouldings weighing as little as 0.03 g to be injection moulded.

Low voltage heating is particularly recommended for injection moulding of such thermally sensitive materials as PA 66 and PA 46 (Stanyl, DSM), PBT and plastics with class V0 flame-retardant additives.

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One disadvantage of this type of heating is the thick, rigid leads (16-25 mm² cross-section), requiring extra space in the mould for their location (they make it difficult to place cavities next to one another). Nozzles heated by a 24 V current with a maximum power of 25 A have been developed for applications with a small nozzle pitch or in large multi-cavity moulds, and this has enabled the lead cross-section to be reduced to 4 mm².

Other disadvantages include the need to use special thermoregulators and current transformers.

4.2 HR manifolds

The HR manifold is the central component of an HR system; in it are the flow channels feeding the melt to the HR nozzles.

For manifold design or selection, the following conditions should be met:

- provision of identical cavity filling conditions in multi-cavity moulds;
- minimisation of pressure losses in manifold channels;
- maintenance of unaltered temperature along the flow path to prevent fluctuations in melt viscosity, and in extreme cases overheating and thermal damage;
- no 'dead' zones where melt is left behind;
- low energy consumption;
- good thermal insulation between manifold and mould to reduce heat losses and temperature control difficulties;
- short heating time on start-up;
- maintenance of leaktightness between manifold and nozzle;
- ease of purging when plastic colour is changed and ease of cleaning;
- good durability and ease of heater replacement.

These conditions should particularly be borne in mind when manifolds are being made by and for oneself.

In view of these requirements, and of the wide variety of mould designs and methods of installation, many types of manifold have been developed. The main criterion by which they may be divided is the heating method (see Chapter 1.2):

- manifolds with external heating (also known as HOT) (Figure 4.59a);
- manifolds with internal heating (also known as COOL) (Figure 4.59b).

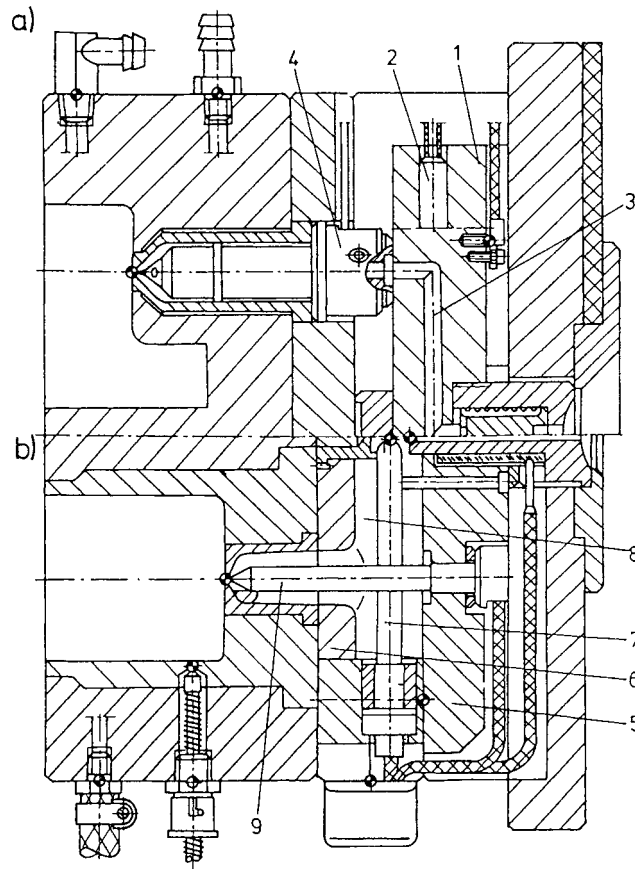


Figure 4.59 Main types of HR manifold (taking part of a standard mould base as an example

a - with external heating; b - with internal heating; 1 - manifold; 2 - cartridge heater;
3 - channel; 4 - tip nozzle; 5, 6 - manifold plates; 7 - insert with cartridge heater;
8 - channel; 9 - torpedo (*Reproduced with permission from STRACK Normalien GmbH*)

One factor that is of great importance to the user is the difference between a normal power supply (220/230 V) and a low-voltage one (24 V, 5 V), since the heating method depends on this, and consequently also the thermal regulation equipment and the connection method. There are also mixed systems, a typical example of which would be a manifold powered by normal voltage while the nozzles have a low-voltage supply.

4.2.1 Manifold with external heating

The operating principle of externally-heated manifolds has already been described in Chapter 1.2. This is the traditional manifold design, which is still the dominant one in the market.

The main advantages of this system are:

- the potential for the elimination of dead spots in channels by design (no melt left behind);
- a low risk of thermal degradation of melt because of the short time spent by melt in channels;
- the ease of change of type of plastic or colour;
- the low pressure losses in the channels;
- the potential for use of all types of nozzles. In pin-type shut-off nozzles, only a smaller adaptation of the manifold block is needed;
- considerable freedom of cavity positioning;
- ease of achieving natural or rheological flow balance.

4.2.1.1 Manifold design

Manifolds are divided in terms of their mechanical design into:

- plate manifolds;
- pipe manifolds.

Plate manifolds. The standard plate manifold (Figure 4.60) has a flow channel which is usually drilled in the axis of symmetry of the plate.

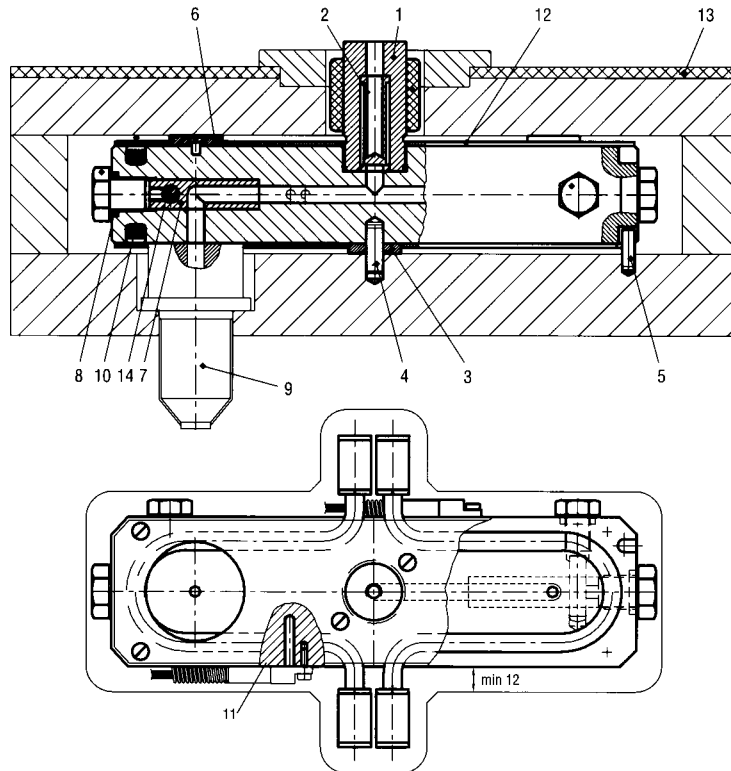


Figure 4.60 Layout of plate manifold

1 - sprue bushing; 2 - melt filter; 3 - support pad; 4 - aligning pin; 5 - dowel pin; 6 - pressure disc; 7 - end plug; 8 - metal seal; 9 - HR nozzle; 10 - tubular heater; 11 - thermocouple; 12 - reflector sheet; 13 - insulation plate; 14 - pin (*Reproduced with permission from Hasco Normalien Hasenclever GmbH & Co.*)

The channel must be polished. In the centre of the manifold is a sprue bushing (1), on the opposite side is a support pad (3) taking the pressure from the injection machine cylinder and a pin (4) aligning the manifold. A second pin (5) located in the end of the manifold sets its angular position. The manifold is pressed against the HR nozzles located in the mould by pressure pads (6) on the opposite side of the manifold. The transfer from the

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flow channel into the channel leading to the nozzle should be rounded and without any dead spots where the melt might get left behind. For this purpose, a shaped end plug (7) is fitted in the channel. The end plugs are quite long, enabling the exit channels (to the nozzles) to be made and distributed in a certain size range. The tube (or cartridge) heaters (10) are situated parallel to the channel. A temperature sensor (11) is situated between sprue bushing and nozzle. The manifold may have extra thermal insulation by aluminium reflectors (12) reflecting thermal radiation. The insulation plate (13) prevents penetration of heat to the injection moulding machine platen.

In the example given, the manifold is an intermediate product intended for completion and assembly at the user/mould manufacturer. Standardisation of this sort has enabled the manifold to be delivered without delay to the mould manufacturer.

The manifold of another system (Figure 4.61a) has detailed differences from the previous one in that it is first fastened by two bolts to the mould plate, which makes mould installation easier.

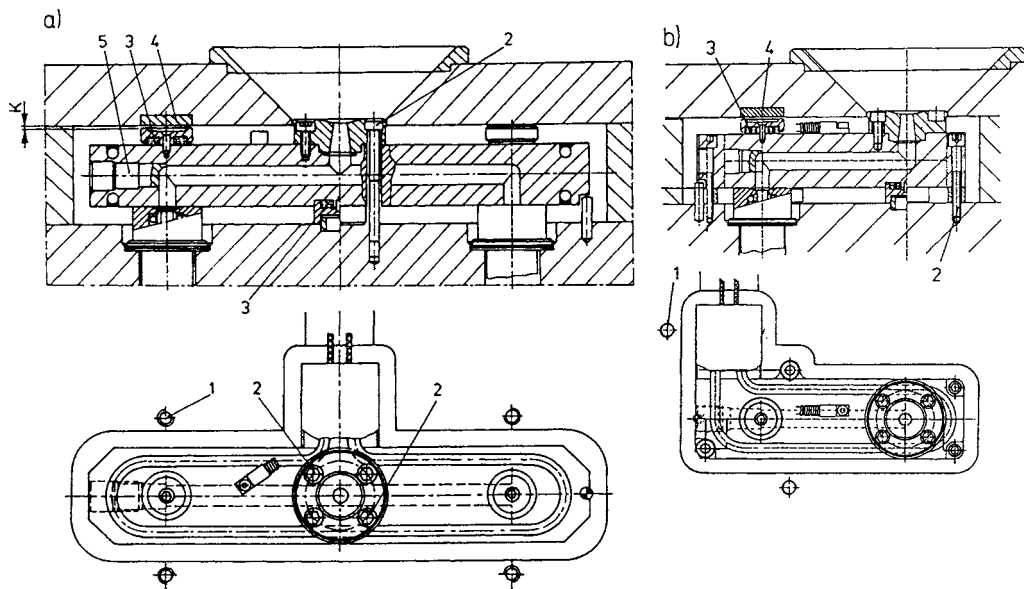


Figure 4.61 Examples of plate manifolds

a - manifold for two nozzles; b - asymmetrical manifold for one nozzle;
1 - extra plate torsion bolts: clamping and cavity plates; 2 - bolts (size M6) clamping manifold to plate; 3 - ceramic pad; 4 - hardened insert; 5 - end plug; K - assembly gap (in a cool condition) (*Reproduced with permission from Dynisco HotRunners*)

The manifold is pressed against the nozzles by ceramic pads in a steel body, which improves heat insulation. The manifold is held in place with the aid of hardened plates set in the clamping plate, which prevents damage (gashing) of the soft plate during thermal expansion of the manifold.

For a manifold with a single nozzle (Figure 4.61b), it is possible to shift the one injection point from the mould axis if the injection machine does not have the potential for co-axial movement of the injection cylinder.

In the case of manifolds intended to operate in conjunction with a shut-off nozzle, modification is necessary to pass the pin from the nozzle to the cylinder and for any other blanking off of the flow channel. An example of such a manifold is shown in Figure 4.62.

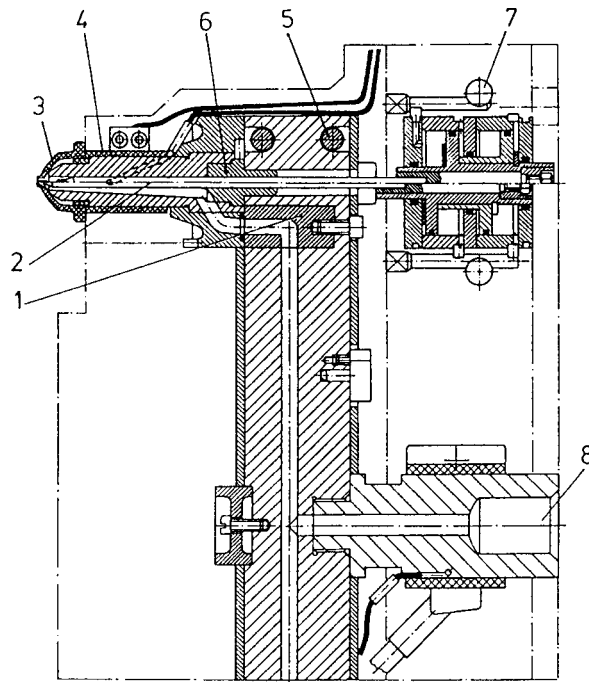


Figure 4.62 Manifold with shut-off nozzle [21]

1 - edge channel insert; 2 - pin with cylindrical closure; 3 - insulation chamber bushing; 4 - band heater; 5 - tubular heater; 6 - pin guide; 7 - cylinder cooling; 8 - sprue bushing with decompression chamber. (Reproduced with permission from H. P. Männer, *Kunststoffe*, 1995, 85, 2, 166, Figure 6. © 1995 Carl Hanser Verlag)

Tubular manifolds. An example of a tubular manifold is a design in which the flow channel is in a tube. The tube is heated by coil heaters in ceramic insulation and is set in a hole in a plate transferring the external load (see **Figure 4.63**). The low mass of the tubular manifold and its insulation by air gaps means the plate temperature is relatively low. Because of the very small temperature fluctuations, this manifold is recommended for the injection of plastics that are difficult to process, LCP, PA 66, PBT, PC, PEEK, PET, PSU, PVC with glass fibre, etc.

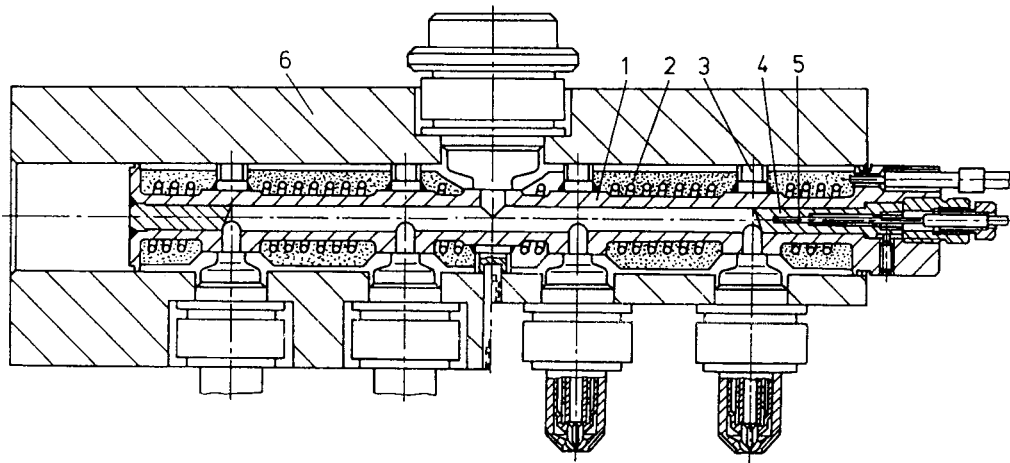


Figure 4.63 Tubular manifold (220 V)

1 - tube with HR; 2 - heater; 3 - clamping element; 4 - end plug; 5 - thermocouple;
6 - manifold plate (*Reproduced with permission from Günther Heißkanaltechnik GmbH*)

Very favourable conditions occur in a manifold (see **Figure 4.64**) in which the channels are located in tubes made of stainless steel which are welded and embedded in copper alloy in a steel body.

The heaters are embedded in the same body. Because of the good thermal conductivity of the manifold, a very even temperature distribution is achieved, with a longer heater life and a 50% reduction in energy consumption. The shape of the channels - gently rounded with very smooth internal surface - makes it easier to change the colour of the melt. This manifold is suited to the injection of chemically aggressive plastics, and even fluoroplastics. The tubes may have any kind of bends, which enables the nozzles to be positioned asymmetrically while maintaining equal flow paths (identical tube lengths).

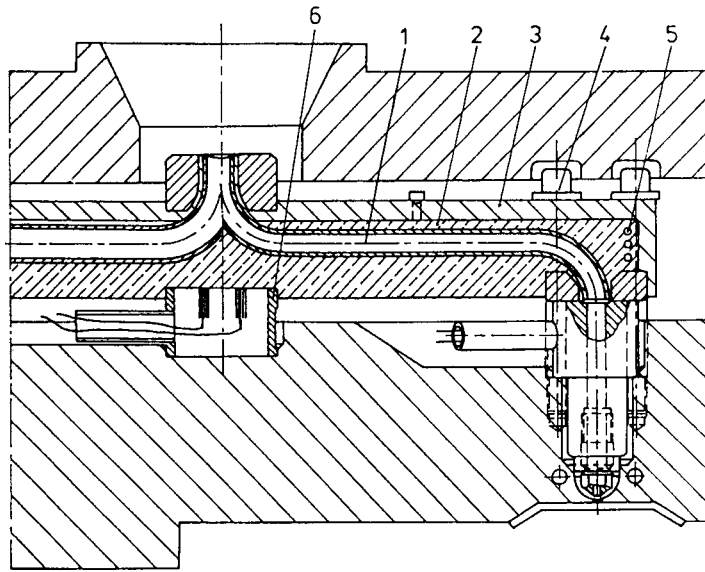


Figure 4.64 Tubular manifold

1 - flow channel tube; 2 - copper alloy; 3 - body; 4 - nozzle fastening bolts; 5 - embedded tubular heater; 6 - locating ring (*Reproduced with permission from Unitemp SA*)

Another type of tubular manifold is a manifold comprising a bushing and pipe connectors (see **Figure 4.65**) making up a modular system, allowing manifolds with various numbers of nozzles to be installed from standardised modules.

In the example given, the manifold comprises a sprue bushing, two T-junctions, six bushings and four nozzles.

The telescopic connector used between the bushings and the other components of the manifold enables thermal expansion to be compensated.

The telescopic connector is rendered leakproof by a fit with a very small clearance (0.005 mm, lapped aperture) and by differentiation of thermal expansion. The bushings are heated by band heaters, whereas the connectors are heated by cartridge heaters. The basic nozzle in this system is one with a heated torpedo. The nozzle cartridge heater may easily be replaced through a hole in the mould clamping plate.

The system is designed to mould large products (minimum 40-50 g/nozzle). Its advantage is a low weight, resulting in limited thermal losses and reduced heating power. The shape

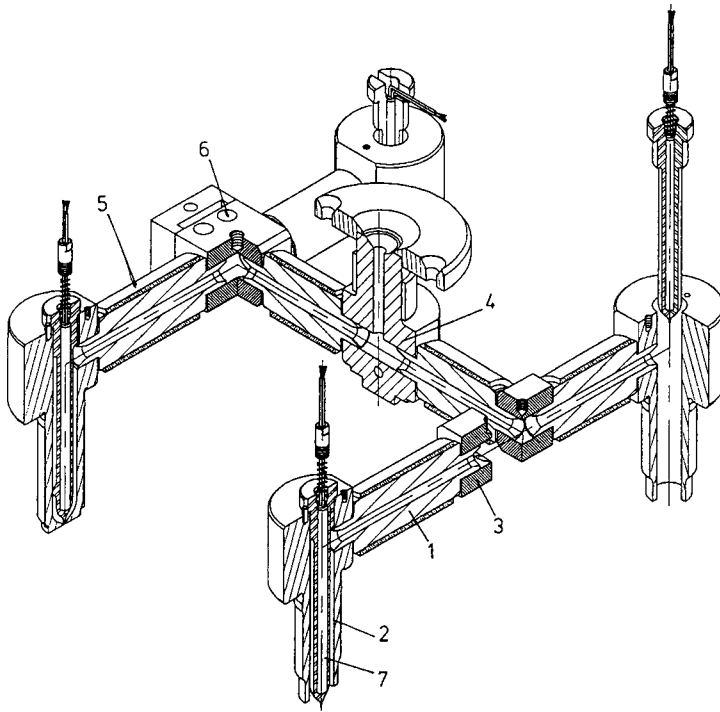


Figure 4.65 Tubular manifold

1 - bushing; 2 - nozzle; 3 - connector; 4 - sprue bushing; 5 - band heater;
6, 7 - cartridge heater (*Reproduced with permission from the Rabourdin Group*)

of the manifold enables the cavity plate to be better supported. According to the manufacturer, the system is totally leaktight.

The tubular manifold (see **Figure 4.66**) contains a tube equipped with pivot pins at the melt delivery points.

These pivot pins are fitted with a tight clearance fit, in connectors which are supported by the manifold housing.

Through an insert which interacts with the nozzle, the pressure on the nozzle is transferred directly to the mould clamping plate. The heaters are set and embedded on the tube between the pivot pins and insulated by a jacket that reflects thermal radiation. Because of the low weight of the tube, there is a lowering of energy consumption to 1/6th of the energy necessary for a plate manifold in its traditional version (according to the manufacturer).

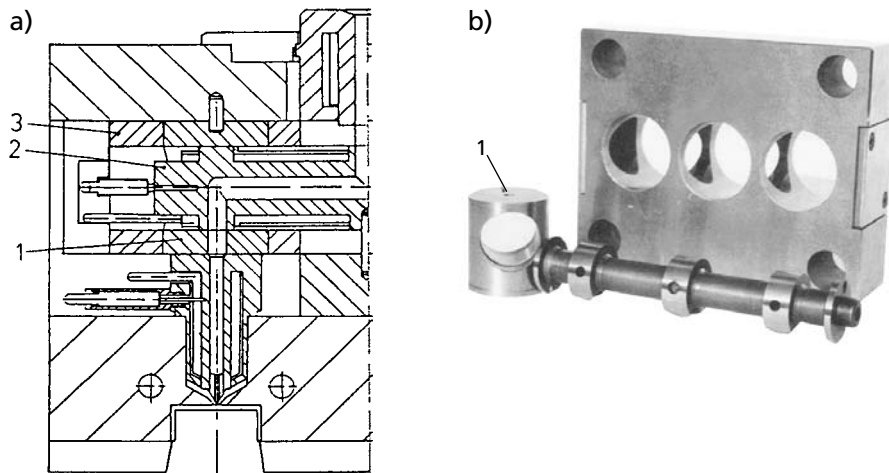


Figure 4.66 Tubular manifold

a - location of manifold in mould; b - parts of manifold; 1 - cylindrical insert; 2 - tubular manifold; 3 - manifold body (*Reproduced with permission from Heitec Heißkanaltechnik GmbH*)

The shape of the manifold depends on the way the flow channels run, and this in turn depends on the number and distribution of the nozzles. The number of nozzles in standard HR systems is generally a multiple of the number 2 (2, 4, 8, 16, 32, 64) or the number 3 (3, 6, 12, 24, 48, 96). Application of this principle ensures a symmetrical distribution of cavities in the mould and makes it easier to achieve natural balance in cavity filling and a modular mould design.

In current manifold design, the aim is to maintain a natural flow balance, i.e., equal flow paths to all nozzles. In line with this condition, the way the channels run in the manifold also depends on the structural layout of the manifold. **Figure 4.67** shows some channel layouts that ensures that the natural balance condition is met, and thus also that the cavities are set out parallel to each other.

To reduce the weight of the manifold, and in so doing to bring power consumption down, the best shape for the manifold is one that matches the channel layout. The distribution and method of installation of the heaters also has a bearing on manifold shape. Typical manifolds are shaped like one or more letters H, X or Y (see **Figure 4.68**), while frame (closed) shapes are avoided, since temperature differences may cause internal stresses in the manifold. The shape of the manifold should also allow extra cavity plate supports to be put in.

Small manifolds may be successfully made in the shape of a round plate.

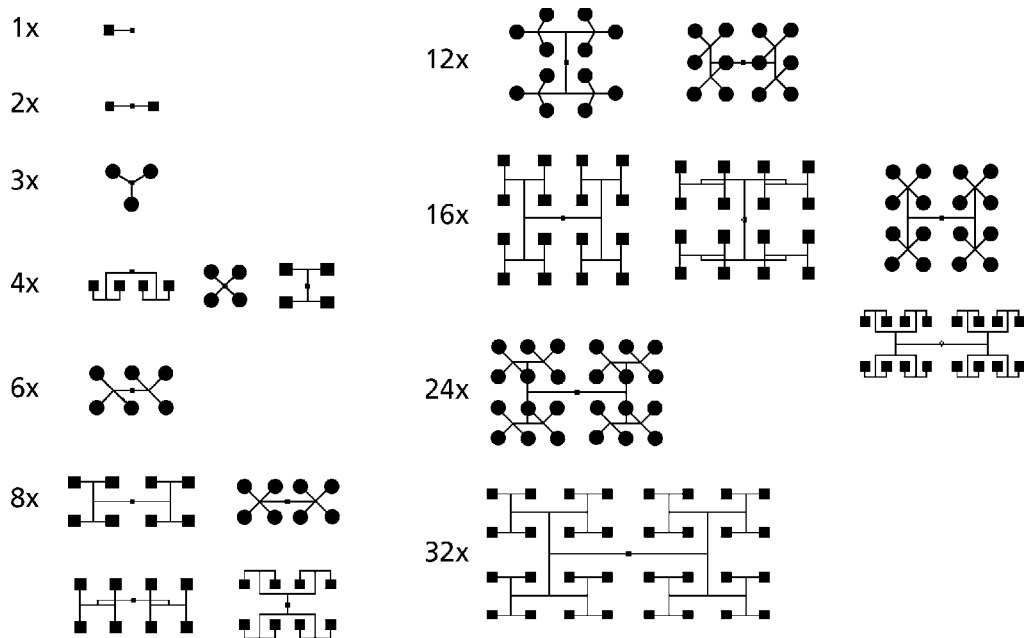


Figure 4.67 Nozzle layout and course of HR channels in manifolds with natural flow balance. Some of the designs are two-level

(Reproduced with permission from Dynisco HotRunners)

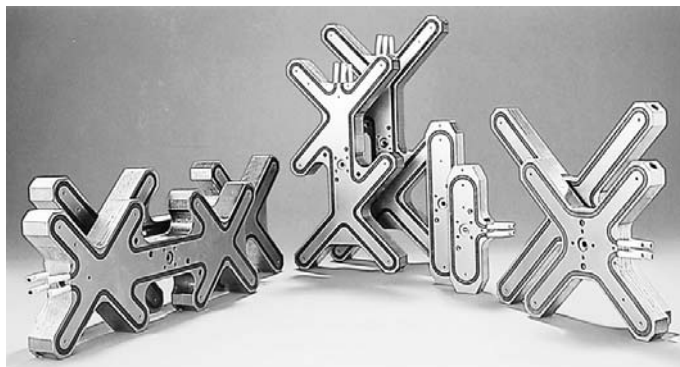


Figure 4.68 Examples of standard plate manifolds

(Reproduced with permission from Husky Injection Moulding Systems Limited)

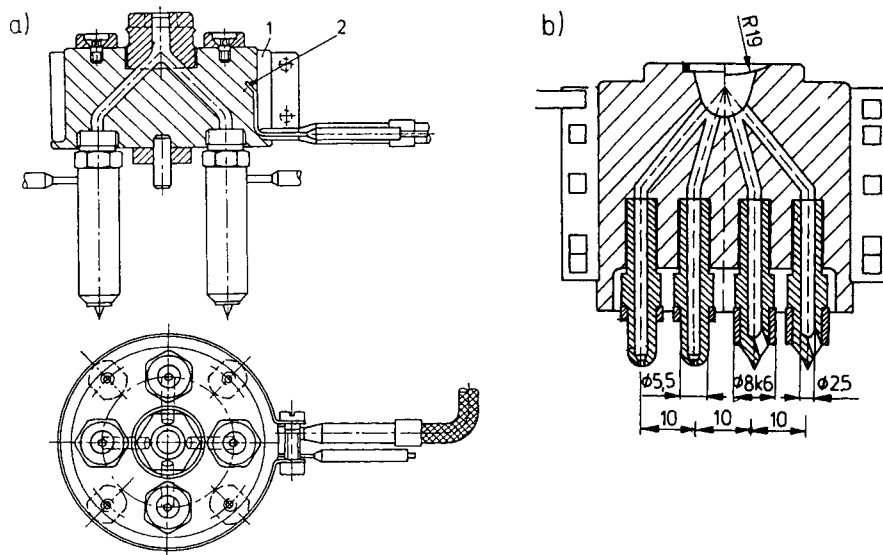


Figure 4.69 Plate manifold with screw-in nozzles

a - in peripheral layout (*Reproduced with permission from INCOE International*)

b - in series layout (*Reproduced with permission from EMP*);

1 - band heater; 2 - thermocouple

Figure 4.69a shows a manifold produced in versions for 2-12 nozzles and a corresponding nozzle-to-centre distance of 12-43 mm.

The inclined positioning of the channels does away with end plugs, while the small size of the manifold has enabled a single (band) heater and a single thermocouple to be used. This design has kept the manifold price fairly low. There is also the potential here to have 2-4 nozzles in a row (**Figure 4.69b**) with a very small pitch of 10-15 mm.

The condition of maintenance of a natural flow balance with a larger number of cavities in the mould or with a particular cavity layout, has given rise to numerous cavity designs with channels situated on two or even three levels. A multi-level design has long flow paths and high pressure losses (see Chapter 7). Rheologically balanced manifolds are an alternative (see **Figure 4.49**).

A new design concept for manifolds is shown in **Figure 4.70**. Channel sectors with a change of direction are milled in split inserts, thus reducing the need for end plugs and the risk of melt being left behind.

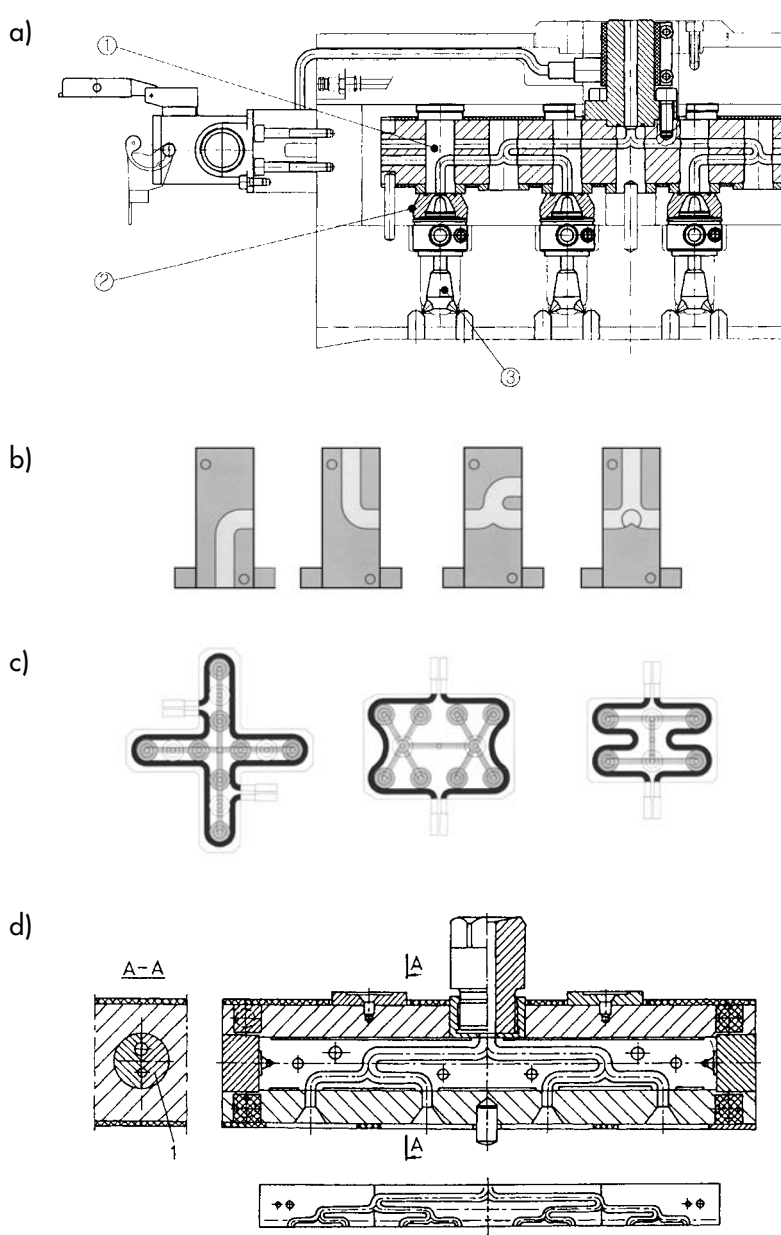


Figure 4.70 Two-level manifold

a - manifold with transverse inserts for 4 nozzles; b - types of transverse insert; c - insert layout; d - two-level manifold with longitudinal insert for 4 nozzles and (below) for 8 nozzles (reduced scale); 1 - HR directional insert; 2 - hardened support ring; 3 - nozzle
 (Reproduced with permission from EWIKON Heißkanalsysteme GmbH & Co. KG)

These inserts consist of two vacuum-soldered halves that are shrink-fitted in the manifold with an insert temperature of $-5\text{ }^{\circ}\text{C}$ and a manifold temperature of $450\text{ }^{\circ}\text{C}$.

In the design shown in **Figure 4.70a**, the inserts are located transversely in the manifold, while in **Figure 4.70d** they run lengthways. This type of design gives natural balance in cavities laid out in a row, which is very beneficial in split-cavity moulds.

The demand for a manifold for three cavities situated in a single row sometimes means using a simple design (see **Figure 4.71a**) without a natural flow balance, and with consequent production problems.

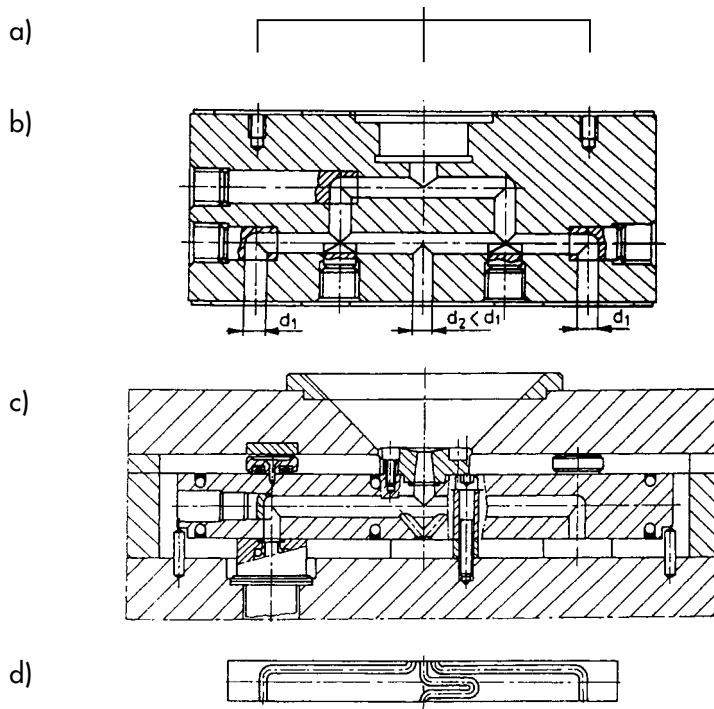


Figure 4.71 Example of manifolds for three nozzles set out in one row

a - diagram of manifold in state of non-equilibrium; b - two-level manifold with rheological flow balance (b *Reproduced with permission from Hasco Normalien Hasenclever GmbH & Co.*); c - single-level manifold with rheological flow balance (c *Reproduced with permission from Dynisco HotRunners*); d - split manifold insert with natural balance (d *Reproduced with permission from EWIKON Heißkanalsysteme GmbH & Co. KG*)

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The figure shows examples of solutions to this problem with the rheological balance maintained. Because of the flow disruptions that occur, it has been necessary to eliminate the central channel located opposite the sprue bushing channel. In **Figure 4.71b** a two-level manifold has been used, with a central channel with a diameter that is smaller than the diameter of the outside channels. In **Figure 4.71c**, a manifold with two small-diameter inclined channels has been used.

The solution to this problem for three cavities while maintaining natural balance was made possible by the use of a manifold with split inserts (**Figure 4.71d**), with the layout illustrated in **Figure 4.70**.

The method of diffusion welding of plates enables manifold channels (see **Figure 4.72**) and also cooling channels with complex paths to be produced [22].

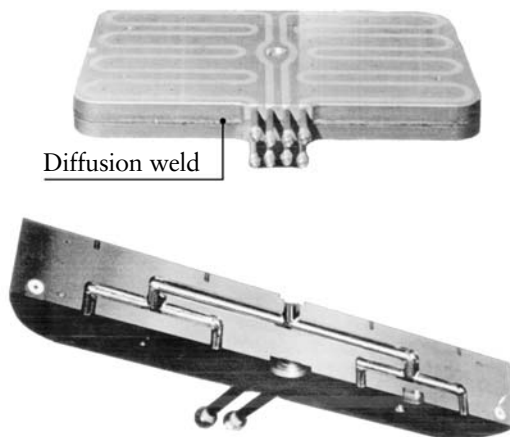


Figure 4.72 Examples of split and diffusion-welded manifolds with milled channels

a - manifold with vertical division; b - manifold with horizontal division

(Reproduced with permission from EOC Normalien)

Multi-level (tiered) manifolds are also made up from separate units (in the form of beams, cross-pieces, etc.), enabling flow paths to be shortened. One interesting manifold system is a modular design in which, for example, the main manifold cross-piece connects to four intermediate cross-pieces (see **Figure 4.73**).

This makes it possible to design multi-level manifolds for 4-64 nozzles. This system gives the user considerable freedom to locate nozzles in the mould using standard manifolds, which lowers the cost of the mould.

Another example is a unit comprising two round manifolds of the type illustrated in Figure 4.69 and a plate manifold (see Figure 4.73b).

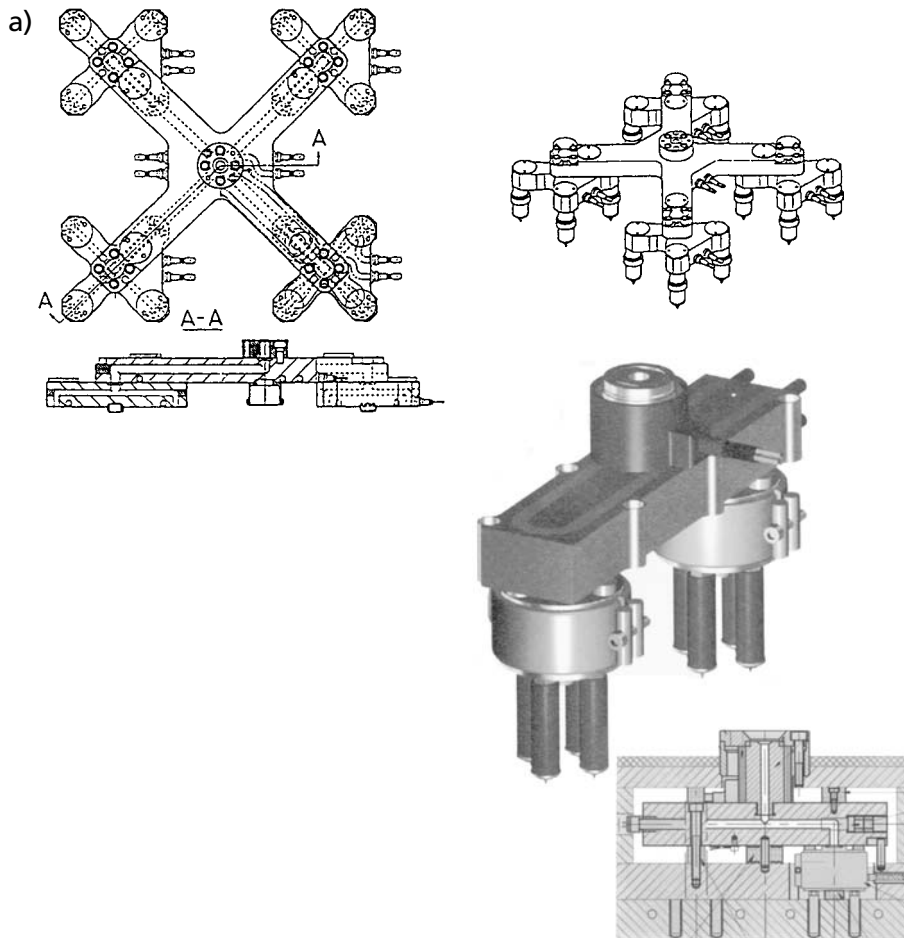


Figure 4.73 Two-level manifold of modular design

a - for a 16-cavity mould (4 x 4) (*Reproduced with permission from Mold-Masters; US Patent 4,761,343 [23]*); b - for an 8-cavity mould (2 x 4) (*Reproduced with permission from D-M-E Belgium*)

In the manifold shown in Figure 4.74, inserts that branch into three or four channels have been utilised.

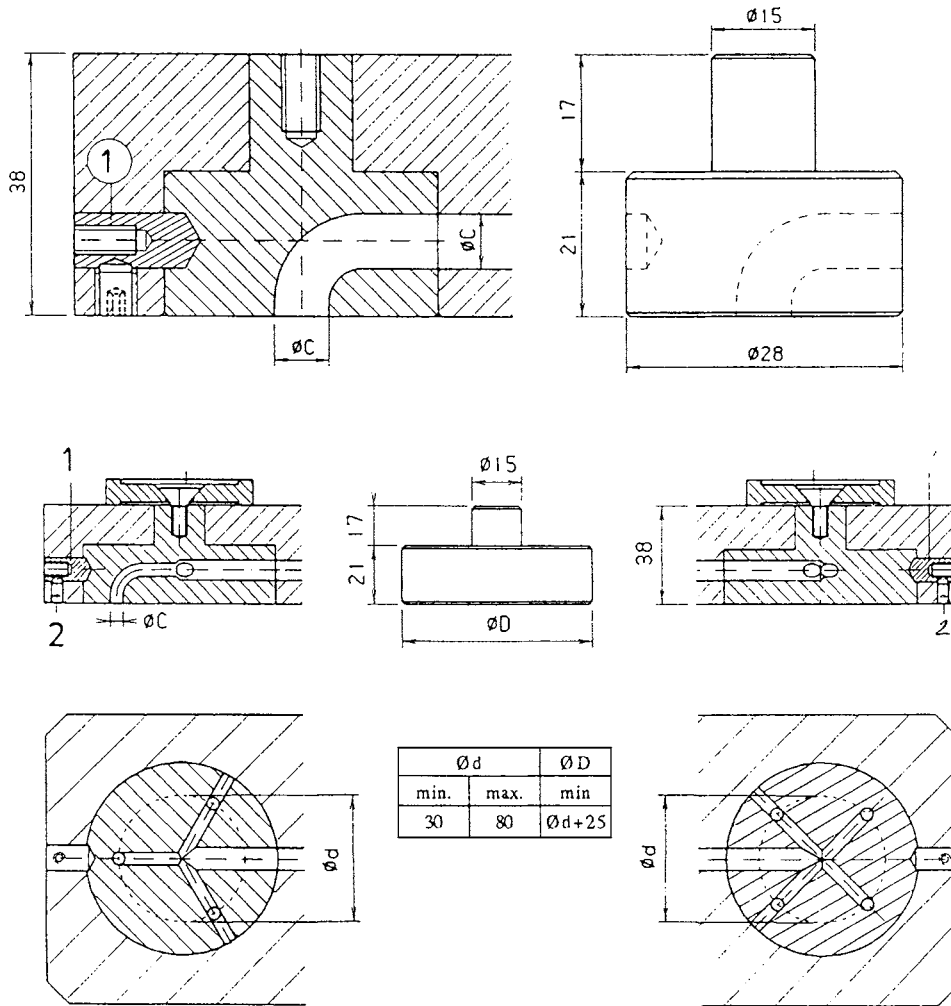


Figure 4.74 Plate manifold with inserts dividing the main flow channel
1 - fastening pin; 2 - retaining screw (*Reproduced with permission from EMP*)

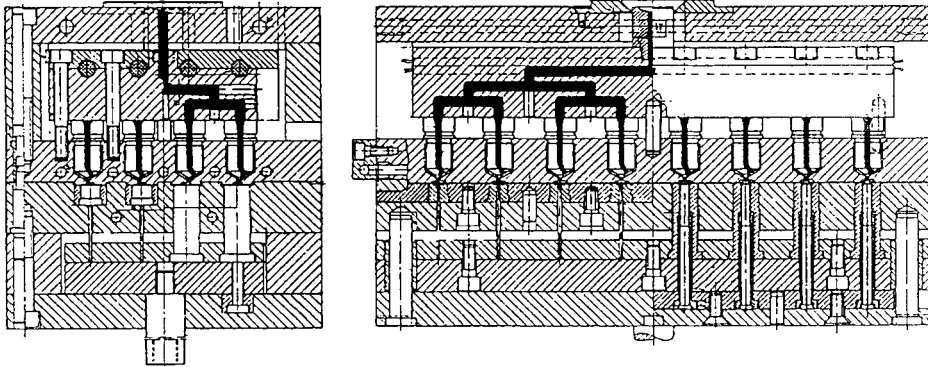


Figure 4.75 Three-level manifold with tip nozzles, with 5 V heating in 32-cavity mould for producing push-buttons [15]

(Reproduced with permission from R. Löhl, Kunststoffe, 1985, 75, 12, 878. © 1985, Carl Hanser Verlag)

Figure 4.75 shows a mould with a three-level manifold providing natural balance in a 32-cavity mould for producing push-buttons made of POM. Use of a low-voltage nozzle heating system has enabled the distance between nozzles to be reduced. Each of the sets of four nozzles has its own control system. The manifold has two heating zones. The multi-level gating system occupies half of the height of the mould.

As may be seen from this example, achieving a natural flow balance in the mould may be of such significance for product quality that an increase in the degree of complexity, and also in mould cost, is of relatively minor importance. There are, however, cases in practice where calculated rheological balancing cannot be avoided, despite all its limitations.

This is true of:

- moulds for the production of complicated or large products, i.e., moulds with many injection points, e.g., vehicle bumpers, battery bodies, strips with long flow paths, protective meshes for loudspeakers, etc. Manufacture of complex products may be associated with the imposition of a strictly defined method of cavity filling, with different pressure losses in individual segments of the cavities, which precludes the use of manifolds with natural balance;
- multi-cavity moulds, known as ‘family’ moulds, for the production of sets of items from the same plastic and with the same shrinkage, but of differing size;
- the need to use nozzles of differing size, length or even type in a mould (see **Figure 4.76**).



Figure 4.76 Specially-made manifolds with different nozzles, individually designed for large rheologically balanced injection moulds

(a Reproduced with permission from INCOE International; b Reproduced with permission from Mold-Masters; US Patent 4,761,343 [23])

Channel dimensions are determined by their diameter and length, and also indirectly by their volume. They arise out of conditions that are:

- structural - number and distribution of cavities or injection points;
- process-oriented - admissible pressure drop (generally not more than 350 MPa) and flow rate (shear stresses);
- physical - admissible time spent by the melt in channel. Ideally there would be total purging of channels for each injection, or a melt dwell time equal to 10-20% of the plastic degradation time at the operating temperature [24].

These are frequently mutually-contradictory conditions. The admissible pressure drop means that the smallest channel diameter used is 6 mm. Because of the risk of melt spending longer than the admissible time in the HR, channels larger than 10 mm are not recommended for the injection of smaller products. Special attention should be given to channel diameter selection when plastics of very high viscosity are being moulded, as these are generally thermally sensitive. This imposes technical restrictions (despite economies) when HR manifolds are used in moulds for small products. In moulds for large products, the channel diameter in a manifold with external heating can reach 16 mm.

The recommendations concerning channel selection may therefore be formulated as follows:

- small channel diameter - to reduce the time spent by the melt in the channel (for thermally sensitive plastics) and for more rapid colour change;
- large channel diameter - in processes where a high injection pressure is needed for plastics that are not easy flowing and for products with a high L/g (flow path/product weight) ratio, and for shear-sensitive plastics.

Channels in the manifold generally have the same diameter, although there are numerous exceptions. Flow channels linking a distributor channel to a nozzle may have a smaller diameter adapted to the diameter of the nozzle channel. Channels in tiered manifolds may have diminishing diameters. The diameters of channels in manifolds with rheological flow balance are individually calculated to within 0.1 mm.

How great the influence of the channel diameter on pressure losses and temperature rise in the melt may be is illustrated using an example (see **Table 4.1**) from a computer simulation [1]. The simulations were performed for several plastics, two channel diameters and two injection rates.

The result of the simulation enabled the following conclusions to be drawn:

- pressure losses in the HR system were 25-30% lower than in CR systems for the same channel diameter, depending on the injection rate but regardless of the type of plastic;
- pressure losses in an 8 mm channel were 40-60% lower than in a 6 mm channel, depending on the type of plastic;
- a high injection rate causes a significant rise in temperature in certain plastics (in the example, PC in a 6 mm channel), which may cause them to thermally degrade. The temperature rise in a CR system is still greater, but momentary, whereas the melt in an HR system is subject to the action of an elevated temperature throughout the time it spends in the channels.

The termination of drilled channels is a problem area in a manifold, since the melt may get held up here if the termination is not made correctly. Various designs are encountered, using horizontal plugs or vertical inserts.

The traditional design is a plug pressed into the channel which is protected from turning by a side pin and tightened by a screw (see **Figure 4.82a**). It is in this position that

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machining of the plug termination is carried out - milling using a rounded end mill and polishing. The plug is then removed for its sharp edges to be chamfered.

A better solution is to use a plug with a larger diameter than that of the flow channel, which enables sharp edges to be avoided (see **Figure 4.60**). The plug may be fixed in place by a pin and additionally sealed using a metal seal or by welding (see **Figure 4.61**).

The termination of a channel milled in a vertical insert is shown in **Figure 4.70**. Another type of insert is shown in **Figure 4.74**.

Materials used. Materials used for manifolds have high demands in terms of hardness:

- in order to withstand the large surface pressures required to seal the assembly;
- in order to prevent seizure of the contact surface with the nozzles during thermal expansion of the manifold.

These conditions are met by using toughened alloy steels (at about 32 HRC on delivery), e.g., DIN 1.2312 steel with a strength of about $1100 \text{ N/mm}^2 = 1100 \text{ MPa}$ (thermal conductivity 35 W/mK). Some manufacturers, however, make clamped (not bolted-on) manifolds with a higher strength value, i.e., 35-40 HRC. Use has also been made of DIN 1.2767 hardening and DIN 1.2764 carburising steels.

Manifolds designed to operate at very high temperatures are made of hot work steel, e.g., DIN 1.2343 or DIN 1.2714.

Manifolds designed to process chemically aggressive plastics (such as PVC) are made from corrosion-resistant steels, or else the channels are chromium-plated. Manifold contact surfaces must be ground.

NB! Manufacturing manifolds from steel that has not been heat treated or from aluminium alloy soon gives rise to melt leaks and damage to other components of the HR system.

4.2.1.2 Fastening and sealing of manifolds

Two basic conditions should be met when manifolds are fastened:

- the whole HR system should withstand leaks, with the thermal expansion that occurs taken into account;
- heat losses in the manifold should be limited.

Manifolds are fastened in the mould by tightening the mould plates, or by being directly bolted on.

In practice, hybrid systems are increasingly frequently encountered, where the manifold is simultaneously bolted on and clamped down, which reduces the risk of seal failure. Much attention is given to ensuring that manifolds with external heating can withstand leakage. Manifolds with screw-in nozzles have been developed for this reason.

Clamped manifolds. In the clamped manifold (see **Figure 4.60**), leakproofing between nozzle and manifold is achieved by a clamping plate applying pressure to a pressure disc fastened to the manifold on the opposite side to the nozzle. The manifold is usually fastened to the mould with a gap that depends on the assembly height and the temperature difference between manifold and mould, and in some systems with a certain height surplus (see Chapter 4.5). The required pre-tension is achieved after heating of the system and thermal expansion of the manifold and nozzles. The manufacturer's recommendations should be observed, as these take into account the rigidity of the assembly components and the admissible surface pressures, and will have been verified in practice. An increase in the clamping force may lead to permanent deformation of the clamping surfaces and a loss of leaktightness.

The contact area of the pressure discs with the mould clamping plate has been reduced (by recessing) to decrease heat losses, and very large surface pressures are transferred through them (see Chapter 4.2.1.5).

System leakproofing also depends on mould rigidity, and to increase this, some manufacturers recommend extra torsion on the mould plates clamping the manifold by bolts located near to the nozzles - two bolts per nozzle (see **Figure 4.61**). The aim is to increase the clamping force in the open mould and eliminate the risk of leakage caused by residual melt pressure in the HR system.

Leakproofing in an HR system depends crucially on correct fitting, which should be carried out in the following sequence [25] (see **Figure 4.77**):

- 1) locate nozzles in mould plate and check whether their height is identical (above the plane of the plate) to a tolerance of ± 0.01 mm;
- 2) grind support pad level with nozzle plane to a tolerance of ± 0.01 mm;
- 3) insert manifold (without seal rings), check whether dowel pin has the necessary clearance in the manifold and bolt manifold to mould plate (if there are bolts);
- 4) bolt down plate or risers;

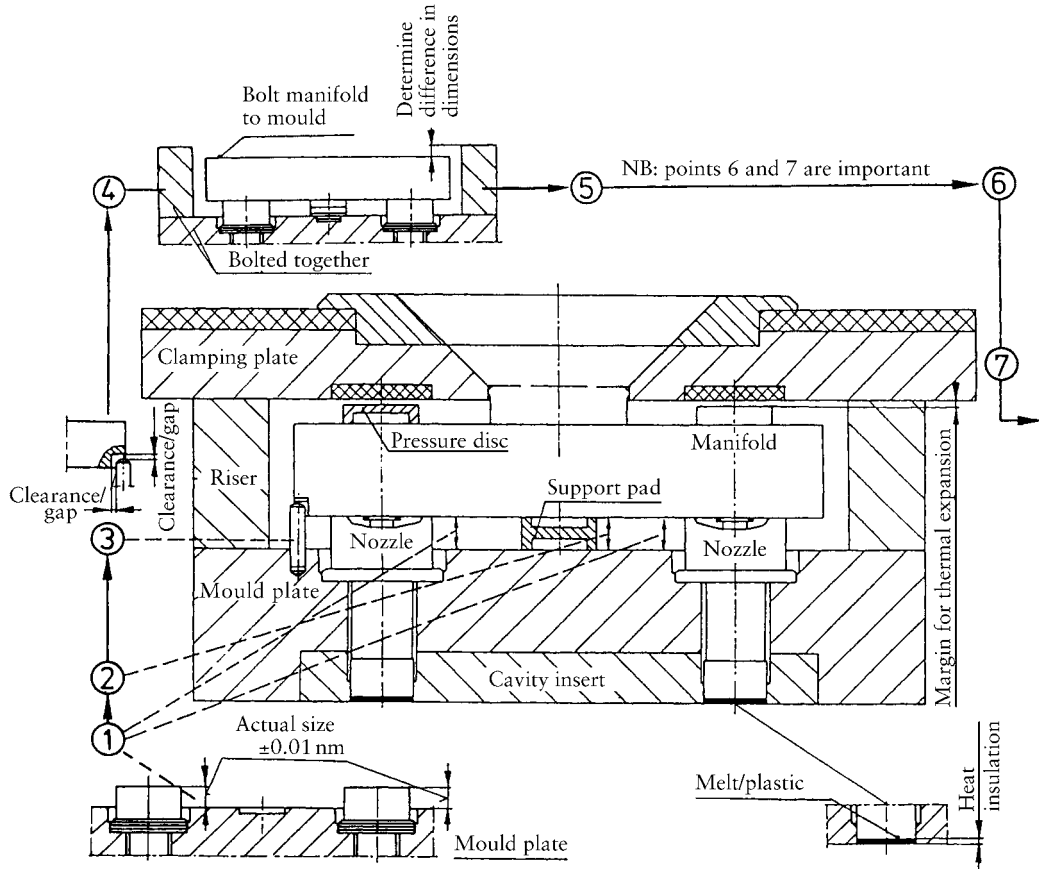


Figure 4.77 Sequence of assembly (1-7) of HR layout with a clamped manifold - for key, see text

(Reproduced with permission from Dynisco HotRunners)

- 5) grind pressure discs (or riser) to obtain manufacturer's recommended clearance (in the manifold in question, the clearance is 0.05 mm. After heating of the system and thermal expansion of approximately 0.1 mm, the interference is about 0.05 mm (see also Chapter 4.5);
- 6) remove manifold, place seal rings in nozzles (ring protrudes some 0.3 mm above nozzle plane), install manifold. Point 6 does not apply to systems in which leak proofing is achieved solely through contact of manifold and nozzle (without seal rings);
- 7) tighten mould clamping plate.

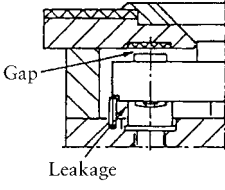
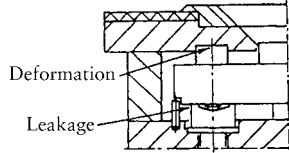
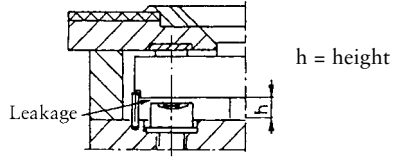
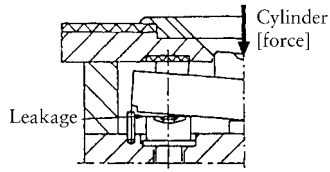
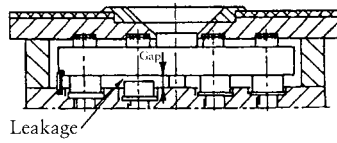
Assembly Error	Problems in Operation
1. Excessive gap (no pre-tension) 	Injection pressure forces manifold away from nozzles. Melt leak occurs.
2. Gap too small (excessive pre-tension) 	Pressure discs pushed into clamping plate. This prevents manifold from moving along nozzle surface, nozzles pushed to one side. Melt leak occurs.
3. Support pad too high 	Manifold resting only on support pad. Melt leak occurs.
4. Support pad too short 	Support pad fails to take pressure from injection machine cylinder. Manifold is bent and melt leak occurs.
5. Nozzle height uneven 	The possibility for melt leak from beneath shortest nozzle.

Figure 4.78 HR system assembly errors causing loss of leak proofing
(Reproduced with permission from Dynisco HotRunners)

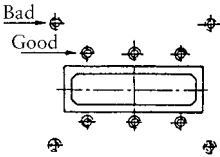
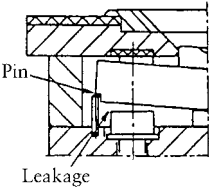
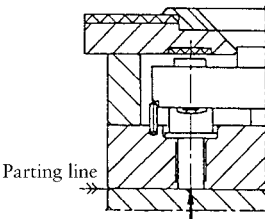
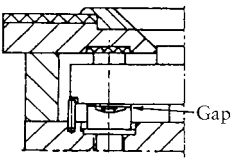
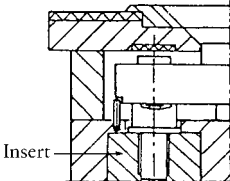
Assembly Error	Problems in Operation
6. Too large distance between clamping bolts and manifold and nozzles 	Thermal expansion in manifold may cause bending of clamping plate if this is too thin (after opening of mould). Melt leak from beneath HR nozzles.
7. Dowel pin too tall 	Manifold rests on pin. Gap between nozzle and manifold causes melt leak.
8. End face of nozzle rests on mould plate 	Nozzle has no space for thermal expansion and becomes compressed. This may cause damage to seals in nozzle and melt leak.
9. Ring seals adopted before height measurement 	Seals stand out approximately 0.3 mm above nozzle plane. Pressure disks are ground down too short. Initial clamping force not achieved after heating of system. Melt leak occurs.
10. Nozzle rests on insert, not on plate 	Bolts clamping insert are not in a state to take the injection pressure or the force of thermal expansion of the nozzle. This causes melt leak.

Figure 4.78 Continued

To achieve conformity between nozzle height and support pad height (step 2), the height of the intermediate plate sometimes has to be adjusted, if there is one in the mould (see **Figure 4.60**). If this is not done, a special support pad needs to be used.

Figure 4.78 shows some typical errors perpetrated when a clamped manifold is being installed, and which could cause a seal failure in the system [25].

Bolt-in manifolds. In a bolt-in manifold (see **Figure 4.79**), a seal is achieved between nozzle and manifold through bolts located either side of the nozzle.

During heating, the manifold is, however, subject to elongation (approximately 0.1 mm/100 mm at 100 °C), which causes skewing and stretching of the bolts; with the passage of time, there may be a fall in the pre-tension of the bolts and a deterioration in leaktightness. For this reason, most manufacturers of bolt-in manifolds nowadays additionally employ pressure discs.

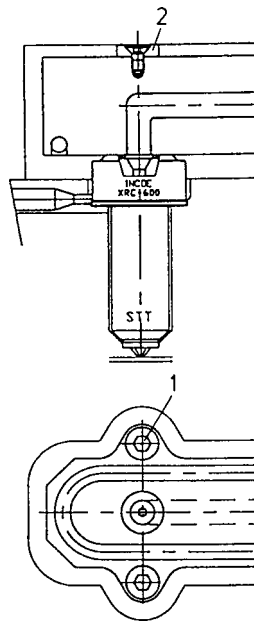


Figure 4.79 Manifold attached by bolts and with extra pressure disc
1 - bolt; 2 - disc (*Reproduced with permission from INCOE International*)

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The problem of bolt skewing in large manifolds may be solved by supporting the ends of the bolts in holes in the mould plate (see **Figure 4.80**).

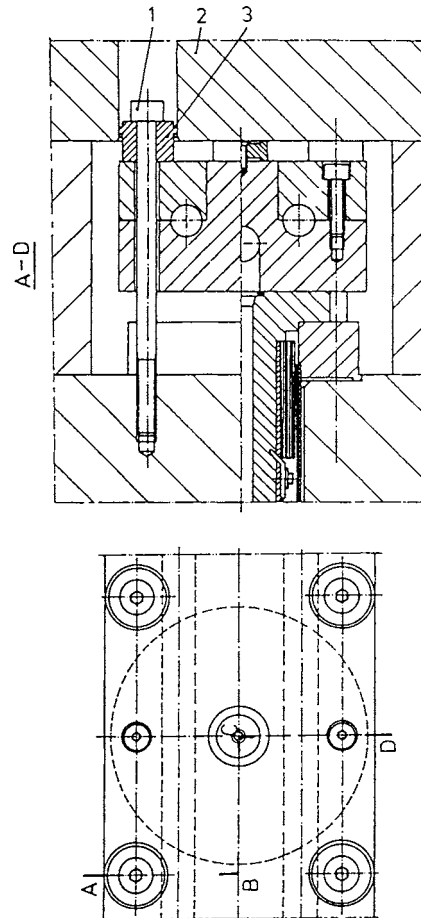


Figure 4.80 Support of bolt ends in clamping plate counters their skewing caused by thermal expansion of manifold

1 - bolt; 2 - clamping plate; 3 - setting bushing (*Reproduced with permission from PSG Plastic Group GmbH*)

Manifolds with screw-in nozzle. The market has in recent years seen the appearance of standard manifolds with screw-in nozzles, the leak proofing of which is guaranteed by the manufacturer (Figure 4.81a and Figure 4.69 and 4.86). In this design the nozzle does not require support, but it is aligned by its end in the cavity plate. This solution allows for a certain limited thermal expansion and the resulting skewing of the nozzle with leak proofing maintained in the threaded connection. A further advantage of this design is that the nozzle does not require a support flange, which enables heat losses to be kept down and the temperature curve to be improved. Whether there is potential for this system to be used is a decision taken by the nozzle manufacturer.

Another design of a similar type is the manifold (see Figure 4.81b) with bolt-in nozzle using four screws (1) via a bushing (2). The nozzle is at the same time aligned in the cavity plate hole by a bushing (3). Adaptation of the nozzle flange between the bushing (2) and the manifold (dimension X) is done in such a way that adequate clamping of the nozzle to the manifold surface is provided, on the one hand, while movement of the

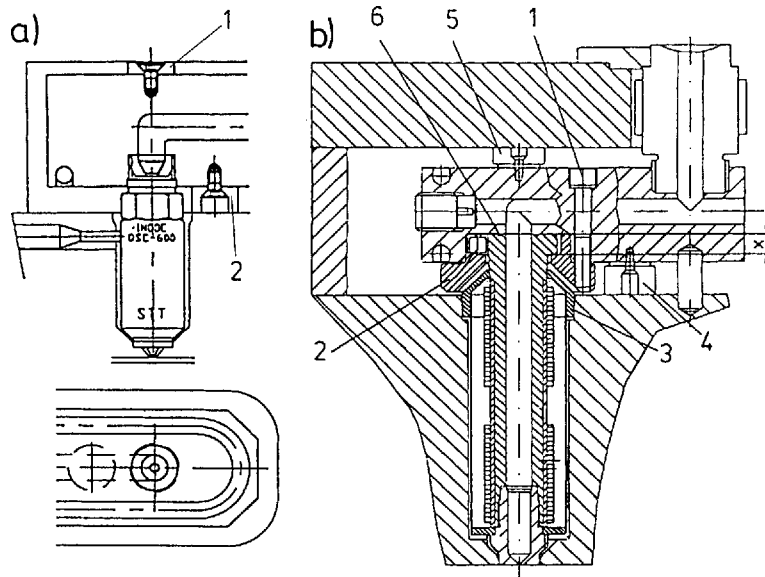


Figure 4.81 Manifolds with bolt-in nozzles

a - with screw-in nozzle; 1 - pressure disc; 2 - support pad (Reproduced with permission from INCOE International); b - with nozzle bolted in; 1 - bolt; 2 - holding bushing; 3 - aligning bushing; 4 - support pad; 5 - clamping bushing; 6 - ring seal (Reproduced with permission from PSG Plastic Group GmbH)

manifold as a result of thermal expansion is permitted on the other. The manifold is positioned between the mould plates using spacer washers (4 and 5), but these do not have a clamping function as in a clamped manifold.

Manifold seals. Most HR system manufacturers employ a flexible tubular seal ring between manifold and nozzle to enhance the guarantee of leak proofing (see Figure 4.82).

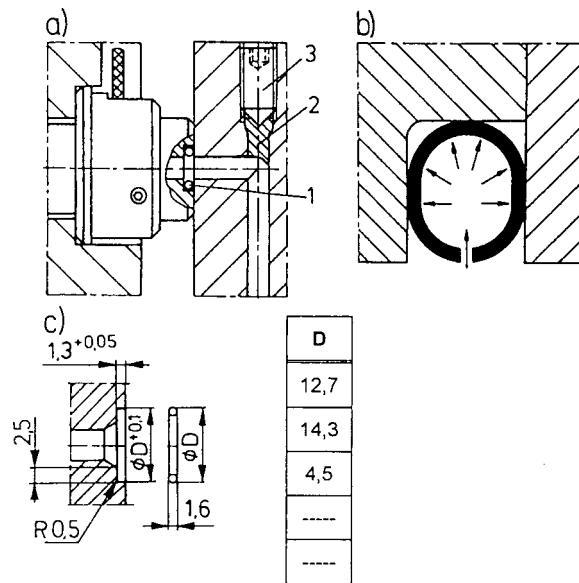


Figure 4.82 Principle of nozzle sealing using a tubular ring

a - assembly method; b - operation of seal; c - dimensions of seal recess; 1 - seal;
2 - plug; 3 - clamping bolt; R - radius

(Reproduced with permission from PSG Plastic Group GmbH)

The ring is made of stainless sheet metal and has several holes on the internal circumference. During the first injection, the molten plastic fills the ring, creating the extra clamping force needed for leakproofing. Seal rings are especially beneficial in the case of low-rigidity moulds, old moulds (deformed) and old injection moulding machines (with non-parallel platen surfaces). These seals should be replaced after each dismantling of the mould, and also after approximately every six months of continuous operation of the mould.

Some HR system manufacturers do not use rings, on the basis that the clamping force between the smooth surfaces of the manifold and the nozzles ensures adequate leaktightness of the system (see **Figure 4.60**), and besides, one is not then left with a space in which the melt may get held up.

Sealing washers made of copper are still encountered in old HR systems.

NB! Copper sealing washers are single-use seals and they must be replaced each time the mould is cooled down. Furthermore, they should not be used in the processing of some plastics because of the destructive effect of copper (see Chapter 3).

Position setting. A manifold must be properly aligned and supported on the mould axis. A dowel pin and support pad are used for this purpose (see **Figure 4.60**), or a locating ring that plays the part of a support (see **Figure 4.64**). Additionally it is necessary to establish the angular setting of the manifold. Most commonly this is done using a dowel pin located on the axis of the longest arm of the manifold (see **Figure 4.60**). The pin is introduced into a groove, not a hole in the manifold, because of thermal expansion.

4.2.1.3 Sprue bushings

Three types of sprue bushing are used (see **Figure 4.83**), made in different versions, depending on the HR system manufacturer:

- open bushings;
- bushings with decompression chamber;
- closed bushings.

Sprue bushings may also be supplemented by a melt filter.

Open bushings. The channel for open bushings may be cylindrical (**Figure 4.83a**) or conical (**Figure 4.61**) in shape. A conical channel helps to prevent melt drooling from the bushing when the nozzle is removed.

The channel of an open nozzle in an injection machine should have a diameter that matches the channel of the sprue bushing (see **Figure 4.84**).

Standard injection moulding machine nozzles have small holes suitable for moulds with CR systems. The increase in the aperture of a nozzle interacting with an HR system reduces pressure losses during injection and clamping, and facilitates decompression. In the event of large channels in nozzle and sprue bushing, the machine has to operate without the removal of the nozzle to prevent melt drooling; but one should not forget to reduce the

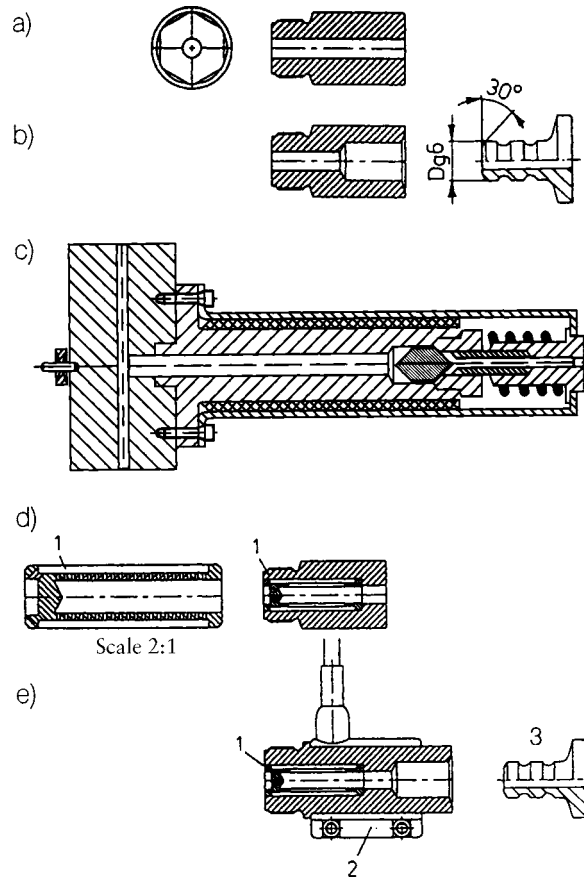


Figure 4.83 Manifold sprue bushings

a - open; b - with decompression chamber; c - shut-off; d - open with filter;
e - with decompression chamber and filter; 1 - filter; 2 - band heater; 3 - tip (plunger)
of injection machine nozzle (*Reproduced with permission from Hasco Normalien
Hasenclever GmbH & Co.*)

injection unit loads. The contact surfaces between nozzle and bushing may be round or flat. In the case of round surfaces, better leaktightness occurs when the radius R_{KD} of the nozzle termination is about 1 mm smaller than R_{KT} of the sprue bushing cavity.

When a traditional injection machine operating cycle is used for quick-setting plastics with removal of the injection unit, a cold plug forms in the standard nozzle tip. This may be the cause of a fault that is hard to identify - clogging of one of the gates of an HR nozzle.

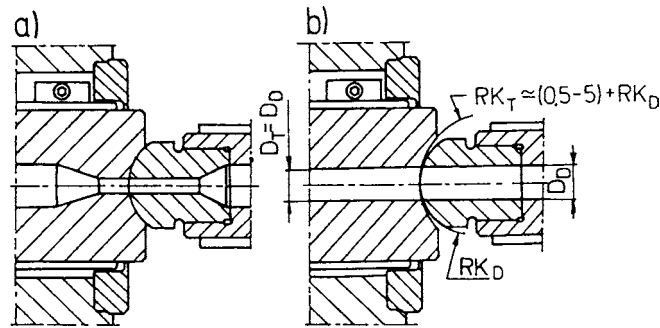


Figure 4.85 Matching of injection machine nozzle and sprue bushing of manifold

a - standard nozzle and bushing with narrowed channel; b - nozzle with enlarged channel (recommended for HR) (*Reproduced with permission from Husky Injection Moulding Systems Limited*)

Bushings with a decompression chamber are used with the aim of decompressing molten plastic in an HR system, which prevents stringing and drooling from HR nozzles in a rapidly-opened mould and air getting into the sprue bushing. Air subsequently compressed during injection reaches a high temperature and may cause burning of the melt (a phenomenon colloquially if imprecisely known as the ‘diesel effect’). When PA is being injected, oxygen from the air causes degradation of the melt and the appearance of dark stripes on the moulded item.

In the design shown in **Figure 4.83b**, the cylindrical end (plunger) of the injection machine nozzle is introduced into the bushing channel. After the end of the holding phase, the machine nozzle is withdrawn by a few millimetres inside the bushing channel, causing decompression of the melt in the channels. Because the machine nozzle does not leave the bushing channel, drooling from the sprue bushing cannot happen.

These bushings are primarily used with short injection cycles, where the cooling time is too short for the gate to freeze. Prevention of drooling also ensures that the shot weight is reproducible, which is important for the injection of precision products.

Decompression nozzles with cylindrical tips with a diameter from 12 mm and H7/g6 fit are commonly used. Some sources [26] recommend the use of diameters no smaller than 16 mm and lengths of at least 35 mm, with a 0.2 mm clearance, as the film that is formed protects the tip from abrasion and there is self-cleansing by the slight drooling. During injection there is sealing of the nozzle by the pressure of the end of the plunger or by the taper of the body as an alternative.

Closed bushings (Figure 4.83c) are equipped with a non-return valve in the channel making it impossible for the melt to drool following retraction of the nozzle or for air to get inside. Their use is advantageous with nozzles closed mechanically, as decompression of the manifold is not required in this case.

A melt filter (Figure 4.83d) is used with small gates which are easily blocked as a result of mechanical impurities in the melt. A filter must be used when recycled material is being injected. The filter may be located in an open sprue bushing (see also Figure 4.60) or in the injection machine nozzle. A drawback to the filter is the substantial pressure loss, as much as 30%, depending on the type of filter. For this reason, filters with a filter area of at least 125 mm² are recommended.

There are also sprue bushings which contain both a melt filter and a decompression chamber (see Figure 4.83e). However, the pressure loss brought about by the filter considerably reduces the decompression efficacy. In moulds for small precision items where decompression is essential, use of a filter in the bushing is not recommended.

Heating. Short sprue bushings do not, as a rule, need heating. Long bushings and bushings for injection of quick-setting plastics are equipped with a band heater (see Figure 4.84e). A suitable reflector built into the mould is a good guarantee against flooding with melt drooling from the nozzle.

4.2.1.4 Manifold heating and insulation

The heaters used for external heating of plate manifolds are of the cartridge or tubular resistance type operating on 230 V AC current. Tubular manifolds are heated by 230 V coil heaters or low-voltage 24 V or 5 V, heaters.

Cartridge heaters in a metal body (available on the market) have a very high heating power, which, in combination with their small dimensions, enables a power density of as much as 40 W/cm² to be achieved (for comparison, the power density of a band heater is around 5 W/cm²). To prolong the life of a heater and to reduce the risk of local overheating in the manifold, it is best not to exceed a value of 20 W/cm². This applies to cases where the user/mould manufacturer selects the heaters himself. The heaters are set in reamed holes symmetrically positioned on both sides of the flow channels (wall thickness minimum 10 mm).

Cartridge heaters may be cylindrical or conical in shape (see Chapter 5.1).

An example of the temperature distribution along the flow channel in the manifold is illustrated in Figure 4.85.

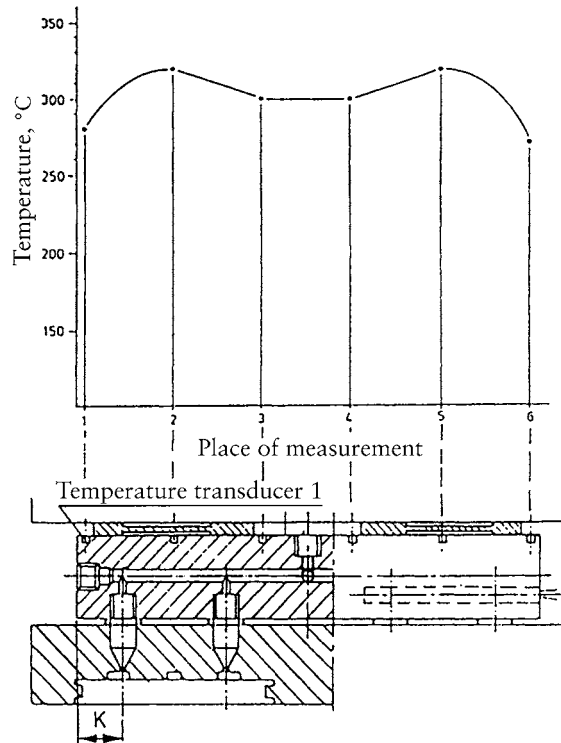


Figure 4.85 Example of temperature profile for a manifold with cartridge heaters [27]

K - distance between nozzle and end of manifold

(Reproduced with permission from HOTSET Heizpatronen und Zubehoer GmbH)

It depends not only on the heating method, but also on the insulation method and the way the manifold is supported, i.e., its cooling curve. Typical of externally-heated manifolds is rapid cooling of the ends of the manifold (measurement points 1 and 6). This is why a certain minimum distance K between the nozzle and the end of the manifold is maintained.

Tubular heaters have become widespread because of their much longer life, though they give a smaller heating power. The heaters are set in channels milled in the manifold surface (see Chapter 5.1), and also inside a cast manifold (see **Figure 4.64**) or inside cast heating plates fastened to the outside of the manifold (Mold-Masters). Usually two tubular heaters per manifold heating zone are used, positioned symmetrically on each side, which makes for a much smaller number of heaters and electrical connections than is the case with cartridge heaters.

Coil heaters used to heat tubular manifolds are shown in **Figure 4.63**.

The power consumption of heaters is provisionally evaluated at 2 W/cm^3 volume of the manifold (see Chapter 5.4).

Heat pipes. In an attempt to balance out the temperatures along the flow path, the company Dynisco HotRunners has fitted its manifolds with rectilinear tubular heaters, and also with heat pipes (see **Figure 4.86**).

The heat pipes are set between the flow channel and the tubular heaters. According to the manufacturer, this method creates isothermal conditions for the process in the manifold, and facilitates the processing of plastics with a narrow temperature window, like PVC.

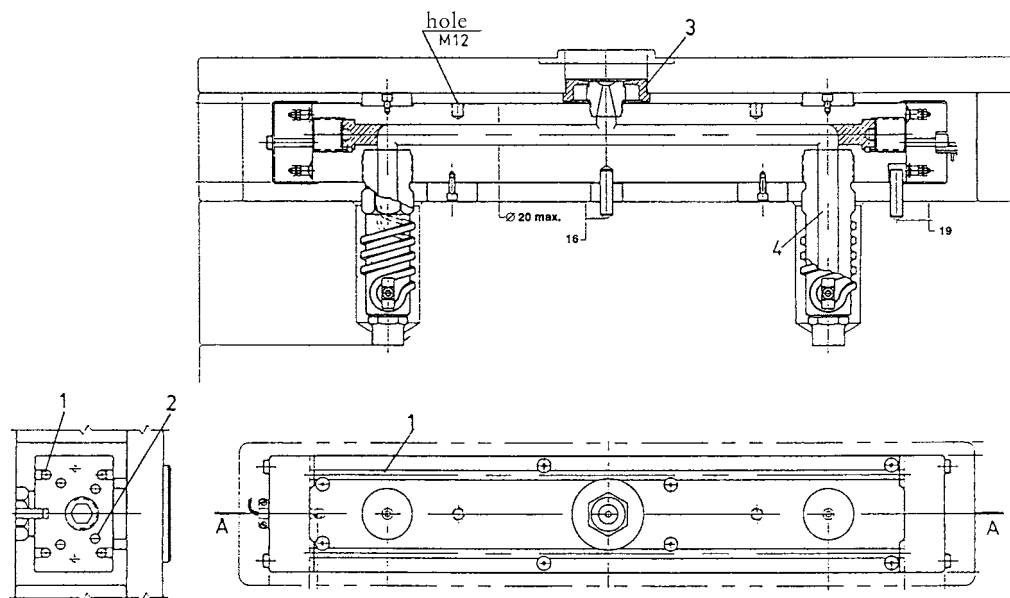


Figure 4.86 Manifold with screw-in nozzles and heat pipes

1 - rectilinear tubular heater; 2 - heat pipe; 3 - locating ring; 4 - screw-in nozzle
M12 - metric gauge of 12 mm

(Reproduced with permission from Dynisco HotRunners)

Fluid heating

Another way to balance out the temperature in the manifold (and even in the nozzles) is the use of a specific fluid, located between the heating element and the flow channel (Schöttli AG). The fluid absorbs heat from the heater and transports it (by convection) to places of lower temperature. The energy consumption is much less than in traditional systems and the system is well suited for heat sensitive plastics.

Heat insulation for a manifold is aimed at limiting heat losses, and also at limiting unwanted heat flows into the mould cavity. The following means of achieving a consistent and uniform temperature distribution are used:

- reduction in heat losses through conduction by reducing the contact area between spacer pads and making them from a material with low thermal conductivity, such as titanium alloys or ceramic sinters. Further heat conduction from the mould to the injection moulding machine platens is prevented by the use of an insulation plate fastened to the clamping plate (see Figure 4.60);
- reduction in heat losses through radiation by providing polished aluminium sheet reflectors around the manifold (see Figure 4.60);
- reduction in heat losses through convection by closure of the space round the manifold. A space that is open in the vertical direction causes a draught of air (chimney effect) which makes precision temperature control impossible. Even in an enclosed space, the consequences of this effect may be reduced by suitable positioning of the manifold (see Figure 4.87).

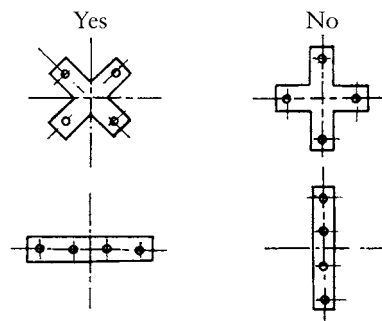


Figure 4.87 Recommended and not recommended position of manifold, with regard to chimney effect

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Insulation materials. The following materials are used for spacer pads:

- tool steel, e.g., DIN 1.2767 steel (hardness approximately 52 HRC, thermal conductivity 33 W/mK), and also DIN 1.2601 and DIN 1.4548;
- titanium alloys, e.g., DIN 3.7165 (compressive strength of 1,000 MPa, thermal conductivity approximately 7 W/mK);
- ceramic sinters (compressive strength 2,100 MPa, thermal conductivity below 2 W/mK).

Epoxy laminate with glass fibre is used for insulation plates (with a compressive strength around 600 MPa at 20 °C, 320 MPa at 130 °C, and thermal conductivity 0.22 W/mK. The use of asbestos has been banned in many countries for health reasons.

4.2.1.5 Manifold housings

A manifold is usually installed in a recess in the spacer plate with a gap of about 10-20 mm at the side to locate protruding components of the manifold and to run leads. In the case of a large manifold, though, a more economic solution is to locate it between the risers. This does away with the need to mill a recess for the manifold, but at the cost of a diminution in mould rigidity. As a result, the most common solution is to create a recess in the plate matching the shape of the manifold (see **Figure 4.88**).

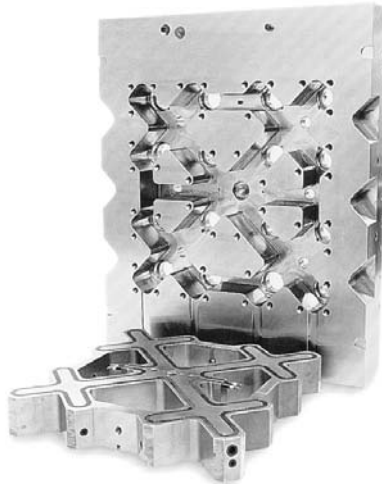


Figure 4.88 Shape of recess in spacer plate precisely adapted to shape of manifold
(Reproduced with permission from Husky Injection Moulding Systems Limited)

The height of the spacer plate must be adapted to the height of the HR system so as to ensure the initial clamping of manifold and nozzles (see Chapter 4.2.1.2).

The space housing the manifold must be closed off to prevent heat losses arising from an air draught. If the manifold space is not totally enclosed, it may be closed off by plates bolted onto the outside of the mould.

The electric leads for heaters and thermocouples are located in grooves milled in the mould plates, and normally run to the top of the mould, on which a standard socket-contact is fastened.

The mould clamping plate is subject to large surface pressures originating from the manifold pressure discs, and there is also a risk of seizure of the plate surface by the discs during thermal expansion of the manifold. It is therefore recommended that the clamping plate be made of toughened steel, or that hardened inserts be located in it (see **Figure 4.61**).

The mould half with HR requires additional cooling to remove the heat generated by the HR system. Cooling of the intermediate plate (the plate installed by the guide pillar pins) is recommended, since in boundary conditions, its thermal expansion may cause skewing of the guide pillars. The cooling connectors in the mould should not be located on the top of the mould, as this creates a risk of flooding of the HR system. Use of shut-off connectors with a non-return valve is recommended, or block connectors for the whole system of temperature regulation circuits.

4.2.2 Manifolds with internal heating

The operating principle of an internally-heated manifold is described in Chapter 1.2. This system has many adherents because of its ease of operation and low cost.

Other advantages of the system include:

- rigidity of mould. The manifold is one of the mould plates, which eliminates bending of the cavity plate during injection;
- small electric power consumption (50% lower on average), or even several times lower when low-voltage heaters are used, because the heaters are located inside the channel. The melt is thus heated directly, while the manifold plate is insulated by a frozen layer of melt in the channel, which means that it only heats up to temperatures of around 40-60 °C;

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- thermal insulation of the manifold is not required, since the manifold plate temperature is similar to that of the mould;
- natural sealing of the manifold by the frozen layer of melt in the channels, with no risk of drooling at split points;
- ease of installation, since there is no need to take thermal expansion of the manifold into account or to use spacers or clamping bolts;
- ease of maintenance of system and rapid start-up;
- lower mould height;
- fewer mould cooling requirements.

Limitations to the use of an internally-heated system arise out of the following factors:

- the cavity positioning is governed by the position of the heaters. This makes it difficult to achieve a natural flow balance. However, tiered manifolds have been designed;
- lack of control of the thickness of the insulation layer of solidified plastic means it is not possible to calculate the rheological flow balance accurately;
- melt left behind in the channels decomposes with the passage of time and may cause disruption to production. In this respect, this system is best suited to processing of thermally stable plastics (PS, PE, PP, etc.), although under certain conditions engineering plastics may also be processed. The system therefore requires regular cleaning of the channels;
- some systems only allow tip nozzles with tips to be used.

4.2.2.1 Manifold design

A distinction is made among internally-heated manifolds between:

- manifolds with cartridge (resistance) heaters;
- manifolds with low-voltage heaters.

Manifolds with cartridge heaters running on 230 V current are usually part of the mould plate (see **Figure 4.89**) or stand alone as a plate manifold (see **Figure 4.90**).

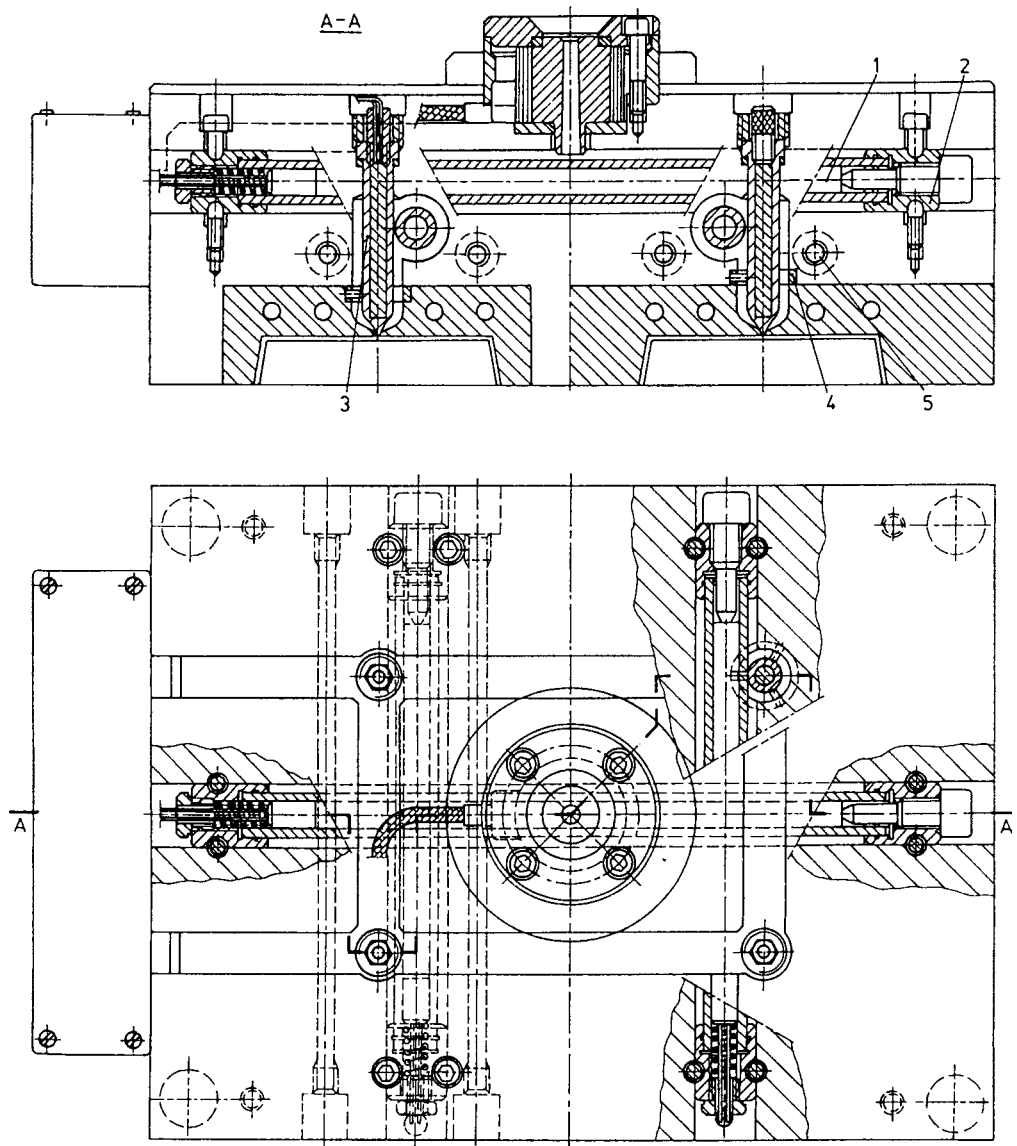


Figure 4.89 Two-level manifold with internal heating, type COOL ONE

1 - tube with cartridge heater; 2 - heater/plug bracket; 3 - torpedo with cartridge heater;
 4 - locating ring; 5 - cooling channel (if required)
 (Reproduced with permission from D-M-E Belgium)

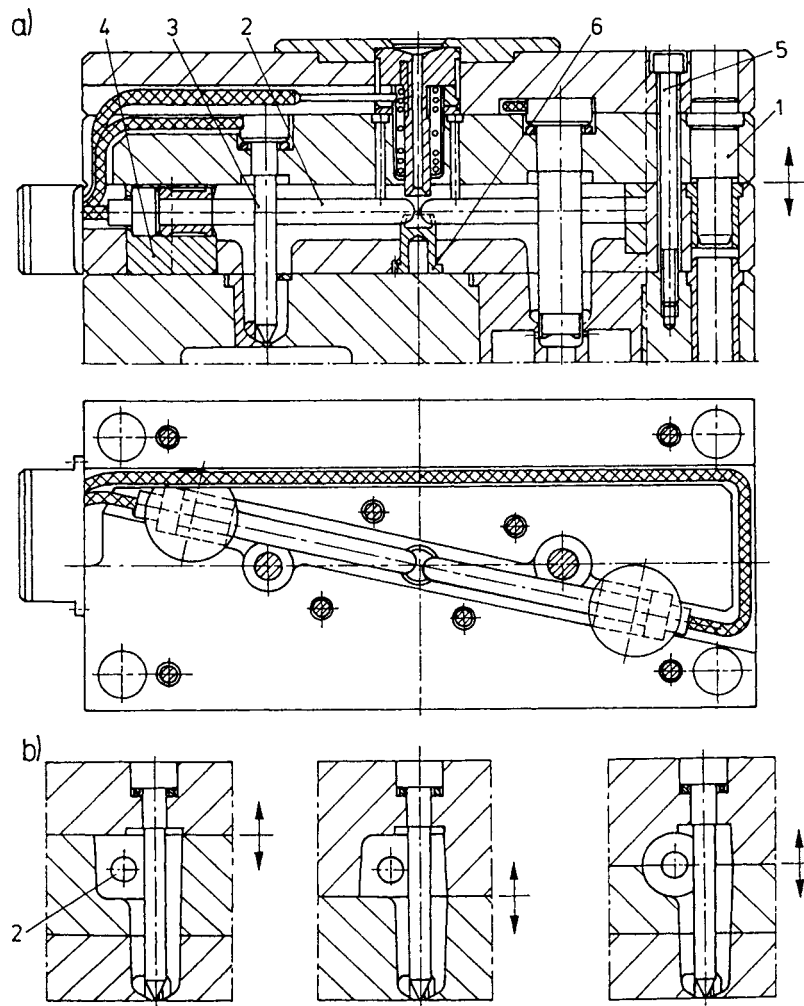


Figure 4.90 Split manifold with internal heating

a - manifold design; b - flow channel shapes used and manifold split;
 1 - guide (aligning) pillar of manifold plate; 2 - mandrel with cartridge heater; 3 - torpedo; 4 - heater mounting; 5 - bolts connecting manifold; 6 - heater tip bracket
 (Reproduced with permission from STRACK Normalien GmbH)

In the classic D-M-E version, the manifold has large-diameter (24-50 mm) drilled flow channels in which cartridge heaters in a tubular body are located. The melt thus flows through an annular channel between 4 and 9 mm wide (see Chapter 1). Because of the heating pipe in the centre of the channel, the channels cannot cross over as in externally-heated manifolds, but must be connected adjacently. Torpedoes must also be connected with a butt joint to the flow channels. This creates certain restrictions as regards the mould cavity arrangement, and it is not easy to achieve a natural flow balance (see Figure 4.91).

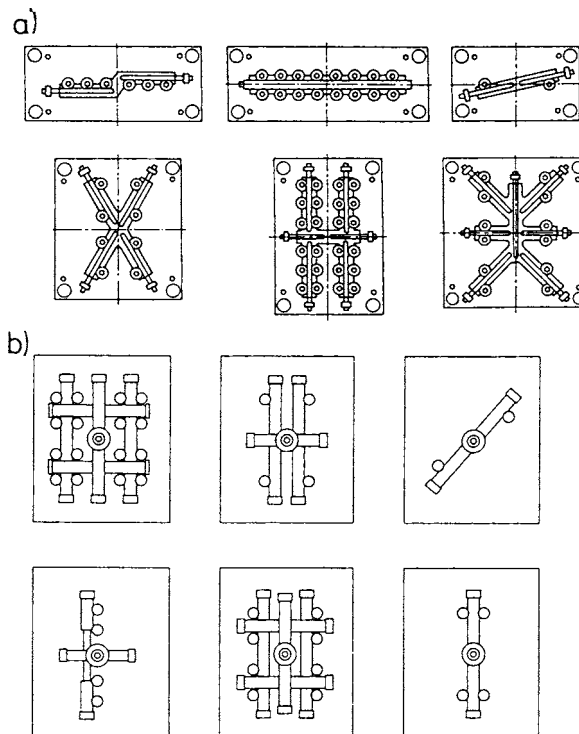


Figure 4.91 Examples of torpedo layout (injection points) and flow channels in manifold with internal heating

a - in Strack system (*Reproduced with permission from STRACK Normalien GmbH*);
b - in D-M-E system (*Reproduced with permission from D-M-E Belgium*)

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Manifolds may be manufactured in a standard mould plate and supplied by the manufacturer, or manufactured and installed using a standard catalogue drawing by the mould manufacturer. It is recommended that extra cooling channels be located between the flow channel and the mould cavity.

To simplify cleaning, and also colour changes, a split manifold design has been developed, where the manifold may be rapidly dismantled when the mould is removed from the injection machine. The flow channels may be located in one or both halves of the manifold, and they may intersect as a result of the use of heaters set in one end of the channel. The ends of the heaters must be supported to prevent their being skewed by the flow of melt. To clean the manifold, the heating should be switched on, the manifold opened up and the heaters and torpedoes pulled out of the frozen sprue.

Injection trials by STRACK using plastics with contrasting colours enabled the melt cross-section in the channel to be studied, and the thickness and lie of the liquid core to be determined. It transpired that with a gap width of 6 mm:

Plastic	Fluid layer thickness (mm)	Elastic (transitional) layer thickness (mm)	Frozen layer thickness (mm)
PC	1.5	2.0	2.5
PE	3.0	-	3.0

Following optimisation of the channels, it was confirmed experimentally that the following plastics could be injected: ABS and glass fibre, ASA, CA, EVA, PA and glass fibre, PE, PMMA, POM and glass fibre, PP and glass fibre, PS, soft PVC, SB, SAN and glass fibre.

Manifolds with low-voltage heaters operating on a 5 V current are fitted with heating elements (bars) located in protective pipes coated with a titanium nitride film to obtain a better resistance to abrasion (see **Figure 4.92**).

In the example given, the nozzles are located adjacent to the flow channels in the manifold, as a result of which the number of channels may be reduced with a certain shift away from natural balance.

The advantage of manifolds with low-voltage heating is the rectilinear temperature distribution in the heating element, which facilitates processing of plastics with a narrow temperature window. The manifold heating time is very short.

When the power supply is 5 V and 125 or 100 A, these heaters have a power of 625 or 500 W, respectively.

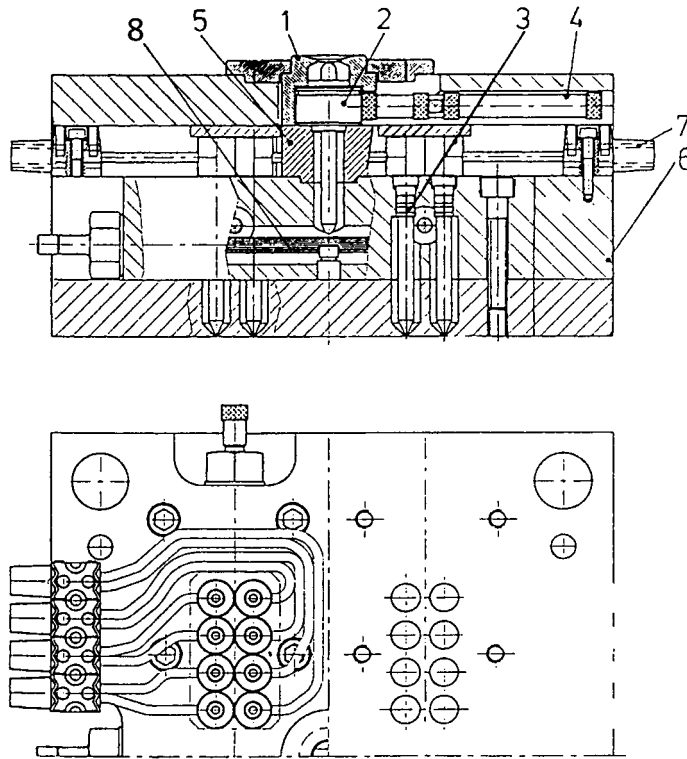


Figure 4.92 Manifold with internal low-voltage heating to 32-cavity mould

1 - sprue bushing housing; 2 - sprue bushing torpedo; 3 - manifold torpedo; 4 - torpedo power cable; 5 - spacer bushing; 6 - manifold; 7 - connection module; 8 - bar heater

(Reproduced with permission from EWIKON Heißkanalsysteme GmbH & Co. KG)

4.2.2.2 Nozzle installation

Use of an internal channel heating system, coupled with the low manifold plate temperature, have enabled torpedoes to be set within the manifold and for them to be used to heat the exit channels. A torpedo is normally fitted in a fixed manner (see **Figure 4.93**), but there is also the potential to fasten it in such a way that it can move (**Figure 4.93b**).

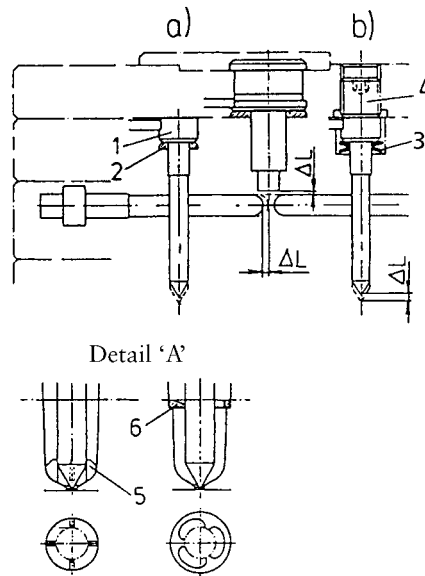


Figure 4.93 Methods of setting torpedoes in manifold with internal heater

a - fixed; b - moving; ΔL - change in dimensions as a result of thermal expansion;
1 - torpedo; 2 - pad; 3 - spring; 4 - adjusting screw; 5 - locating ribs; 6 - locating ring

(Reproduced with permission from Strack Normalien GmbH)

In this design, the torpedo flange is fastened between a disc spring and an adjusting screw. By turning the screw, the position of the torpedo end in the gate may be rapidly adjusted during mould trials in the injection moulding machine (following removal of the mould from the fixed platen of the machine). The centre fitting of the torpedo end in the gate is ensured by ribbed protuberances in the bottom of the insulation chamber, or by a locating ring set in the manifold.

As has already been mentioned, the problem of thermal expansion does not arise in this type of manifold, but compensation for thermal expansion ΔL of torpedoes and heaters is required.

Nozzles with the power lead running in from the side (see **Figure 4.94**) are set between the manifold and the cavity plate in the axis of the channel (not adjacent). These nozzles may be in the form of a torpedo, a multi-tip nozzle or an edge nozzle.

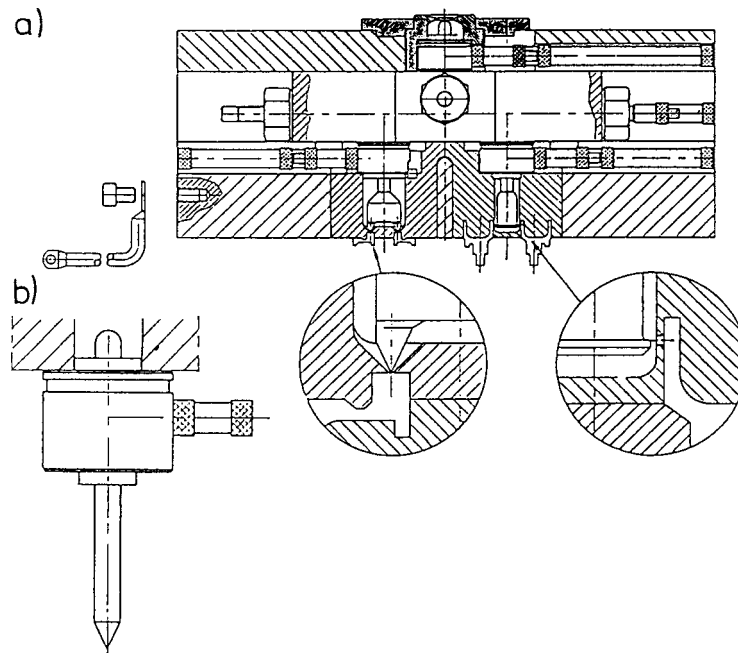


Figure 4.94 Setting of torpedo (nozzle) under manifold

a - method of setting and fastening nozzles; b - seating shank and flange of low-voltage-heated nozzle

(Reproduced with permission from EWIKON Heißkanalsysteme GmbH & Co. KG)

4.2.2.3 Sprue bushings

In view of the low temperature of the manifold plate, the sprue bushings must be heated. Both external and internal heating is used (for the use of a torpedo, see **Figure 4.92**).

In the example of a sprue bushing with external heating that is given (see **Figure 4.95**), the heater is embedded in a copper beryllium bushing, and to achieve better heat distribution, a copper beryllium ring is deployed in the end of the bushing, with copper beryllium pins in the bushing flange.

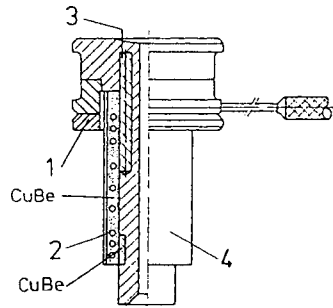


Figure 4.95 Heated sprue bushing with extra temperature balancing

1 - spacer ring; 2 - heater; 3 - copper beryllium conducting pins; 4 - stainless steel jacket
(Reproduced with permission from STRACK Normalien GmbH)

4.3 Enclosed HR sets

The link between proper functioning of an HR system and the correct choice of system components and their installation, on the one hand, and the trend towards less mould treatment and shorter delivery times on the other, have combined to lead some manufacturers to offer enclosed HR sets. These sets are built from normal components or made up to individual orders when these components are not available to build the required mould, e.g., special shape or size of manifold, special nozzle length.

A major benefit arises from the use of ready-made HR sets in the case of HR systems with shut-off nozzles with built-in pneumatic or hydraulic drive.

The HR set shown in **Figure 4.96** comprises a fully-fitted manifold, shut-off nozzles and pneumatic cylinders, plus two installation plates.

The set is equipped with all the essential power (plug-in sockets), cooling and compressed air connections, and also with installation pillars and bushings, as well as threaded holes for attachment to the cavity plate. The set is thus ready to be installed on the mould, and it is also possible to remove the set from the mould on the injection machine with subsequent ease of replacement of a damaged tip or nozzle heater. The set is tested prior to delivery.

One design novelty in the HR set described, is the way the nozzle seal is ensured by clamping it to the manifold using a set of disc springs (14). The leakproofing of the system is thus made independent of the operating temperature, i.e., the thermal expansion of the manifold (in other words, the set may be used for different plastics with a processing

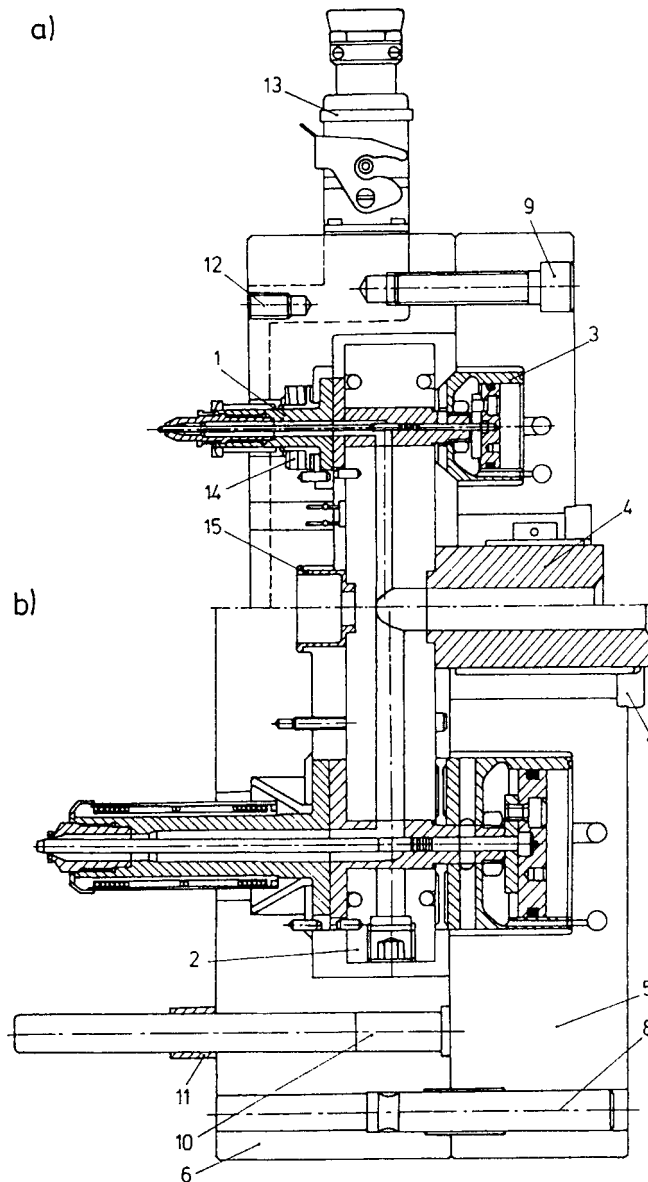


Figure 4.96 Enclosed HR set ready to be fitted to mould

a - low volume (750 series); b - high volume (1250 series); 1 - HR nozzle; 2 - manifold;
 3 - pneumatic cylinder; 4 - sprue bushing; 5 - clamping plate; 6 - spacer plate;
 7 - locating ring; 8 - dowel pin; 9 - bolt; 10 - guide pillar; 11 - guide bushing; 12 -
 threaded hole; 13 - push-in socket; 14 - compression spring; 15 - support/locating pad
(Reproduced with permission from Husky Injection Moulding Systems Limited)

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temperature difference of up to 200 °C). Another innovation is the linking of the cylinder to the manifold, as a result of which the valve pin is not subject to shear stresses during expansion of the manifold. The cylinder has no bottom, is sealed by clamping to the lower installation plate and functions as a manifold support.

The design of the enclosed HR set (see **Figure 4.97**) shown in a position separate from the rest of the mould is based on a similar principle; this position is therefore prior to installation with the mould or after opening on the injection machine for servicing of the nozzles.

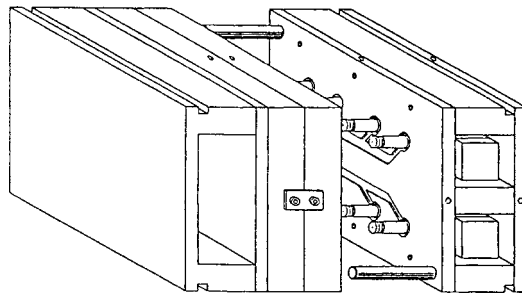


Figure 4.97 Enclosed HR set in position separated from mould

(Reproduced with permission from Dynisco HotRunners)

4.4 Moulds with insulated channel

In moulds with an insulated channel there is no manifold, and the large-diameter channels are located between the two mould plates. The operating principle of the system is based on utilisation of the insulating properties of the plastic without heating of the channel. The external frozen layer of melt protects the fluid central core from freezing (see Chapter 1.2). The simplicity of design of the system has, however, restricted its application to plastics with a wide processing temperature window and to short injection cycles (cycle time less than 20-30 seconds). The system is cheap and leakproof, but its use requires continuity of operation to be observed. A break in operation means that the mould has to be opened in the channel plane and the frozen runner removed. The runner also needs removing when the type of plastic or its colour is changed, but this may be carried out on the injection machine. Another advantage is that channel purging is not required. The large runner cross-section makes it difficult to recycle (mill) the waste.

The moulds of this system were designed with a large-diameter flow path (approximately 18-25 mm) situated between the mould plates (see **Figure 4.98a**). This channel is then led up to the cavity or to the cold runner of the mould. The critical point in the system was rapid freezing of the melt in the gate zone, which limited use of the system to plastics of types PS and PE.

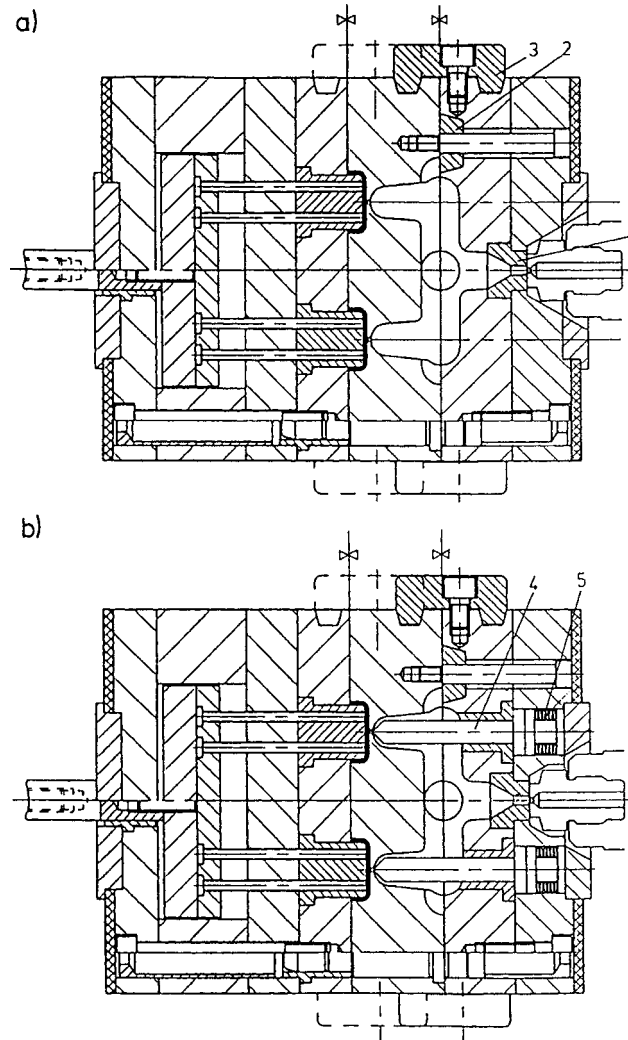


Figure 4.98 Mould with insulated channel

a - ordinary; b - with heated torpedo shutting off gate; 1 - sprue bushing; 2 - knock-off strip; 3 - clamping strip; 4 - torpedo; 5 - spring (*Reproduced with permission from Arburg*)

Hot Runners in Injection Moulds

Satisfactory operation of the system in practice is attained when a heated torpedo is introduced into the gate opening. The frozen runner is removed on the injection machine after separation of the mould in the channel plane through the use of clamping strips (3), which can be moved to the required mould parting line.

The system was modified (by DuPont) to enable processing of crystalline plastics by introducing a moveable torpedo shutting off the gate with the aid of a spring (5) (see **Figure 4.98b**). This torpedo counters the melt freezing in the gate zone, while at the same time by closing the gate it prevents drooling of the melt when the mould is opened. The knock-off strips (2) were intended to knock the frozen sprue off the torpedo when the mould was separated.

4.5 Thermal expansion of HR sets

Thermal expansion of an HR set may cause adverse dimensional changes, inadmissible mechanical loads and deformation. HR system manufacturers do take this problem into consideration, but the taking of certain compensatory measures is down to the user when he is installing the system.

When a nozzle is being installed, consideration should be given to its thermal elongation, so that when the mould and nozzle are heated, the end face or tip of the nozzle adopts the position recommended by the supplier. The user must, therefore, calculate the size of the mould from the nozzle flange to, for example, the end face of the gate, in the case of a tip-type nozzle (see **Figure 4.99a**).

Some suppliers give a value for thermal elongation of nozzles which is a function of the temperature difference, but if such data are not forthcoming, the calculation is carried out using the formula:

$$L_F = L_d [1 + \alpha (T_d - T_F)], \text{ mm} \quad (4.1)$$

where:

L_F and L_d are the size of the mould and the nozzle, respectively, at room temperature in mm;

α is the thermal expansion coefficient, K^{-1} (13×10^{-6} for steel at a temperature of 20-200 °C);

T_d and T_F are the nozzle and mould temperatures, respectively, in °C.

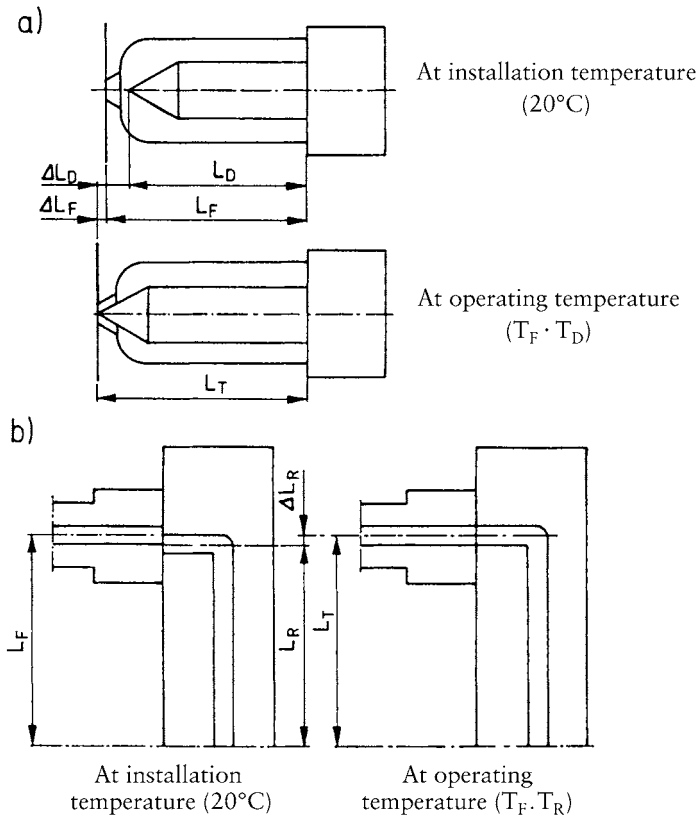


Figure 4.99 Adjustment for thermal elongation

a - of nozzle; b - of manifold

In cases where there are different materials present, e.g. a torpedo made of copper alloy, the calculation is performed using the formula:

$$L_F = L_D \frac{1 + \alpha_d \cdot (T_d - 20)}{1 + \alpha_F \cdot (T_F - 20)}, \text{ mm} \quad (4.2)$$

where: α_d and α_F are the thermal expansion coefficient of the material of nozzle and mould, respectively.

The thermal expansion coefficient values of materials used in HR system building are given in Table 4.2.

When installing a manifold, consideration should be given to:

- 1) elongation of the manifold in transverse directions, which influences the position of the exit channels;
- 2) elongation of the manifold (and also of the nozzles and spacer pads) along the mould axis, which influences the contact surface load and the leaktightness of the system.

In the first case, transverse elongation of the manifold has to be taken into consideration in such a way that, when the mould and manifold have been heated, the nozzle and manifold channel are in a coaxial position (see **Figure 4.99b**). The nozzle position is set when the cavities were positioned, so the user must calculate the size of the manifold from channel axis to mould axis from the formula:

$$L_R = L_F \cdot [1 - \alpha \cdot (T_r - T_F)], \text{ mm} \quad (4.3)$$

where: L_R and L_F are the size of manifold and mould, respectively, at room (installation) temperature, in mm;

T_R and T_F are the manifold and mould temperature, respectively, in °C.

In the second case, axial elongation of the manifold, nozzle and spacer pads need to be taken into consideration so that when the mould and HR system are heated, the pre-tension is attained in the set that does not exceed the admissible surface pressure between pad and clamping plate (this is normally the most loaded place in the set). **Figure 4.100a** shows diagrammatically an HR system installed without a gap.

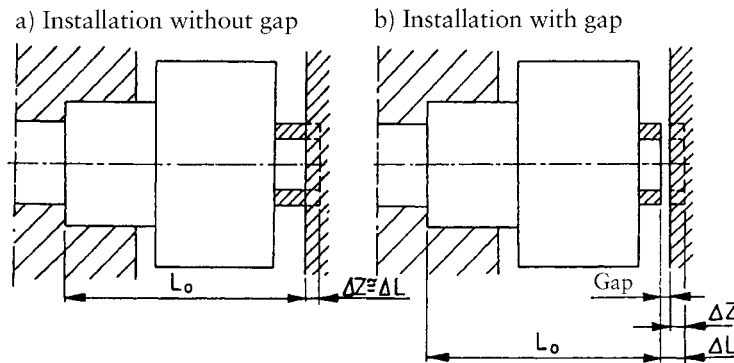


Figure 4.100 Ways of installing an HR set that ensure initial clamping after heating
a - without gap; b - with gap (at installation temperature)

After heating of the mould and HR system to operating temperature, elongation of the set takes place:

$$\Delta L = L_o \cdot \alpha \cdot \Delta T, \text{ mm} \quad (4.4)$$

where: L_o is the height of the set at room (installation) temperature in mm;

$\Delta T = T_r - T_F$ which is the temperature difference between the manifold and the mould in °C.

The stress evoked by thermal expansion of the set is:

$$\sigma = \frac{\Delta L}{L_o} \cdot E, \text{ MPa} \quad (4.5)$$

and with equation (4.4) substituted in:

$$\sigma = \alpha \cdot \Delta T \cdot E, \text{ MPa} \quad (4.6)$$

where E is the elasticity modulus in MPa (2.1×10^5 for steel).

In most applications, thermal stresses would exceed the admissible surface pressure (assuming rigid installation), causing indentations to appear on the plate surface (see the example calculation). The manifold is therefore usually installed with an appropriately selected gap (see **Figure 4.100b**). Some suppliers, e.g., Mold-Masters, give an installation clearance value for the whole set (including the nozzle) and as a function of the temperature difference, while others give a general value which does not take the temperature difference into account. For example, a manifold dimensioned for PC ($\Delta T = 210$ °C) has twice the elongation of a manifold dimensioned for POM ($\Delta T = 100$ °C), which needs to be considered. If it is not, the risk arises that the manifold dimensioned for PC will not be leakproof when POM is injected, and conversely, that a manifold calibrated for POM will be overloaded when PC is injected.

Calculation of the assembly clearance is difficult, since the components of the set (nozzle, manifold, pad) have different cross-sectional areas and may be made of materials with different modulus, E , meaning that they will be subject to different elastic strains. Furthermore, analytical inclusion of installation strains is not possible, and the solution requires a mathematical finite elements method to be used.

Example of calculation

This example illustrates application of the formulae 4.1-4.6 to make calculations for a mould intended for PC injection.

Length of torpedo

$$L_d = 40 \text{ mm}$$

$$T_d = 300 \text{ }^{\circ}\text{C}$$

$$T_F = 90 \text{ }^{\circ}\text{C}$$

- The depth L_F of the initial chamber for the torpedo (see Figure 4.100a) intended for PC injection is:

$$\Delta T = (300 - 90) = 210 \text{ }^{\circ}\text{C}$$

$$\text{from equation (4.1): } L_F = 40 (1 + 13 \cdot 10^{-6} \cdot 210) = 40.11 \text{ mm}$$

- Depth of initial chamber for copper beryllium alloy torpedo:

$$\text{from formula (4.2): } L_F = 40 \frac{1 + 17.5 \cdot 10^{-6} \cdot (300 - 20)}{1 + 13 \cdot 10^{-6} \cdot (90 - 20)} = 40.16 \text{ mm}$$

- Distance L_R of manifold exit channel from mould axis (**Figure 4.99b**) with distance of nozzle from mould axis $L_F = 100 \text{ mm}$:

$$\text{from formula (4.3): } L_R = 100 \cdot (1 - 13 \cdot 10^{-6} \cdot 210) = 99.73 \text{ mm}$$

- Elongation ΔL of set (**Figure 4.100a**):

$$\text{where height of set } L_0 = 75 \text{ mm:}$$

$$\text{from formula (4.4): } \Delta L = 75 \cdot 13 \cdot 10^{-6} \cdot 210 = 0.20 \text{ mm}$$

- from formula (4.6), the thermal stress in the set is:

$$\sigma = 13 \cdot 10^{-6} \cdot 210 \cdot 2.1 \cdot 10^5 = 570 \text{ MPa}$$

If the manifold and the clamping plate are made of toughened steel (DIN 1.2312) with an elastic limit, Re of 800 MPa, the admissible surface pressure, P_{dop} , will be:

$$p_{dop} = \frac{Re \cdot 0.8}{2}$$

where 2 is the safety factor.

$$P_{dop} = 800 \cdot 0.8/2 = 320 \text{ MPa} < \sigma = 570 \text{ MPa},$$

and therefore installing the manifold without a gap risks rapid damage to the contact surface between plate and washer. An installation gap should therefore be envisaged (Figure 4.100b).

It should be pointed out that for POM, $\Delta T = 100^\circ\text{C}$ and $\sigma = 270 \text{ MPa}$, so the manifold may be installed without a gap, and even with a little interference.

Calculation of manifold clamping Δz may be made approximately, assuming a stress distribution in the HR set in line with the stress-conic propagation principle. This makes for 5 calculation zones of different rigidity (see Figure 4.101).

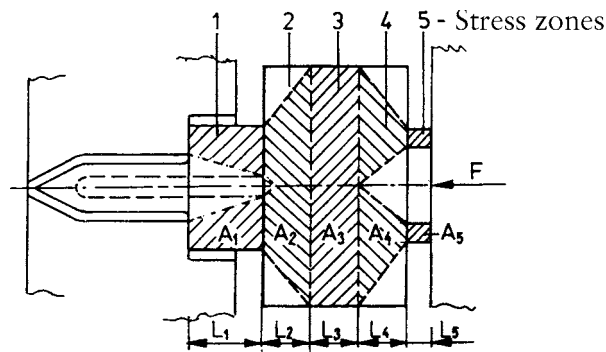


Figure 4.101 Thermal stress distribution in an HR set:

zones: 1 - nozzle flange; 2, 3, 4 - manifold; 5 - pressure disc; A_1 to A_5 - active surfaces of cross-section

In view of the complex nature of the calculations, only their results are given.

Example (continued)

- clamping force (calculation for spacer pad) $F = 108 \text{ kN}$

Hot Runners in Injection Moulds

- interference $\Delta z = 0.04$ mm
- elongation resulting from thermal expansion $\Delta L = 0.20$ mm

$$\text{hence installation gap} = \Delta L - \Delta z = 0.20 - 0.04 = 0.16 \text{ mm}$$

In practice, a smaller gap is left (greater clamping), since the manifold structure is also subject to deformation.

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5 Thermal Balance and Temperature Control

An HR system must be in a state of thermal equilibrium, which means that heat losses must be compensated for by heating. In the ideal case, an HR system will be in an isothermic state.

The thermal equilibrium of any HR system is governed by variable and fixed values of all components of the thermal balance of the mould/injection moulding machine/ambient conditions system. The fact that variable factors are always present means that automatic temperature control and regulation of the HR system must be used to keep deviations from the required temperature to a minimum. The following initial conditions must be fulfilled:

- selection of heating system for individual sections of HR system taking into account process criteria;
- use of heating elements of the correct design and power;
- positioning of heating elements in structure;
- identification of heating zones and temperature measurement points;
- provision of insulation;

and also, from the user's point of view, these conditions:

- durability;
- ease of replacement where necessary;
- resistance to mechanical damage, leaks and corrosion;
- reliability and safety of connection.

5.1 Heaters and thermocouples

Various types of heater are used, depending on the requirements made of individual HR system elements and their design (see Chapter 4). They are manufactured and made available by specialist firms or by the manufacturers of standard mould bases with special recommendations for their installation and use.

Hot Runners in Injection Moulds

The heaters most commonly used are:

- coil and coil-band heaters for nozzle heating;
- cartridge and tubular heaters for manifold heating.

The coil heater is usually designed with two heating coils located side by side and inserted in magnesium oxide inside a stainless steel tube. Magnesium oxide is a material which combines high electrical resistance with fairly good thermal conductivity. If the heater tube has a round cross-section (see **Figure 5.1**), the contact between the heater (a) and the surface of the nozzle is linear and heat transfer takes place chiefly through radiation. Because of this, the thermal density on the heater surface is limited to 3.5 W/cm^2 .

A heater with a coil of rectangular cross-section (b), or more often a flattened oval cross-section, has a greater contact area with the nozzle, which allows some of the heat to be transferred by conduction. This reduces the heat load and improves the thermal balance. The thermal density used is $6\text{-}15 \text{ W/cm}^2$.

The non-heated zone at the beginning of the heater in the connection zone is at least 55 mm (tube length). At the end of the heater (near the face of the nozzle), where the thermocouple is located, a short non-heated zone is again used (10-15 mm).

The temperature distribution (see **Figure 5.2**) may be shaped by increasing or decreasing the coil winding pitch. The most common type of winding is what is known as logarithmic winding, which takes account of the greater heat take-up in the parts of an HR nozzle which are in contact with the mould, i.e., in the flange and face sections. Each heater is thus adapted to the thermal characteristics of the nozzle, and should not be replaced by a heater of a different type. **Figure 5.2** shows a heating profile described as 40-20-40 obtained by a variable winding.

The heater (**Figure 5.1c**) is applied to a copper pipe, restricted by copper rings and closed off by an outer jacket of stainless steel. The copper pipe enables heat to be transferred uniformly from heater to nozzle and improves heating of the nozzle at the 'dead' ends of the heater, while the jacket counters outward heat radiation. This design provides a uniform temperature distribution in the nozzle, especially at high operating temperatures, and good durability. The admissible thermal density for such heaters is up to 15 W/cm^2 .

Heaters cast into a block or bushing of copper alloy (see **Figure 5.1d**) are described in the examples given in Chapter 4. They feature the greatest durability and admissible heat loading.

Band heaters which have a spirally twisted heating tube inside (see **Figure 5.1e**), of small diameter (1.8 mm or flattened 1.3 mm x 2.3 mm), are used mainly for nozzle flanges.

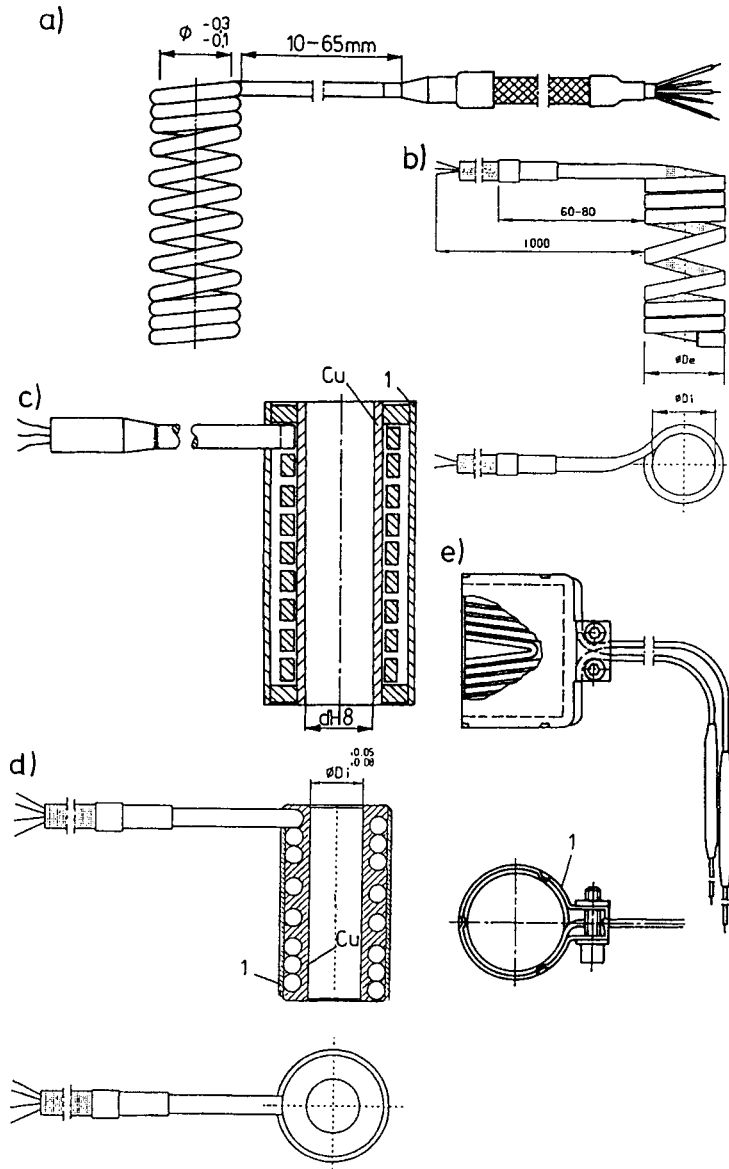


Figure 5.1 Types of coil heater for nozzles

a -with round cross-section [1]; b -with rectangular cross-section; c -with coil wound on copper tube [1]; d -with coil embedded in copper; 1 -reflector sheet;
e - with clamping strip [1]; De - external - external diameter; Di - internal diameter

(a and d reproduced with permission from HOTSET Heizpatronen und Zubehör GmbH; b, c & e reproduced with permission from EMP)

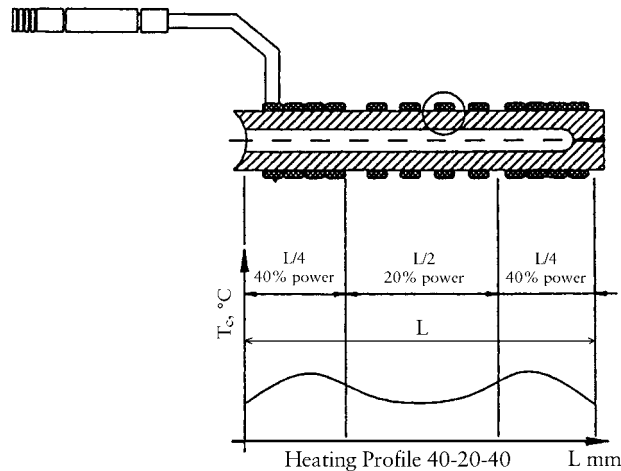


Figure 5.2 Coil heater with 40-20-40 heating profile
(Reproduced with permission from the Rabourdin Group)

There is a trend for coil heaters of increasingly small diameter (Hotset) to be introduced, as this enables the nozzle pitch to be made smaller. New developments in 220/230 V heaters of type (d) (see **Figure 5.1**) are beginning to compete successfully with low-voltage heaters. The durability of 230 V and 5 V heaters is also becoming comparable.

Cartridge heaters are cylindrical or conical in shape (see **Figure 5.3**). The external shape has an impact on many of the usage properties of heaters.

A cylindrical heater (a) has the disadvantage that, for practical reasons, it cannot be set in a hole without leaving a gap. Precision manufacture is needed, with the hole drilled to H7 tolerance (ISO standard tolerance). With a recommended installation allowance of between 0.02 and 0.08 mm, depending on the heater diameter, thermal expansion can theoretically cause the heater to touch the wall of the hole. When the heater has been replaced several times and cleaning (of corrosion) has taken place, this allowance gets larger. The larger the allowance, the worse the transfer of heat to the manifold (see **Figure 5.4**), so the operating temperature of the heater tends to rise, and the heater may become overheated and suffer damage. The thermal density of cast-in cylindrical heaters is limited to 20 W/m² to ensure that they have adequate durability. To improve heat conduction, the heater is set in the hole using a conductive paste. With time, however, the paste causes the heater to become ‘baked into’ the hole, which makes it difficult to replace when damaged.

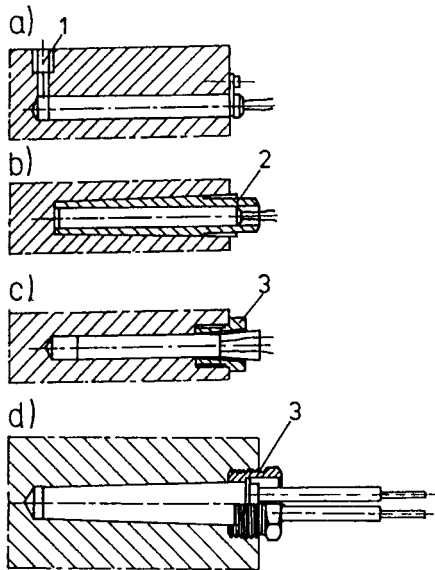


Figure 5.3 Cartridge heaters

Methods of fastening cylindrical heaters [2] (a, b, c) and conical heaters (d) which facilitate their removal

1 -threaded hole for pump connection;
2 -conical bushing with thread; 3 -threaded bushing (a, b, and c reproduced with permission from D. Schauf, *Kunststoffe*, 1979, 69, 11, 777, Figures 18a, 18b and 18c. © 1979, Carl Hanser Verlag;
d reproduced with permission from Hasco Normalien Hasenclever GmbH & Co.)

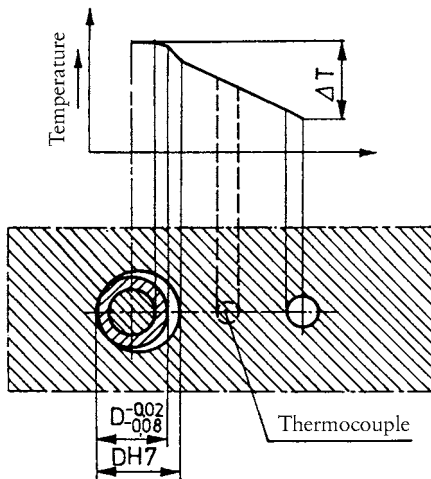


Figure 5.4 Temperature drop in manifold on path between cartridge heater and flow channel [1]

(Reproduced with permission from Hotset Heizpatronen und Zubehör GmbH)

Many companies recommend using an aqueous magnesium oxide solution rather than paste; this not only conducts heat very well when the water has evaporated, but also helps to get the heater out. Both this agent and others, especially those preventing corrosion (used even where the gap is very small) are available in spray form.

Hot Runners in Injection Moulds

Note. When conductive agents are applied it is necessary to protect the connecting terminals of heaters and thermocouples, as well as existing connections, from being covered by them otherwise there is the risk of a short circuit.

One practical way of removing heaters is to force them out using an ordinary grease pump. A threaded hole needs to be provided in the manifold to connect the pump (see **Figure 5.3a**).

Another method is to set the heater in a conical brass bushing with a dismantling thread (b). A further method of removing the heater is to use a threaded tightening ring, e.g., with a conical heater flange (c).

To solve the problem of cylindrical heater replacement, a manifold has been developed with a strip that holds the heater down (see **Figure 5.5**). The drawback to this design is the diminished rigidity of the manifold.

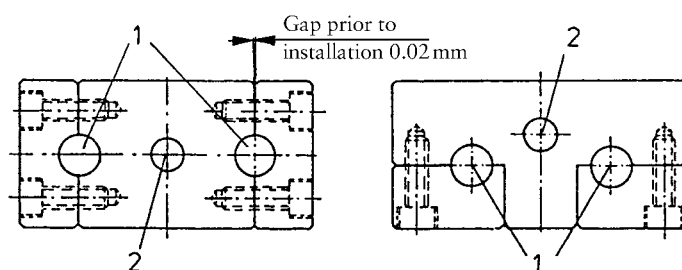


Figure 5.5 Manifold with clamping strips to fasten cylindrical cartridge heaters [1]

1 - heater; 2 - flow channel

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Fitting and replacement problems do not occur when a conical heater with a 1:50 taper is used. This heater is set in a hole without a gap, which doubles heat transfer. Its removal is facilitated by a threaded bushing (see **Figure 5.3d**). Use of conical heaters is limited, however, because their diameter increases with their length.

Logarithmic winding of resistance wire is also used to provide a more uniform temperature distribution (see **Figure 5.6**). A fall in temperature at the two ends of the heater arises because they are not heated for a length of some 10 mm (insulation).

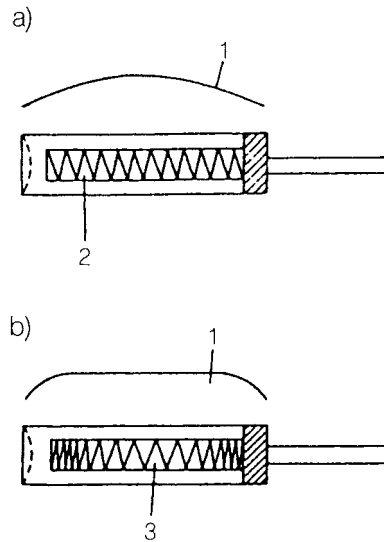


Figure 5.6 Thermal characteristic (1) of heaters

a - of cartridge heater with constant pitch winding (2); b - of cartridge heater with logarithmic winding (3)

One major rationalisation that reduces this detrimental fall in power is use of a housing with a flat copper bottom that transfers and conducts heat well. Heating elements of this sort are used in, for example, torpedoes with a heat-conducting tip.

Some companies put a pressed copper plate in the bottom of the heater hole to improve heat conduction to the end of the torpedo tip (see **Figure 5.7**).

When holes for heaters are drilled in the manifold, it is essential to:

- maintain symmetry relative to the flow channel;
- keep a minimum distance away from the manifold wall, of at least one heater diameter in size (see **Figure 5.8**);
- location of the heaters in the middle plane of the manifold block - this reduces the risk of warping and thermal stresses occurring;
- location of the thermocouple at an identical distance between the heaters.

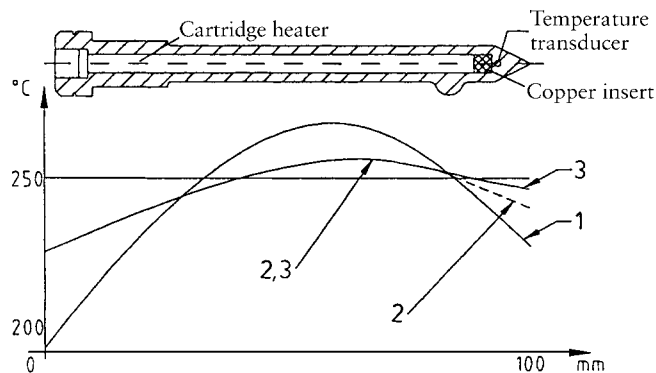


Figure 5.7 Temperature distribution in torpedo heated by cartridge heater
 1 - with normal winding; 2 - with logarithmic system winding; 3 - curve modified through use of copper insert
(Reproduced with permission from the Rabourdin Group)

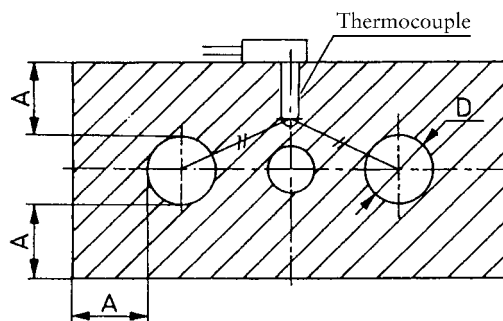


Figure 5.8 Positioning of heater holes (D) in the manifold.
 The distance, A, should be bigger than the diameter, D, of the heater.

It is recommended that a small hole be drilled at the end of the heater holes to help gases to escape during heating.

Direct temperature measurement for cartridge heaters may be made using a thermocouple pressed into the bottom of the heater housing.

The trend towards heater minimisation while maintaining high heater power levels, up to as much as 35 W/m², has led to a group of heaters coming into being that may also be

classified as cartridge heaters. An example of this is nozzles in which the casing of the torpedo is a covering for an internally pressed heater (D-M-E Belgium). In this type of integral cartridge heater, only the inserted thermocouple is replaceable.

Moisture absorption. All heaters absorb moisture from the air at room temperature, particularly in the cooling phase. This is caused by the hygroscopicity of the internal ceramic insulation. Cartridge heaters are especially vulnerable to moisture. During the heating phase, when current flows through the moist heater, there may be an insulation breakdown between the wires of the coil and damage to the heater. **Figure 5.9** shows the fall in resistance of dry and moist magnesium oxide insulation as the temperature rises.

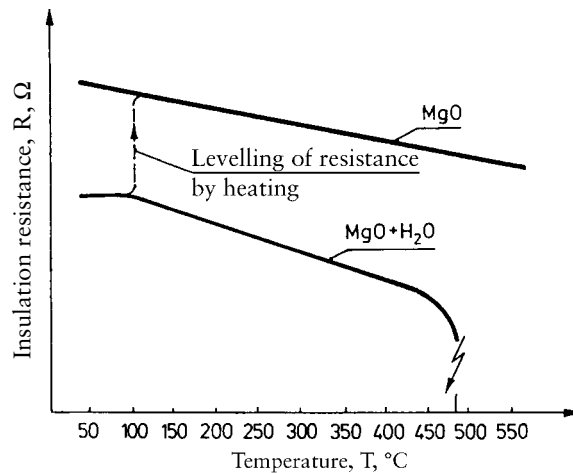


Figure 5.9 Resistance of dry and damp magnesium oxide insulation in a cartridge heater
(Reproduced with permission from PSG Plastic Group GmbH)

The graph indicates the need to remove moisture from the insulation before the heater is heated up to operating temperature. This is done at 100 $^{\circ}\text{C}$ for around 15 minutes, and should be programmed into the temperature control system. Every time the temperature of the HR system falls below 50 $^{\circ}\text{C}$, this operation needs to be repeated (the 'soft start' phase - see Section 5.5).

Tubular heaters (see **Figure 5.10**) have found a use in HR system designs because of their potential to bend and be adapted to the shape of the manifold, and because of their good durability and linear temperature characteristic.

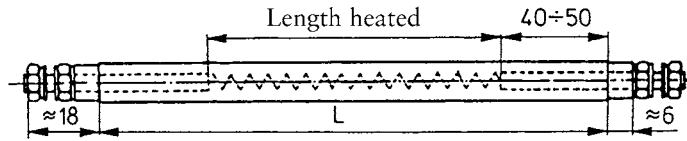


Figure 5.10 Tubular heater [1]

(Reproduced with permission from Hotset Heizpatronen und Zubehör GmbH)

In contrast to other heaters, there is a single coil inside the tube, and the positive and negative wires are located on opposite sides of the heater. This design largely eliminates the possibility of insulation breakdown. The cold ends of the heater, some 50 mm in length, are not heated and should be situated outside the manifold. One operational fault that occurs is that these ends get broken when care is not exercised in servicing. The thermal density of a tubular heater is about 15 W/cm^2 .

When tubular heaters are correctly positioned, a balanced temperature is achieved over the whole length of the flow channel and in the vicinity of the nozzle. Another advantage is the small number of connection leads and the limited number of heating zones.

The heaters are set in grooves cut into the manifold, in parallel to and symmetrically with the flow channel on both sides. Fastening of the heaters is carried out by embedding in a mass with added nickel or copper with good thermal conductivity, or by soldering using a copper alloy (see Figures 4.62 and 5.11a), pressing (see Figures 4.61 and 5.11b) in a groove with a counter-taper, or using a shaped copper strip (Figure 5.11c), or simply by clamping with an aluminium sheet (see Figure 5.11d) or with a plate with milled

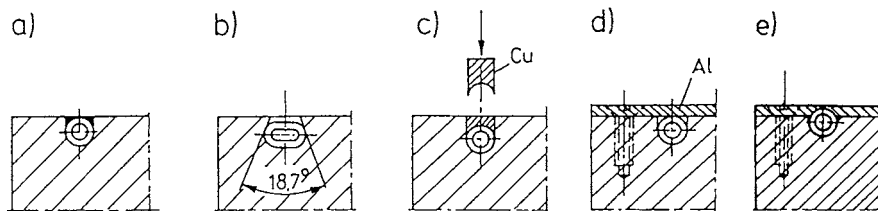


Figure 5.11 Methods of fastening tubular heaters in a manifold

- a - setting in conductive paste or soldering; b - pressing in channel with counter-taper;
- c - pressing with copper strip; d - clamping under a sheet; e - clamping using a plate with profile groove

groove. The two latter methods make it easy to change the heater using one's own resources. In older designs, the heaters are potted in high thermal conductivity cement.

Heater bending usually takes place on bars fastened to the manifold plate tangentially to the groove curvature, and the heater is pushed into the groove with each bending. The minimum bend radius of a tubular heater depends on its diameter and is 5-16 mm [1]. This technique requires a certain amount of experience.

If a heater is bent according to the dimensions on the manifold drawing, it will not entirely fit into the groove. Manifold manufacturers use special templates for the bending. When ordering spare heaters for non-standard manifolds, it is usually necessary to send the manifold to the manufacturer, or else spare heaters should be purchased together with the manifold.

The thermocouple acts by creating a difference in potentials (measured in mV), which may be interpreted as a temperature.

The thermocouple most commonly used in HR systems is iron-constantan (Fe-CuNi), which provides a linear characteristic between 200 and 350 °C. Nickel-chromium-nickel thermocouples are also used.

The most commonly used types of thermocouple are shown in **Figure 5.12**:

- an angled thermocouple (a) set in a hole on the front surface of the manifold;
- a rectilinear thermocouple (b) set in a deep hole made in the side of the manifold, and pressed against the bottom of the aperture by a spring;
- a wire thermocouple (c) may be bent, and provides freedom of choice of the place where it is set. This thermocouple is also used in nozzles.

A thermocouple in a manifold with external heating should be located between the heater and the flow channel (see **Figure 5.4**). Positioning the thermocouple in the external (cooler) zone of the manifold may cause overheating of the melt in the channel, which should be remembered if the user himself is assembling the manifold. Another solution employed is that shown in **Figure 5.8**, since here there is transmission of good information concerning the channel temperature.

The thermocouple in a manifold with internal heating is usually built into a cartridge heater.

Depending on the heating profile, nozzle manufacturers use two thermocouple positions: in the central part of the nozzle or in the front end (see **Figure 5.13**).

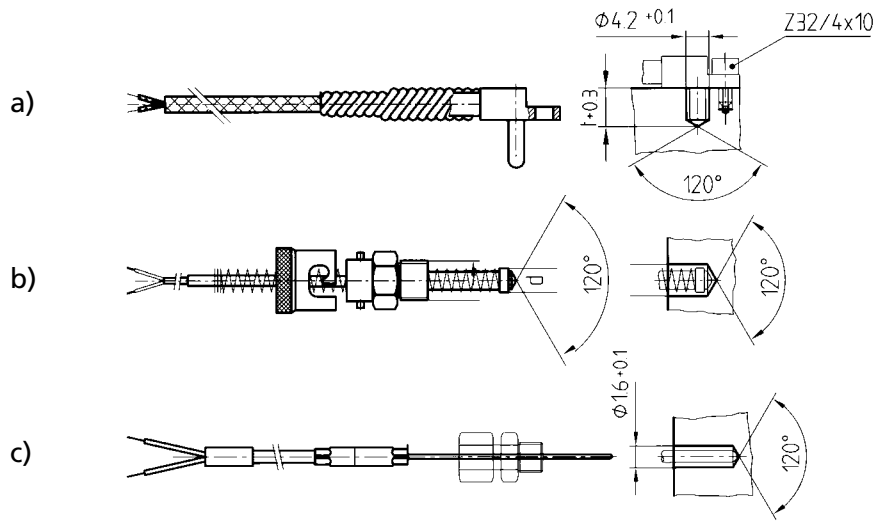


Figure 5.12 Types of thermocouple

a - angled, screw-fastened; b, c - rectilinear, fastened by threaded bushing
(Reproduced with permission from Hasco Normalien Hasenclever GmbH & Co.)

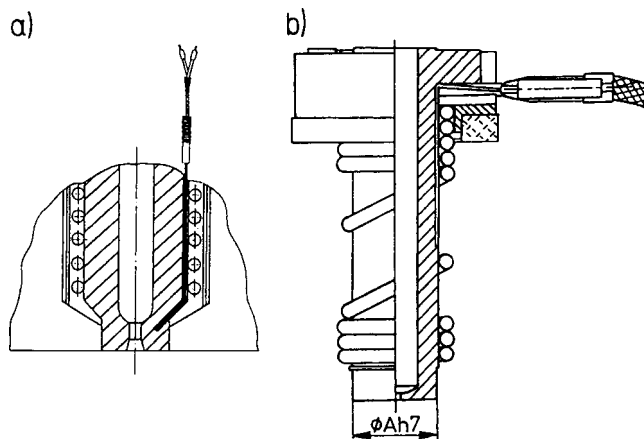


Figure 5.13 Positioning of thermocouple in nozzle

Ah7 - the diameter at tolerance, h7

a - in gate zone [1] (Reproduced with permission from Hotset Heizpatronen und Zubehör GmbH); b - in central part of nozzle (Reproduced with permission from Heatlock AB)

In nozzles which, because of their design and the heater used, feature a uniform temperature distribution, the thermocouple may be situated in a hole drilled in the front end of the nozzle (a). This enables the temperature to be monitored in the gate zone and melt freezing to be controlled at this point. In nozzles which, because of their design and the heater used, have their highest temperature in the central part, the thermocouple is located in this part (b) in a groove made on the side of the nozzle. This enables a check to be kept on the peak nozzle temperature, and prevents the melt from overheating. A thermocouple may also be situated inside the heater, in its unheated end.

It is clear from what has been said previously that the user must know where the thermocouple is situated if he wishes to control the nozzle temperature properly.

5.2 Heating zones

Use of HR systems requires a division into heating zones in such a way as to make independent temperature control possible for the melt flowing into each of the cavities. This means that:

- each HR nozzle creates its own zone;
- the HR manifolds create one or more zones, depending on the size and number of the nozzles, the position of the flow channels and the type of plastic, and also on the quality demands (see **Figure 5.14**);
- additional heaters for the nozzles or sprue bushing may also create separate zones.

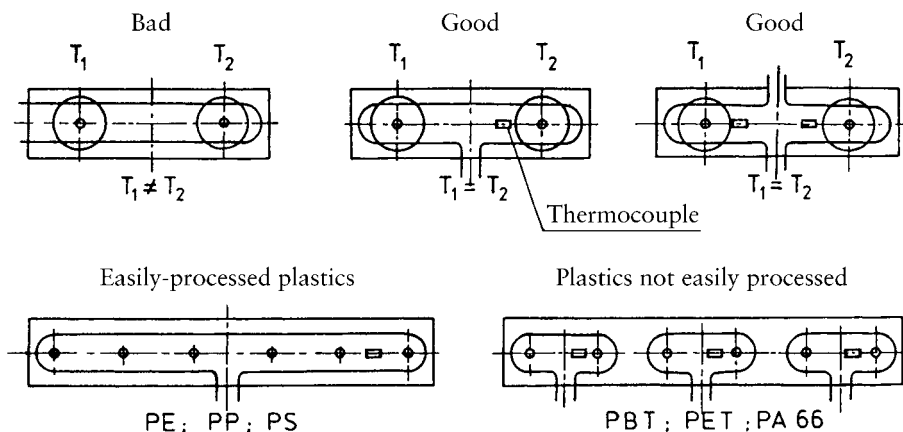


Figure 5.14 Principle of arrangement of tubular heaters in manifold block and division into heating zones. T_1 and T_2 are manifold temperatures.

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Each heating zone has a single thermocouple. In practice, in naturally-balanced multi-cavity moulds, symmetry of positioning of individual heaters in a single zone is assumed, and also symmetry of the mutual positioning of individual zones. Restricting the number of manifold zones in multi-cavity moulds does reduce the mould cost, but has an adverse effect on precision of regulation and temperature fluctuation. Use of the appropriate socket-contact, which again is divided into the corresponding zones, guarantees that the individual zones in the HR system are correctly connected. Heater leads and thermocouple leads from every zone are connected to the specific pair of socket pins. The socket pins for the thermocouple must be made of the same material as the thermocouple leads, e.g., iron-constantan, nickel-chromium-nickel, or else spurious temperature readings will be given. The earthing leads are connected to the socket housing. There are sockets for various numbers of zones on the market, e.g., 1, 2, 4, 6, 8, 12. When there are more zones than this, two or more sockets are used together.

Each heating zone has its own heat regulator. The combined power of the heaters in a zone may not exceed the power transferred by the regulator, which must be considered when dividing an HR system into zones.

Heating zones should be numbered in a way that matches the numbering of the mould cavities, and marked, for example, on a data plate on the side of the mould. This prevents any erroneous connection of heating zones to regulators or inappropriate heating of zones. An example of logical numbering of zones is shown in **Figure 5.15**.

The numbers 1-8 have been given to the nozzles/cavities, starting with the nozzle which is nearest to the guide pillar with the smallest diameter, and proceeding clockwise. The numbers 9-11 have been allocated to the manifold zones in a similar sequence (9-10 - side distributor channels, 11 - main channel), and 12 has been allocated to the sprue bushing as the final component of the system.

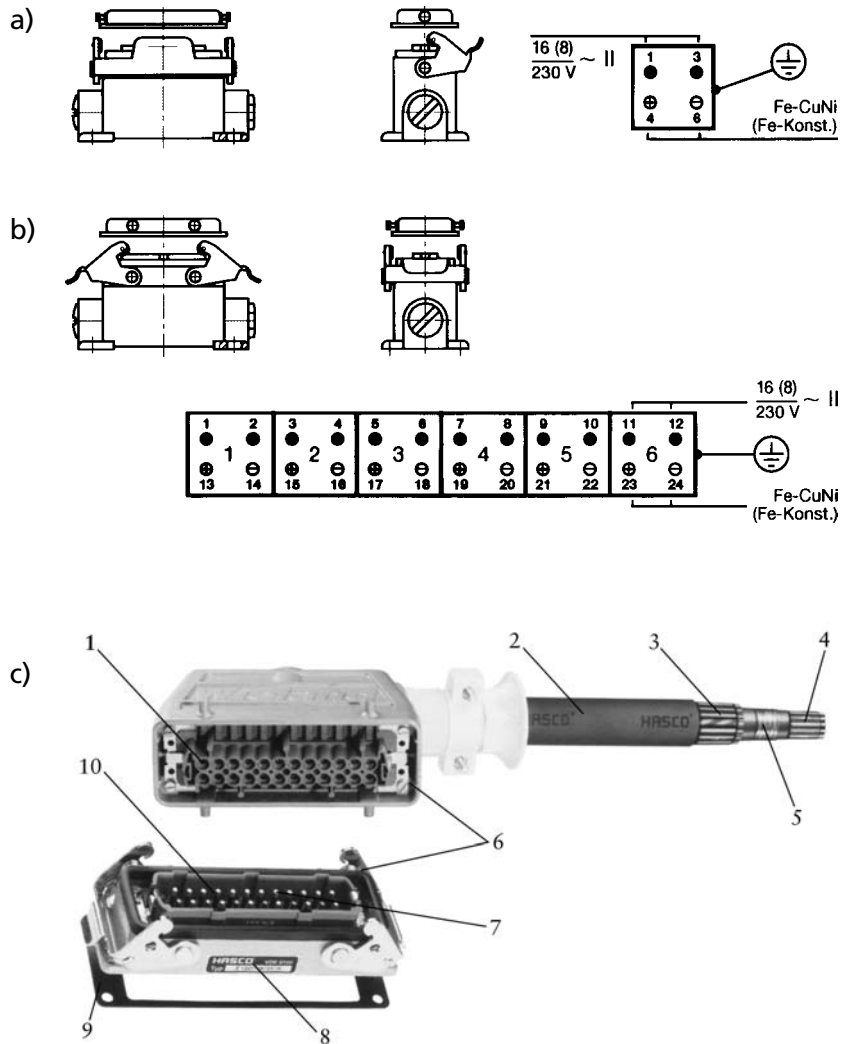


Figure 5.15 Examples of HR system socket-contacts

a - for 1 heating zone; b - for 6 zones (1-12 -pins for heater connection, 13-24 - pins for thermocouple connection); c - set of pins (view): 1 - socket; 2 - covering; 3 - 1.5 mm² power cable; 4 - 0.5 mm² thermocouple cable; 5 - screening mesh; 6 - metal casing; 7 - pins (as in VDE 0100); 8 - data plate; 9 - seal; 10 - internal housing; d - 4 socket-contacts installed on a mould; e - connection diagram for manifold and nozzle heaters to socket-contact (6 zones): 1 - nozzle; 2 - cartridge heater; 3 - reduction in number of leads; 4 - socket-contact

(Reproduced with permission from Hasco Normalien GmbH & Co.)

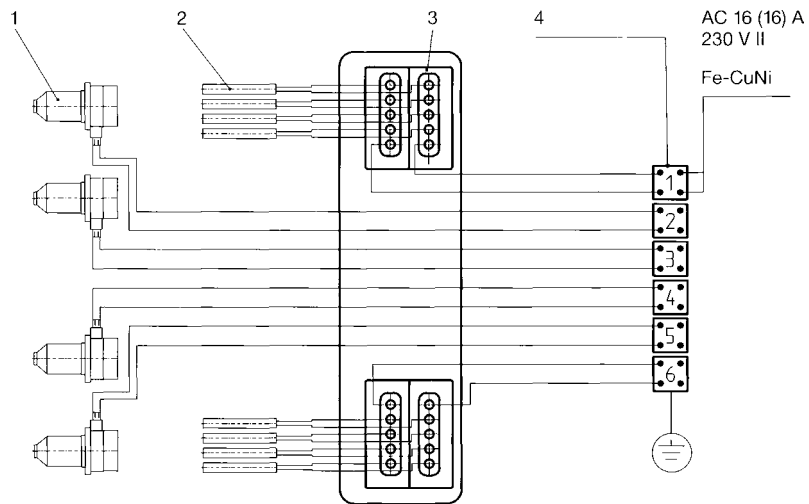
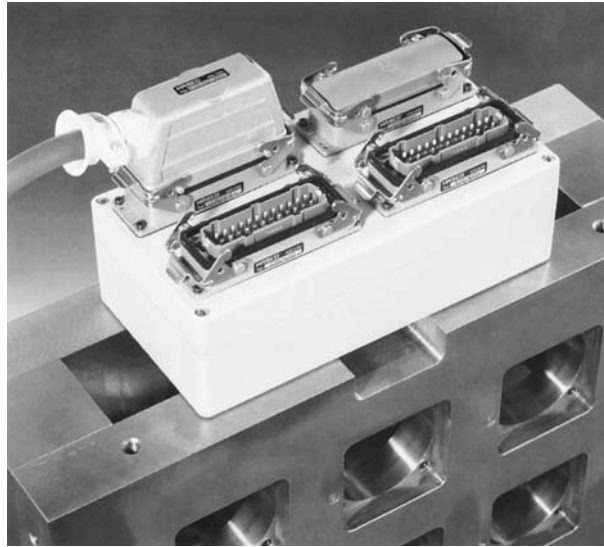


Figure 5.15 Examples of HR system socket-contacts *Continued*

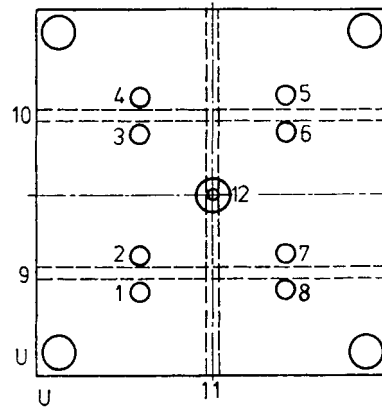


Figure 5.16 Example of marking of heating zones
 1-8 - nozzles; 9-11 - manifold; 12 - sprue bushing
(Reproduced with permission from D-M-E Belgium)

5.3 Heat losses

The heat losses in an HR system comprise losses caused by conduction of heat, convection and radiation from the manifold and from other components of the system to the mould, and perhaps also to the ambient air. The dominant heat losses, which are crucial to the energy balance of the system, are those originating from the manifold, but the user has only a limited amount of influence over these losses, through proper installation and application of the required insulation.

Heat conduction is internal transport of heat in solid bodies (mould parts), liquids (plastic melt, cooling agent) and gases (air). Through-wall heat conduction (see **Figure 5.17a**) is described by the equation:

Heat flux

$$Q_p = \frac{\lambda}{s} \cdot A_p \cdot \Delta T, \text{ W} \quad (5.1)$$

Where: λ is the thermal conductivity coefficient, W/mK (see Table 4.2);
 s is the wall thickness, m;

A_p is the cross-sectional area of the wall (height x length), m²;

ΔT is the temperature difference over the wall thickness, K (here the manifold temperature T_1 less the temperature of the structure or mould plates T_2);

$$\Delta T = T_1 - T_2$$

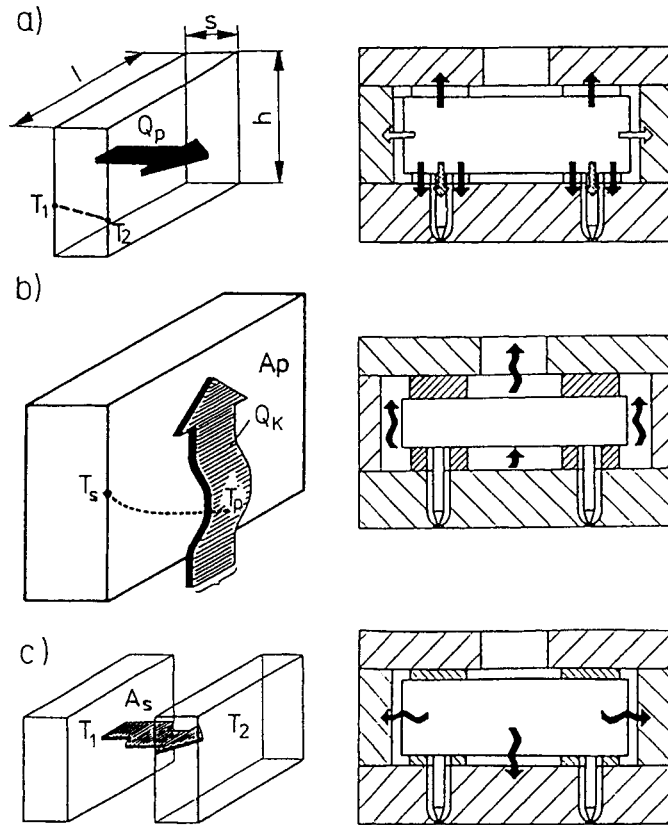


Figure 5.17 Heat losses in HR system manifold

a - via conduction; b - via convection; c - via radiation

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Heat conduction from the manifold takes place chiefly via the spacer pads and fastening bolts, and perhaps also via the non-heated sprue bushing. A diminution in heat losses caused by conduction may be attained by:

- reducing the heat flow cross-section A_p by reducing the contact area of the spacer pads;
- use of a material with a lower thermal conductivity, which means making the spacer pads of stainless steel, titanium alloy or sintered ceramic material;
- use of manifold fastening bolts that are made of stainless steel (see **Table 4.2**).

Convection is heat transfer via a fluid flow (plastic melt, cooling agent) or gas (air). Convection (see Figure 5.18b) is described by the equation:

Heat flux

$$Q_k = \alpha_k \cdot A_k \cdot (T_s - T_p), \text{ W} \quad (5.2)$$

where: α_k is the heat transfer coefficient (for natural air convection in the manifold, $\alpha_k = 5\text{-}10 \text{ W/m}^2\text{/K}$);
 A_k is the wall area, m^2 ;
 T_s is the wall temperature (of the manifold), $^{\circ}\text{C}$;
 T_p is the ambient (air) temperature, $^{\circ}\text{C}$.

Heat exchange via convection takes place between manifold and structure and sometimes even between the manifold and the air outside the mould.

The means used to reduce convective heat losses are:

- enclosure of the manifold space, particularly to eliminate the air draught in a vertical direction;
- screening of the manifold or the inside of the structure using insulation plates.

Radiation is the transfer of heat between surfaces of solids not in contact with each other and at different temperatures. A so-called black body absorbs all radiation heat, whereas a white body reflects part of it. Radiation (see Figure 5.17c) is described by the equation:

Heat flux

$$Q_s = \alpha_p \cdot A_s \cdot \Delta T, \text{ W} \quad (5.3)$$

where: A_s is the wall area, m^2 ;
 α_p is the thermal radiation coefficient determined from the relationship:

$$\alpha_p = C \cdot \frac{\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4}{\Delta T}, \frac{\text{W}}{\text{m}^2\text{K}} \quad (5.4)$$

where: T_1 is the temperature of wall 1 (*manifold*), K;
 T_2 is the temperature of wall 2 (*housing*), K;
 C is the radiation constant, $\text{W/m}^2\text{K}$;

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For the manifold walls, the following values are used:

bright polished	$C = 0.40$
dark, oxidised (rusted)	$C = 2.62$
bright, aluminium sheet coated	$C = 0.18$
dark, aluminium sheet coated	$C = 0.22$

Heat exchange through radiation takes place between manifold and structure. The means employed to reduce heat losses through radiation are:

- keeping the manifold walls clean and polished;
- screening of the manifold using polished aluminium sheet;
- screening of the manifold or the inside of the structure using insulation plates.

In practical applications, a combined formula for heat losses via convection and radiation may be utilised:

$$Q_{ks} = (\alpha_k + \alpha_p) \cdot A_r \cdot \Delta T, \text{ W} \quad (5.5)$$

where: A_r is the total manifold area, m^2
 Q_{ks} is heat losses

5.4 Power consumption

The power required to heat the manifold is made up of:

- the power required to heat the manifold, i.e., the heat needed to heat the manifold up to operating temperature in the set time;
- the power required to compensate for heat losses via conduction, convection and radiation.

Power consumption for manifold heating is determined using the formula:

$$N_n = \frac{Q}{60 \cdot t}, \text{ kW} \quad (5.6)$$

because $Q = m \cdot c \cdot \Delta T$

where: Q is the heat for manifold heating, kJ;

m is the mass of the manifold, kg;

c is the specific heat of the manifold material, kJ/kgK, (0.48 for steel);

ΔT is the temperature difference between manifold and mould, K;

t is the manifold heating time, in minutes (usually 20-30 minutes, depending on the size of the manifold and the processing temperature);

so:

$$N_n = \frac{m \cdot c \cdot \Delta T}{60 \cdot t}, \text{ kW} \quad (5.7)$$

From formulae 5.1 and 5.5, the total power consumption for manifold heating in time t is:

$$N = N_n + \frac{(Q_p + Q_{ks})}{1000}, \text{ kW} \quad (5.8)$$

For a rough evaluation, a formula based on assessment of the thermal efficiency of the HR system is used:

$$N = \frac{m \cdot c \cdot \Delta T}{60 \cdot t \cdot \eta}, \text{ kW} \quad (5.9)$$

where: η is the thermal efficiency coefficient (usually 0.4-0.7); $\eta = \frac{N_n}{N}$

Equation 5.9 may be used as a basis to determine the power and number of heaters when a manifold is being designed by a user. The result, however, depends on the right efficiency coefficient value being adopted.

When an HR system manifold is being designed, computer simulation programmes are also used.

Calculation example. As an example, the power demand is calculated for a manifold (see Figure 4.60) 80 x 500 x 46 in size supported on three spacer pads Ø25/Ø14 x 5. The manifold is designed to operate at a maximum temperature of 360 °C with a mould temperature of 100 °C.

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- Power consumption

$$\text{mass of manifold} \quad m = 0.8 \cdot 5.0 \cdot 0.46 \cdot 7.85 = 14.4 \text{ kg}$$

$$\text{where steel density} \quad = 7.85 \text{ kg/l}$$

$$\text{temperature difference} \quad \Delta T = 360 - 100 = 260 \text{ K}$$

$$\text{from formula (5.7)} \quad N_n = \frac{14.4 \cdot 0.48 \cdot 260}{60 \cdot 20} = 1.5 \text{ kW}$$

- Power loss through conduction via the spacer pads:

$$\text{area of pads} \quad A_p = \frac{\pi}{4} \cdot (0.025^2 - 0.014^2) \cdot 3 = 0.001 \text{ m}^2$$

- thermal conductivity coefficient (from Table 4.2):

$$\text{for 1.2312 grade steel (DIN)} \quad \lambda = 25 \text{ W/m K}$$

$$\text{for titanium alloy} \quad \lambda = 7 \text{ W/m K}$$

hence using Equation 5.1, for pads made of steel:

$$Q_p = \frac{25}{0.005} \cdot 0.001 \cdot 260 = 1300 \text{ W}$$

whereas for titanium alloy pads:

$$Q_p = \frac{7}{0.005} \cdot 0.001 \cdot 260 = 365 \text{ W}$$

- Loss of power through convection and radiation:

$$\text{manifold temperature} \quad T_1 = 273 + 360 = 633 \text{ K}$$

$$\text{mould temperature} \quad T_2 = 273 + 100 = 373 \text{ K}$$

- Radiation coefficient:

$$\text{- for dark surfaces:} \quad \alpha_p = 2.62 \frac{\left(\frac{633}{100}\right)^4 - \left(\frac{373}{100}\right)^4}{260} = 14.2 \frac{\text{W}}{\text{m}^2 \text{K}}$$

$$\text{- for aluminium sheet screens:} \quad \alpha_p = 1.2 \text{ W/m}^2 \text{ K}$$

The convection coefficient is taken as: $\alpha_k = 10 \text{ W/m}^2 \text{ K}$

Area of manifold: $A_r = 0.134 \text{ m}^2$

Screened area: $A_o = 0.08 \text{ m}^2$

According to Equation 5.5, the loss of power through convection and radiation is:

$$Q_{ks} = (10 + 14.1) \times 0.134 \times 260 = 840 \text{ W}$$

while for a screened manifold (as shown in Figure 4.61)

$$Q_{ks} = [(10 + 1.2) \times 0.08 + (10 + 14.1) \times 0.054] \times 260 = 570 \text{ W}$$

- Total power consumption of manifold

	Conventional manifold	Manifold with Al and Ti insulation
Heating power	1,500	1,500
Power to cover conduction losses	1,300	365
Power to cover convection and radiation losses	840	570
Power to cover electrical losses, 10%	365	245
Total	4,005	2,680

The previous example shows how use of modern insulating materials reduces power consumption by around 30%.

The calculated power level of 2,680 W is needed at the moment the operating temperature is attained, when heat losses reach their full value. To sustain the operating temperature, however, about 935 W is required to cover losses, plus a power surplus of 550 W (about 20% of total power) for effective control, i.e., a total of around 1,500 W, or about 55% of total power.

The manifold should thus be equipped with four heaters of 800 W.

As a reminder, the power of an electric heater is calculated from the formula:

$$N = \frac{U^2}{R}, \text{ W}$$

where: U is the voltage, V
R is the resistance, Ω

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It can be seen from the formula that the heater power given for 230 V will be about 9% lower when 220 V is used, because:

$$\frac{220^2}{230^2} = 0.91$$

When selecting heating elements, therefore, the nominal voltage of the country in question should be considered.

To get a rough idea of the power, a calculation may be made based on assumed values for the coefficients of thermal and electrical efficiency:

- for a conventional manifold $\eta = 0.4 \times 0.9$

$$N = \frac{N_n}{\eta} = \frac{1.5}{0.4 \cdot 0.9} = 4.2 \text{ kW}$$

- for a manifold with heat insulation $\eta = 0.6 \times 0.9$

$$N = \frac{N_n}{\eta} = \frac{1.5}{0.6 \cdot 0.9} = 2.8 \text{ kW}$$

More general still is the empirical determination of the required heating power depending on manifold weight. As an approximation, 200-250 W/kg manifold weight is taken, on the basis that as weight rises, power consumption falls, but the start-up time gets longer.

For the *given* example, for $m \cong 15 \text{ kg}$, a power of $N \cong 3\text{-}3.75 \text{ kW}$ is obtained.

5.5 Temperature regulators

The purpose of a temperature regulator in an HR system is to measure the temperature and keep it at the level of the set value. A typical temperature control circuit is shown in **Figure 5.18**.

As a simplification, it may be said that the signal from the thermocouple in voltage form is related to the temperature and is compared as the actual value 'x' with the set value 'w'. As a result of the comparison, the regulator transmits a signal 'y' to the setting unit of the regulator, which might be for example a solid-state relay. Its task is to proportion the heater power.

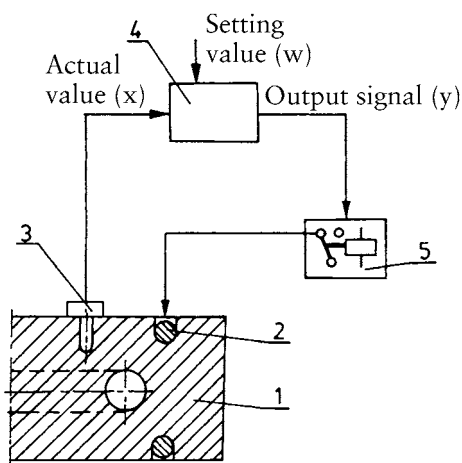


Figure 5.18 Typical temperature control circuit

x - actual (regulated) value; w - setting value; y - output signal; 1 - manifold; 2 - heater; 3 - thermocouple; 4 - regulator; 5 - regulator setting unit

The development of HR technology was closely matched by the development of temperature regulators. To begin with, an industrial potentiometer was employed, in which the voltage level was manually set so as to attain the required temperature. This system thus demanded constant supervision. Then a mechanical temperature regulator came into use, acting on an on/off principle (see **Figure 5.19**), with feedback.

This means that heating is either proceeding at full power, or it is switched off (ON-OFF). This control method causes large temperature fluctuations, which often exceed the range of processing temperatures for engineering plastics.

Of crucial importance for the use of HR technology was the development of electronic regulators with feedback. Depending on how this feedback is set up, a characteristic acting proportionally (P), differentially (D) or integrally (I) is obtained. In such regulators, heating is regulated in a stepless fashion by limiting the power. The heating power is subject to diminution when there is a rapid temperature rise, but increases proportionally when there is a rapid fall in temperature. Temperature jumps are thus avoided, which is important in the processing of engineering plastics. The reduced operating voltage and the so-called soft start function prolong the life of the heater.

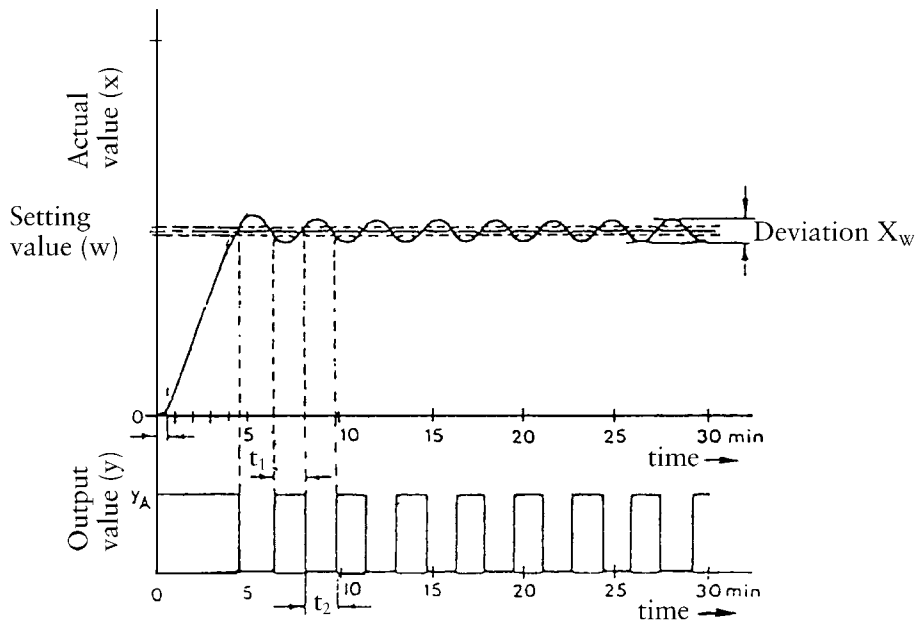


Figure 5.19 Diagram of operation of mechanical regulator ON-OFF

t_1 - operating time; t_2 - disconnection time

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Figure 5.20 illustrates the operating principle of several types of regulator:

- a P regulator (a) in which the regulation deviations X_w depend on the installed heating power. A narrow proportionality range causes a reduction in deviations X_w . A disruption, e.g., a fresh injection (control disruption as a result of introduction of a new batch of melt with different temperature), however, brings about new fluctuations X_w ;
- a Proportional-Integral-Differential regulator (PID), in which regulation deviations X_w are subject to slow extinction (b);
- a D-Proportional-Integral-Differential (DPID) regulator (c) in which control begins virtually without the set value ' w ' being passed. Deviations X_w don't exist. Disruptions, e.g., injection, are rapidly adjusted for;
- a μ C regulator, i.e., a microprocessor regulator with self-adaptation (d), in which control begins without the set value being passed, and disruptions are very rapidly adjusted for.

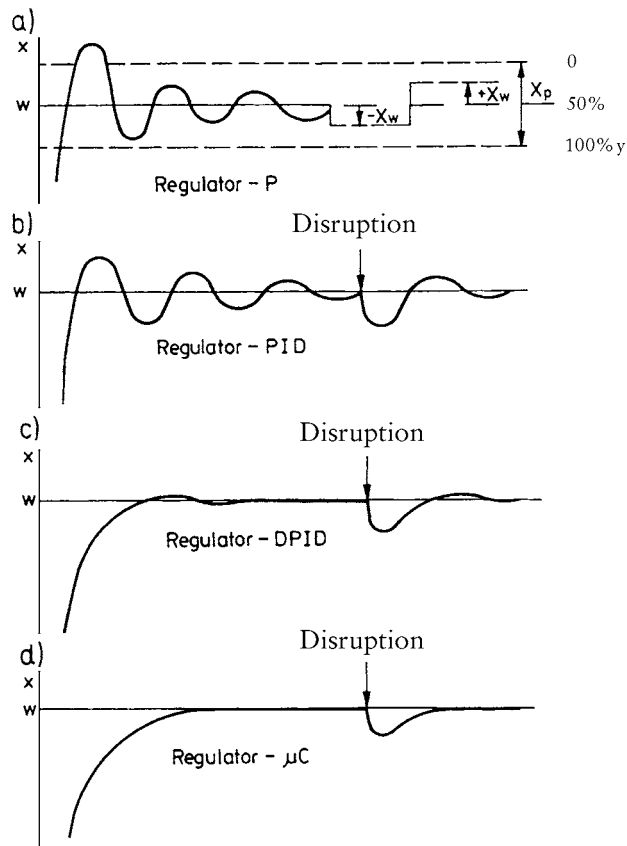


Figure 5.20 Diagrams of operation of electronic temperature regulators

a - electronic regulator P; X_w - regulated value deviation; X_p - proportionality range; y - output value; b - PID regulator; c - DPID regulator d - μC regulator with self-adaptation

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The attainable precision of temperature control depends not only on the regulator itself, but also on other factors, such as:

- the temperature difference between the point of measurement and the hot runner;
- the tolerance of the thermocouple;
- the error caused by the thermocouple lead;

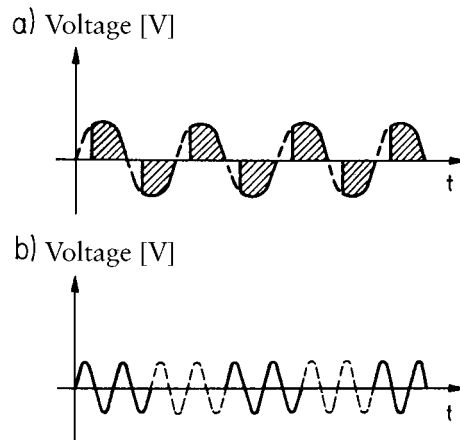


Figure 5.21 Methods of controlling heater power via temperature regulator

a - phase control; b - pulse group control

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- the characteristic of the setting element: X_p (proportionality range), t_i (integral time), t_d (differential time);
- mains voltage fluctuations;
- temperature variations in the melt introduced into the HR system;
- mould and ambient temperature variations.

Heater power control by the regulator setting element may take place in two ways (see **Figure 5.21**):

- phase control (a). The regulator actuator element feeds the heater with a constant output signal by cutting out a section of the sine current wave;
- pulse control (b). The regulator actuator element feeds the heater with a pulse output signal, e.g., 24 V - on, 0 V - off. Switch-over does not, however, take place in each half-wave, only after a group of pulses.

The operation of a regulator with an actuator element with phase control under production conditions (at a given temperature of 250 °C and a cycle time of 15 seconds) (see **Figure 5.22**) will now be considered. During plastic injection friction heat is generated in the nozzle gate, which causes a temperature rise by some 10 °C above the set level. It may be

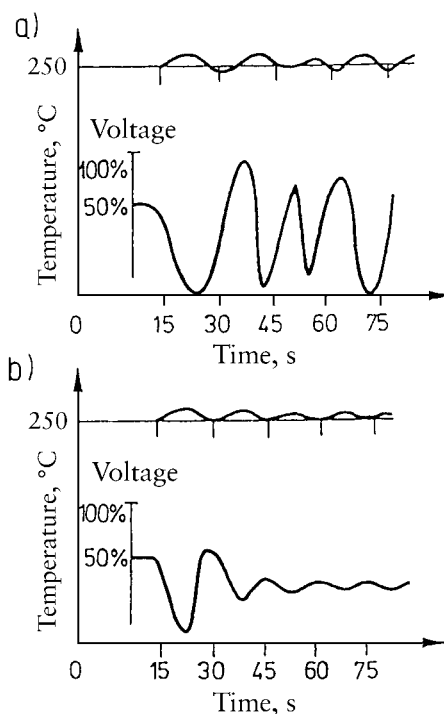


Figure 5.22 Graph of regulator operation under production conditions

a - DPID regulator with triac controller; b - microprocessor regulator.

Temperature set at 250 °C, cycle time 15 s

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seen from the graph that a temperature rise occurs every 15 seconds. It is not possible to do anything about this, because the system is designed to heat, not cool, the nozzle.

As may be seen from curve (a), a PID type regulator causes a gradual fall in voltage as temperature rises, down to 0 when a set temperature deviation is exceeded. If the temperature begins to fall when about 10 seconds has elapsed, the regulator causes a gradual increase in voltage. At the moment of the next injection, about 15 seconds after commencement of operation, the temperature value is 5 °C below the set level and begins to rise. The nozzle simultaneously receives an uncontrolled portion of friction heat, which brings about a fresh and higher temperature rise, but this time at another place on the time scale. Voltage fluctuations reach 100%. It may be seen from **Figure 5.22a** that the nozzle attains different temperatures at the point of successive injections. If there are a number of nozzles in an HR system, temperature differences between nozzles may occur.

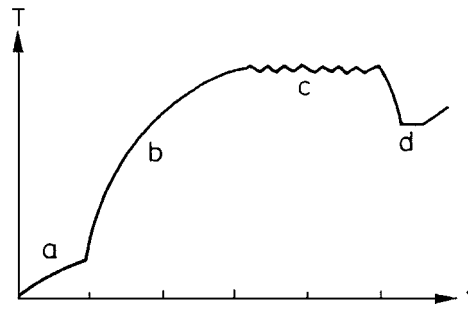


Figure 5.23 Phases of operation of HR system temperature regulator with microprocessor

a - soft start; - heating; c - operation; d - break in operation

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A microprocessor regulator has an auto-adaptation algorithm, which means that the regulator adapts its control method to the real temperature curve (b). After the first injection, the temperature rises by 10 °C as in the previous case, but it does not fall below the set value, since the regulator engages the voltage a greater time in advance. With subsequent successive temperature rises, the regulator measures the time between successive temperature rises and uses this to shift the power curve. As a result, voltage disconnection takes place in advance so that the nozzle is not being heated at the moment when it is getting warmer through friction heat. This leads to much smaller temperature fluctuations, while at the same time the power (voltage) curve is flattened out, which increases heater life.

The most recent generation of microprocessor regulators features a memory enabling settings to be stored for a large number of moulds.

The action of the microprocessor regulator may be divided into the following phases (see **Figure 5.23**):

- a - 'soft start' and monitoring of action. Commencement of heating takes place at low voltage to remove moisture from the heaters. Various methods of heating are used, depending on the type of regulator, e.g., at a voltage generating about 10% of heating power. In this method, the heater temperature rises at a rate of about 10 °C/minute until a temperature of 90 °C is reached, following which the heaters are kept at this temperature for about 15 minutes. In other regulators heating is continued until a satisfactory heater resistance value is attained. The regulator also monitors the correctness of connection of the thermocouple leads.

- b - *heating* takes place initially at a set full heating power, which is then reduced as the set temperature is approached.
- c - *continuous operation* takes place as described above. The microprocessor records the impact of external factors on the temperature curve and carries out control optimisation. At the same time it signals any disruptions to the operation of the system, such as for example damage to or short-circuiting of the heater, current flow through the earthing lead, damage to the thermocouple, damage to the regulator, transgression of admissible set temperature deviations, etc.
- d - *break in operation*. This function enables the temperature to be lowered automatically (or manually) to a level not threatening thermal degradation of the melt.

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6 Filling Balance

The increase in the number of requirements made of injection moulded products has made it increasingly necessary to maintain a cavity filling balance in the mould, so that HR systems must match up to the following basic injection moulding principles:

- in multi-cavity moulds for identical products, melt should be fed to each cavity at the same temperature and rate and under the same pressure. This ensures simultaneous filling of all cavities and facilitates transfer of the holding pressure for the same period of time;
- in multi-cavity moulds for different products (known as family moulds), melt should be fed to each cavity with parameters that enable the cavities to be filled simultaneously;
- in single-cavity moulds with multiple injection points, melt should be fed to each injection point with parameters that enable the filling of defined cavity zones, i.e., giving a product with a set position of the plastic weld line. While the mould is being filled, there must be no mutual encroachment of the flow fronts that gives disturbances to structure.

Apart from improving product quality, filling balance makes the injection process easier to carry out (broader range of processing parameters). Achieving a filling balance is dependent on proper organisation of the HR system.

There are two ways of achieving balance (see **Figure 6.1**):

- by designing a system of runners with equal length flow paths. This provides a natural or geometrical balance (b);
- by designing a system of runners in which the same pressure drops occur, and the different length flow paths are compensated by variable runner cross-sections. This provides rheological or calculated balance (a).

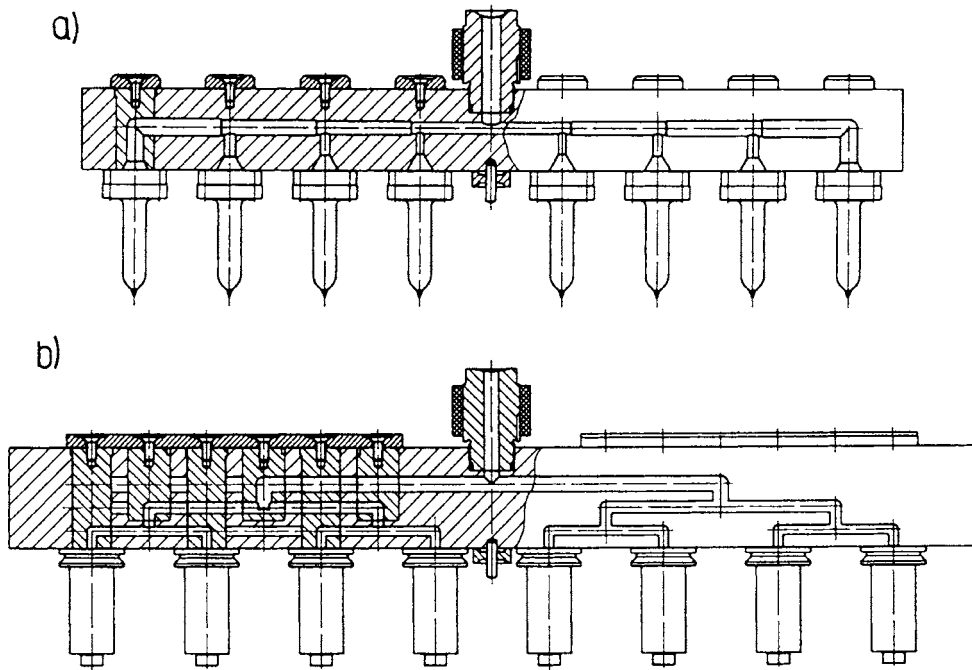


Figure 6.1 Flow balancing in an HR system manifold

a - rheological; b - natural

(Reproduced with permission from EWIKON Heißkanalsysteme)

There are cases where the optimum solution is to design a mixed runner system. The first part of the runner system is in natural balance, while the second is rheologically balanced (see Figure 6.5d).

Sometimes balancing of filling is done by having different nozzle temperatures, but this is not recommended, as it causes varying shrinkage and internal stresses in the moulded pieces.

It should be emphasised that obtaining 100% filling balance is not easy, since it also depends on other factors, e.g., measurement deviations for individual cavities, local differences in the temperature distribution in the mould, and uneven venting of the cavities.

It may, however, be assumed (according to Ewikon) that maintaining filling balance is of minor significance when very small moulded items are being produced.

6.1 Natural balance

Natural (geometrical) balance is based on the flow paths being so arranged that the length of the channels to all cavities or to all gates in a single-cavity mould are identical. Examples of channel layouts giving natural balance are shown in **Figure 4.67**. In moulds with a large number of cavities or with cavities arranged in a line, e.g., in slide moulds, multi-level solid or modular manifolds are even used (see Chapter 4.2). One very good design has been discussed earlier (see **Figure 4.65**) - a manifold with curving and welded pipes (**Figure 6.2**), sections of which of identical length may be flexed to suit, then embedded in a single copper block.

Natural balance may only be used for identical products (in multi-cavity moulds), or with symmetrical cavity filling via multi-point gating (in a single-cavity mould). The channel cross-sections are equal or successively diminishing in more branching systems. To achieve balance, it is important to maintain the same size for all gates.

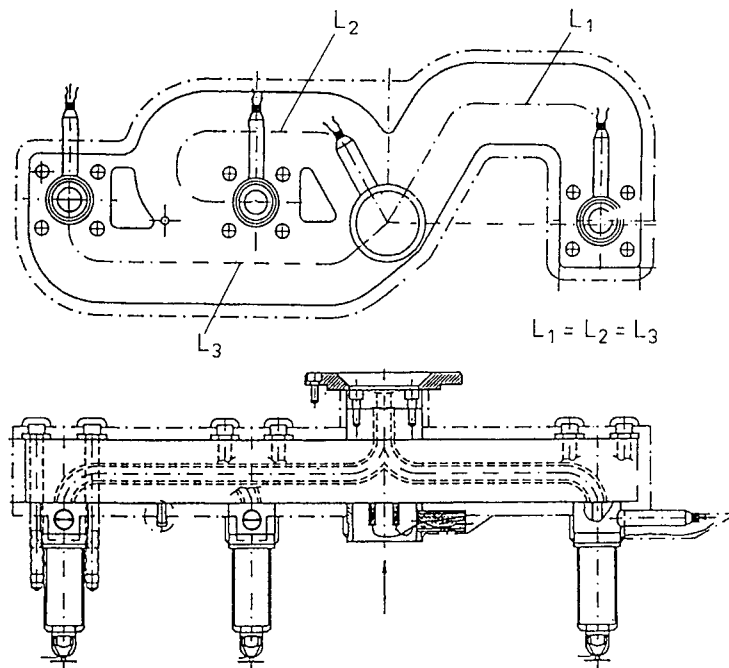


Figure 6.2 Tubular manifold with three nozzles and natural flow balance (equal tube lengths)
 L_1 , L_2 and L_3 - flow lengths

(Reproduced with permission from Unitemp SA)

Hot Runners in Injection Moulds

Maintaining natural balance in melt supply wherever possible is currently one of the criteria used to judge whether an injection mould has been properly designed. It is so important that despite the greater expense, even three-level manifolds are found.

One drawback to natural balance may be channels that are too long in some configurations, which may cause a large pressure drop and a long time spent by the melt in the HR system.

With multi-point injection of asymmetrical products, more balanced cavity filling may sometimes be achieved by appropriate positioning of the product in a mould (see **Figure 6.3**). After inversion of the product (b), a balancing of the flow paths in the HR system is achieved.

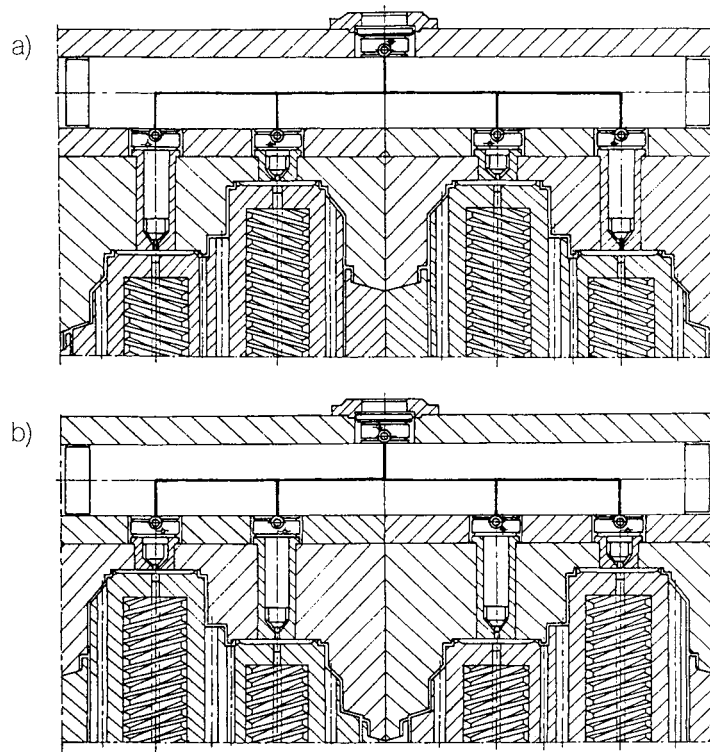


Figure 6.3 Orientation of pieces in a mould to improve filling balance
a - different flow paths in HR system; b - flow paths brought closer together
(Reproduced with permission from Günther Heißkanaltechnik GmbH)

6.2 Rheological balance

Rheological balance (computer-simulated or calculated) is based on flow paths being so organised that by altering the channel cross-section, i.e., reducing the diameter of short channels and increasing the diameter of long ones, a state of pressure balance is attained. In this way shorter channel systems and simpler manifolds may be achieved than in a system with natural balance. There are some limits, though - the channel cross-section may not be too widely differentiated.

One drawback to rheological balance is that it is only maintained for set operating parameters - injection temperature and rate. A change in parameters or use of another material - even one of the same type but from a different manufacturer - causes changes in viscosity and shifts away from a state of balance. An HR system is, however, less vulnerable to parameter changes than a CR system.

In multi-cavity moulds for different products, or in single-cavity moulds with multiple gating and an asymmetrical division of the product into filling zones, balancing of filling by a rheological method is the only technical solution. In this case the runner and the cavity have to be treated as a single rheological system, in which the flow paths are added together. Such systems normally require the use of computer simulation, and the HR system is custom made for a specific mould. The best-known mould filling programmes on the market are MOLDFLOW, C-MOLD, CADMOULD, I-DEAS and STRIM, and there are in addition a number of three-dimensional programmes of local scope. The flow in channels may be simulated with sufficient accuracy using simple two-dimensional programmes, although they tend not to be used these days.

The classic example of a rheologically balanced mould is a mould for a vehicle bumper (see **Figure 6.4**).

In this mould there are eight HR nozzles which are balanced by varying nozzle channel diameters in the 11-18 mm range, thus giving identical pressure drops at the ends of nozzles A-D. Cold runners and the moulding item zones corresponding to them are balanced in the form of separate systems.

In moulds for identical products, the cavity does not need considering, and rheological analysis is restricted to the runner. The flow in a hot runner is rheologically simpler than that in a cold runner - heat exchange with the hot wall of the channel and the occurrence of friction heat in a large channel cross-section are minor. This circumstance sometimes allows a simple analytical method of calculating pressure drop to be used, without making allowance for changes in melt viscosity as a result of temperature fluctuations. This is an approximate method which may be used instead of computer simulation, if the latter is unavailable or too expensive. It is an interesting alternative for the user who makes his own decision as to the manifold design

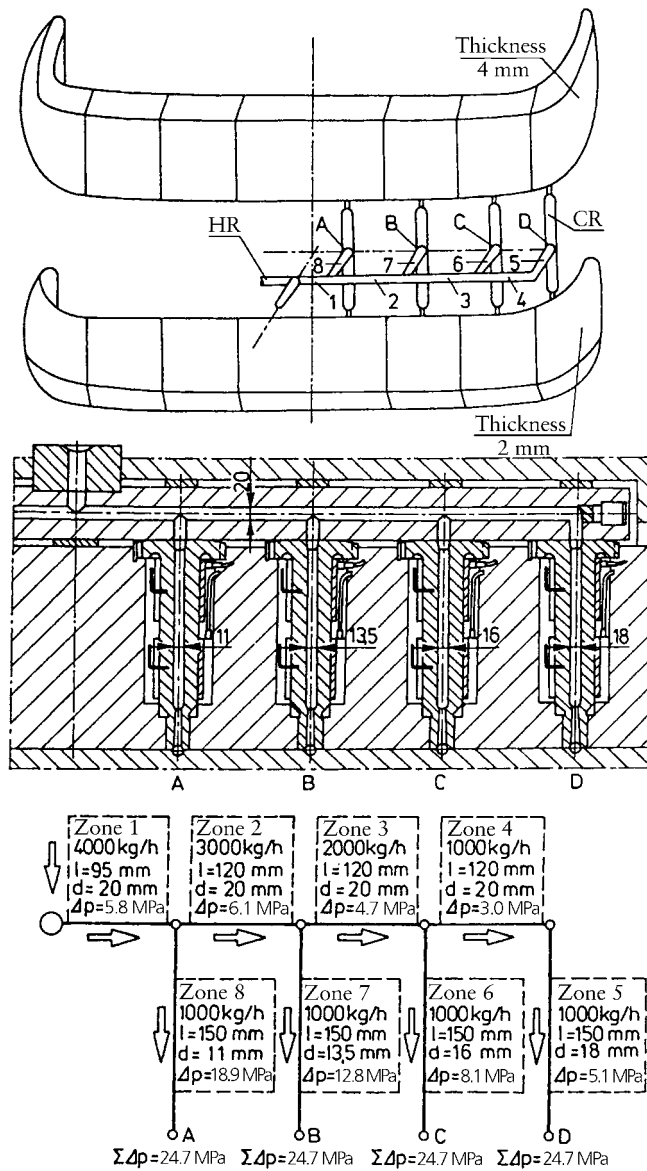


Figure 6.4 Rheological flow balancing in HR system of mould for vehicle bumper [1]

(Reproduced with permission from H. Bangert, H. W. Paffrath and G. Wubken, *Kunststoffe*, 1982, 72, 10, 661, Figures 11a and 11b. © 1982, Carl Hanser Verlag)

and installs the system by his own efforts, or for the case where moulds are ordered from a supplier who does not make rheological adjustments to them.

The theoretical principles will not be discussed here because of lack of space, but the calculation method will be described. To calculate the pressure drop, the flow rate in the channel, the shear rate for a channel, the melt viscosity and the shear stress must be calculated, in turn:

The flow rate in the channel:

$$Q = \frac{v}{t}, \text{ cm}^3/\text{s} \quad (6.1)$$

where: v is the volume of melt flowing through the channel in question, cm^3

t is the injection time, s

(roughly up to 1.5 s for an injection volume of up to 50 cm^3 , and 1.5-2.5 s for an injection volume of 50-250 cm^3).

The shear rate for a channel of round cross section:

$$\dot{\gamma} = \frac{32 \cdot Q}{\pi \cdot d^3}, \text{ 1/s} \quad (6.2)$$

where: d is the channel diameter, cm.

The melt viscosity $\eta = f(T_l, \dot{\gamma})$, in $\text{Pa} \cdot \text{s}$, is dependent on the shear rate and the melt temperature, and is read off from the diagram for the plastic being processed (see Chapter 3.1.3).

The diagrams are supplied by the plastic manufacturers. One place they may be found is in CAMPUS the plastics property database.

The shear stress:

$$\tau = \eta \cdot \dot{\gamma}, \text{ Pa} \quad (6.3)$$

Now we may calculate the pressure drop in the channel:

$$\Delta p = \frac{4 \cdot L \cdot \tau}{10^5 \cdot d}, \text{ MPa} \quad (6.4)$$

where: L is the channel length, cm.

Hot Runners in Injection Moulds

Assuming that this method is being used to calculate the pressure drop for a given channel diameter, but that the reverse operation is not possible. This means that to balance the second channel calculations must be performed for several selected diameters (by an iteration method) until a pressure drop is obtained, that is the same as that in the first channel.

The above dependences may be characterised generally by saying that the pressure drop in the channel is proportional to the channel length, L and inversely proportional to the cube of the diameter $1/d^3$. Melts containing glass fibre show a 10-30% greater pressure drop.

In the event that the difference in pressures requiring balancing is too great (large number of cavities), the channel size difference may be too great, and the system unstable, i.e., too sensitive to injection parameter fluctuations. The solution then is to organise part of the system with natural balance (see **Figures 6.5c and 6.5d**), which allows rheological balancing of the rest of the system.

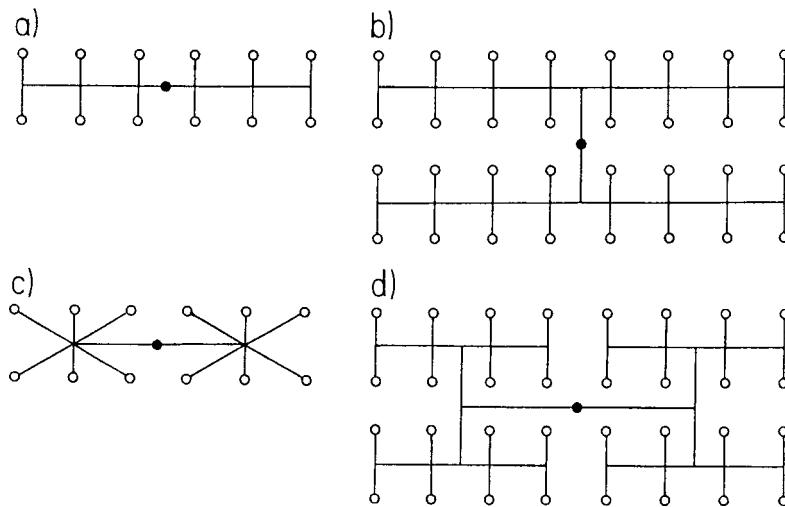


Figure 6.5 Examples of a channel system in a 12- and 32-cavity mould

a, b - no natural balance, difficult to achieve rheological balance;
c, d - partial natural balance, easy to achieve rheological balance

Calculation example

An 8-cavity split-cavity mould for a handwheel made of Ultraform S (POM) produced by the company TELI. The cavities, laid out in a single row, require channel balancing, either natural, with a three-level manifold, or rheological, with a standard manifold (see Figure 6.6).

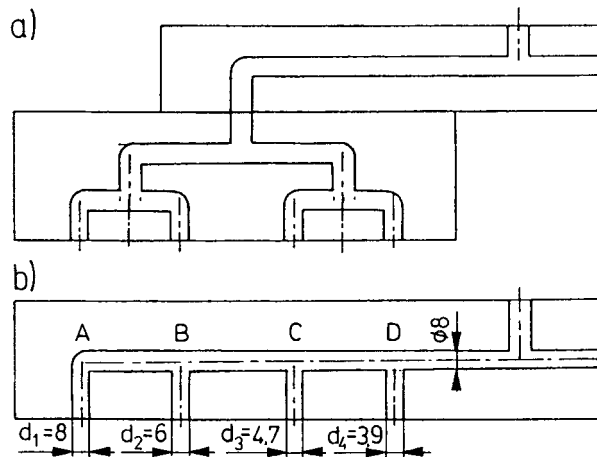


Figure 6.6 Two versions of flow balancing in an eight-cavity split-cavity mould
 a - 3-level manifold with natural balance; b - standard manifold with rheological balance
 d_1, d_2, d_3, d_4 - diameters

In view of the lower cost and short lead time for the manifold, rheological balancing is chosen, and is performed in a Hasco manifold (intermediate product).

$$\text{Injection volume} \quad V_w = 3 \text{ cm}^3 \cdot 8 \text{ cavities} = 24 \text{ cm}^3$$

$$\text{Injection temperature} \quad T_w = T_d = T_r = 200 \text{ }^\circ\text{C}$$

$$\text{Injection time} \quad t_w = 0.5 \text{ s}$$

In the manifold supplied there was an 8 mm main flow channel. A diameter of $d_1 = 8$ mm for the first outlet channel into the cavity was taken, and a series of calculations was performed as in Figure 6.7.

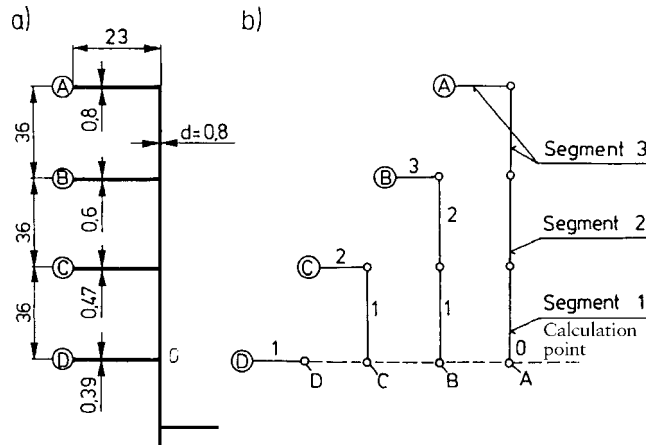


Figure 6.7 HR flow diagram in 8-cavity split-cavity mould

a - layout of cavities and channel geometry;
b - division of flow paths into calculation segments

One-half of the system of channels (the other is symmetrical) was divided into four flows, and each flow was divided into segments. The flows to cavities A and B comprise three segments, flow C - two segments, and flow D - one segment. The calculation starts from point 0 and 3/8 of the injection volume flows through segment A1, 2/8 of the volume through segment A2, and 1/8 of the volume through segment A3. Calculation of the pressure drops in these segments gives a combined pressure drop for flow A of $2.3 + 1.7 + 1.7 = 5.7$ MPa (see Table 6.1). Flow B has segments B1 and B2 in common with flow A, and segment B3, 2.3 cm long, needs to be balanced with segment A3, 5.9 cm long, so that the pressure drop is 1.7 MPa. For the purposes of the example, performing the following calculation:

Flow rate in segment B3 for volume $V = 24/8 = 3 \text{ cm}^3$:

$$Q = V/t_w = 3/0.5 = 6 \text{ cm}^3/\text{s}$$

Using a channel diameter of 0.6 cm.

Shear rate from Equation 6.2:

$$\dot{\gamma} = \frac{32 \cdot 6}{\pi \cdot 0.6^3} = 280 \text{ l/s}$$

From the diagram of $\eta(\dot{\gamma})$ for Ultraform S (see Figure 6.8) the viscosity value, that corresponds to this rate can be determined, $\eta = 380 \text{ Pa}\cdot\text{s}$.

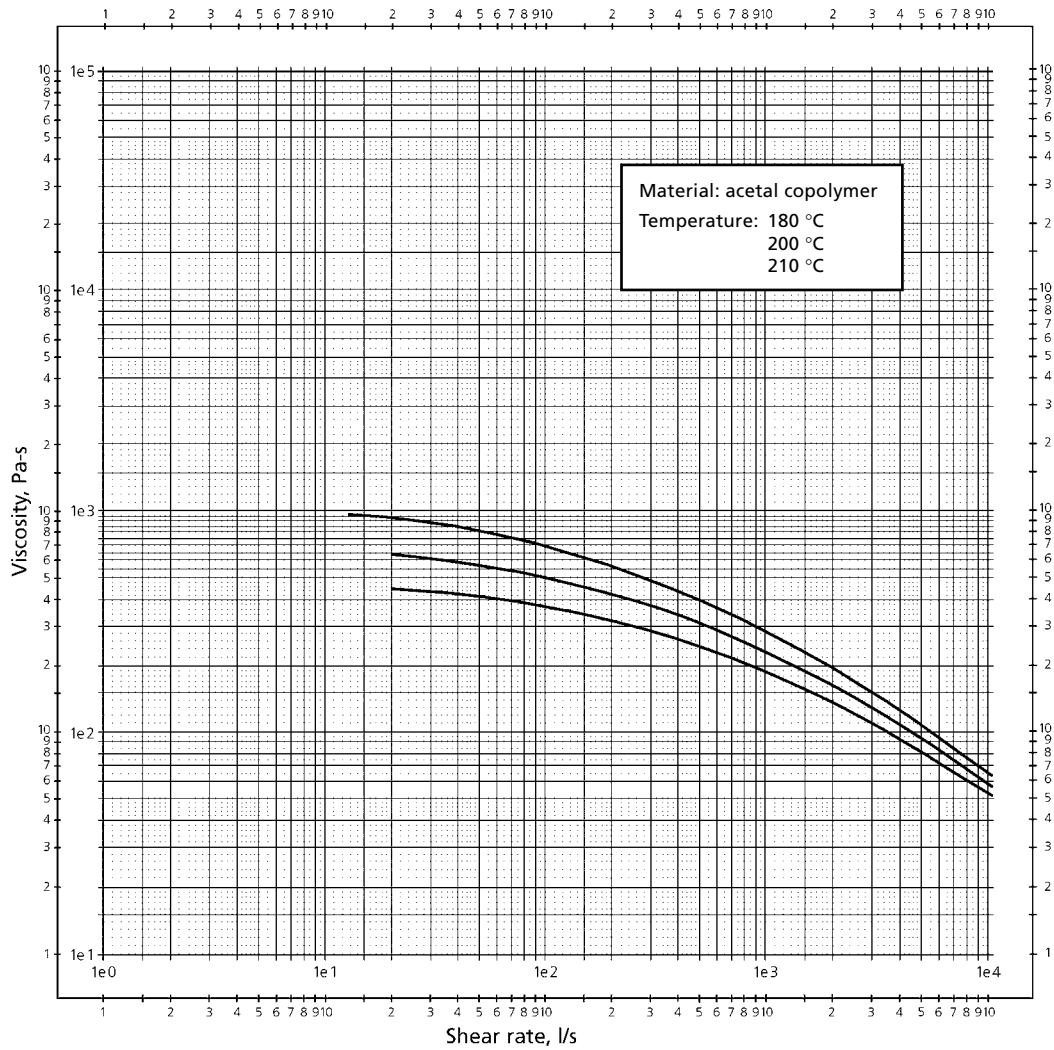


Figure 6.8 A viscosity diagram for acetal copolymer

The pressure drop in segment B3 for channel length $L = 2.3$ cm, from Equation (6.4), is:

$$\Delta p = \frac{4 \cdot 2.3 \cdot 380 \cdot 280}{10^5 \cdot 0.6} = 1.6 \text{ MPa}$$

It thus almost matches the pressure drop in segment A3 (1.7 MPa); in the event of a poorer match, the calculation would need to be repeated for a different channel diameter. Through calculations for the outlet channel of cavity C, performed using the same principle, where a Δp of 3.3 MPa is needed and for the channel for cavity D, where a Δp of around 5.7 MPa is needed, suitably diminishing diameters and an identical pressure drop for all channels were obtained (see Table 6.1).

Table 6.1 Rheological calculations for an eight-cavity mould from Figures 6.6 and 6.7						
Segment no.	Flow rate	Channel diameter	Channel length	Shear rate	Viscosity	Pressure drop
	cm ³ /s	cm	cm	l/s	Pa·s	MPa
Flow A						
1	18	0.8	3.6	360	350	2.3
2	12	0.8	3.6	240	400	1.7
3	6	0.8	5.9	120	480	1.7
					Total	5.7
Flow B						
1	18	0.8	3.6	360	350	2.3
2	12	0.8	3.6	240	400	1.7
3	6	0.6	2.3	280	380	1.6
					Total	5.6
Flow C						
1	18	0.8	3.6	360	350	2.3
2	6	0.47	2.3	590	290	3.3
					Total	5.6
Flow D						
1	6	0.39	2.3	1030	230	5.6
					Total	5.6
<i>Conclusion: $\Delta p_A \cong \Delta p_B = \Delta p_C = \Delta p_D = 5.6$ MPa. The difference of 0.1 MPa in the flow to cavity A is within the admissible error limits.</i>						

Curves for the pressure drops for the example calculated are shown in the graphs in Figure 6.9.

It should be stressed once again, though, that the filling balance for this mould will be dependent on use of the same plastic and the given injection time and processing temperature. A change in these parameters will cause a change in the melt viscosity and different pressure drops in the flows to cavities A-D.

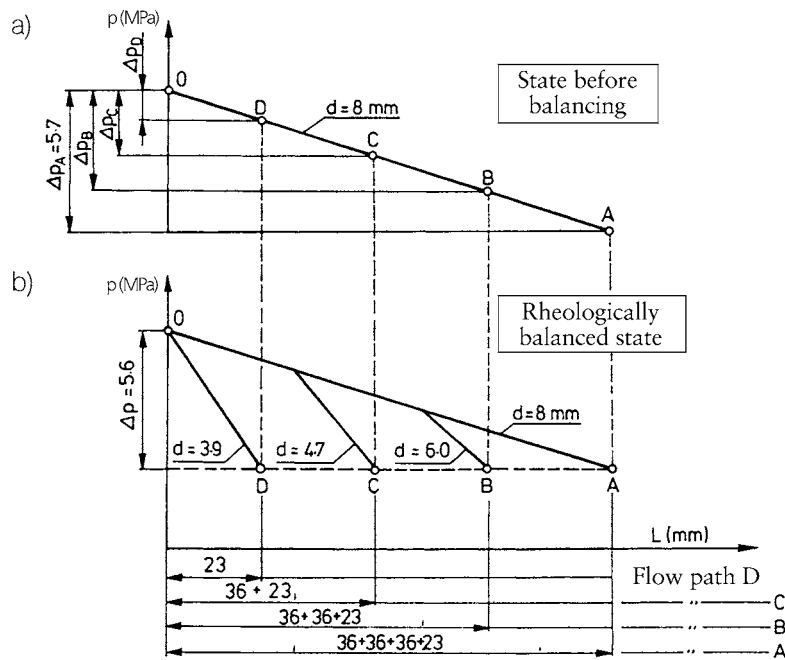


Figure 6.9 Pressure variations in channels of an eight-cavity mould before and after rheological balancing

- a - assuming identical diameter of all channels, $d = 8$ mm;
- b - after differentiation of outlet channel diameters

One interesting design is a mould (see Figure 6.10) in which the different distances between the injection points and the manifold required the use of spacing connectors.

One connector is made for each pair of nozzles of identical length. Rheological adjustment for the channels was performed in the connectors and in the nozzles.

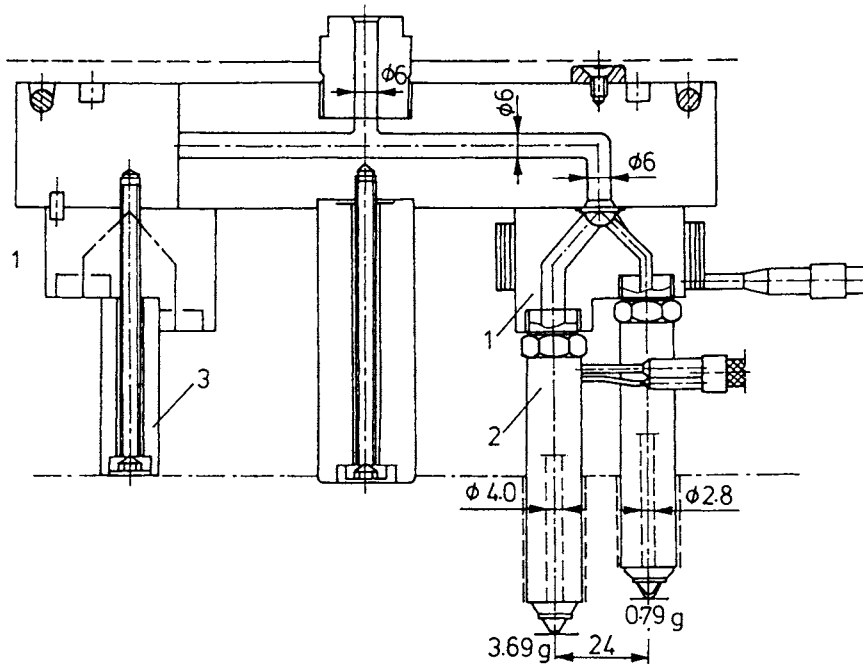


Figure 6.10 Manifold of quadruple mould with eight injection points to mould thermoplastic rubber seals on inserted PP caps - rheologically balanced mould [2]

1 - spacing connector; 2 - nozzles; 3 - support bushing

(Reproduced with permission from G. Strasser and J. E. Steinmann, *Plastverarbeiter*, 1993, 44, 2, 30, Figure 7. © 1993, Hüthig Verlag)

The balancing of HR systems with internal heating on the rheological principle is virtually impossible to do and can only be approximate. The fundamental problem is the structure of the computer flow model, which allows for the cyclical variability of the thickness of the flowing layer of melt in the hot runners. Approximate methods are therefore used for such systems, chiefly differentiation of the size of the gates.

In a mould (see **Figure 6.11**) with an internally-heated manifold (EWIKON), the need arose to balance the flow to 15 injection points.

Using a two-level system of channels in the manifold, partial natural balance was achieved. Rheological adjustment was performed through differentiation of the insulating torpedo chamber diameters. This differentiated the thickness of the flowing melt layer around the torpedoes.

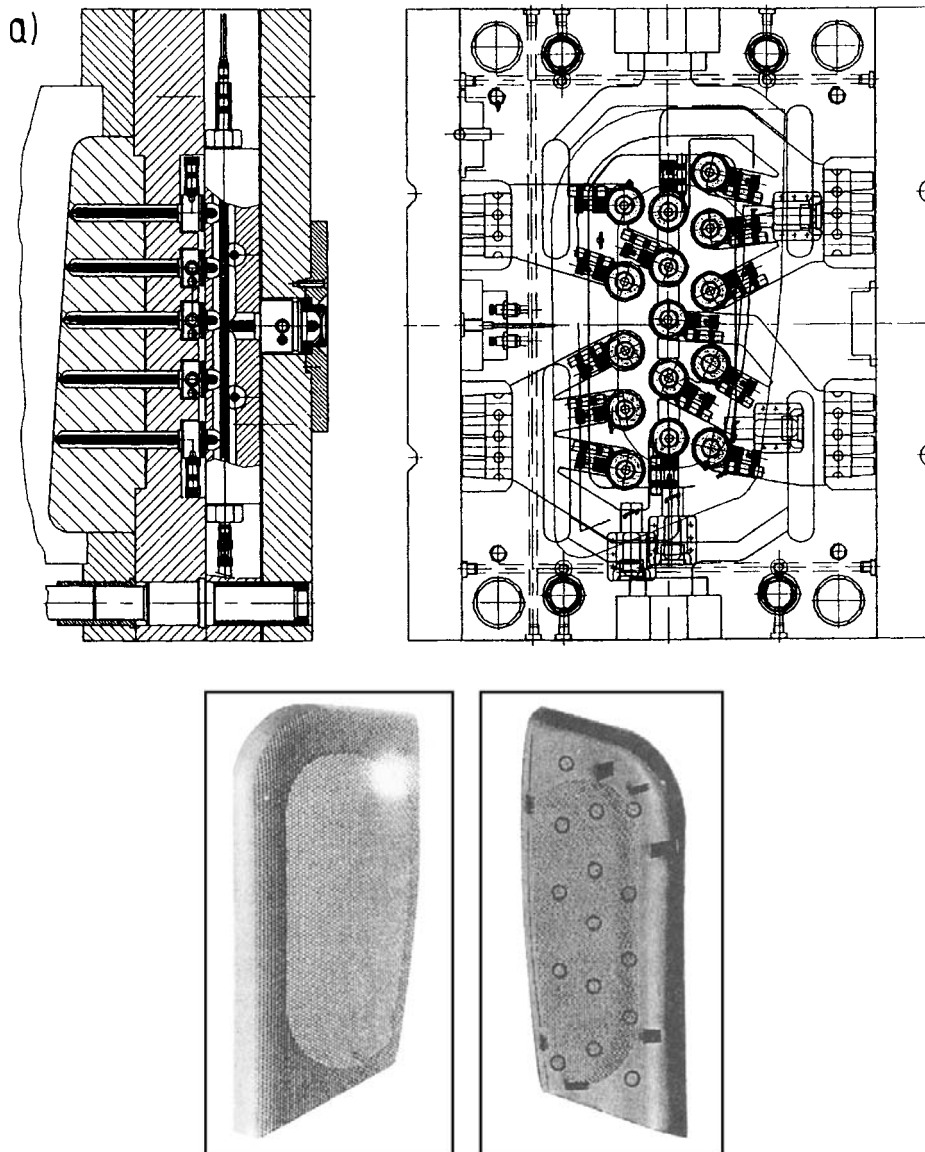


Figure 6.11 Single-cavity mould for PC loudspeaker casing with 15-point injection in an internally-heated mould [3]

a - mould design; b - moulded piece; view from front and rear

(Reproduced with permission from H. Vogel, *Plastverarbeiter*, 1992, 43, 10, 30, Figure 4 (a) and Figures 2 and 3 (b). © 1992, Hüthig Verlag)

Hot Runners in Injection Moulds

Most companies manufacturing HR systems have simple calculation programmes based on the same principle: repetition of calculations until identical flow conditions are achieved in the manifold and nozzle channels.

References

1. H. Bangert, H. W. Paffrath and G. Wubken, *Kunststoffe*, 1982, **72**, 10, 661.
2. K. Gauler, *Plastverarbeiter*, 1993, **44**, 2, 42.
3. H. Vogel, *Plastverarbeiter*, 1992, **43**, 10, 30.

7 Choosing an HR System

The choice of an HR system depends on numerous economic, technical and even organisational factors. This problem should be considered on the basis that each mould is a component part of a production system, comprising - apart from the mould - the injection moulding machine with peripheral equipment operating in a specific organisational system.

The lowest level of risk occurs when a standardised ready-made system is purchased - manifold plus nozzles. In justifiable cases of atypical geometry or cavity positioning, the manifold may be produced by one's own efforts, or from a semi-finished product. A better guarantee is obtained, however, by ordering a ready-made manifold, and at least consulting the nozzle manufacturer.

The following negative tendencies are seen when an HR system is being chosen:

- purchase of the cheapest possible system, solely on the basis of price competitiveness; the eventual cost balance may, however, turn out negative;
- selection of an unnecessarily complex system for processing of plastics that are easy to handle from the processing aspect;
- the tendency to use universal designs and, for example, a preconceived desire to utilise the same nozzles with different moulds and plastics;
- the use of HR system solely to satisfy one's own ambitions as a symbol of modernity;
- failure to compare different types of system from different manufacturers.

There are several dozen companies offering standardised HR systems. Manufacturers of injection mould bases also supply HR systems.

These companies' catalogues generally contain technical drawings with installation dimensions, and quite often examples of use. It should be remembered that the guidelines given in catalogues, e.g., gate diameters, only refer to nozzles from the manufacturer in question.

Catalogues are also supplied on diskettes, and are adapted for various computer-aided design (CAD) systems, most often AutoCAD.

CAD catalogues contain drawings of HR components (not showing dimensions) adapted to the inclusion of a mould on the drawing. This enables the mould drawing time to be shortened.

A catalogue should be supplemented by a current price list for the year. The price given will include the agency commission and often delivery costs too, which makes financial calculations clearer.

The basis for selection is made by deciding whether, given all the prevailing circumstances, HR technology should be used to produce a given product (Chapter 2).

The following analysis is an abbreviated statement of the information given in the previous chapters.

7.1 Definition of HR system

The starting point for selection of an HR system is to define the specific tasks which constitute the selection criteria. Taking these as a basis, we decide in turn on the design features, and this puts us in a position to define the HR system needed (see Figure 7.1).

7.1.1 Type of system

A cost and benefit comparison provides a basis for taking the first decision, whether to use a full HR system or a joint HR and CR system.

Other factors influencing the type of system are:

- the potential for simplification of the mould design with HR and CR (simpler runner system and cooling system);
- the product size - for very small pieces it may be necessary to use an HR and CR system, e.g., with tunnel gates;
- a product shape making it impossible to run the nozzles into the mould cavity;
- process demands - automation, method of break-off and removal of any sprue, waste management.

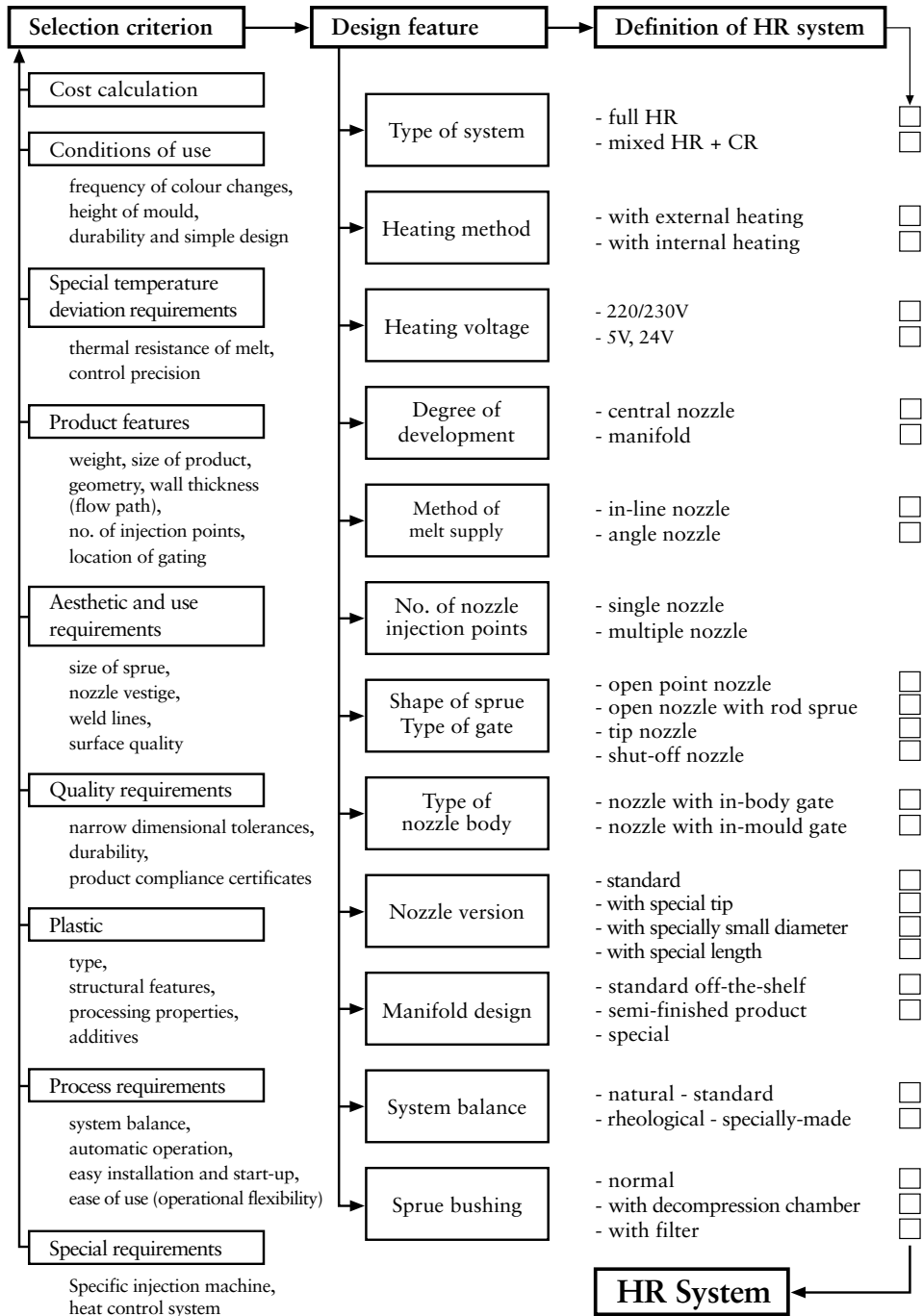


Figure 7.1 HR system selection scheme

7.1.2 Heating method

The choice between internal and external heating, particularly of the manifold (see Chapter 1) depends on the following factors:

- *Colour changing.* Purging the channels with internal heating is difficult. A colour change from dark to light or the transition to a translucent plastic requires mechanical channel cleaning;
- *Design and process considerations.* There are some factors for choosing internal heating such as the simpler design of an HR system, lower mould height, low energy consumption, lower purchase price, ease of operation, lower risk of disruptions to production and low external temperature of manifold. So far, however, a system with internal heating rules out use of a shut-off nozzle (an exception being EWIKON);
- *Processing properties of plastics* - thermal resistance. With internal heating there is melt hang-up and higher shear stresses during flow through the annular channel of the manifold, which hinders use of this system for plastics with limited thermal resistance;
- *Flow balancing.* Because of the non-uniform nature of the flow and the enforced nozzle positioning geometry, it is difficult to balance the flow with internal heating; this restricts the potential to achieve narrow dimensional tolerances for moulded pieces. Systems with external heating may be effectively balanced, and ensure a rapid change of colour and easy start-up. All nozzle types may be used with them.

7.1.3 Heating voltage

The great majority of HR systems offered are equipped with heating using a 230 V current. The following considerations may weigh in favour of using 5 or 24 V heating:

- thermal sensitivity of plastic and the need to restrict temperature fluctuations to ± 2 °C;
- the need to use nozzles of reduced diameter, which is governed by the size of the heating element.

Low-voltage heating requires the use of a transformer and special equipment to convert the current and control the temperature.

7.1.4 Degree of expansion

The potential to use only a central nozzle or the need to build in a manifold have a fundamental bearing on the design and cost of the mould. This choice depends primarily on:

- the number and positioning of the cavities. As a reminder, even in a multi-cavity mould it is sometimes possible to use a multiple central nozzle;
- use of a combined HR and CR system. The potential then arises to reduce the number of manifold nozzles, and even to replace the manifold by a central nozzle;
- the product design. It may have a bearing on the number and distribution of the injection points;
- the height of the mould structure;
- the balance of costs.

The variety of possibilities for choice of a central nozzle is shown in **Figure 7.2**.

7.1.5 The melt supply method

The melt supply method, i.e., locating the gate on the front or side surface of the moulded piece, governs whether an in-line or angle nozzle is used. As with CR systems, this choice depends on, among other things:

- the product design;
- the condition of cavity filling meeting quality requirements;
- the potential to achieve a set direction of molecule and plastic filler orientation;
- the need to reduce the impact of the notch effect in the gate zone;
- the potential to locate the gate in line with aesthetic requirements. The need to locate the gate on the side surface often enforces the use of an auxiliary cold runner with tunnel gate;
- sprue break-off with in-line nozzles and sprue shear-off with angle nozzles.

In-line nozzles may also be led at a certain angle to an inclined piece wall. Angle nozzles are generally run to a side wall.

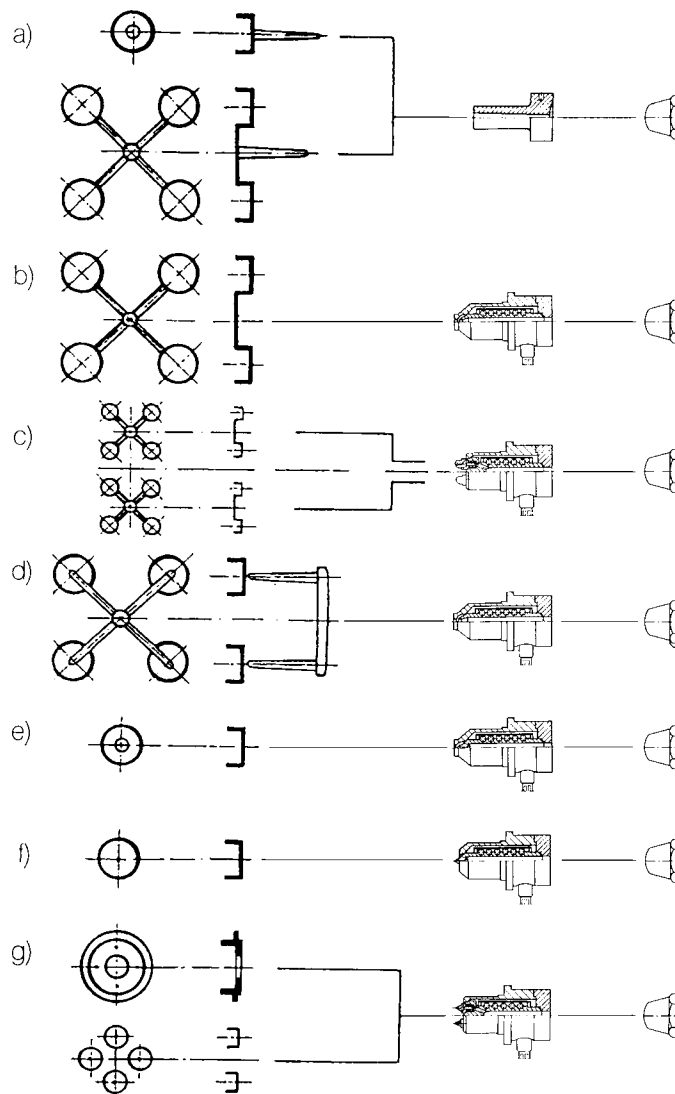


Figure 7.2 Examples of central nozzle selection

a - CR sprue bushing; b - open nozzle - gating to CR; c - two-point open nozzle - gating to CR; d - open nozzle - gating to CR in mould with intermediate plate; e - open nozzle; f - tip nozzle with partial body; g - 4-point tip nozzle with partial body

(Reproduced with permission from Hasco Normalien GmbH & Co.)

The number of injection points in a nozzle depends on, among other things:

- the product design and quality requirements. A typical gear or roller wheel with hub normally requires three injection points to make the piece round, not oval;
- the product size and the cavity location in the mould. It is advantageous to use cavity systems enabling multiple nozzles to be employed. One nozzle may then fill two to six cavities. This helps to bring down the cost of an HR system (a multiple nozzle is cheaper than a set of single nozzles with manifold), and makes the system easier to balance.

The shape of the sprue remaining on the product depends on:

- the gate design and dimensions;
- the type of plastic and the thermal conditions governing the place where the sprue breaks off and whether there is a string of melt.

The nozzle selection governs which of the following sprue types is obtained (see **Figure 4.3**):

- a point (conical) sprue remaining on the piece is obtained through the use of open nozzles, with which there is the strongest tendency for gate stringing to occur. It is located on the front surface of the piece.
- a rod-type sprue is obtained through use of open nozzles with a long gate. It is located in the cold flow channel, or sometimes on the moulded piece, in cases where lack of space prevents the nozzle being run into the mould cavity, or where additional heat insulation is needed between the insulation chamber and the mould cavity. A rod-type sprue needs to be trimmed off.
- an annular sprue arising because a tip nozzle is used.

In practice, a distinction is made between (see Chapter 4.1.1):

- a ‘technical’ gate of larger diameter facilitating flow and with a reinforcing cone.
- a ‘cosmetic’ gate of smaller diameter and without a reinforcing cone or cylinder, leaving a smaller sprue on the piece. This sprue may be located on the front or an oblique surface of the piece; it is the least visible, and the tip end counters stringing.
- there is no sprue with shut-off nozzles, which leave no more than a valve pin vestige on the piece. They are located on the front surface of the piece.
- there is also no sprue with edge nozzles, which leave a sprue trimming vestige on the piece, as with a CR system tunnel gate. They are located on the side surface.

The type of gate, defined by the shape of the sprue desired or the need for there to be no sprue, is crucial in deciding the nozzle type. Remember that the gate plays the part of a cyclically operating thermal valve (even when closed by a pin), which shuts off the flow of melt. It should also be borne in mind that the small size of the gate causes a large thermal and mechanical load to be imposed on the melt passing through. The choice of gate type will therefore be additionally governed by:

- the resistance of the melt to shear stress. Too high a flow rate governed by the shear rate will cause both a rise in temperature and degradation of the melt structure, and mechanical rupturing of the molecular chains. The best flow conditions are provided by shut-off nozzles which have the largest sized gates and by open nozzles. The greatest shear stresses occur in tip nozzles, and this restricts their use in the processing of shear-sensitive plastics like LCP or PC.
- the rheological properties. Open nozzles feature the smallest pressure losses, and are therefore the most suitable for processing high-viscosity plastics, e.g., PC.
- foaming additives. Only shut-off nozzles, which prevent foaming of the melt in the hot runner, may be used for plastics with foaming additives.
- the type of heating. Manifolds with 230 V internal heating require torpedoes to be used, in other words annular gates. Manifolds with 5 V and 24 V internal heating enable a full range of nozzles to be employed, even shutoff nozzles (Ewikon).
- ease of service. Dirt removal takes more effort with tip-type nozzles. In the case of shut-off nozzles, skilled staff are required, and professional and regular monitoring of their action.

Type of nozzle body. The body is a mechanical and thermal screen, and its type depends primarily on the plastic structure. In the case of amorphous plastics, which feature slow freezing, intensive heat removal is needed, and thus the use of what are called ‘cold’ gates. In the case of semi-crystalline plastics (apart from PE and PP), which feature ‘fast’ freezing (crystallisation), gradual heat removal is needed, and so the use of ‘hot’ gates (see Chapter 4.1.1 and Table 3.2). In the case of PE and PP, moderate heat removal is needed, with the use of ‘elevated temperature’ gates.

The nozzle body type is selected as follows:

- full-body nozzles, i.e., with the gate inside the body, provide thermal insulation for the gate (‘hot’ gate), and are intended primarily for processing semi-crystalline plastics. These nozzles leave a visible vestige from their face on the product surface, which may be undesirable from the aesthetic aspect.

- partial-body nozzles or body-less nozzles (torpedoes), i.e., with the gate in the mould, give good gate cooling ('cold' gate), and are primarily intended for the processing of amorphous plastics, and also of PE and PP. In the case of high temperature plastics, these nozzles must have a design which ensures good heating of the insulation chamber.

Plastic can 'hang up' in the insulation chamber of a partial-body nozzle and in the channel in which a torpedo is located. For this reason they may not be suited for processing of thermal-sensitive plastics like PVC or POM, plastics with flame-retardant additives or plastics with organic colouring agents. They may also give problems during colour changes.

When selecting a nozzle for a specific plastic and production type, the manufacturer's recommendations must always be checked, since the specifics of the nozzle design may give rise to a shift away from the stated selection principle or increase the universality of the nozzle. Further, the process parameters, and particularly a long cycle time, may cause restrictions to use of the nozzle or the need to modify it. Depending on the size of the range, suppliers offer universal nozzles or nozzles tailored for strictly defined applications.

Nozzle versions. Standard full-body nozzles are supplied with a minimum diameter gate, which may be increased within certain limits depending on need. An elongated nozzle version has also been designed which makes it possible to adapt the shape of the nozzle front to the shape of the piece, as well as nozzles with replaceable tips and gate inserts, which make it possible to replace a point gate by an annular one, i.e., to convert an open nozzle into a tip-type nozzle or vice versa, or to alter the material of the tip or gate. This also concerns gates in the mould, which should as far as possible be put in with replaceable inserts.

When choosing a nozzle, consideration should be given to:

- the abrasive action of mineral fillers and glass fibre, which cause especially rapid wear to tip nozzles and require the use of replaceable tips made of hard alloys, sinters or hard coatings. Molybdenum sinters have a five times greater abrasion resistance than copper/beryllium alloys, and a molybdenum thermo-implantation (ionic treatment) increases the resistance by several dozen times. It should be remembered, though, that the thermal conductivity of copper/beryllium is twice that of molybdenum.
- the corrosive effect on the nozzle material of PVC, fluoroplastics, added flame-retardants and other chemical additives. Nickel or chromium coatings or stainless steel are recommended in these cases.
- the effect of the nozzle material on the properties of the plastic. This particularly concerns contact between PP and copper - protective coatings are recommended, or else a change of nozzle material, e.g., to molybdenum. Besides this, it is inadmissible

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to use alloys with beryllium added for direct contact with plastics when manufacturing packaging for foodstuffs, pharmaceuticals or medical equipment.

- the mechanical strength; when nozzles with a casing made of copper/beryllium are used, it should be borne in mind that the strength of copper/beryllium, and thus also the admissible pressure of the plastic, diminish rapidly as the temperature rises. The admissible temperature for use of such nozzles is 280 °C according to Hasco.
- the shape and size of the product; nozzles of especially small diameter need to be used to produce small products. In the case of some large or deep products, e.g., garden chairs, very long nozzles with numerous heating zones need to be used.
- the specific features of the plastic and additives, e.g., tendency for sedimentation of pigments and the occurrence of pellets of them, creation of a weld line when tip-type nozzles are used at the place where the streams of melt divide in laminar flow (ABS, rubber-modified plastics, metallic pigments).

Manifold design. The choice of manifold is not as problematical as the choice of nozzle, since the range of manifolds is much more modest, and in most cases the manifold is made to order, and hence adapted by the HR system manufacturer to use with a specific plastic, product and mould. Manifolds to some extent have their shapes and some dimensions standardised, which should be borne in mind when planning the cavity layout. The minimum cavity spacing is additionally governed by the nozzle diameter.

The choice of manifold is primarily governed by:

- the number and positioning of the HR system gates/nozzles;
- the way in which a filling balance is achieved.

These factors govern the design of the manifold and its minimum dimensions. From the range on offer a manifold is selected that meets the above requirements, or else a manifold is ordered in a special version. It is important to obtain the supplier's assistance in calculating the rheological balance of the system.

The manifold design requires further specification. Depending on the type of plastic, the shot size, the injection cycle time and numerous other factors (compare Chapter 4.2), the user or supplier establishes the channel diameter, the split into heating zones (positioning of thermocouples), the heating element power rating and the manifold equipment (type of sprue bushing and any heating it may require, heat insulation, socket-contact).

Some manufacturers have standard semi-finished manifolds in which they make flow channels to order; there are also semi-finished manifolds on the market with flow channels that are finished (exit channels made) and installed at the customer's premises.

HR system balance. The user may choose a system on the basis of one of two types of balance (see Chapter 6):

- natural balance, which is preferred for standard manifolds. In moulds with a larger number of cavities, or where they are positioned in-line, it may be necessary to resort to multi-level manifolds;
- rheological balance, which is generally used in special manifolds. A rheologically balanced manifold may replace a multi-level manifold, which will enable the flow path to be shortened and the size of the manifold to be reduced. Bear in mind, though, that in this case the injection parameters used in the calculations must be employed, which considerably restricts the scope of regulation, and that computer calculations for channels may be costly.

Sprue bushing. Its selection is discussed in Chapter 4.2.

Other factors which may have a bearing on HR system selection are:

- the price and technical level of the system;
- the heat regulation system in place, and the number of regulators;
- the potential to connect the HR system to the system for supervision and parameter registration of the injection machine;
- the speed of delivery;
- the level of technical staff, the potential for rheological balancing of channels by the supplier;
- the speed of delivery of spares.

These considerations should also be included in the initial selection of HR system and supplier.

During the course of the above HR system selection process, it may turn out that some part of the system does not meet the set conditions. One solution may be to build the system out of components from two suppliers, e.g., manifold and nozzles, but then responsibility for the working of the system as a whole effectively falls upon the user.

7.2 Channel and gate selection

Having decided on the HR system, the next step is to establish some details arising out of technical calculations, namely the choice of flow channel diameter for the manifold, the nozzle size and the gate diameter.

Manifold channels. In the event that a complete manifold is purchased, the channel diameters are set by the manufacturer from technical data supplied by the customer, and the manufacturer guarantees that the manifold will do its job.

In the event that the manifold is designed by the customer, if filling balance is achieved in a natural way, the channel diameters may be defined using general recommendations (see Chapter 4.2). The correctness of the adopted channel diameter may be checked by calculation using the condition of the admissible pressure loss in the flow path, but one must have the $\eta(\dot{\gamma})$ diagram for the given plastic (see Chapter 6.2).

The admissible pressure losses in the HR system may be adopted on the basis of the following:

- the nominal injection pressure of the standard injection machine is most commonly 150-160 MPa. The injection machine nozzles usually show a pressure loss of around 10-15 MPa, while HR nozzles have a pressure loss of 10-25 MPa. It is usually assumed in rheological analyses that the pressure loss for cavity filling should not exceed 75 MPa. At least 35 MPa is therefore left for pressure loss in the manifold channels.

The pressure loss balance may take the following form:

injection machine nozzle, maximum	15 MPa
manifold	35 MPa
HR nozzle, maximum	25 MPa
cavity, maximum	75 MPa
Total	150 MPa

As far as possible, the lowest possible injection pressure loss should be applied; this means striving to achieve a reasonable compromise between the tendency to utilise large channel diameters and to reduce the channel volume.

Deciding the diameter of channels with internal heating is something that requires some experience, and very often some consultation with the manufacturer is needed. For milled channels, good results have been obtained using the method of passing a melt with contrasting colouring through the channel (measuring of frozen layer thickness, then adjustment to shape and size of channel, according to Strack).

Nozzle type. Every manufacturer has their own code designations for the nozzles they offer. This contains not just the type definition, but also certain characteristic features, for example the size.

To make selection easier, the catalogues give recommendations for the use of individual types of nozzle for the most commonly used plastics.

Nozzle size. The manufacturers generally offer several sizes for a given nozzle type. The choice of nozzle size is primarily governed by the shot size and the fluidity of the plastic. The limiting parameter for nozzle use is basically the admissible melt flow rate (cm^3/s) through the channel (d, L), and consequently the admissible shear rate of the plastic and the pressure drop in the nozzle. Thus the greater the viscosity of the melt, the smaller the admissible flow rate. To help in nozzle selection, suppliers very often give the admissible shot size (cm^3 or g) for plastics of low, medium and high fluidity (see Table 7.1), sometimes making allowance for the nozzle length. These recommendations are of a provisional nature, since individual plastics may be produced in varieties with a broad range of viscosity values, e.g., PP, PC. More precise nozzle selection is achieved using the admissible flow rate criterion (cm^3/s), but this requires the injection time to be determined.

Table 7.1 Maximum shot size for CLEANFLOW nozzles depending on fluidity of plastic (Eurotool)			
Plastic fluidity	Plastic	Shot size (g)	
		Open nozzle	Tip nozzle
Low	PE, PP, PS	200	170
Medium	ABS, ASA, PA, PBT, PET, POM, PPO, SAN	150	120
High	PC, PEEK, PEI, PMMA, PPS, PSU	80	60
ASA: acrylonitrile styrene acrylate			

The nozzle size is also governed by the external dimensions, and particularly by the diameter of the flange, which restricts the interval between injection points.

Gate diameter. Of all the geometric features of HR system components, the gate size is the one that has the greatest influence over product quality.

Suppliers employ various criteria for gate diameter selection, in the form of easy-to-read diagrams or tables. One should ascertain whether the recommended gate diameters are for an open nozzle or a tip-type nozzle. The user should also be aware that the diagrams and tables are only valid for nozzles of a certain design, and cannot be used to select nozzles from another manufacturer.

Several examples of selection using different criteria are given below:

- a diameter selection diagram depending on shot weight and melt viscosity, with the plastics divided into three fluidity groups (see Figure 7.3).

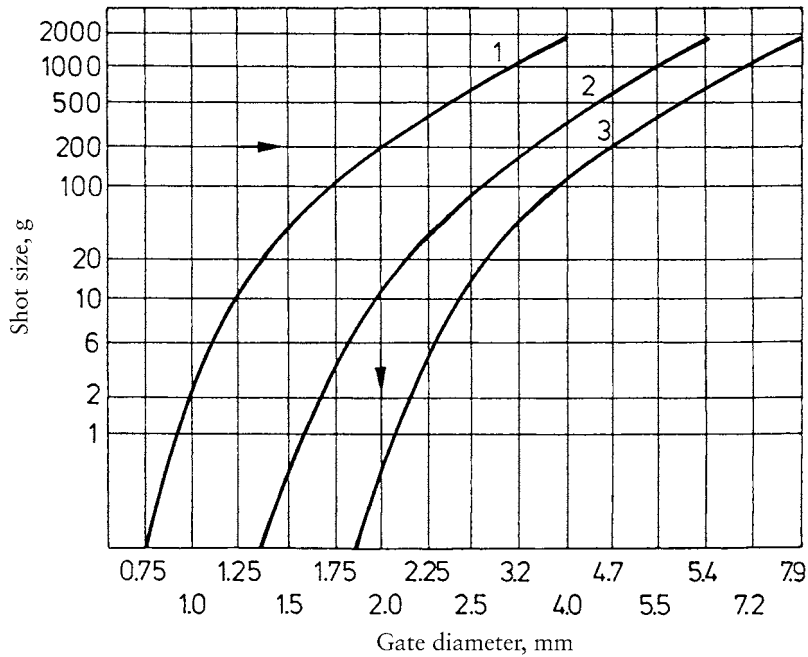


Figure 7.3 Nozzle gate diameter selection diagram using criteria of shot size and plastic fluidity

1 - high-fluidity plastics: PE, PP, PS; 2 - medium-fluidity plastics: ABS, PA, POM, SAN; 3 - low-fluidity plastics: PC, PMMA, PPO, PUR

(Reproduced with permission from Heatlock AB)

Use of this type of diagram is not particularly precise, however, as the plastics in each group, and even certain types of plastic of a set type, have significantly differing viscosities.

Example. The weight of a moulded piece made of PS (a high-fluidity plastic) is 200 g.

The recommended gate diameter is $d = 2$ mm.

- diameter selection diagram depending on flow rate and admissible shear rate of melt (see Figure 7.4). The flow rate Q , is calculated as in Chapter 6.2.

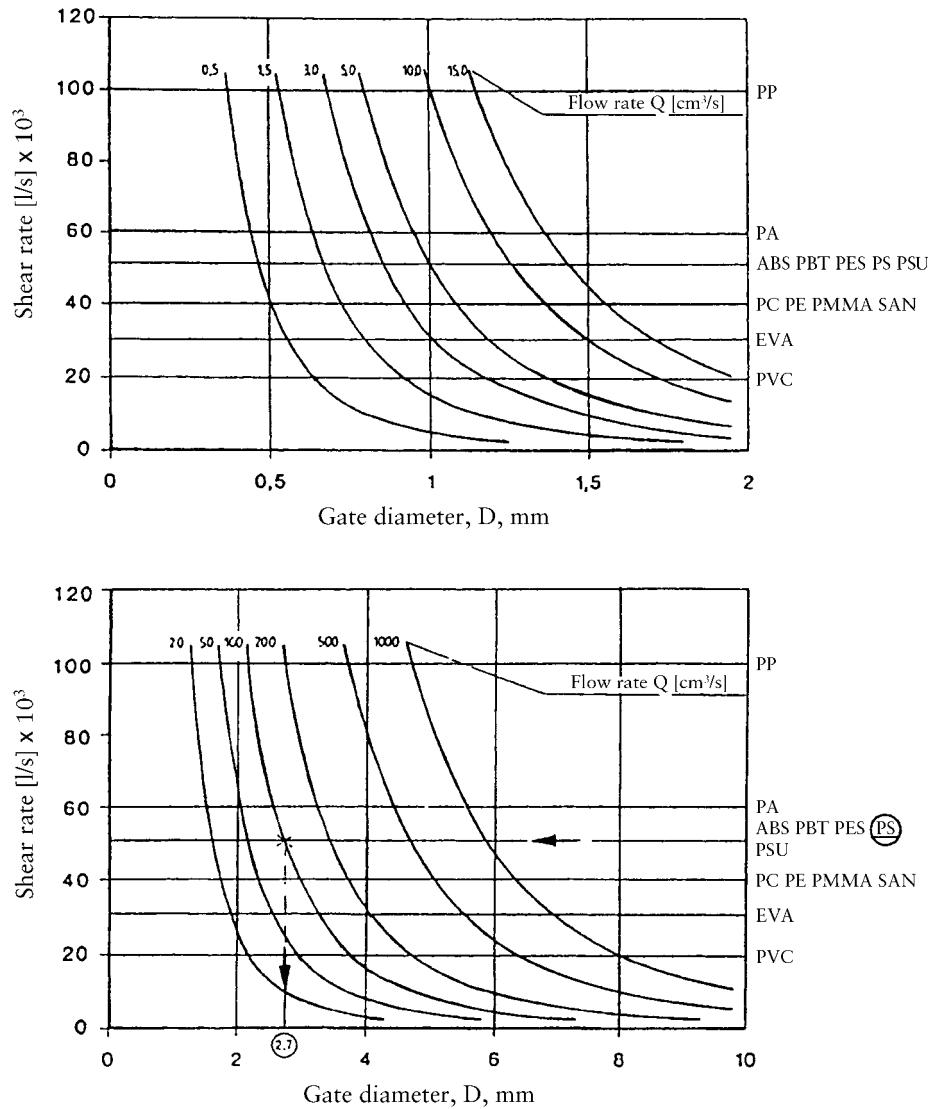


Figure 7.4 Nozzle gate diameter selection diagram using criterion of admissible plastic shear rate

(Reproduced with permission from PSG Plastic Group GmbH)

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Example. The weight of a moulded piece made of PS is 220 g, and the specific gravity of PS is 1.1 g/cm³.

The predicted injection time is around 2 s.

The flow rate $Q = 220/(1.1 \times 2) = 100$, cm³/s.

The admissible shear rate from the diagram $\dot{\gamma} = 50,000$, s⁻¹.

The recommended gate diameter $d = 2.7$ mm.

- diameter selection diagram depending on shot weight and piece thickness (see Figure 7.5). This criterion makes allowance for the geometry of the piece.

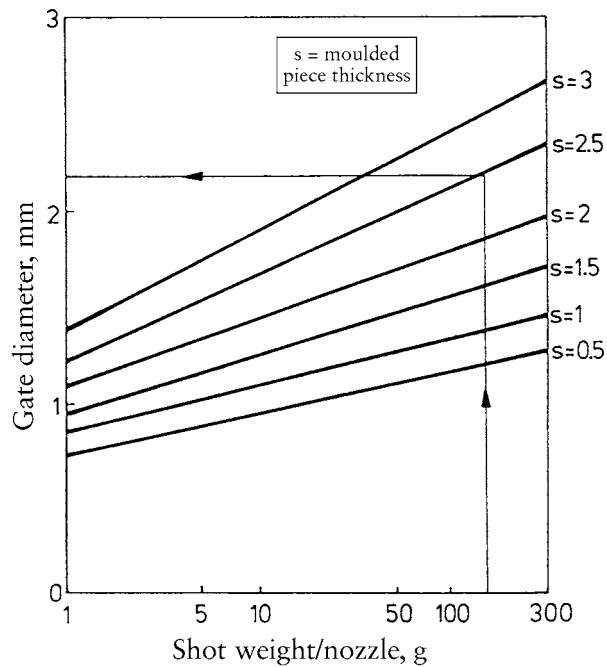


Figure 7.5 Nozzle gate diameter selection diagram for open nozzles using criteria of shot size and moulded piece thickness

(Reproduced with permission from Dynisco HotRunners)

Example. The weight of a moulded piece made of PS is 150 g.

Piece thicknesss = 2.5 mm

Recommended gate diameter $d = 2.2$ mm

- diameter selection table depending on wall thickness and area of moulded piece (see **Table 7.2**). The diameter selection here is based on both the flow and the freezing characteristics of the plastic. The table deals with high-fluidity plastics (PE, PP, PS); for other plastics the diameter needs to be enlarged using the coefficients given.

Table 7.2 Nozzle gate diameter selection diagram based on moulded piece size criterion (Dynisco)										
Area of piece (mm ²)	Wall thickness (mm)									
	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	3.00	4.00
600	0.90	0.90	0.90	0.90	0.90	0.90	0.95	1.00	1.12	1.27
1200	0.90	0.90	0.90	0.92	1.00	1.05	1.12	1.17	1.32	1.50
1800	0.90	0.90	0.95	1.02	1.10	1.17	1.25	1.30	1.47	1.68
2400	0.90	0.90	1.02	1.10	1.20	1.25	1.35	1.40	1.58	1.78
3000	0.90	0.95	1.07	1.17	1.25	1.32	1.42	1.47	1.65	1.88
6000	1.00	1.12	1.27	1.37	1.50	1.58	1.68	1.76	1.98	2.26
12000	1.17	1.32	1.53	1.65	1.78	1.88	2.00	2.08	2.36	2.67
18000	1.30	1.47	1.68	1.83	1.96	2.06	2.21	2.31	2.62	2.97
24000	1.37	1.58	1.80	1.96	2.10	2.24	2.39	2.49	2.80	3.18
30000	1.45	1.65	1.90	2.06	2.24	2.36	2.51	2.64	2.95	3.35
36000	1.53	1.73	1.98	2.16	2.34	2.46	2.64	2.77	3.10	3.53
42000	1.58	1.80	2.08	2.26	2.41	2.57	2.75	2.87	3.23	3.66
48000	1.65	1.88	2.13	2.34	2.51	2.64	2.82	2.97	3.33	3.79

For highly-crystalline plastics (PA, PBT, POM), the diameter should, however, be a minimum of 2.4 mm.

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Nozzles feature certain minimum gate diameters: which are ready-made, in the case of full-body nozzles, or recommended for the particular application, in the case of partial-body nozzles. Full-body nozzles are offered in a version with the smallest gate diameter for the given nozzle size. For partial-body nozzles, the recommended minimum gate diameter for the plastic in question is given. Some suppliers give maximum gate diameters for each nozzle (with a set admissible shot weight), after which the choice of diameter is made on the basis of the melt, piece and process characteristics (see **Table 7.3**). These factors are always worth considering for the purpose of adjusting the diameter obtained using the diagrams.

Example. A 24-cavity mould for PS cups with a 1 mm wall thickness. The Mold-Masters tip nozzle used has a gate diameter range of 0.6-1.6 mm (average 1.1 mm).

The indications given in the table enable the size to be optimised.

The plastic is an amorphous material, and the lack of filler and additives point to selection of a small gate diameter.

The piece moulded - the shot weight is substantially lower than the admissible value for the selected nozzle and the average g/L ratio point to selection of an average diameter, but the 'cosmetic' gate and the lower-than-average wall thickness point to a small gate diameter.

Process - the wide range of injection temperatures suggests selection of a small diameter, but the high injection rate points to a large gate diameter.

With the above factors in mind, a gate diameter of $d = 0.8$ mm was adopted.

Gate length. The gate should be as short as possible, to reduce the vestige on the piece and to limit throttling of the flow. In practice, its length is dependent on mechanical strength, and is usually 0.2-0.5 mm, depending on gate diameter.

Some nozzles have a gate that passes uninterruptedly into an insulation chamber, i.e., does not have a defined length (see **Figure 4.35**).

Table 7.3 Influence of properties of plastic, features of piece and process parameters on gate size (according to Mold-Masters)			
GATE	GATE DIAMETER		
point annular shut-off side	Small	Medium	Large
	← gate diameter modification directions →		
PLASTIC			
structure	amorphous	crystalline	high-crystalline
molecular weight	low	medium	high
MFI	high	medium	low
reinforcing or filling additives	-	low content	high content
flame retardant additives	none	-	present
sensitivity to temperature and shear	not applicable	admissible	applicable
freezing	slow	normal	fast
MOULDED PIECE			
shot weight	small	medium	large
ratio of wall thickness to flow path, g/l	low	medium	high
tolerance	broad	medium	narrow
gate vestige	small	medium	large
application	mass-produced products	-	engineering products
PROCESS			
range of injection temperatures	broad	medium	narrow
injection rate	low	medium	high
pressure drop created	high	normal	low
effect of holding pressure	minor	-	major

8 Special Injection Processes Using HR

8.1 Sequential and cascade moulding

The development of injection moulding technology during the last decade has led to a significant diminution in the thickness of large products. A typical wall thickness nowadays would be 2-3 mm, compared to 4-6 mm previously. This has, however, become a cause of very perceptible weld and flow lines being left. They also have a bigger impact than before on the mechanical properties of products and the quality of painted and film coatings.

Conventional multiple injection causes weld lines to appear between nozzles, and in the case of difficult configurations there may also be a trapping of air by streams of melt meeting one another (Figure 8.1). Computer flow simulation makes it possible to determine where the weld line will be and to move it to a less visible or less heavily loaded place by varying the flow channel sizes or altering the nozzle position. When a mould has been manufactured, though, the opportunity to move the weld line is lost. Simulation programmes do not make it clear how visible this line will be, either.

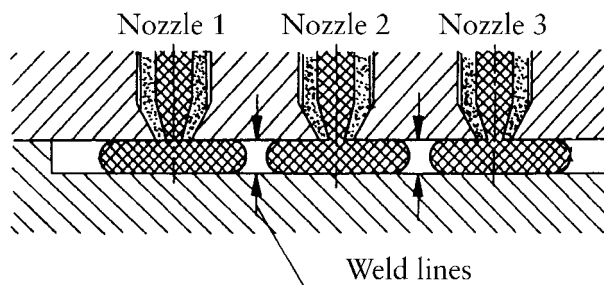


Figure 8.1 Conventional multiple injection moulding always causes weld lines in the plastic, and there is a risk of air being trapped between them [1]

(Reproduced with permission from Injection Moulding International, 1997, 2, 2, 47, Figure 2. © 1997, Abby Communications, Inc.)

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Two special injection moulding methods have been developed to get around this problem, both based on HR systems with multiple gating: sequential moulding and cascade moulding. Both methods require the use of shut-off nozzles with independent control.

Sequential moulding is based on mutually independent opening and closing of the nozzles in the mould cavity in such a way as to allow the weld lines to be shifted until they reach an optimum position. This technique is used for products of large area and with numerous apertures which cause weld lines to appear. The use of simulation clearly provides a good starting point for optimisation of nozzle control.

Nozzle control takes place using one of the following methods:

- utilising the core pulling control programme present in the injection machine;
- with the aid of induction sensors installed on the injection machine screw movement path;
- using special control equipment triggered by the injection start signal.

One example of use for smaller products is a box with a lid with an elastic hinge (**Figure 8.2**). Generally when products with a hinge are made, the recommendation is to position the gating in the larger half of the box, resulting in a good-quality hinge. One drawback is the large pressure drop in the hinge, which may cause a sink, shape change or serious shrinkage in the lid. Putting the gating in both halves, meanwhile, would require rheological optimisation of the HR system to prevent a weld line in the hinge.

Correcting the line shift by changing the size of the gates would make for a difference in filling conditions, and would thus lead to different shrinkage of both parts of the piece.

With sequential control of the nozzles it is possible to fill the lid and hinge before beginning to fill the box. The weld line will be located on the bottom of the box, and its position may easily be adjusted.

Another example of the use of sequential injection is a multi-cavity mould for products of varying size, e.g., a box and a cover. The HR system in this case would require rheological balancing, or an alternative would be sequential filling, i.e., successive filling of cavities by nozzles opening one after another.

One drawback, though, would be a little lengthening of the injection cycle.

Cascade injection is based on cavity filling by successively opened nozzles in such a way as to create just one melt flow front, resulting in an absence of weld lines. This method is

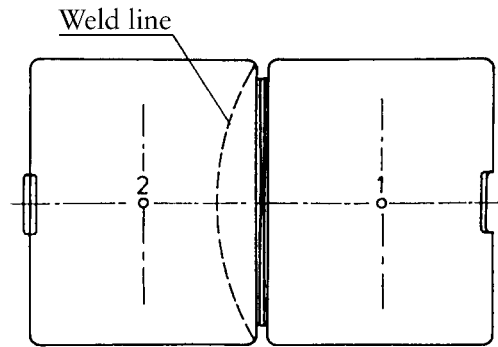


Figure 8.2 Sequential moulding of a box with flexible hinge provides freedom in locating the weld line. 1, 2 - injection points

particularly used for long, narrow products like car window seals and vehicle bumpers, where the nozzles may be situated in series.

The operating principle is illustrated in **Figure 8.3**. It should be pointed out that injection commences through the middle nozzle. The adjacent nozzles only open when the flowing melt front passes them. The middle nozzle may remain open or closed, as required. When the cavity has been filled by the final pair of nozzles, all the nozzles must be open to execute the holding phase. The number of nozzles and the geometry of the HR system should be established using a simulation programme. An example of a mould for cascade injection is shown in **Figure 8.4**. Cavity filling is carried out in this case from the end, and nozzle opening is controlled as a function of the movement of the screw.

Cascade injection is finding increasing use in moulding of textile linings for the vehicle industry.

One restriction on the use of sequential and cascade injection moulding is the need to use expensive shut-off nozzles and an additional control system.

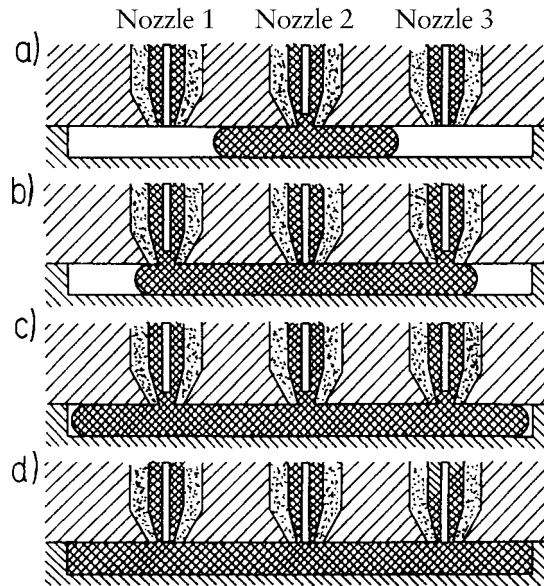


Figure 8.3 Cascade moulding using shut-off nozzles makes it possible to fill the cavity without a weld line [1]

a - opening of middle nozzle 2; b - opening of outside nozzles 1 and 3; closure of nozzle 2;
c - final cavity filling and holding phase, with all nozzles open; d - closure of nozzles

(Reproduced with permission from *Injection Moulding International*, 1997, 2, 2, 47, Figure 3. © 1997, Abbey Communications, Inc.)

8.2 Moulding with decorative films

In place of expensive overprinting on products, increasing use is being made of the method of injection onto printed films inserted into the mould, which is called 'in-mould decoration' (IMD).

There are different versions of this technology:

- insertion into the mould of suitably cut printed sections of film made from the same material as the basic moulding, e.g., PP foam film on a thin-walled packaging box or cup.
- insertion into the mould of printed polyester film fed from a roll. The overprinted layer remains on the piece like a transfer print. This method is used to make radio

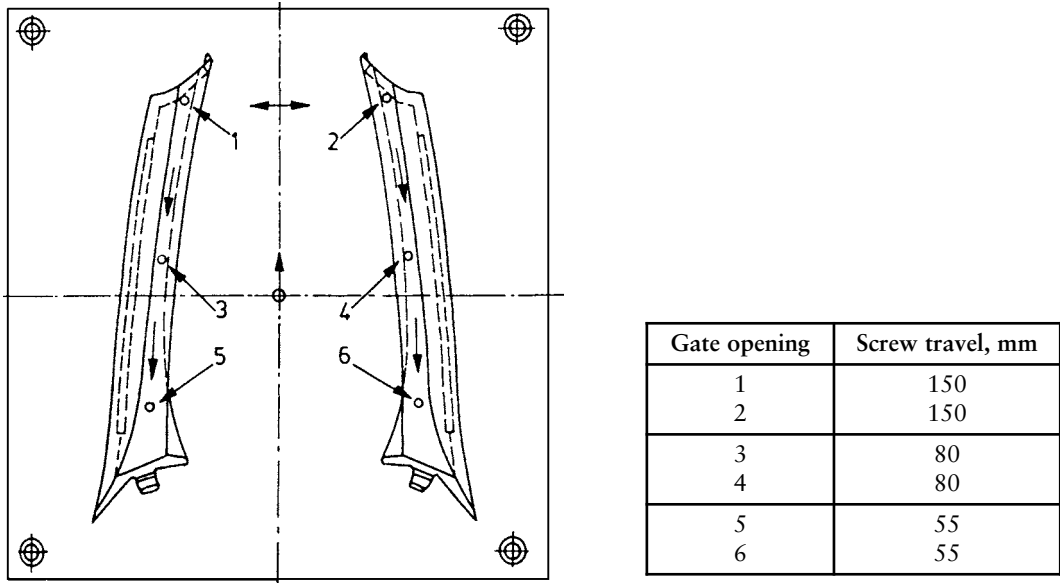


Figure 8.4 Two-cavity mould for vehicle interior strips, for cascade moulding. The nozzle opening sequence is determined by the position of the screw during injection [2]

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dials, casings for electrical equipment, e.g., Philips razors, imitation wooden linings for vehicle fittings, face powder compacts, e.g., with a malachite effect, emblems, company symbols, toys, etc.

- insertion into the mould of translucent PC film with a coloured overprint for vehicle dashboard indicators.
- insertion into the mould of thick decorative or protective films (up to 0.8 mm), which are initially warmed (thermoforming) and injection of melt onto them, e.g., recycled plastic. Uses are vehicle hub caps, helmets, screens, and so on.

In all cases the film is an external layer on the moulding, which means that the melt has to be injected through a core located in the fixed half of the mould.

Locating the gating at the side most often causes deformation of the film, with shifting and deformation of the overprinting of the design. Only single- or multiple-point frontal melt feed ensures that the right conditions are provided for proper flow in the cavity.

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The best solution here has turned out to be moulds with an HR system, mainly because of the low pressure losses in the channels for large products, the greater range of flow rate regulation and the potential for full automation of mould operation. In the case of manufacture of thin-walled labelled products, this is the only solution that is technically and economically justified. It has been necessary, however, to improve manifold insulation and to use tip-type nozzles preventing the occurrence of a cold plug effect and gate stringing, and to provide more accurate melt temperature regulation making allowance for the melt flow rate and the friction heat generated.

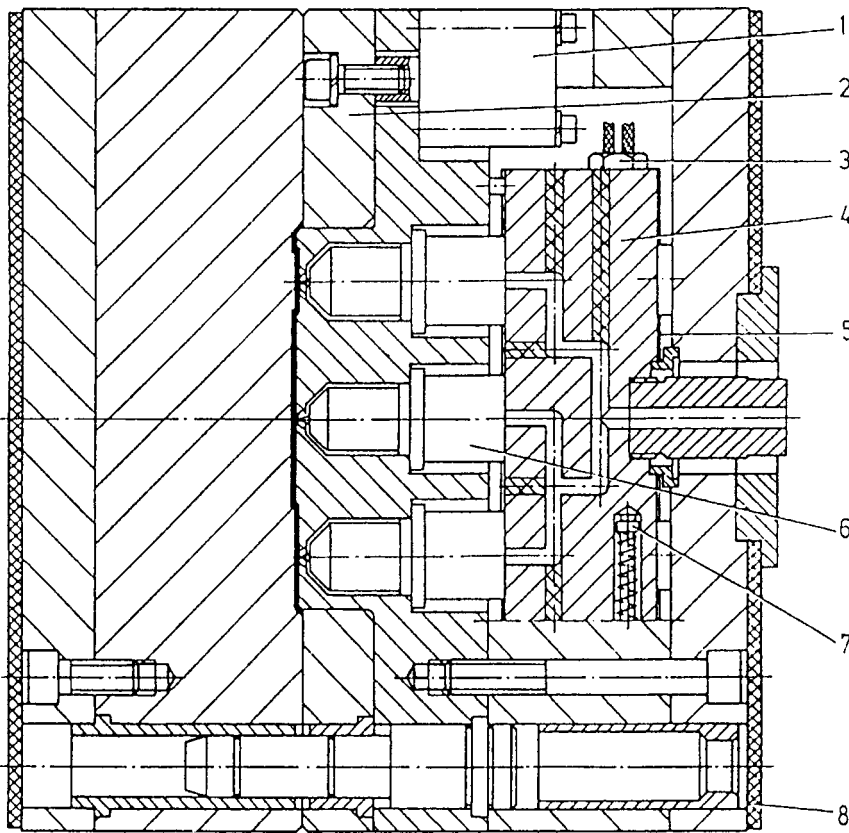


Figure 8.5 Mould for moulding onto printed film for a radio dial [3]

1 - hydraulic cylinder; 2 - stripper plate; 3 - cartridge heater; 4 - manifold; 5 - aluminium sheet reflector; 6 - HR nozzle; 7 - thermocouple; 8 - insulating plate, 600 kN/mm²

(Reproduced with permission from M. Böcklein and H. Eckardt, *Kunststoffe*, 1986, 76, 11, 1030, Figure 6. © 1986, Carl Hanser Verlag)

In a mould for radio dials (**Figure 8.5**), three HR nozzles have been used [3]. The cavity was fitted with a pressure meter and thermocouple, enabling the mould temperature and holding pressure to be monitored directly, thus minimising shrinkage of the plastic and making it reproducible. Too much shrinkage could cause delamination of the decorative layer.

8.3 Moulding with textile linings

Injection onto textile linings, or ‘in-mould lamination’ (IML), has seen continuing development in recent years because of demand from the automobile industry. This method is used to mould strips, covers, screens and linings for vehicle interiors from PP, ABS and ABS-PC with a textile surface.

In an IML mould, the cavity is in the moving half of the mould because of the need to inject into the non-visible side of the piece. This means that both the ejection system and the HR system must be located in the fixed half of the mould.

An example of an IML mould is shown in **Figure 8.6**. The HR nozzles are closed by pneumatic cylinders, and the ejector plate is also driven by a pneumatic cylinder, to prevent any oil leaks from fouling the lining. The mould has a ‘telescopic’ closure to cut off any surplus lining.

The (moving) half of the mould with the lining has to be intensively cooled, since the lining functions as insulation and makes it difficult to cool the piece. The heat insulation of the lining also causes an asymmetrical rate distribution at the flow front in the piece cross-section (**Figure 8.7a**). Asymmetrical cooling of a flat piece may lead to its deformation, with warping towards the lining (**Figure 8.7c**). Particular demands are made of HR nozzles in the case of production of pillar strips with a V-shaped cross-section (**Figure 8.8**). The nozzle zone here requires intensive cooling to counteract deformations towards the centre.

For this application, a nozzle set in a shaping insert with a bottom filled by diffusion with copper and containing a cooling channel has been designed.

When the cavity is being filled, meeting of melt flow fronts from opposite directions is inadmissible, as this may cause wrinkling of the textile lining. If there are several injection points, cascade moulding should be employed (see Section 8.1), which guarantees uniform holding of the fabric against the mould wall by a single spreading flow front. Furthermore, when the nozzle pitch and the piece thickness are being decided, an equally low pressure drop in each filling zone must be provided. Rheological simulation of cascade moulding is likely to be developed soon.

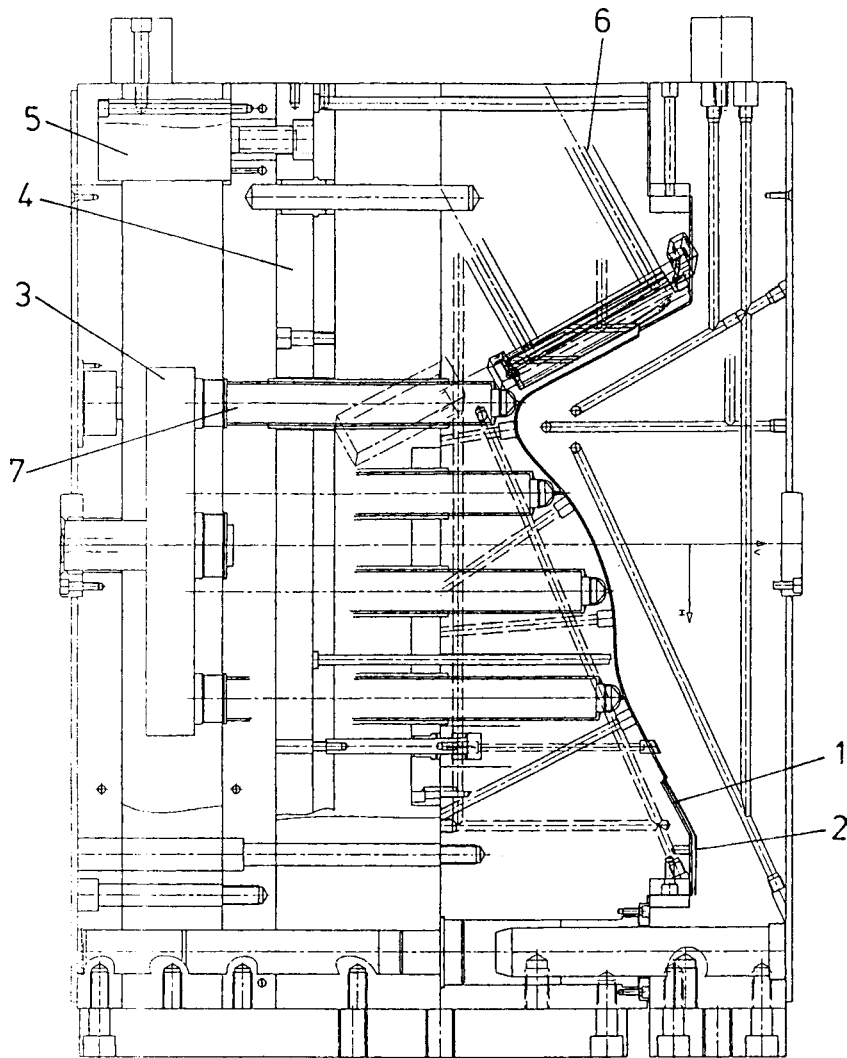


Figure 8.6 Mould for moulding onto textile linings [4]

1 - cavity; 2 - textile material; 3 - HR manifold; 4 - ejector plate; 5 - pneumatic cylinder; 6 - cooling channels; 7 - shut-off nozzle

(Reproduced with permission from G. Kaufmann, *Kunststoffe*, 1996, 86, 11, 1656, Figure 1. © 1996, Carl Hanser Verlag)

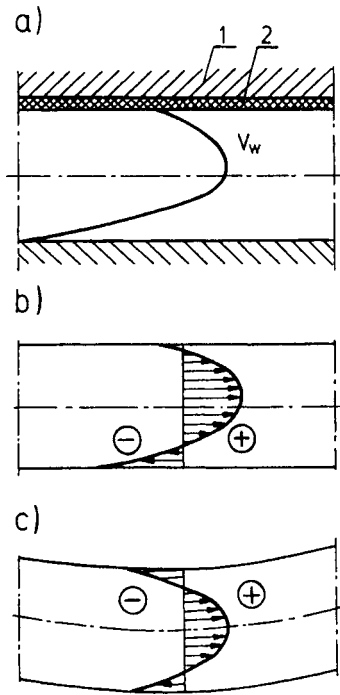


Figure 8.7 Phenomena occurring in mould when moulding onto textile linings

1 - lining; 2 - mould; a - asymmetrical flow front distribution; b - internal stress distribution in moulding; c - deformation of moulding caused by tendency of internal stresses to reach a state of balance
 V_w - flow rate; + - tensile stress; - - compressive stress

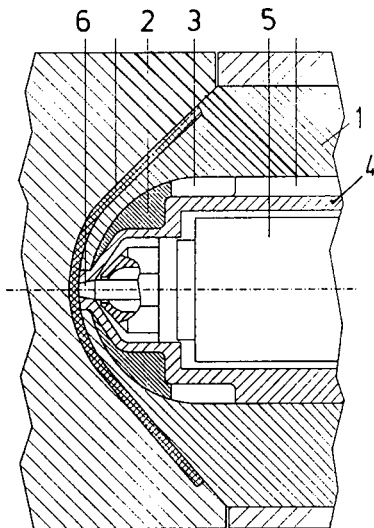


Figure 8.8 Shut-off nozzle in mould for moulding onto textile linings [5]

1 - mould insert; 2 - copper deposited by diffusion;
 3 - cooling channel; 4 - internal insert;
 5 - nozzle; 6 - valve pin

(Reproduced with permission from G. Kaufmann and G. Bagusch, *Kunststoffe*, 1994, 84, 3, 239, Figure 5. © 1994, Carl Hanser Verlag)

8.4 Multi-component moulding

The principle of multi-component moulding has been used for many years. It requires the use of injection machines with several injection units and in most cases the potential for the table to move (turn or slide) with one of the mould halves. The next fragment of the piece remaining in this half of the mould is injected in during the following cycle.

In another version of the process, injection of different materials takes place simultaneously from all injection cylinders, and flow control is required in such a way that the melt meets at a strictly set line, e.g., PMMA of different colours in vehicle rear lights.

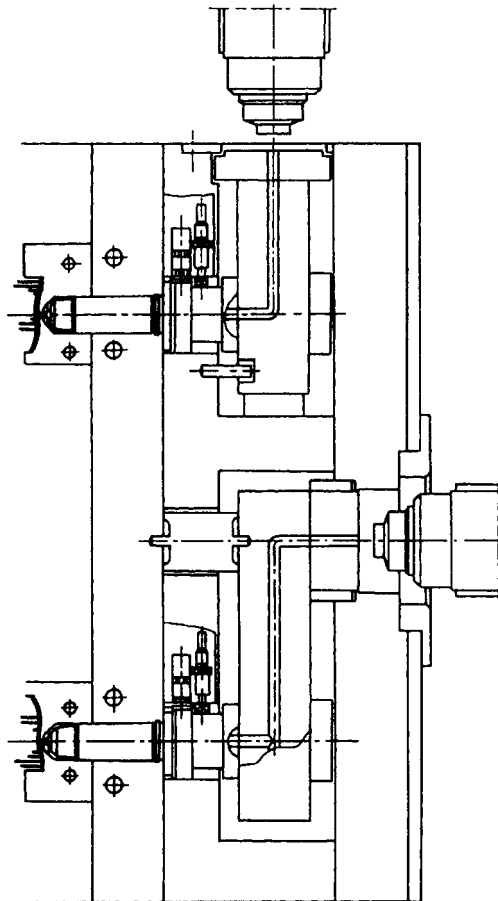


Figure 8.9 HR mould for moulding of two-colour terminals
(Reproduced with permission from *Günther Heißkanaltechnik GmbH*)

Problems when designing these moulds arose from the introduction of the melt with numerous injection points, achieving flow balance, and frequently, difficulties in removal of the cold sprue - if there was a need to have one.

Figure. 8.9 shows how this problem may be resolved with injection from two cylinders, one horizontal and one vertical, into two independent HR systems.

This technology is increasingly being used to produce large pieces, for example internal parts of vehicle doors, where there is additional lamination of a strip of textile lining with a more flexible plastic. The two-manifold system shown in **Figure 8.10** allows multiple injection of two plastics via nozzles that are closed hydraulically. The channels of each manifold comprise bent and welded tubes of the same length, cast into a single block with heating elements. This design was made possible by the two plastics having the same injection temperature.

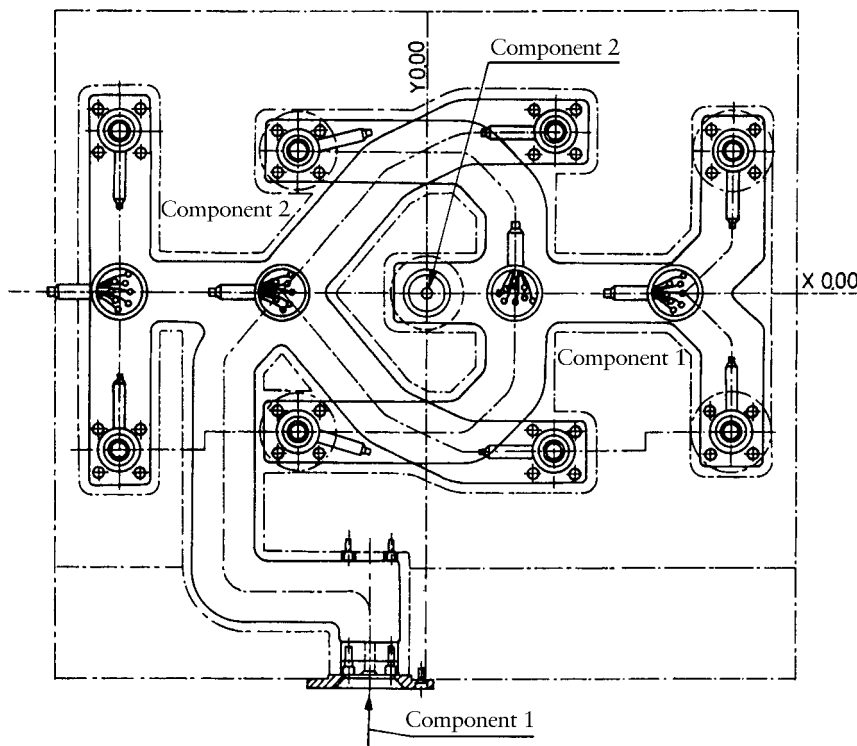


Figure 8.10 HR manifold of mould for moulding of two plastics for internal screen of vehicle door. X and Y are the origin of the mould

(Reproduced with permission from Unitemp SA)

Hot Runners in Injection Moulds

Because two materials with different processing properties are most often injected, nozzle and gate types that are adapted to them have to be used. According to information from one of the major manufacturers of injection moulding machines, combinations like those shown in **Figure 8.11** are most frequently used, with hard plastic - soft plastic systems easily predominating.

The expanding range of use of two-component hot-crosslinked silicone elastomers is leading to the appearance of injection machines and moulds in which a thermoplastic melt is injected using HR and a hardening plastic from a separate cylinder.

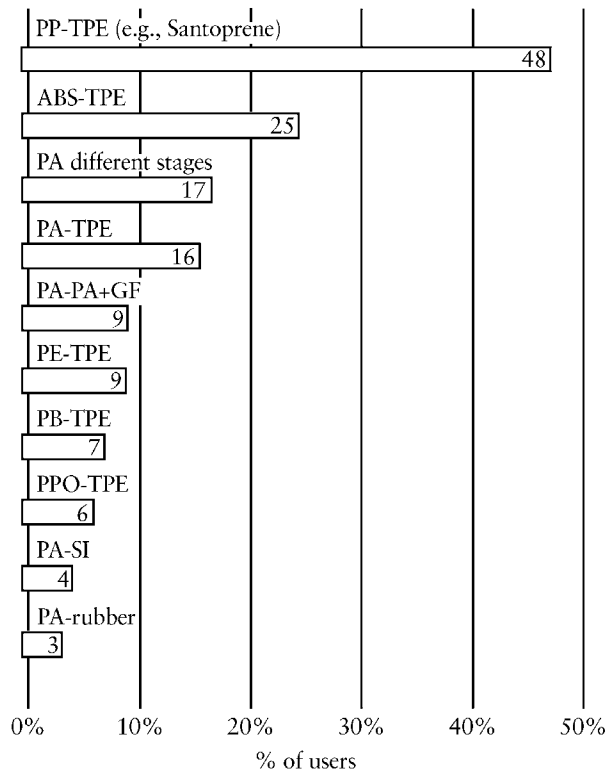


Figure 8.11 Most frequently used combinations of plastics for two-component moulding, according to survey carried out by Krauss-Maffei among 1,100 respondents [6]
SI - silicon

*(Reproduced with permission from Plastverarbeiter, 1996, 47, 8, 82, Figure 8.
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8.5 Injection of high-temperature group plastics

High-temperature engineering plastics do not require specially-designed HR systems. The following conditions should be borne in mind, however:

- injection takes place at 300-400 °C;
- melt temperature fluctuation tolerances are restricted to a few degrees celsius;
- high mould cavity temperatures are used, sometimes up to 220 °C;
- the price of the plastic may be as much as £30/kg;
- in many cases recycling of waste is not recommended.

The following general recommendations for HR system design then arise:

- special attention needs to be given to uniform temperature distribution along the flow path in the manifold and nozzle channels;
- careful selection of channel and gate diameters so as to avoid temperature rises resulting from heat friction;
- changes in flow direction to be as gentle as possible, e.g., from the main channel of the manifold to the nozzle channel;
- thorough elimination of the potential for the melt to hang up at nozzle seal locations;
- careful polishing of channel surfaces.

Fluoroplastics feature high viscosity combined with a low resistance to shear stresses. Large channel diameters and very large gates, with a diameter of as much as 5 mm, are recommended [7]. This requires nozzles with a valve pin to be used. In a plasticised state, the melt has a strong corrosive effect on steel (chemical reaction of fluorine and iron). Steel with a high nickel content is therefore recommended, or else nickel coatings. To improve heat conduction, internal copper beryllium alloy inserts are used in the nozzles, which are pressed into elements made of hardened nickel steel.

A seal with rectangular, not round cross-section should be used to seal the contact between nozzle and manifold.

Polyarylates: PAR, polyarylester (PAE), aromatic polyester (APE), HTPC. The viscosity of these plastics is even greater than that of PC, and does not diminish as the shear rate rises. The channels should have relatively large cross-sections. The minimum gate diameter

Hot Runners in Injection Moulds

is 1.2 mm. The lowest possible injection rates should be used. When there is a break in operation, the temperature should be reduced to 160-170 °C. When production of items made from PAR is commenced, it is a good idea to first inject well-dried PC, then raise the temperature and purge the PC with PAR. The reverse procedure should be used for cleaning purposes.

Polysulphones: *polyaryl sulphone (PAS), PES, PSU*. Their fluidity is like that of PC. The shortest possible channels with increased diameters should be used.

PEI polyimides: In contrast to PAI, fluidity is very good. Very high injection pressures are used, up to 150 MPa in the cavity, so much greater in the HR.

Liquid crystal polymers (LCP). Their molecules are macro-crystals which orientate themselves during flow in the direction of the greatest shear. As the shear rate rises, there is a steep fall in the viscosity of the fluid melt. Because of this, when an HR system is used one should [8]:

- design diminishing channel cross-sections from the injection machine nozzle to the gate;
- use very small channel cross-sections in the manifold, e.g., 3 mm;
- use, where possible, an HR manifold and a cold sprue feeding the melt to the cavity; this gives better results than when injection is direct from HR nozzles;
- eliminate melt weld lines which greatly reduce the strength of the moulded piece when LCP plastics are used;
- strive to obtain high flow rates and short gate freeze-off times, and thus also short holding times.

8.6 Thermoplastic elastomer moulding

The next group of plastics requiring the use of certain HR system designs is thermoplastic elastomers (TPE). From twenty years of experience, the following recommendations may be made [9]:

- only use manifolds with external heating;
- nozzles with a torpedo in the channel (annular gate) should not be used;
- where possible, channels with a gentle change in flow direction should be used;

- polish manifold and nozzle channels well;
- get rid of dead spots in which residual material may hang up;
- balance flow well.

The most critical area is the gate; use of open gates is recommended in this case. Experimental establishment of the optimum geometry using replaceable nozzle tips is a good idea.

Problems in automation of mould ejection of elastomers, and particularly thermoplastic polyurethane (TPU) which adhere strongly to the mould, may have an impact on reproducibility of the cycle time, and thus also on the reproducibility of the thermal parameters of the process.

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9 Special HR Mould Designs

Because of both the shape of products, and the influence of process demands, sometimes it is necessary to use non-standard HR designs. If standard nozzles cannot be used, special nozzles are designed, e.g., very long or very small-sized nozzles. If there is continuing demand, manufacturers of components for normal HR systems will increase their range to include the sub-units required. There is an increasing range of different manifolds, since the melt needs to be delivered from the side or even from the bottom of a moulding, and in stack moulds from both sides of the manifold.

Adapted injection moulding machines, for example, with a greater platen spacing, and process equipment to take the optimised new moulds are also being designed.

9.1 HR in moulds for large pieces

One of the largest mouldings made to date weighed 60 kg - it was a type Tel H 90 telephone booth made of foamed PC. The mould weighed 185 tonnes. An HR system with eight controlled shut-off nozzles was used in this instance. The installed power was 46.5 kW. The mould had 32 heating zones. Eight thermostats had to be used to regulate the temperature of the mould itself.

The floor of the booth, 970 x 915 x 70 mm in size, made of the same material, and with a wall thickness of 8.5 mm, weighed 12.8 kg. In the HR system mould [1], a specially-made type X manifold (see **Figure 9.1**) with 18 mm channel diameter and a spacing of 480 x 480 mm for the four injection points was used. When foamed PC is injected, the condition of a very high injection rate and instant gate shut-off following injection of a set quantity of melt must be observed. Because of this, 6.5 mm diameter gates with valve pins driven by double-action hydraulic cylinders (Incoe) were used.

The cost of large injection moulds is so high that the risk of error in the design phase must be eliminated. This condition may only be met when CAD computer design simulation is employed, both for the product (shape of cavity) and for the runner system, to look at rheological balancing of the filling, pressure distribution, heat removal, shrinkage, internal stresses and strains.

Hot Runners in Injection Moulds

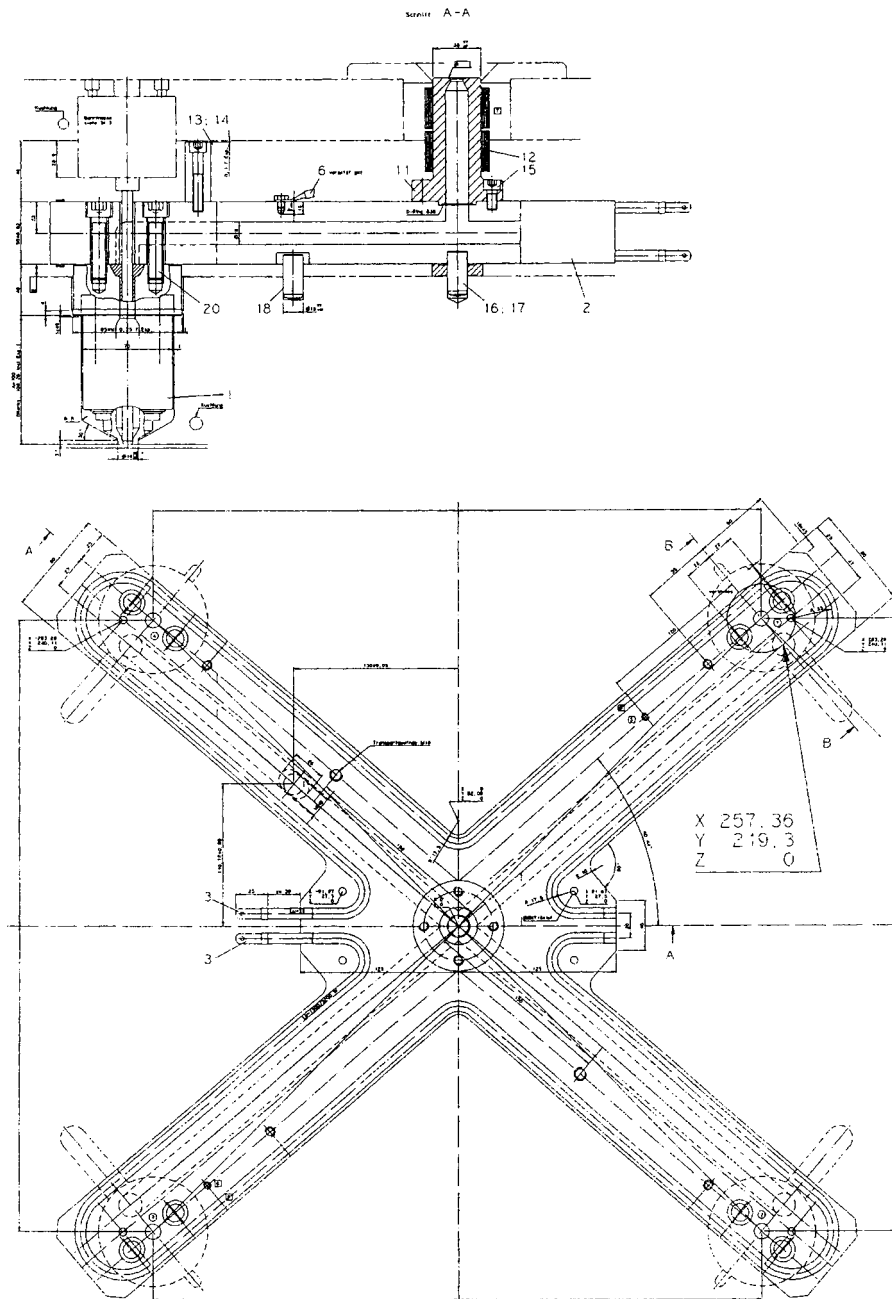


Figure 9.1 Mould HR system for a foamed PC telephone booth base [1]
 (Reproduced with permission from *Plastverarbeiter*, 1994, 45, 3, 70, Figure 3.
 © 1994, Hüthig Verlag)

As an example, this method was used to optimise the design of an external shield for a vehicle bumper made from a PC/PBT alloy (Xenoy). After the wall thickness had been reduced to an average of 2-2.5 mm (it had been 2.5-3.2 mm), and using a high-speed receiving robot, a 30% or so reduction in the cycle time was achieved [2]. An analysis of the uniformity of distribution of melt flow front during cavity filling using mould flow simulation software, showed a need to use ten injection points on the inside of the moulding.

The way the melt supply was done in practice is shown in **Figure 9.2a**. Since the bumper shield has to be varnished later, none of the typical HR vestiges like folds, sinks, tarnishing,

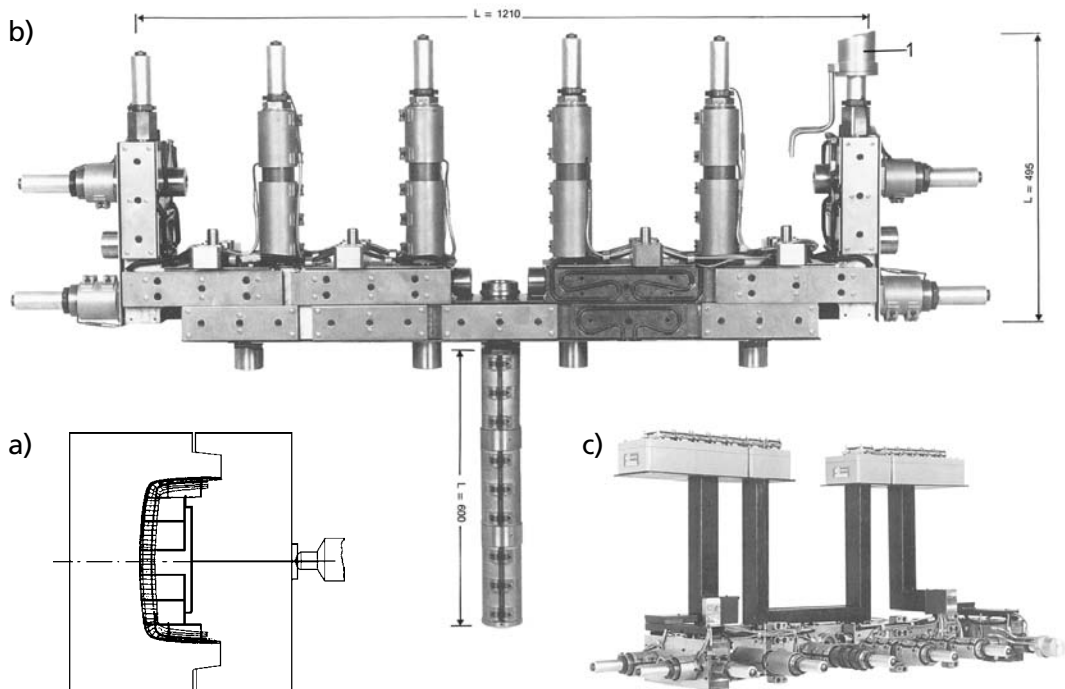


Figure 9.2 Optimised HR system in mould for thin-walled bumper shield made of PC/PBT alloy

a - diagram showing course of runners; b - three-arm manifold - cooled sprue bushing 1 fitted on one of the nozzles; c - complete manifold with cabling

(Reproduced with permission from Dynisco HotRunners)

etc., must be left on its outside. To achieve this a sprue bushing (1) had to be used with a very short conical cold sprue (see **Figure 9.2b**), fitted with a separate cooling circuit taking in the end of each nozzle.

The use of nozzles screwed into the manifold has enabled a one-piece manifold with fixed cabling to be created (see **Figure 9.2c**), which has greatly simplified mould installation and maintenance. The manifold is screened by reflective plates.

Moulds with HR of this type, with direct injection have replaced the earlier HR and CR system shown in **Figure 6.4**.

In the case of a single-cavity mould for moulding of a distribution board for the Volkswagen-Golf car, a design with nine HR nozzles was used (see **Figure 9.3a**), some of them being located at an angle to the mould axis [3].

The nozzle ends were adapted to the shape of the moulding. The manifold is equipped with 11 temperature regulation circuits. To compensate for the thermal expansion in a large manifold, nozzles set in intermediate blocks were used in this design.

A design of a different concept is shown in **Figure 9.4**. Eleven nozzles of different types are used to mould a distribution board made of PP and 30% talc. They are all located co-axially in the mould [3]. Three of them feature a side cut-off gating, and all the nozzles are of the partial-body type. The gates are in hard inserts with an individual cooling circuit.

As may be seen from the examples given, in many large moulds with deeply shaped cavities it is essential to use various types of very long nozzle. Elongated central nozzles are used in cases where the moulding ejection system is located in the fixed mould half.

Figure 9.5 shows a standard nozzle from a length range of 160-800 mm. The nozzle has replaceable ends with gate and with tip, which allows it to be used as an open nozzle (a), a tip nozzle (b) or an open nozzle with sprue gate (c). The nozzle has only two heating zones: in the front and the rear part of the nozzle. The central part, which has no contact with the mould, has such small heat losses that it does not require heating. A copper/beryllium alloy jacket between the casing and the heating elements improves heat distribution.

It should be pointed out that the steel ends with tip and nose are also set in copper/beryllium bushings. The flow channel diameter may be between 8 and 20 mm, depending on the result of rheological simulation.

Partial manifold standardisation is also an option. The modular manifold system described in Chapter 4 (see **Figure 4.65**) makes it easy to combine even large HR systems with nozzles of different types (see **Figure 9.6**).

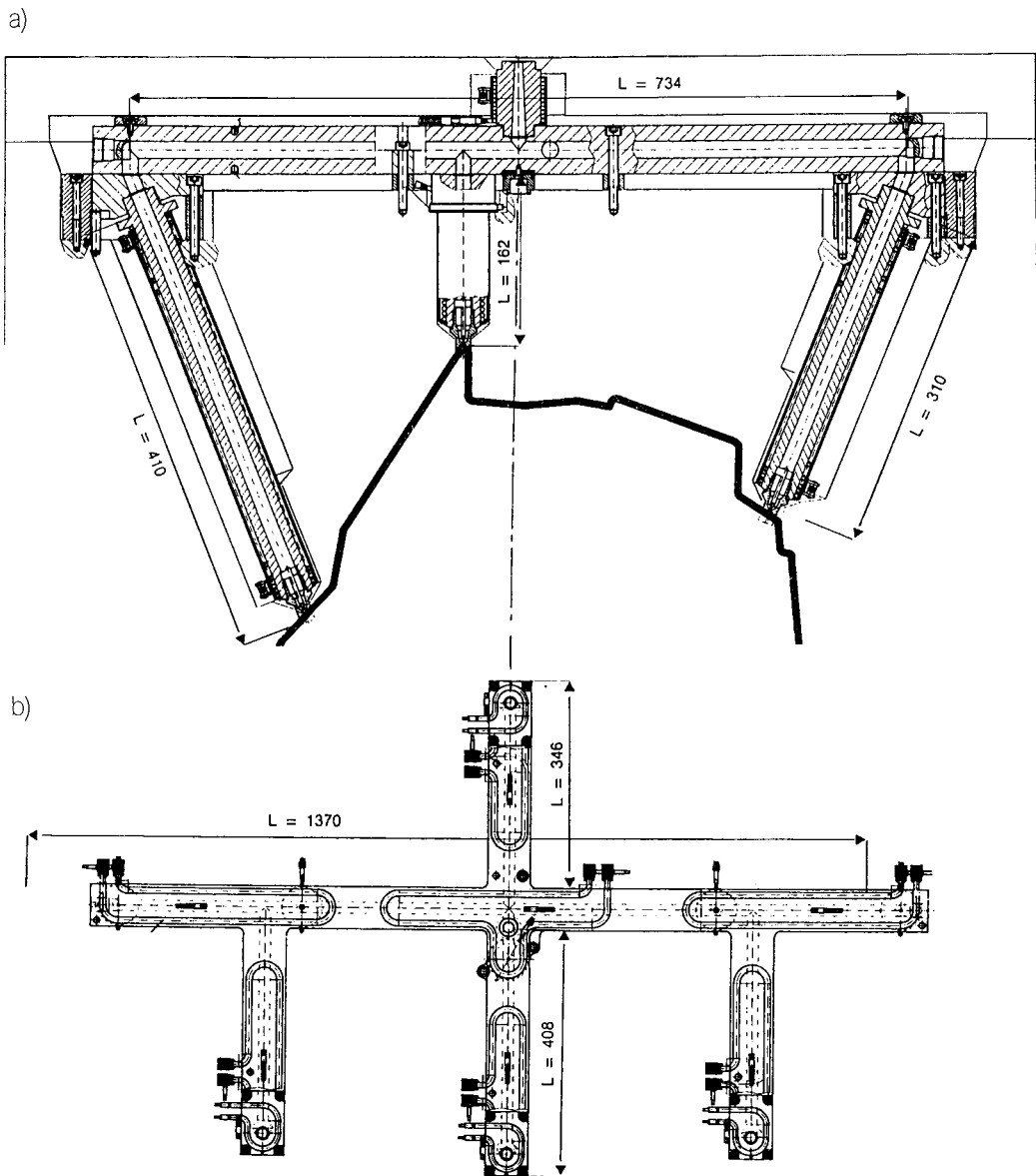


Figure 9.3 HR system in mould for vehicle distributor board using nozzles positioned at an angle

a - siting of nozzles; b - shape of manifold and distribution of tubular heaters embedded in copper

(Reproduced with permission from Dynisco HotRunners)

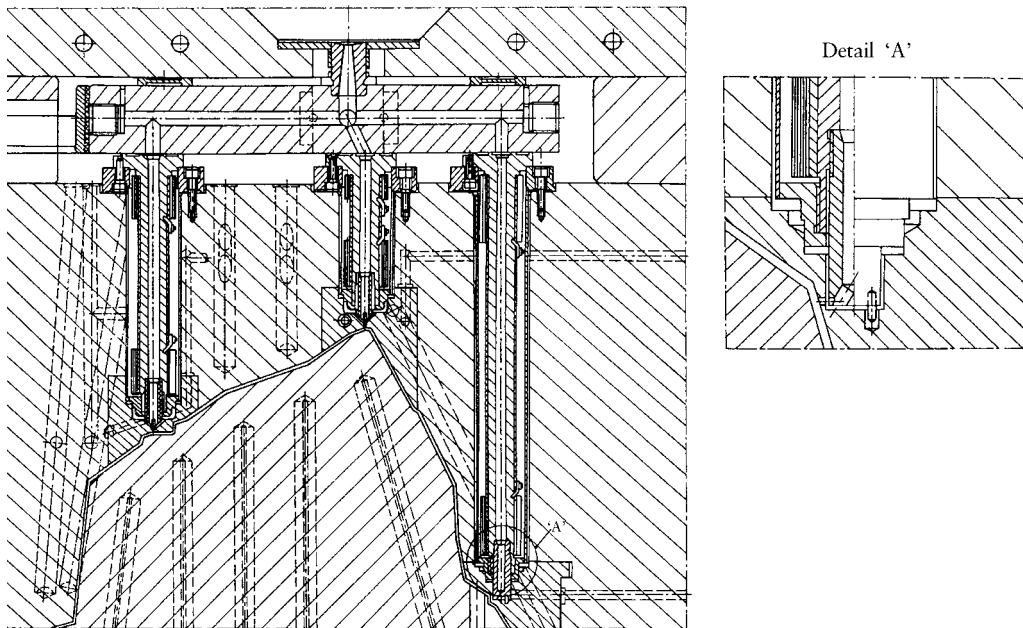


Figure 9.4 HR system in mould for distributor board with eleven type THERMOJECT-IV co-axial nozzles
(Reproduced with permission from PSG Plastic Group GmbH)

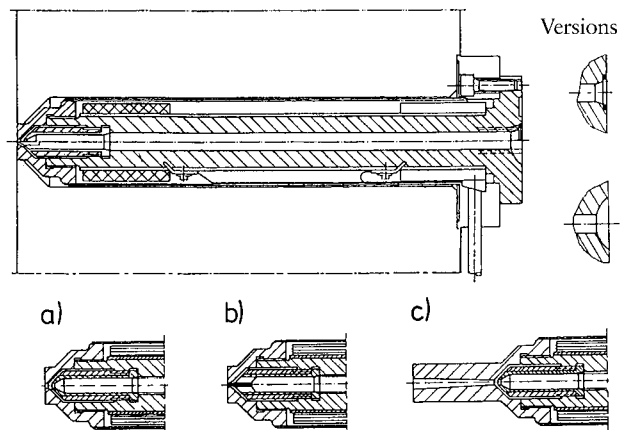


Figure 9.5 A 160-800 mm extended nozzle with replaceable tips
a - open nozzle; b - tip nozzle; c - open nozzle with sprue gate
(Reproduced with permission from PSG Plastic Group GmbH)

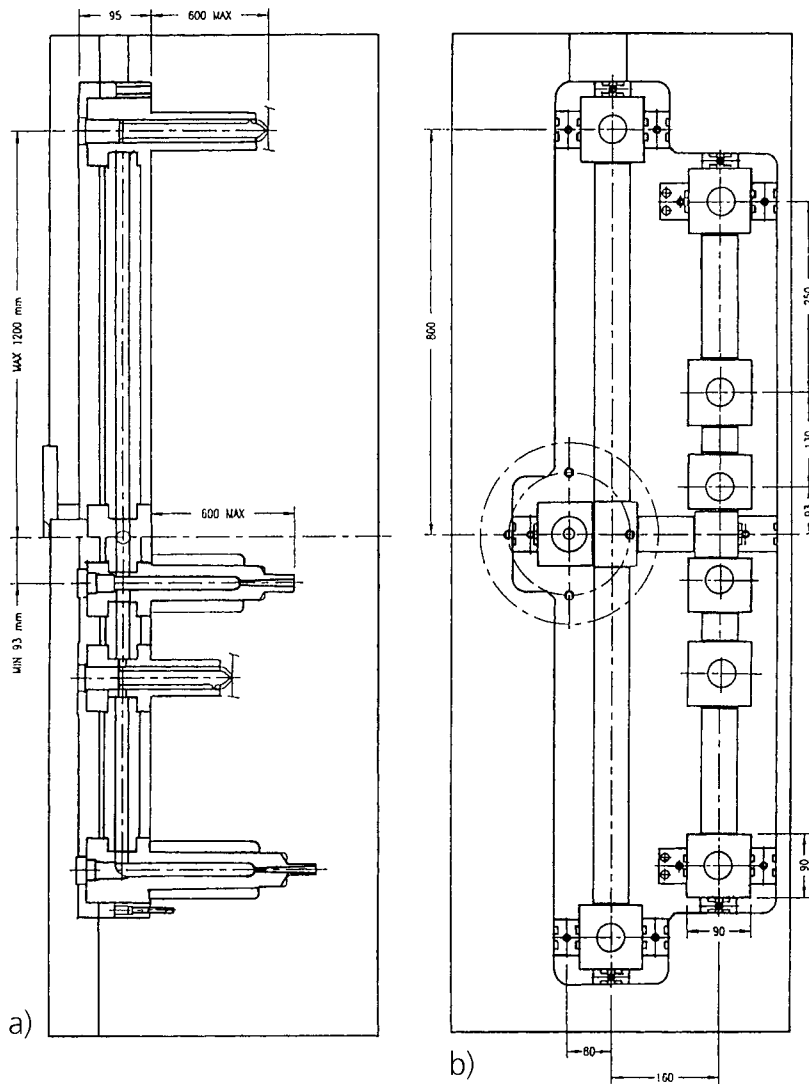


Figure 9.6 Modular manifolds for large moulds, made up of tubular elements

a - cross-section of manifold; b - view from above

(Reproduced with permission from the Rabourdin Group)

9.2 HR in moulds for small mouldings

The concept of a small moulding covers mouldings weighing from hundredths of a gram to several grams, for which very high dimensional precision and quality requirements are usually needed [4]. When large products are being produced, the mould design is chiefly governed by criteria to do with cavity filling and pressure loss in the HR system, whereas other requirements must be met for small products, because:

- very high requirements are set for gate selection and the vestige left behind when the sprue is broken or cut away;
- injection of a cold plug of melt into the cavity from the gate is not acceptable;
- the mould size may be determined by the minimum pitch between injection points;
- often the use of auxiliary cold runners cannot be avoided.

The nozzle pitch is governed by the diameter of the nozzle mounting and heating element. In a mould with in-line cavity layout (see **Figure 9.7**), nozzles with contiguous flat mountings of rectangular cross-section are used.

The development of heating equipment and miniaturisation of heating elements are enabling the nozzle axis pitch to be made smaller. Recently designed nozzles with a diameter of 10 mm, heated by a 230 V current, are beginning to compete with nozzles fitted with 5 V heaters.

Because of the typical areas of use - microelectronics, precision parts for mechanisms and parts for medical technology, etc., high temperature engineering plastics are increasingly used here, which makes it necessary to apply very restricted thermal injection parameters (even down to ± 2 °C). In such instances it is still best to use low voltage heaters with a rectilinear temperature characteristic.

Since the critical point for many plastics is the time spent by the melt under a thermal load, attention should also be given to the combined time spent in the HR and the injection machine cylinder (see Chapter 3.1). When small HR moulds are used, one major problem is selection of an injection machine small enough not to be operating below the lower limit of the machine's nominal injection capacity ($0.25 V_{nom}$) without an unnecessary increase in the multiplicity of the mould.

Machine designs have recently appeared in which a multiple nozzle with valve pins, typical of an HR system, was used as an injection machine nozzle [5, 6]. The mould itself does not then have a gating system apart from the gates in the cavities.

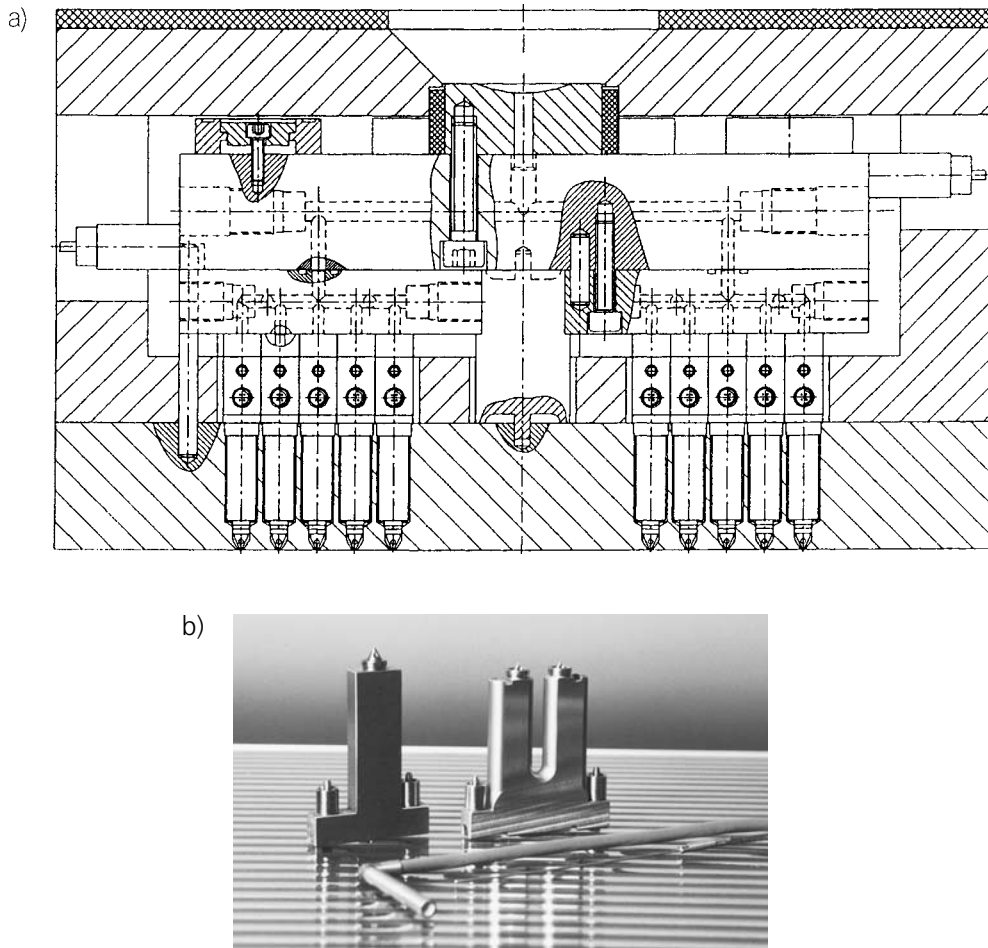


Figure 9.7 Multi-cavity mould with in-line layout of nozzles with flat mounting
a - method of nozzle installation; b - single and double nozzles
(Reproduced with permission from Günther Heißkanaltechnik GmbH)

9.3 HR in moulds for thin-walled tubular mouldings

Thin-walled tubular mouldings come in the shape of pipettes, syringe components, pen cartridges and so on.

These products may be moulded using an HR and CR system with tunnel sprue. This system, however, is not economic for mass production. Consequently an HR system with

side gating nozzles is normally used (see **Figure 4.50**). These nozzles have the drawback that a cold plug occurs, lowering the quality of thin-walled mouldings. A system with a tip nozzle for side injection has been developed by Mold-Masters to eliminate this defect.

This system is illustrated using the example of a mould for a pipette, with quadruple nozzles (see **Figure 9.8a**).

In this system, the tip (2) is introduced into the gate by dividing the cavity into sections (4) and (5). The tip is aligned in the gate using a bushing (3), and thermal expansion of the nozzle takes place towards the injection machine cylinder. The cylinder thrust is transferred by the insert 6 which is telescopically immersed in the nozzle, allowing the nozzle to extend freely in length.

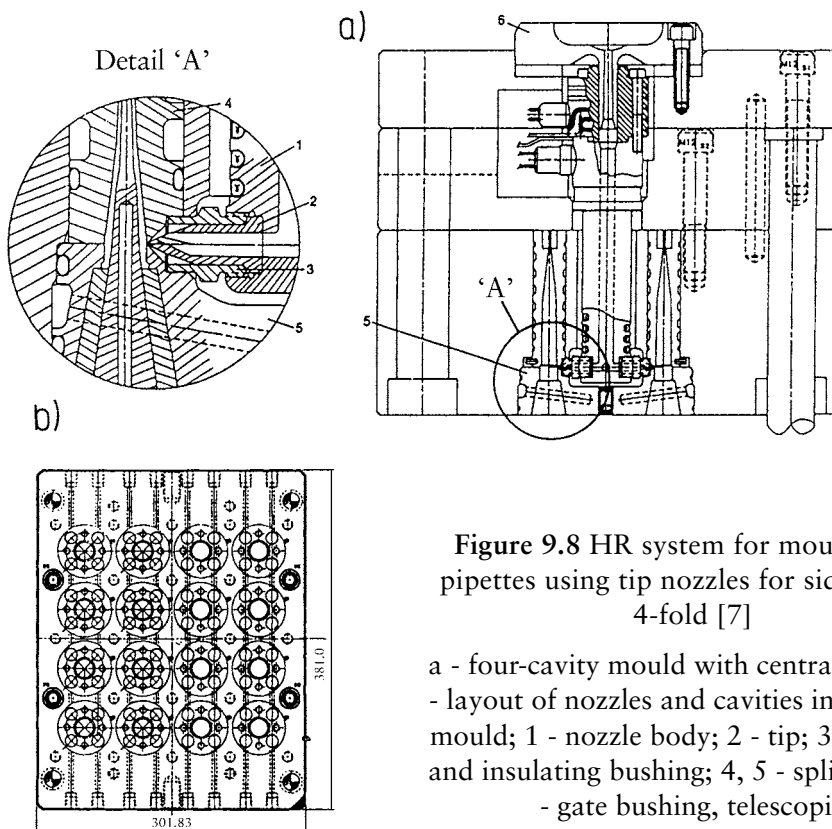


Figure 9.8 HR system for moulding of pipettes using tip nozzles for side gating, 4-fold [7]

a - four-cavity mould with central nozzle; b - layout of nozzles and cavities in 64-cavity mould; 1 - nozzle body; 2 - tip; 3 - aligning and insulating bushing; 4, 5 - split cavity; 6 - gate bushing, telescopic

(Reproduced with permission from *Injection Moulding International*, 1997, 2, 6/7, 58, Figure 8. © 1997, Abby Communications, Inc.)

The nozzle is installed in the mould in the following sequence:

- introduction of nozzle casing (1) into the mould;
- screwing in of nozzle ends (2) and (3);
- fastening of female mould insert (5).

The nozzle meets the demands associated with processing of all semi-crystalline plastics, as well as CAB, PMMA, PPO, PVC, TPU and styrene plastics.

Figure 9.8b shows the nozzle and cavity distribution in a 64-cavity mould (16 x 4).

9.4 HR in stack moulds

Stack moulds are increasingly being used in mass production of products, and especially of consumer goods, e.g., audio cassette boxes, laboratory glassware, shallow products such as containers, trays, etc., as they double the number of cavities in the mould when an injection machine of a similar closure force is used. The injection cycle is slightly extended, but when selecting the machine a suitably large capacity and injection rate and plasticisation capacity must be borne in mind. A stack mould is also taller, and needs a larger opening movement. Because of the level of complexity, the cost of a stack mould roughly corresponds to at least the price of two ordinary moulds.

The main element in each stack mould is the central plate containing the HR manifold and nozzles and the cavities. One difficult problem which is crucial to the design of the HR system is the way the melt is to be fed to the manifold.

The simplest method is based on an injection cylinder located perpendicular to the shut-off system feeding melt from the side to the manifold channel (see **Figure 9.9**). Because of the need to transfer the nozzle thrust during injection, the manifold must rest on a support pad.

However, angled injection moulding machines, and especially large ones, make up only a tiny fraction of the injection machines in use.

The manifolds most frequently used have a very long heated sprue bushing located on the mould axis and operating on the principle illustrated in **Figure 9.10**. As can be seen, the melt flowing out of the sprue bushing may, when the mould is taken away from the injection machine nozzle, get into the ejector plate space.

In the diagram of the mould shown in **Figure 9.11a**, two sprue bushings meet each other in the mould parting line.

For design reasons it is difficult to use shut-off nozzles in stack moulds. Problems arise from the installation in the moulds of cylinders, which by nature are of substantial height.

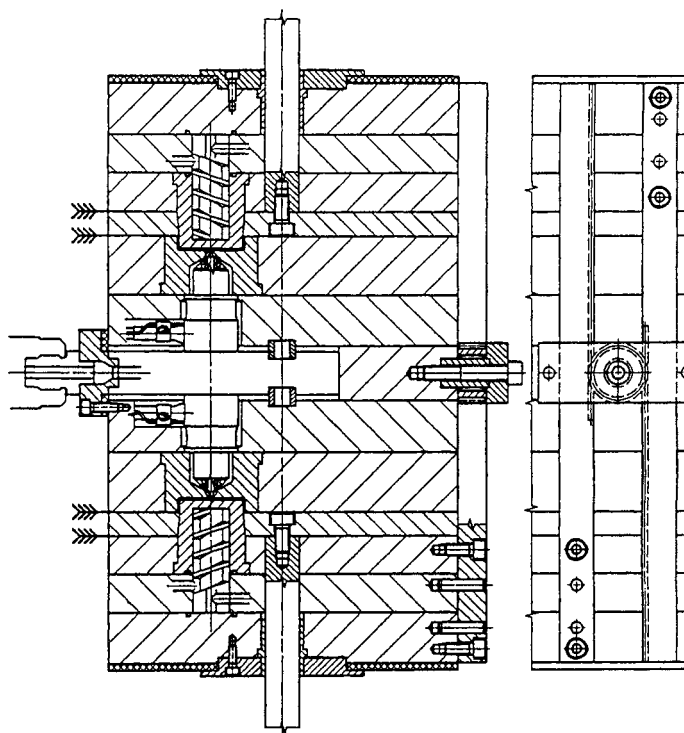


Figure 9.9 Stack mould with HR manifold adapted to work with angle injection machine
(Reproduced with permission from Arburg)

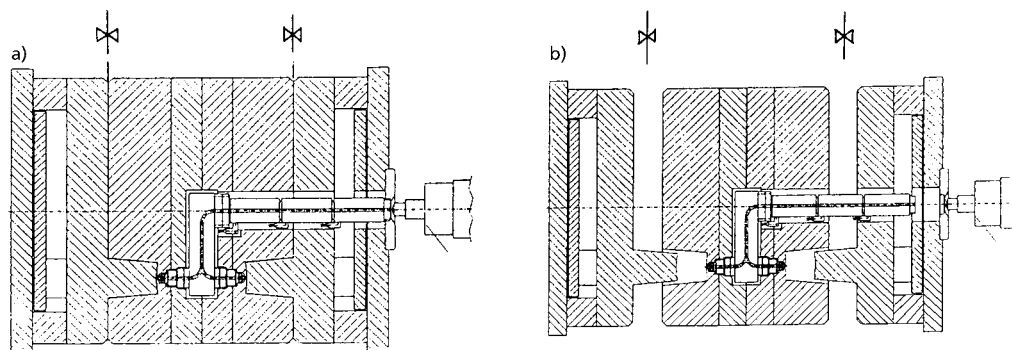


Figure 9.10 Diagram showing the operation of a stack mould with axial central melt flow to manifold [8]. a - closed manifold; b - open manifold

(Reproduced with permission from G. Bagusch and U. Kolter, *Kunststoffe*, 1995, 85, 6, 759, Figure 2. © 1995, Carl Hanser Verlag)

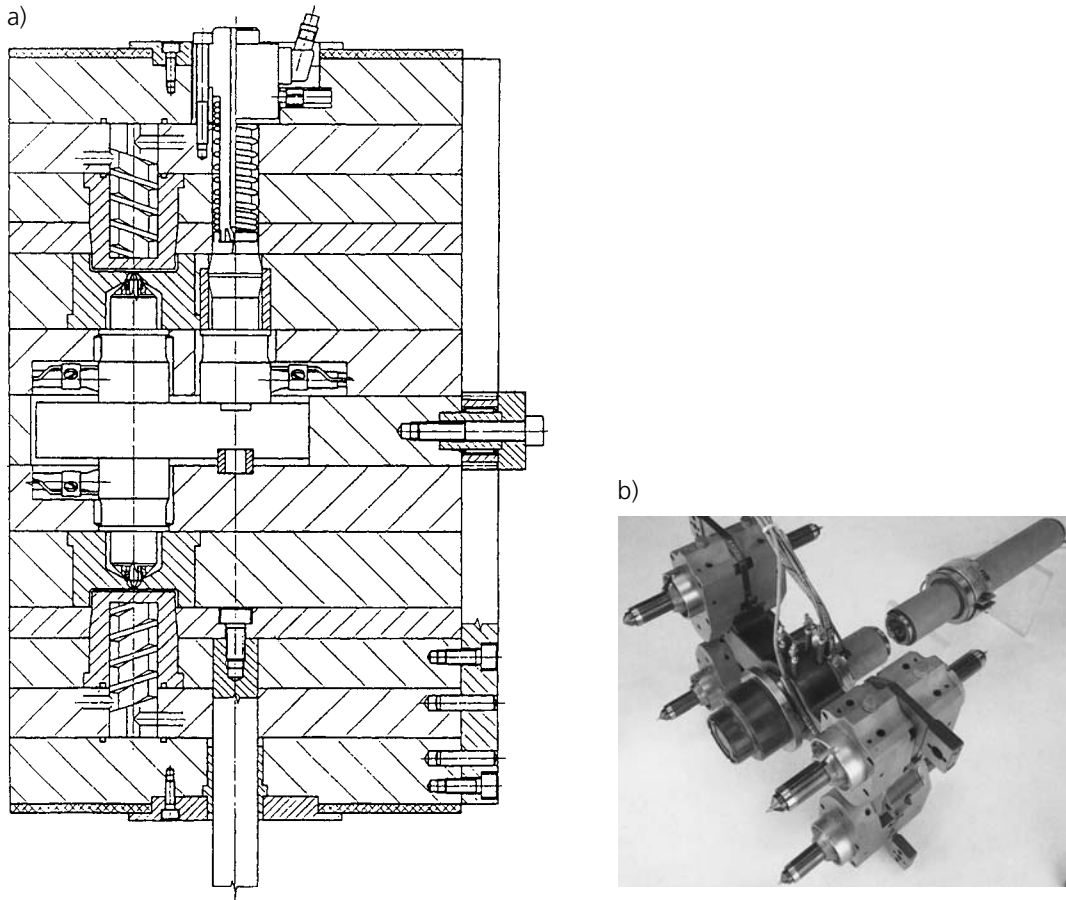


Figure 9.11 Stack mould with split sprue bushing

a - diagram of mould; b - view of manifold

(Reproduced with permission from Arburg)

Figure 9.12 shows a 16-cavity stack mould with HR (of an older type) for the moulding of a bottle base of HDPE. Shut-off nozzles with pneumatic cylinders located to the side of the nozzles were used for the moulding. The manifold is also fed with melt via two shut-off nozzles meeting on the parting line. The standard sprue bushing used would get in the way of falling mouldings, and would require a greater cavity spacing. During injection, the feed nozzles open first, then the nozzles to the cavities, and this might be in a set sequence. The stripper plate drive is made up of a system of racks and gear wheels located on both sides of the central part of the mould.

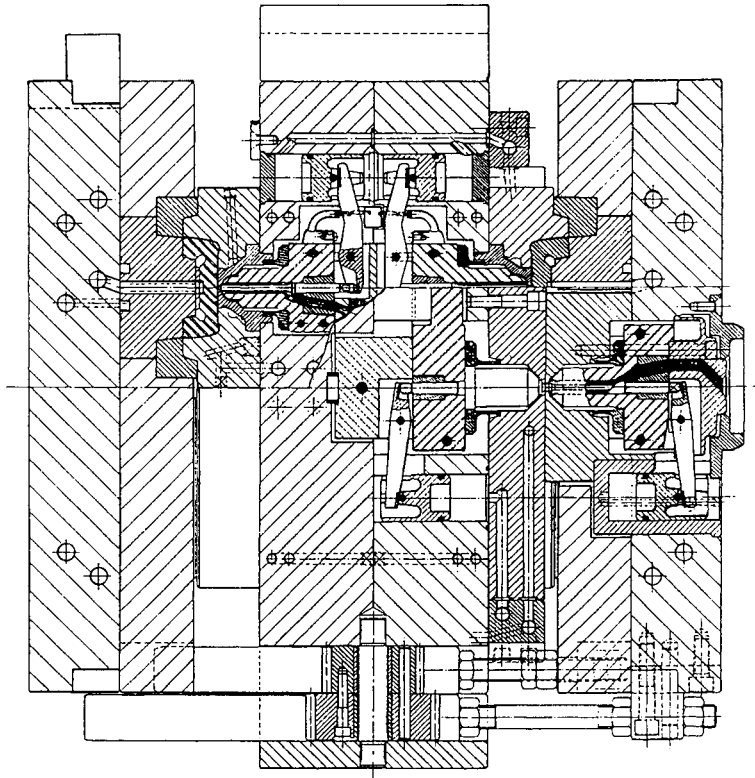


Figure 9.12 Fragment of a 16-cavity stack mould for a bottle base using pneumatically-operated shut-off nozzles
(Reproduced with permission from Mold-Masters)

A simple stack mould design is provided by a shut-off nozzle with an annular cylinder (**Figure 9.13**). An example of a very compact manifold design with shut-off nozzles and an integrated drive combined with the nozzle casing is illustrated in **Figure 4.43**.

In view of the advantages of HR systems with internal heating (described in Chapter 4.2.2), they are also used in stack moulds. Of particular importance here is the potential to reduce the mould height. **Figure 9.14** shows a fragment of a stack mould with a long sprue bushing, internally-heated manifold and two-way torpedo. A characteristic feature of this system is that the manifold is the mould plate.

Serious problems are encountered in the design of stack moulds with two cavities (1+1), since in this instance it is not possible to use a central melt feed to the manifold via a sprue bushing. It is then necessary to design a system that delivers the melt from the side of the manifold.

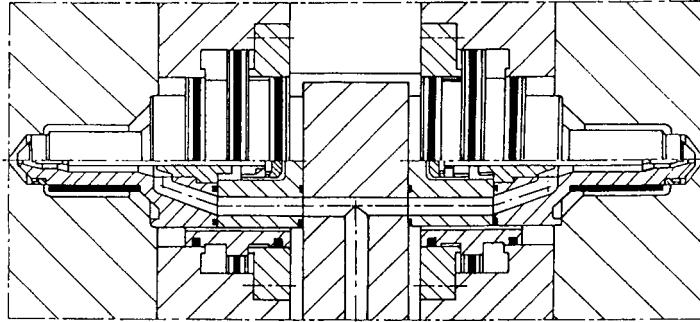


Figure 9.13 Location of shut-off nozzles with ring cylinder in stack mould
(Reproduced with permission from PSG Plastic Group GmbH)

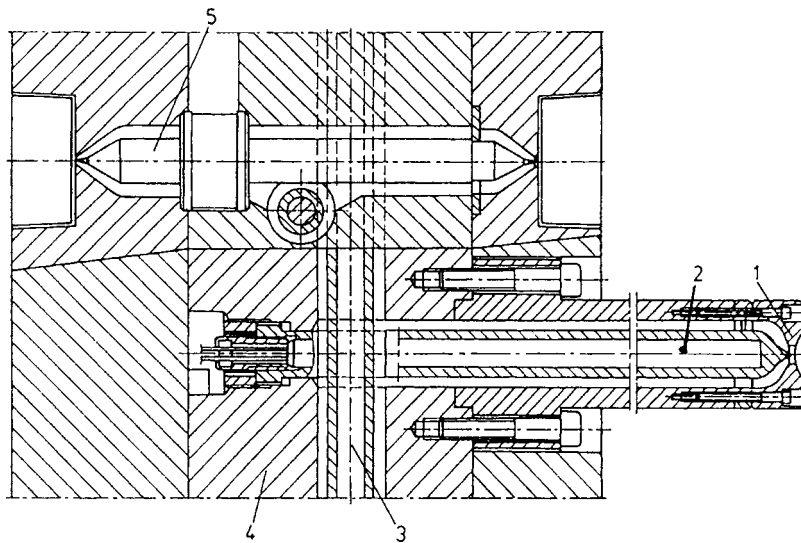


Figure 9.14 Example of use of an HR system with internal heating in a stack mould
1 - sprue bushing; 2, 3 - cartridge heaters; 4 - manifold; 5 - two-way torpedo
(Reproduced with permission from D-M-E Belgium)

Figure 9.15 shows different versions of the side method of melt delivery. Design (a) requires a strictly defined admissible mould opening path. In design (b), two shut-off nozzles make up a side branch. In case (c), there is a space (intermediate chamber) between the side feed nozzles which is filled with melt. The small plate remaining there each time is removed by ejectors. This design makes it easier to seal the nozzle contact.

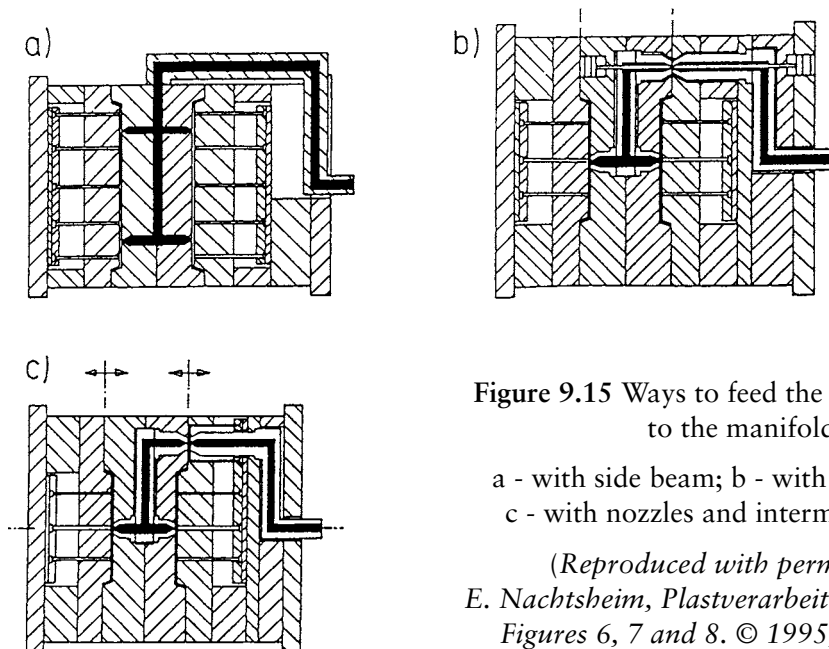


Figure 9.15 Ways to feed the melt from the side to the manifold [9]

a - with side beam; b - with shut-off nozzles;
c - with nozzles and intermediate chamber

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E. Nachtsheim, *Plastverarbeiter*, 1995, 46, 6, 50,
Figures 6, 7 and 8. © 1995, Hüthig Verlag)

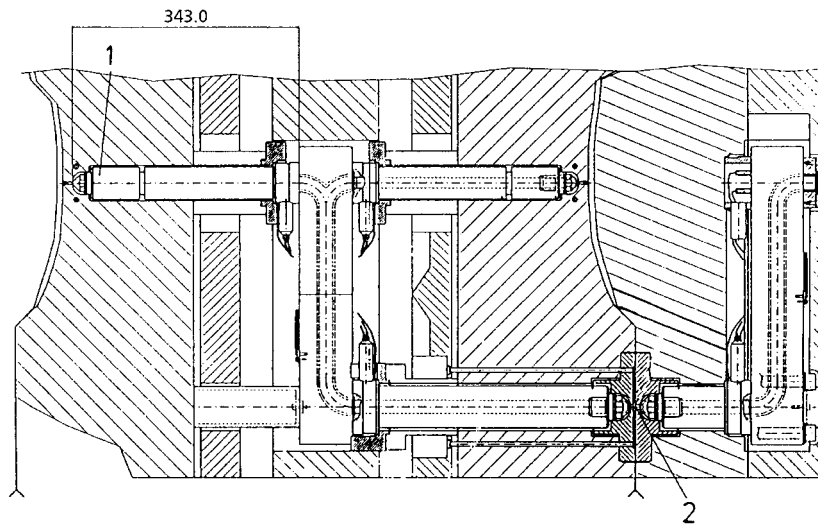


Figure 9.16 Example of design of HR system for two-cavity mould (1 + 1) [8]
1 - nozzle; 2 - flat, cavity, working as an insulation between nozzles

(Reproduced with permission from G. Bagusch and U. Kolter, *Kunststoffe*, 1995, 85,
6, 760, Figure 6. © 1995, Carl Hanser Verlag)

Figure 9.16 illustrates a solution to this problem for a two-cavity mould for vehicle interior components weighing 1.2 kg. The HR system is made up of two separable units:

- HR manifold in the fixed part of the mould with feed nozzle situated in the external zone of the mould (operating principle as shown in Figure 9.15c);
- manifold in central section of mould with feed nozzle and six open nozzles (2 x 3) with a short sprue gate.

A completely different concept of an HR system in a stack mould (Figure 9.17) was used to mould two parts of a pallet from PP (6.3 kg and 2.3 kg). There are two manifolds in this mould

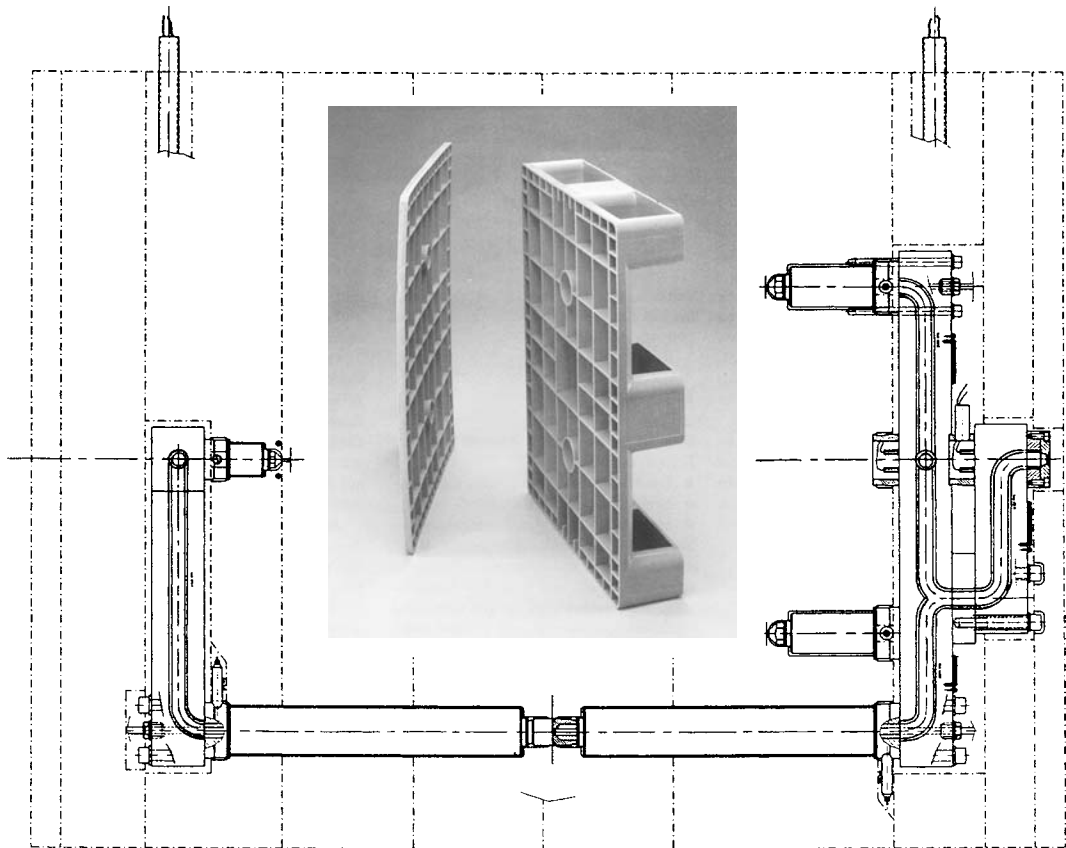


Figure 9.17 HR system with two manifolds in stack mould

(Reproduced with permission from Unitemp SA)

(6 and 2 injection points), located in the fixed and moving halves of the mould. The manifolds are linked by two long shut-off nozzles located at the side of the mould. This enables the HR system to be detached without any risk of melt leakage when the mould is opened.

9.5 Moulds with HR in long cores

Use of an HR system makes it possible to deliver the melt from the inside of the product, regardless of the core length. One restriction is the diameter of the core, since a space is needed to locate effective cooling between the nozzle and the shaping surface of the core. In these applications, nozzles with low voltage heating are slightly preferable because of the low external surface temperature of the nozzle.

Figure 9.18 shows a fragment of a multi-cavity mould for a feeder made of PP. The long nozzle (1) is located in a bushing (2) with a double screw cooling channel leading right up

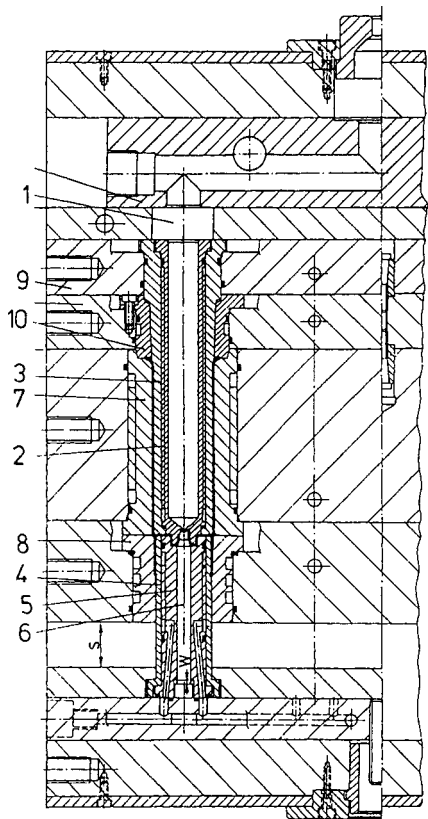


Figure 9.18 Example of location of HR nozzle in long core

- 1 - nozzle; 2 - cooling channel; 3 - core;
- 4, 5, 6 - moveable shaping cores;
- 7, 8 - cavities; 9 - stripper plate;
- 10 - stripper ring

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to the face of the core (3). The ejector system is also interesting. In the first phase of mould opening with travel s , the pack of cores (4), (5), (6) set in the ejector plates remains still (connected to the fixed half of the mould), resulting in ejection of the moulding from the cavities (7), (8) which allows it to remain on the core (3). The core (6) makes an additional movement w allowing the moulding to be released. In the final phase of opening, there is ejection of the moulding from the core (3) using the stripper plate (9) via the insert (10).

Figure 9.19 shows a fragment of a four-cavity mould for a turn button. As before, the long nozzle is located in a bushing with a double screw cooling channel, inside the unscrewing mechanism. Unscrewing takes place by means of a central barrel and a gear transmission.

Figure 9.20 illustrates a fragment of a mould for a cover with hole and internal screw thread. The nozzle is located inside a bushing with cooling channel, and the bushing is inside the core shaping the hole in the moulding. The moulding is injected via CR. Unscrewing takes place before the mould is opened using a gear transmission.

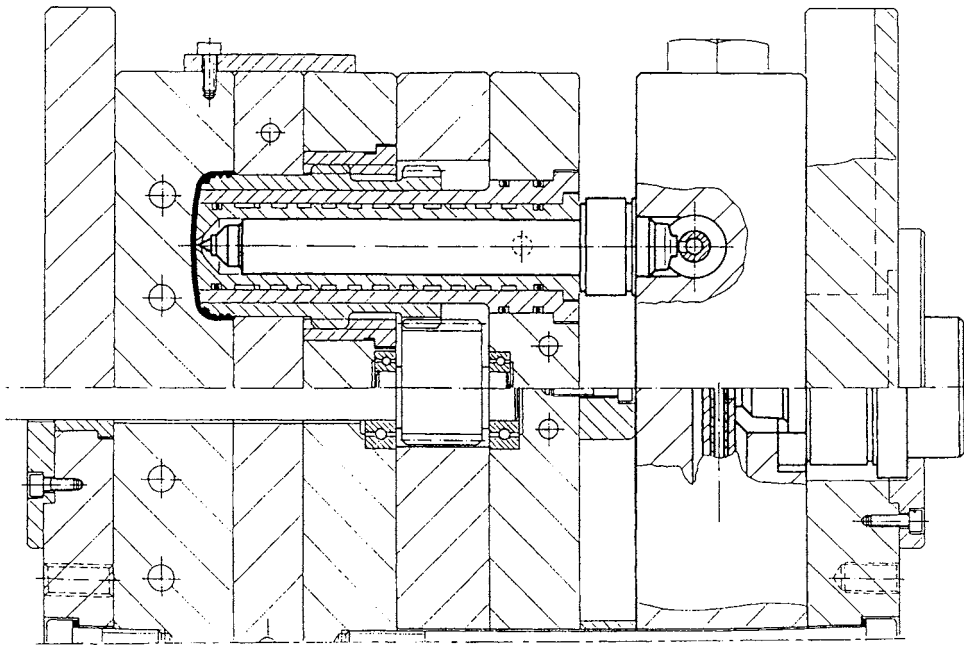


Figure 9.19 Example of location of tip nozzle inside unscrewing male mould
(Reproduced with permission from Günther Heißkanaltechnik GmbH)

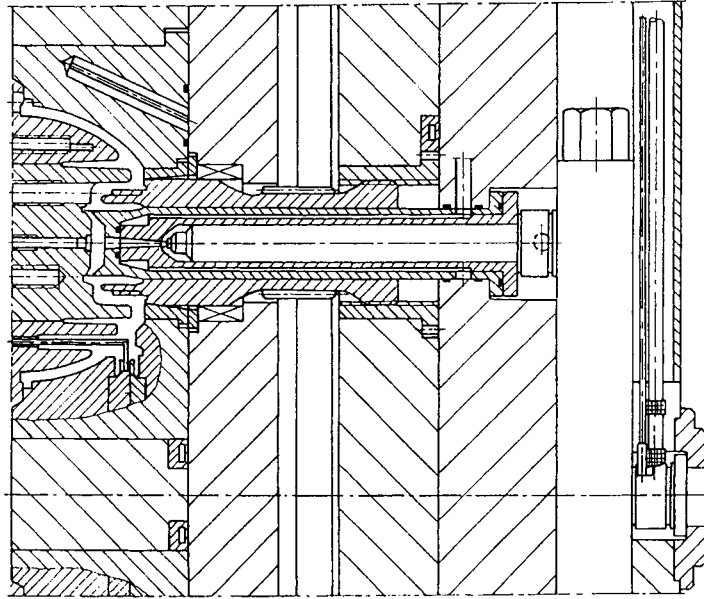


Figure 9.20 Example of location of open nozzle with sprue gate inside unscrewable core
(Reproduced with permission from Günther Heißkanaltechnik GmbH)

9.6 Moulds with HR for moulding without a weld line

This group of nozzles includes nozzles with a side film gate which is cut-off in the closed mould after the end of the holding phase. Because the melt is relatively soft at the moment of truncation, the cutting vestige is almost invisible.

A shut-off nozzle (see **Figure 9.21**) is intended for injection via a hole in the moulding. In this original design, the standard valve pin is replaced by a pin with a piston end, and the operating sequence of the cylinder is reversed. Prior to injection, the pin is introduced into the hole in the cavity, thus forming a film gate. After the holding phase, the pin is withdrawn, causing the gate to be cut off and the nozzle closed. The frozen tubular sprue is introduced into the nozzle and then melted. Using the pin end, a hole is made in the moulding. In the standard version, the pin is 3.2 or 4.75 mm in diameter.

Nozzles of the design shown in **Figure 9.22** are made to order for a specific product, with a hole 7-60 mm in diameter. A nozzle comprises three parts:

- a casing (1) with external heating, fastened to the mould plate;

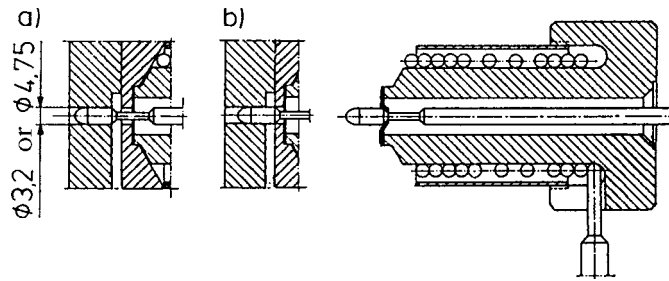


Figure 9.21 Nozzle shut-off by pin forming hole in moulding
a - pin position during injection; b - after end of holding period, pin is withdrawn and gate is cut off

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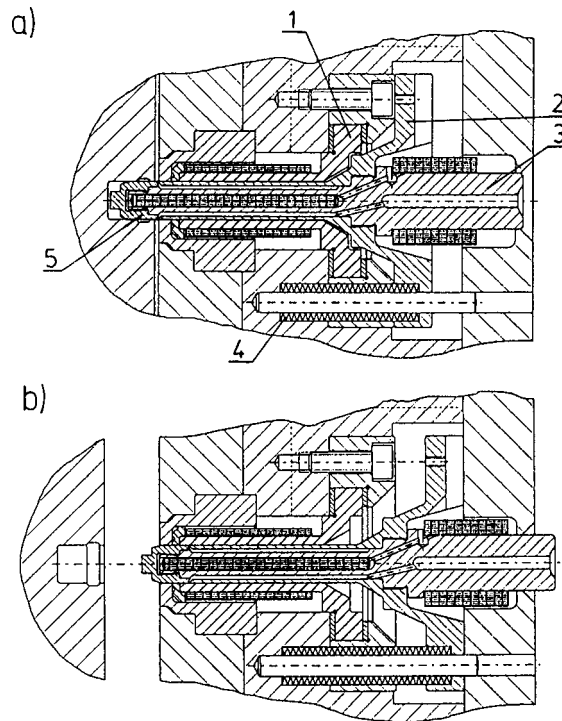


Figure 9.22 Shut-off nozzle with side film gate for compact discs
a - open gate in closed mould; b - closed gate in open mould; 1 - casing; 2 - moveable bushing; 3 - mandrel; 4 - spring; 5 - shaping pin

(Reproduced with permission from Xintech Systems AG)

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- a bushing (2) set so that it slides inside the casing (1), and driven by springs (4);
- a mandrel (3) screwed into the bushing (2), with external heating of the rear section and internal heating in the front section. At the end of the mandrel is a shaping pin 5.

The melt flows through the central channel in the mandrel (3), then through three slanting channels, the annular channel between the mandrel (3) and the bushing (2) and through a film (ring) gate between the bushing (2) and the pin (5).

After the end of the holding phase and removal of the injection machine nozzle, the springs (4) cause the bushing (2) with mandrel (3) to withdraw, and the gate is then cut off. The hole in the moulding is shaped using the pin (5).

The nozzle shown in **Figure 9.22** is used to mould compact discs. The ring gate guarantees optimum filling and the least possible shape deviation.

Figure 9.23 shows a nozzle adapted to film injection into the outside edge of the product, a credit card containing a processor. In this design, the cross-section of the bushing (2) and the pin (5) is square in shape.

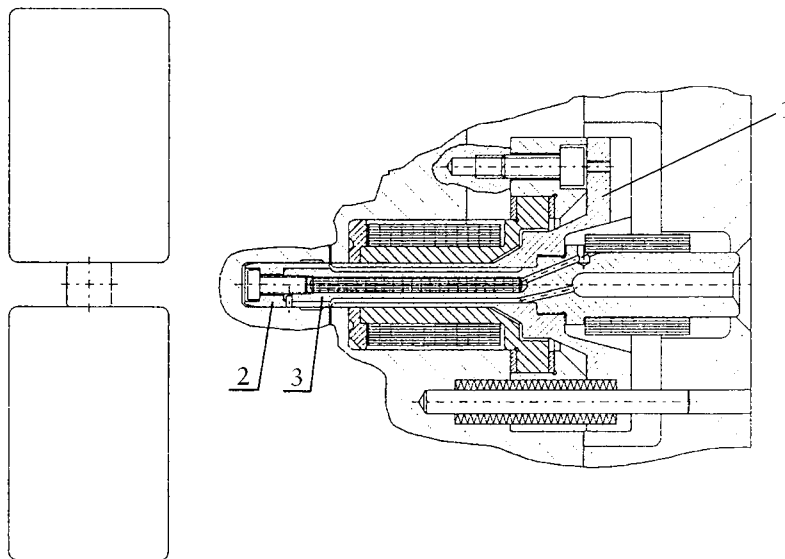


Figure 9.23 Shut-off nozzle with side film gate for credit cards

1 - moveable bushing; 2 - shaping pin; 3 - mandrel

(Reproduced with permission from Xintech Systems AG)

The nozzle for film injection is also used to mould a roller ring with ball bearing (Figure 9.24). In this design the whole nozzle is pushed out of the cavity under spring pressure, causing the gate to be cut off. The arrow on the figure indicates the melt compression zone causing mixing of the melt streams from the three flow channels. This, coupled with the use of a film gate all round the periphery, prevents the occurrence of a weld line in the moulding. The Xintech designs in Figures 9.22, 9.23 and 9.24 are patented.

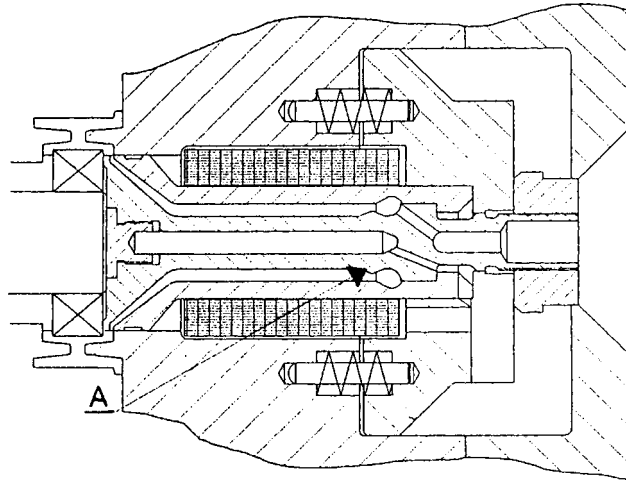


Figure 9.24 Shut-off nozzle with film gate for roller ring
A - mixing zone

(Reproduced with permission from Xintech Systems AG)

9.7 Non-standard methods of melt distribution in HR moulds

The need to use non-standard HR designs must always be carefully thought through; in many cases, however, it may in practice lead to a simplification of the mould design.

In the traditional design, a melt flow that is not along the axis of a single-cavity mould requires the use of a manifold (see Figure 4.61). This will, however, increase both the cost and the height of the mould.

Moving the central nozzle away from the mould axis causes an asymmetrical mould structure, asymmetrical loading of the ejection system and an asymmetrical stress distribution in the injection machine columns. The effective mould clamping force is diminished.

Figure 9.25 shows an example of a central nozzle for cold runner injection set at an angle of 17 degrees. The two ends of the nozzle were chamfered, and a new recess to align the injection machine nozzle was created. The nozzle exit channel, initially a 6 degree taper, was widened on one side towards the opening, giving it a gradient of 17 degrees. The nozzle was protected against rotation by a locating pin.

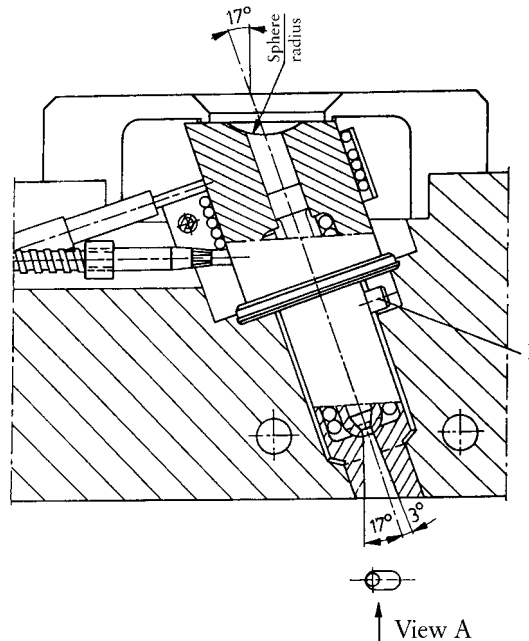


Figure 9.25 Central nozzle positioned at an angle
1 - locating pin

(Reproduced with permission from Dynisco HotRunners)

It should, however, be emphasised that only some nozzles will ‘withstand’ an inclined loading by the injection machine cylinder clamping force, and such an application will require acceptance on the part of the nozzle manufacturer.

Long nozzles positioned obliquely in a large mould are shown in Figure 9.3, and, as an alternative, use of nozzles with side gate (see Figure 9.4).

With internal heating it is also possible to use nozzles with a heated internal torpedo for non-standard methods of melt distribution (Figure 9.26). In case (a) the cavities are

clamped by side taper keys to withstand the oblique clamp of the nozzles. Version (b) is similar to the designs used in stack moulds. In this mould, the transverse run of the cavities was caused by the length of the mouldings and the need to use hydraulic units to withdraw the cores. In design (c), the oblique position of the moulding and the similar position of the HR nozzles was governed by the direction of disengagement of the moulding walls (masking screen) during opening of the mould.

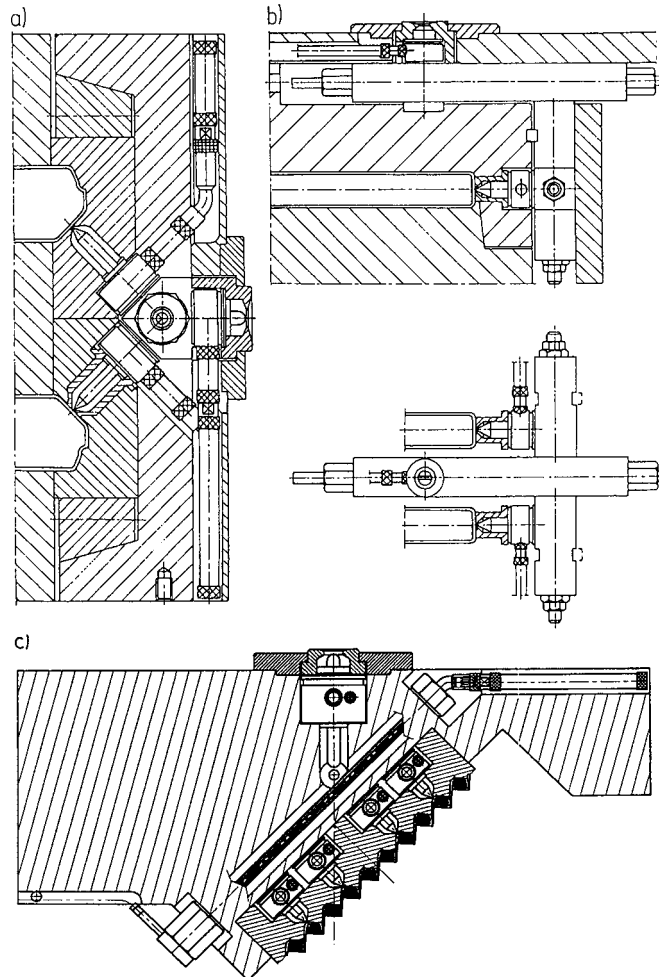


Figure 9.26 Examples of unconventional possibilities for HR use
a - injection onto slanting surface; b - frontal injection in parting line;
c - multiple angled injection

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9.8 Modular units for moulds with HR nozzles

Mass production of certain products, for example caps for packages, bottle preforms, etc., have created a demand for modular mould units.

A modular mould unit for a cap, comprising a set as follows: HR nozzle, cavity, ejector bushing and core complete with cooling system, is shown in **Figure 9.27**. The special design of the temperature regulation channels has trebled their surface area (in relation to the conventional product), and a turbulent coolant flow has been arranged, giving very intensive cooling and a shortening of the cycle time. The parts of the set are made of stainless steel and coated in titanium nitride, providing resistance to corrosion and abrasion. The nozzle tip is made of tungsten carbide.

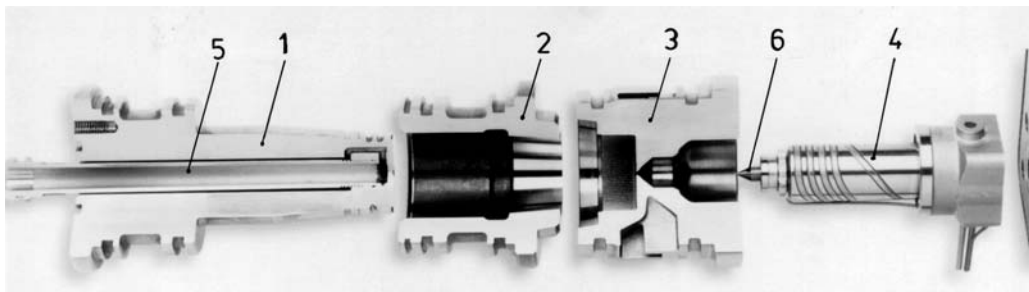


Figure 9.27 Modular unit for mould for package closure caps

1 - core; 2 - stripper bushing; 3 - cavity; 4 - HR nozzle; 5 - cooling insert;
6 - tungsten nozzle tip

(Reproduced with permission from Mold-Masters; US Patent 5,443,381 [10])

A module for preform production (see **Figure 9.28**) comprises an HR shut-off nozzle, a cavity bottom insert with insulation chamber and gate and split segments shaping the thread. The special design of the temperature regulation channels (with a zigzag direction) allows intensive cooling of the thick-walled end of the preform with thread, preventing the PET from crystallising. All the shaping parts of the module are made of stainless steel because of the aggressive action of PET decomposition products. The nozzle valve pin guide is made of tungsten carbide. The module manufacturer simultaneously supplies a complete HR system.

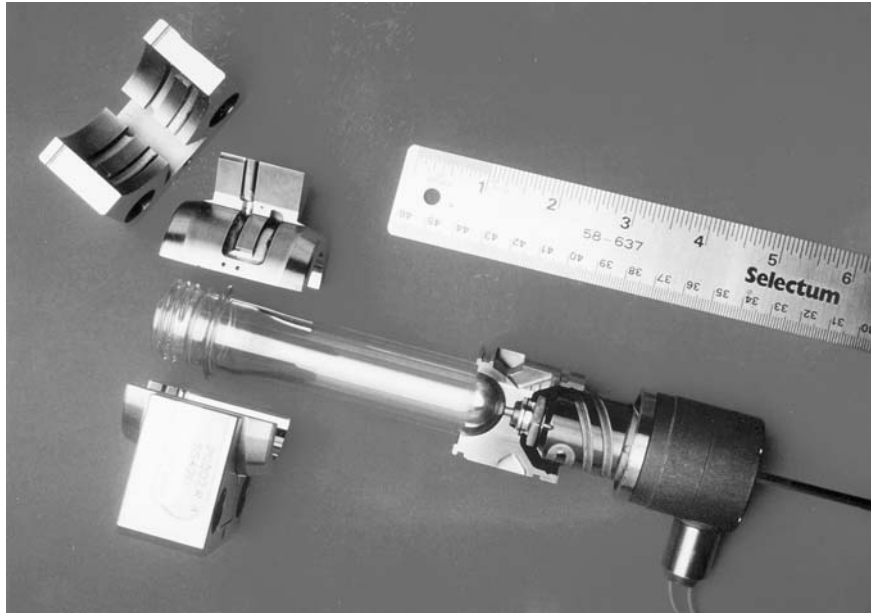


Figure 9.30 Modular unit for mould for PET bottle preforms
(Reproduced with permission from Mold-Masters; US Patent 5,599,567 [11])

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10 Use of Moulds with HR

HR systems are vulnerable to damage. The additional requirements relating to the design of other functional systems and automated operation raise the level of responsibility for proper management of the moulds. This relates to:

- mould inspection and trial;
- preparing the mould for operation;
- start-up;
- routine operation and servicing;
- maintenance and storage;
- observance of work safety principles.

HR moulds are for use in mass production, i.e., continuous operation, and the high cost of any downtime must be considered. Only highly-skilled staff may be involved in work with these kinds of moulds. Supervisory staff must be familiar with the mould documentation to be able to identify the HR system used and adapt process instructions to it. This also means that when a ready-made mould is purchased, the contract must insist on supply of full technical documentation and process instructions for use.

10.1 Mould acceptance

From the purchaser's point of view, checking of the mould carried out on his own injection moulding machine is best. If mould inspection takes place at the manufacturers, however, a few basic principles which are of particular importance for HR moulds need to be applied to avoid problems later on:

- the mould set-up, all connections and preparatory operations should be carried out in the presence of the person inspecting the mould;
- the course of operations, parameter settings, subsequent optimising alterations and so on should be explained and noted;

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- if not in the trial record already, a note should be made of:
 - the type of injection machine and its integral equipment, e.g., nozzle type and process fittings (thermostat, heat regulator, robot, moulding removal control equipment, etc.);
 - the type, name and manufacturer of the material and the additives used - if this is not a material supplied by the mould purchaser;
 - the process parameters in the sequence of optimising adjustments performed;
 - the time taken for the HR system to heat up to operating temperature;
- during successive cycles, observations should be made of the uniformity of the flash from individual nozzles (whether the diameter is the same);
- check:
 - the size of the sprues - they should be of the same diameter and height;
 - uniformity of filling of all cavities;
- while trials are going on, check for the appearance of:
 - stringing of the moulding from the nozzle;
 - spontaneous gate drooling;
 - drooling from the sprue bushing;
 - non-uniformity of movement of the valve pins;
- when good mouldings have been achieved and after at least five cycles, samples should be taken for dimensional checks (according to DIN 16 901 [1], after 16 hours);
- request a colour change from dark to light, and when the mould has cooled off completely, repeat the trial without removing the mould and cleaning;
- note the time taken for the colour change, the number of cycles and the temperature conditions employed;
- compare the mouldings produced with the mouldings from the previous trial;
- establish what defects have occurred, particularly around the gate on the outside and inside of the moulding;
- be present when the mould is taken down and cleaned, to check:

- that the system is leakproof and that there are no melt leaks in manifold area;
- no imprints or seizure of plates at points of contact with support pads;
- no scorching of hanging melt, especially around the nozzle seals;
- request or order spares and especially seals and heating elements (particularly sets of curved tubular heaters);
- make acceptance of the mould and signing of the trial record dependent on receipt of full design documentation for the mould and servicing instructions for the system.

The proper functioning of an HR system is linked to trials of:

- full automation of mould operation (release and ejection of moulding);
- efficiency of temperature control (cooling) zones (leak tests, thermocouple measurement of uniformity of temperature distribution in all cavities around gate in core and cavity).

When inspecting a mould, a check should be made that the plugs and sockets match the connections present in the heat-regulation cabinets, and whether they have the right number of control modules.

When used moulds are undergoing trials, it is necessary to make a more thorough analysis of the HR system, especially as the relevant documentation rarely still exists.

Because some toolmakers in some countries try to keep costs down by making HR nozzles themselves, it is necessary to make sure that there are special guarantees of durability and output, especially for processing of engineering plastics or in cases where the moulds have very short operating cycles. Checks should also be made on the materials employed and their hardness, surface finish and channel and gate manufacturing tolerances, flow balance, the clearance between the heating elements and the manifold apertures, the seals, the dead space - in other words, all those components of the system which are accepted on merit when ready-made components are purchased from renowned manufacturers of standard HR systems.

10.2 Preparation of a mould for operation

Before an HR mould commences operation, the following preparations are needed:

- connection and checking of the mould temperature regulation system;

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- connection of hydraulic leads/compressed air and checking of action of shut-off nozzles (this only relates to new nozzles without melt filling);
- connection of electrical leads;
- checking of mechanical action of mould: opening, closing, withdrawal of ejector, independent drives, etc.;
- checking of mould safety features.

When HR moulds commence operation, the following actions are performed in sequence:

- heating the mould to the operating temperature;
- heating of the injection moulding machine cylinder to the set temperature;
- heating of the HR system to the operating temperature. The heating takes place in two phases: first, what is called 'soft start' (to eliminate moisture from the heating elements), which takes place automatically in modern equipment. If this function is absent, the soft start parameters have to be set manually, e.g., for 15 minutes of heating with a reduced 50 V current at a maximum temperature of 100 °C, or as per the supplier's instructions. In the second phase the system is heated at full power. It is sometimes recommended that a manifold of the clamped type be heated before the nozzles are heated, e.g., by setting an initial nozzle temperature that is about two-thirds of the manifold temperature. This enables a free thermal elongation of the manifold (before it is clamped by the nozzles) without any risk of seizure of the support plate by the spacer pads;
- filling of the HR system with melt (in the case of a new or cleaned system) at very low pressure, preferably by extrusion (screw in forward position) at plasticisation pressure of around 1.5 to 3.0 MPa, or by slow injection under an equally low pressure. The aim of this procedure is to fill the seals (in a system with external heating) or to create an external sealing layer (in a system with internal heating);
- in a system with internal heating it is also recommended that the heating be switched off for around 15 minutes (for more rapid freeze-off of the layer close to the wall);
- setting of injection parameters and commencement of operation when about 2-5 minutes have elapsed.

The system must not be purged at high pressure with the mould open, as this carries the threat of melt leakage between sealing surfaces, a loss of leaktightness and damage (flooding) of the electrical leads.

When thermally sensitive plastics are being processed, e.g., PBT, PET, POM, and nozzles with an insulation chamber are being used, the HR system may first be filled with a thermally stable plastic, e.g., PA 66. This prevents a distribution of melt which hangs in the chamber or creates what is known as an insulating layer.

For the first 15 minutes of operation a watch should be kept over whether there are any melt leaks in the manifold space. Leaks may be indicated by 'shorts' (incomplete filling of the mould) with a previously set specific batching capacity, a fall in injection pressure or gases escaping from the manifold space, etc.

10.3 Ongoing servicing

Observations have shown that the cause of the greatest number of faults even in the best HR systems is poor-quality servicing during production.

Rigorous measures must therefore be put in place to prevent:

- any interference by operators during the process, such as raising or lowering temperatures or pressures, altering times, etc. This is a matter that must be left exclusively in the hands of supervisory staff.
- use of any tools to clear gates.
- use of heating with a burner flame to clear the passage of a gate. Blockages are most frequently caused by an impurity in the melt or a heating system breakdown.
- attempts to repair disabled valve pins by one's own efforts. The most common cause of faults is penetration of micro-particles of plastic into the guide section and abrasion. The nozzle then needs to be removed and cleaned.

Breaks in operation. Some plastics, e.g., PC, may remain in the injection machine cylinder or in the HR system even after a dozen hours when the temperature is set to around 160 °C. The phenomenon of very strong adhesion between the metal surface of the cylinder and the solidified melt may even cause detachment of the nitrided layer, and it is therefore recommended that purging with HDPE always be carried out before any lengthy stoppage. There are no recommendations here for HR systems, but this should be borne in mind particularly for nozzle components with a nickel coating or made of sintered materials.

End of operation. The procedure is similar to that used in the injection moulding machine:

- switch off heating;
- switch off mould cooling only when mould temperature falls to 80 °C.

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Before the heating is switched off for thermally sensitive plastics, the channels of the HR system should be purged through using a thermally stable melt with a similar processing temperature but higher viscosity. For processing of PVC, for example, the system should be purged on start-up and after the end of operation using extrusion-grade LDPE.

High temperature plastics should be purged with PC after a temperature reduction, and then when a second temperature reduction has taken place, with HDPE or PP.

Plastic colour change. The time needed to change the colour or type of plastic depends primarily on the nature of the HR system and on the colour change sequence.

A system with external heating enables the channels to be purged relatively quickly. A system with internal heating does not allow the channels to be purged completely, and in some cases it is necessary to take the manifold apart and clean the channels, torpedoes and insulation chambers manually. Some systems are designed in such a way as to allow the channels to be opened up (see **Figure 4.91**); sometimes this can even be done on the machine without removing the mould.

The time needed to change from a light colour to a dark one is comparatively short (in a system with external heating), but a dark-to-light colour change, or a change from dark to translucent plastic, takes quite a lot of time and sometimes requires a special procedure to be used. Colour changes therefore need planning; for example, a product may commence production in its lightest colour to avoid losses in time and raw materials. Production should end with the system being purged using a natural colour (or a colourless plastic), to make it easier to start the next production run with any colour.

A change in plastic type by purging may be difficult if the plastics have different viscosities. Then the system will need to be dismantled and cleaned.

HR system suppliers usually specify a procedure for colour changes. The general principles of this procedure are given next.

For systems with external heating with a non-shut-off nozzle:

- purge injection machine cylinder with plastic of new colour;
- raise temperature in all HR zones by 10-20 °C (depending on maximum admissible plastic processing temperature);
- perform 10-15 injections (into closed mould), until the 'old' colour is only visible around the gate;

- switch off HR heating and cool the system down. This causes the frozen melt to 'come unstuck' from the channel walls, and makes it easier to mix the 'old' and 'new' melts on re-start. The procedure with cooling and re-heating of the system is applied with a colour change from dark to light;
- heat the HR system to operating temperature;
- inject at a high injection rate until a uniform colour is achieved.

For systems with external heating with shut-off nozzle:

- purge injection machine cylinder;
- inject until 'old' colour is removed from HR (do not raise the temperature because of the risk of flooding the pin guide);
- switch off HR system heating and cool system as for open nozzle;
- Warning! Shut-off nozzle must not be started up at a temperature below the operating temperature, since this could cause damage to pin and gate;
- heat system to operating temperature;
- inject until complete purging has taken place.

For system with internal heating:

- purge injection machine cylinder using natural-coloured plastic;
- heat machine cylinder and HR system to maximum admissible processing temperature (thus increasing the fluid core cross-section in the channel so that the colour change takes place in a larger cross-section);
- purge the system using natural-coloured plastic at high pressure. Extending the holding time may also be of benefit;
- set the appropriate processing parameters and purge the system with plastic of the required colour.

To make the colour change easier, on first start-up the system should be filled with plastic of a natural colour and be purged with the same plastic at each change to a plastic of a different colour.

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If the difference in colour is too large, and streaks of the 'old' plastic are visible, the system needs to be taken down and cleaned, especially around the torpedo tip. Plastic residues may be melted and removed when the dismantled system is heated.

WARNING: do not burn the plastic off with a burner, as this causes a loss of hardness in and damage to system components.

Some systems allow access to nozzles and *cleaning of the insulation chamber* without removing the mould from the machine, e.g., STRACK, Spear System, Husky, Mold-Masters. The mould cleaning procedure is shown in **Figure 10.1**:

- when the mould has been opened in plane (1), the screws (4) should be unscrewed. When the mould is closed, the wedge grips (5) should be secured. When the mould is re-opened, this time in plane (2), it is possible to clean the plastic from the insulation chamber (6). This design greatly reduces the cost of a colour change from dark to light, and especially a change to a translucent plastic.

Jet cleaning of channels with hot aluminium oxide powder, or use of microscopic glass beads in special chambers, are applied for cleansing purposes when HR systems are being renovated.

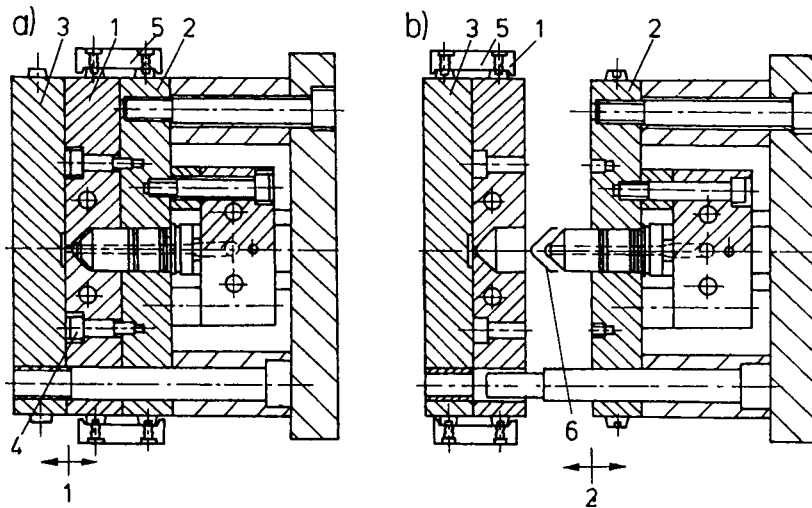


Figure 10.1 Mould with split insulation chamber enabling it to be cleaned on the machine
a - closed mould before injection; b - form open in additional parting line; 1, 2, 3 - mould plates; 4 - fastening bolts; 5 - wedge grip; 6 - plastic from insulation chamber.

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10.4 Maintenance and storage

In order to carry out maintenance work on HR moulds, an additional knowledge of the design principles and use of individual systems is required.

The tips of nozzles and the ends of heating elements are particularly susceptible to mechanical damage. Mould heating as for start-up (from a soft start) generally enables the nozzles to be removed easily and the manifold to be dismantled. It is recommended that:

- abrasive materials are not used to remove plastic;
- damaged components like nozzle ends, damaged tips, etc., are not replaced with home-made items;
- seals, other than those agreed for the system in question, are not used, and especially copper washers;
- tight-fitting heating elements are not removed using a burner; it is better to turn them off on a lathe.

Installation of manifolds sealed by clamping should be performed according to the principles described in Chapter 4.2.1.2. After each dismantling of the mould, and at least once a year, the seals at the nozzle/manifold contact should be renewed. Because of the importance of keeping the cooling circuit channels constantly open, they should be regularly - at least once a year - flushed through to remove boiler scale, contamination and rust using special mixtures of acids with inhibitors.

Storage. All repairs and data relating to the service life of a mould should be recorded on a chart for the mould. The same is true of the HR system.

Because of the considerable vulnerability of heating elements to moisture, the following recommendations are made:

- thorough drainage and blowing of water residues out of temperature regulation channels;
- storage of moulds in a heated room on racks or wooden pallets.

In all cases a mould accepted for storage must be one in working condition that is ready for use at any time.

10.5 Work safety principles

When working with HR moulds, the same type of hazards occur as for operating an injection moulding machine. Within the working space occupied by a mould, however, there is an additional area where consideration needs to be given to the following:

- thermal injuries caused by the high manifold temperature, which may reach 400 °C in the case of high temperature plastics;
- thermal injuries caused by the potential for spontaneous ejection of decomposed plastic (moist PA, POM) from nozzles if the mould was opened and the heating for the machine cylinder and the HR system was not switched off;
- thermal injuries caused by damage to the flexible hoses delivering the medium to the temperature regulation circuits (temperature 100-180 °C) or their being connected in a primitive way;
- mechanical injuries - as with all injection moulds;
- an electric shock may be suffered chiefly when the wrong kind of insulation is used (not resistant to high temperatures), or when non-attested plug systems without any protection against spontaneous disconnection or a lack of mould earthing are used.

It is therefore recommended that:

- whenever there is even a short break in operation, the HR system and cylinder heating be switched off and the cylinder nozzle be withdrawn from the sprue bushing;
- cooling agent connections be made underneath or at the back of the mould, with electrical connections at the top;
- groups of leads be protected against mechanical damage;
- connection couplings or quick fasteners be used for coolant pipes. In no case may pipes be fastened using wire.

Since well-organised production means that moulds are set up already heated up (they are normally taken off hot), protective gloves must be used, and also protective spectacles must be used when using plastics with low thermal resistance.

References

1. DIN 16901
Plastics Moulding; Tolerances and Acceptance Conditions for Linear Dimensions.

11 Disruptions to the Operation of HR Moulds and Typical Moulding Defects

It is a lot easier to identify disruptions to the operation of an HR mould system which occur directly, than it is to establish the real causes of moulding defects associated with them. Many of the causes of disruptions lie outside the HR system, and some occur independently of the use of an HR system. The most important disruptions are discussed in this chapter, together with possible causes and remedies.

11.1 Leaking in HR systems

Seal failure in an HR system and leakage of melt most frequently occur when the pressure in the system exceeds the clamping force of the system components in the mould. The first signal that a melt leak has occurred is very slow heating of the manifold. **Table 11.1** shows some of the causes and remedies of leakage.

Assembly faults causing leaks are shown in detail in **Figure 4.79**.

Table 11.1 Causes and remedies of leakage in HR systems	
Cause	Remedy
Central spacer pad too high	Grind down.
Central spacer pad dented into mould plate	Renew. Reduce cylinder holding force.
Spacer pads too low	Renew or lower manifold housing.
Insufficient force exerted by clamping bolts	Check number and positioning of bolts.
Ring seal not renewed when mould removed	Renew.
Nozzle overheating	Check/renew thermocouple.
Manifold overheating	Check/renew thermocouple; Check/repair mould pressure plate and spacer pads (possible denting or deformation).

11.2 Shut-off nozzle leaves vestige

A vestige is left on the moulding when the nozzle pin fails to shut off the gate. A vestige may also occur if the pin is too hot and draws material out of the moulding. Some of the causes of this are shown in **Table 11.2**.

Table 11.2 Causes and remedies of vestige	
Cause	Remedy
Pin too short or bent	Check/renew pin.
Damaged gate	Check pin length and if necessary shorten. Check concentricity of pin and gate and if necessary renew.
Damaged seal in nozzle drive cylinder	Renew.
Inadequate pin contact with gate	Increase gate zone cooling. Increase length of pin contact with gate.
Inadequate oil/air pressure	Carefully increase pressure (too great a force may damage gate).
Too long holding time (melt cooling in gate zone)	Shorten holding time.

Table 11.3 Causes and remedies of blocked gates	
Cause	Remedy
Gate zone too cold	Reduce cooling of gate zone. Check nozzle type (for crystalline plastics) - is the insulation chamber large enough?
Cooling of end of nozzle too strong	Reduce area of contact between nozzle end and mould. Create an insulating gap between nozzle face and mould plate (for injection into CR).
Too little heat delivery to gate	Increase gate diameter. Shorten gate. Check position of tip in gate.
Gate blockage	Remove dirt (take system apart).
Shut-off nozzle pin stuck in closed position	Proceed as in Table 11.2.

11.3 Gate blocked

A blocked gate is most commonly the result of excessive cooling of the melt in the gate, and may often be caused by an error perpetrated during construction or installation. **Table 11.3** shows some of the causes of a blocked gate.

11.4 Gate stringing or drooling

Gate stringing or drooling is caused by delayed freeze-off of melt in the gate. See **Table 11.4** for some of the causes of stringing or drooling.

Table 11.4 Causes and remedies of stringing and drooling	
Cause	Remedy
Excessive heating of gate zone	Check/renew nozzle thermocouple. Reduce manifold and nozzle temperature. Increase cooling of gate zone. Check gate size and geometry, change nozzle type or end (for amorphous plastics).
Inadequate cooling time	Extend cooling time. Use HR decompression to reduce residual melt pressure in HR.
Shut-off nozzle pin does not close fully	Proceed as in Table 11.2.

11.5 Incomplete mouldings

Incomplete mouldings are caused by a failure to fill the cavities during injection. The way to proceed depends on whether difficulties occurred at start-up, or whether the fault appeared while production was going on. **Table 11.5** shows some of the causes and remedies of incomplete mouldings.

Table 11.5 Causes and remedies of incomplete mouldings	
Cause	Remedy
Inadequate quantity of material	Check whether there has been a change of material. Increase shot size. Check screw non-return valve. Check machine nozzle and HR sprue bushing contact. Check whether there is any drooling of melt from sprue bushing when machine nozzle is withdrawn. Check leaktightness of HR system. Check whether there has been a blockage of one of the gates - clean.
Inadequate pressure in cavity	Increase injection pressure.
Low melt temperature	Raise melt temperature. Check whether the HR system reaches the set temperature and whether there has been any damage to one of the heating zones.
Incorrect switching from injection pressure to holding	Increase holding pressure. Move switching point.
Poor venting	Increase number/size of venting gaps.
Gate size	Check whether all gates are of same size and geometry.
Shut-off nozzle action	Check.

11.6 Sinks

Sinks are a result of free shrinkage of the melt during cooling in the cavity prior to freezing. Further causes of sinks are shown in **Table 11.6**.

11.7 Brown or silver streaks (burn)

One cause of brown and silver streaks on the moulding may be thermal damage to the melt, as a result of which the molecular chains may be shortened (silver tinge) and the molecules damaged (brown tinge). Silver tinges may also be caused by impurities of another material or processing of moist plastic. See **Table 11.7** for more causes of burning.

Table 11.6 Causes and remedies of sinks	
Cause	Remedy
Inadequate packing of melt in cavity	Increase shot capacity. Increase holding time; Increase injection rate. Check screw non-return valve.
Inadequate pressure in cavity	Increase injection pressure. Increase holding pressure, have it act for a longer time (weight check).
Incorrect melt temperature	Reduce melt temperature (injection machine cylinder, HR), if sinks are at gate or thick wall. Raise melt temperature (cylinder, HR) if sinks are away from gate or at thin wall.
Premature gate freeze-off	Increase injection rate. Raise melt temperature (cylinder, HR). Reduce cooling of gate zone. Increase diameter, reduce length of gate.
Premature gate closure	Check (shut-off) nozzle closure time.
Moulding is too hot	Reduce melt temperature. Reduce cavity temperature. Extend cooling time.
Thick ribs	Increase mould cooling in rib zone. Alter product design. Move injection site.

Table 11.7 Causes and remedies of burning	
Cause	Remedy
High melt temperature	Reduce cylinder temperature. Reduce screw rotation speed. Reduce temperature of manifold and HR nozzle. Check/renew thermocouples.
Excessive time spent in hot zone	Shorten cycle time. Delay commencement of plasticisation. Reduce proportion of regrind.
Dead spots	Check possible melt hang-up space in manifold, nozzles and seals.
Over dried raw material	Reduce drying time/temperature.
Regrind	Reduce proportion of regrind.
Melt degradation	Use plastic with higher thermal resistance. Check thermal resistance of dyes and additives.

11.8 Delamination

Delamination means the external layer of the moulding peeling away. See Table 11.8 for some causes and means of correction of delamination.

Table 11.8 Causes and remedies of delamination	
Cause	Remedy
Injection rate too high	Reduce.
High melt temperature	Reduce.
Mould too cold	Raise cavity temperature.
Non-mixing dye	Check mixability and content of dye.
Contamination by other material	Check purity of granules. Check cylinder and HR for presence of another plastic.
Inadequate mixing	Check homogeneity of melt and plasticisation capacity of cylinder.
Damp on granules	Use dry granules. Use heated charging hopper. Reduce amount of plastic placed in hopper at a time.

Tables 11.1-11.8 gives only those defects which could be caused by the HR system. A wider discussion of the defects and causes of their occurrence is contained in the specialist literature on injection moulding technology [1].

References

1. H. Zawistowski and Sz. Zieba, *Setting up an injection moulding process*. PLASTECH - Wydawnictwo Poradników i Książek Technicznych, Manuals and Technical Books Publishing, Warsaw, 1995. [In Polish]

12 The Way Ahead for HR Technology

HR technology is continuing to experience a phase of intensive development brought about by the increasing demands of the plastics processing industry. This industry is faced with a need to meet the following requirements:

- reduction in manufacturing costs, which means full automation, reliability, less down time and increased output;
- quality meeting the expectations of increasingly demanding customers;
- expansion of potential, meaning removal of the barriers to use of HR systems. This particularly involves use of HR in new injection moulding processes, for example decorative lamination, gas-assisted injection moulding, etc., and easier processing of new engineering plastics.

The latest developments in materials science, heating technology, control and so on are being used. This all entails considerable outlay, and only specialist companies are able to engage in such work. The results are evident not only in the quality and reliability of HR system components, but also in the prices that are proportionate to the effort invested.

HR systems continue to be sensitive items of equipment requiring skilled operation and maintenance, and they have their drawbacks and limitations in use. The development of HR technology is consequently moving towards the elimination of these drawbacks too.

The tasks facing the processing industry and the observed trends in development include the following HR system development areas:

- achieving reliable leakproofing in systems with external heating. One approach to this problem is the concept of the nozzle screwed into the manifold, i.e., (INCOE, Dynisco HotRunners).
- reduction in melt temperature fluctuations in systems with 230 V heating. Improvements have been made by using microprocessor-controlled regulators with self-optimisation. Work is continuing to computerise control and to include it into the injection machine control and regulation system. Another way in which this problem is being addressed is through the use of heat pipes which even out the temperature differences that occur (Dynisco HotRunners) or channels filled with a fluid medium (Schöttli).

Hot Runners in Injection Moulds

- use of new materials featuring good heat conductance coupled with a high level of mechanical strength at high temperature, which enables a reduction to be made in the temperature differences in nozzles operating at high temperatures and when plastics with an abrasive and corrosive effect are being processed. Use of molybdenum sinters has brought a considerable improvement.
- use of new heat and thermochemical treatments to increase the abrasion resistance of nozzles (when materials as above are processed), especially at high temperatures. New surface hardening methods are being introduced for this, e.g. ionic implantation of molybdenum sinters, silicon carbide coatings on copper-beryllium parts, and so on.
- reduction in the minimum nozzle spacing. Miniaturisation of nozzles is proceeding hand-in-hand with the miniaturisation of heating elements. Nozzles of 10 mm diameter have already been produced with a 230 V heating element (INCOE).
- elimination of melt hang-up in manifold channels. One approach to this problem is a manifold that is diffusion welded from several parts following milling of the flow channels (EWIKON, EOC), as well as use of tubular manifolds with large bend radii (Unitemp).
- diminution in electricity consumption and heat losses in externally-heated systems. New insulation materials (titanium alloys) and insulation methods (reflector sheets) have been introduced. Sometimes a radical reduction in energy consumption requires a change in the manifold design concept (Heitec).
- standardisation of the system of connections for heating elements and thermocouples in plug sockets so that, for example, one company's system may be connected up to a control cabinet made by another company.
- easier installation and removal of an HR system mould. There is still a lot of room for improvement in this area. A manifold with screw-in nozzles is a compound unit, particularly if it may be removed from the HR mould together with the cabling.
- wider use of computer methods in a 3D system enabling spatial simulation of the behaviour of the melt during flow and setting in the mould to be achieved, as well as designing of complex cavity shapes.
- supply by manufacturers CAD catalogues of HR components and selection programmes, like Eurotool's 'Navigator', which are useful when the selection of nozzle, channel and gate types and so on is being optimised.

Users are increasingly coming to terms with the complexity of the problem, and are establishing close co-operation with the manufacturers of HR systems. Consultation with specialists, the potential to check designs with the aid of computer techniques, assistance with start-up, etc., reduce the risk in building increasingly complex and expensive moulds.

Abbreviations and Acronyms

ABS	Acrylonitrile-butadiene-styrene
APA	Aromatic polyamide
APE	Aromatic polyester
ASA	Acrylonitrile styrene acrylate
CA	Cellulose acetate
CAB	Cellulose acetate butyrate
CAD	Computer aided design
CNC	Computer numerical control
CP	Cellulose propionate
CR	Cold runners
DIPD	D-Integral-Proportional-Differential
EPDM	Ethylene-propylene terpolymer
ETFE	Ethylene/tetrafluoro/ethylene copolymer
EVA	Ethylene-vinyl acetate copolymer
FEP	Fluorinated ethylene propylene
FWC	Flexible working centre
GF	Glass fibre
HDPE	High density polyethylene
HIPS	High impact polystyrene
HR	Hot Runners
HRB	Hardness - Brinell
HRC	Hardness, Rockwell 'C' Scale
HTPC	High temperature polycarbonate
IMD	In-mould decoration
IML	In-mould lamination
LCP	Liquid crystal polymer
LDPE	Low density polyethylene

MBS	Methyl methacrylate-butadiene-styrene copolymer
MFI	Melt flow index
PA	Polyamide
PAE	Polyaryl ester
PAEK	Polyaryl ether ketone
PAI	Polyamide imide
PAR	Polyaromatic
PAS	Polyaryl sulphone
PBT	Polybutylene terephthalate
PC	Polycarbonate
PE	Polyethylene
PEEK	Polyether ether ketone
PEI	Polyether imide
PEK	Polyether ketone
PES	Polyether sulphone
PET	Polyethylene terephthalate
PFA	Perfluor acsyl
PID	Proportional integral differential
PMMA	Polymethylmethacrylate
POM	Polyoxymethylene acetal copolymer
PP	Polypropylene
PPA	Polyphthalamide
PPE	Polyphenylene ether
PPO	Polyphenylene oxide
PPS	Polyphenyl sulphide
PS	Polystyrene
PSU	Polysulphone
PU	Polyurethane
PUR	Polyurethane change to PU
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride

PVT	Pressure-specific volume-time
SAN	Styrene-acrylonitrile copolymer
SB	Styrene-butadiene copolymer
SPC	Statistical proces control
TPE	Thermoplastic elastomers
TPE-A	Polyamide thermoplastic elastomer
TPE-E	Ester thermoplastic elastomer
TPE-S	Styrenic thermoplastic elastomer
TPE-U	Urethane thermoplastic elastomer
TPE-O	Olefinic thermoplastic elastomer
TPU	Thermoplastic polyurethane
T _g	Glass transision temperature

Appendix 1 - List of Hot Runner Suppliers

D-M-E Europa

Industriepark Noord G1
B-2800 Mechelen
Belgium
Tel: +32 15 215011
Fax: +32 15 218235
www.dmena.dmecompany.com

EMP snc di Romandini Rodolfo Rinaldo & C.

Viale A. Merloni 12/G
60044 Fabriano (AN)
Italy
Tel: +39 732 627704
Fax: +39 732 627977
www.emp.it

EOC Normalien GmbH & Co. KG

Postfach 1380
Hueckstr. 16
D-58463 Lüdenscheid
Germany
Tel: +49 2351 437 0
Fax: +49 2351 437 220
www.eoc.de

Dynisco HotRunners BV

Griendweg 9
NL-3295 KV's-Gravendeel
The Netherlands
Tel: +31 78-673 8282
Fax: +31 78-673 8299
www.dynisco.com

Ewikon Heißkanalsysteme GmbH & Co. KG

Siegener Str.35
D-35066 Frankenberg
Germany
Tel: +49 6451-501-0
Fax: +49 6451-501202
www.ewikon.de

Fast Heat International (UK) Ltd.

Unit 28
Hawthorn Road
Eastbourne
East Sussex
BN23 6QA
United Kingdom
Tel: +44 1323 647375
Fax: +44 1323 410355

Guzzini Engineering

Divisione Acilux SPA
SS 571 Km 10,983 – 62019 Recanti
Italy
Tel: + 39 71 75 891
Fax: + 39 71 757 43 73
www.guzziniengineering.com

Günther-Heisskanaltechnik GmbH

Sachsenberger Strasse 1
D-35066 Frankenberg
Germany
Tel: +49 6451-5008-0
Fax: +49 6451-5008-50
www.guenther-hotrunner.com

Hot Runners in Injection Moulds

Hasco-Normalien Hasenclever GmbH & Co.

Im Wiesental 77
D-58513 Lüdenscheid
Germany
Tel: +49 2351-95 70
Fax: +49 2351-95 72 37
www.hasco.com

HEITEC Heisskanaltechnik GmbH

Wolkersdorfer Str.28
D-35099 Burgwald Bottendorf
Germany
Tel: +49 6451-72830
Fax: +49 6451-728383
www.heitec-heisskanal.de

Heatlock AB

Box 236
S-532 23 Skara
Sweden
Tel: +46 511 132 00
Fax: + 46 511 172 85
www.heatlock.com

Hotset Heizpatronen und Zubehör GmbH

Wefelshohler Strasse 48
D-58509 Ludenscheid
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Tel: + 49 23 51 43 02 0
Fax: + 49 23 51 43 02 25
www.Hotset.de

Husky Injection Molding Systems, Ltd.

Zone Industrielle Riedgen
BP 231
L-3401 Dudelange
Luxemburg
Tel: +352 52 11 54 281
Fax: +352 52 11 54 450
www.husky.ca

Incoe International

Carl-Zeiss-Str.47
D-63322 Rödermark
Germany
Tel: +49 6074 89 07 0
Fax: +49 6074 89 07 10
www.incoe.com

Jet Heisskanalnormalien und Zubehör GmbH

Postfach 1154
D-71277 Rutesheim
Germany
Tel: +49 7152 9931-0
Fax: +49 7152 9931-31

Mold-Masters Ltd.

233 Armstrong Avenue
Georgetown
Ontario
L7G 4X5
Canada
Tel: + 1 905 877 0185
Fax: + 1 905 873 2818
www.moldmaster.com

PSG Plastic Group GmbH

Postfach 420162
D-68280 Mannheim
Germany
Tel: +49 621 7162-0
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Rabourdin Industrie

Parc Gustave-Eiffel-4
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France
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www.rabourdin.fr

Appendix 1 - List of Hot Runner Suppliers

Roko GmbH

Postfach 1355
68638 Burstadt
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Tel: + 49 0 62 06 73 41
Fax: + 49 0 621 06 79 898
www.roko.de

Spear Systems

Eastern Plastics Machinery Ltd.
Eastern House
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STRACK Normalien GmbH

Buchenhofener Strasse 19
D-42329 Wuppertal
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Fax: +49 202 385-110
www.strack.de

Thermoplay srl

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11020 Hone (AO)
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Tel: + 39 125 833 211
Fax: + 39 125 803 587
www.thermoplay.it

Unitemp SA

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CH-2822 Courroux
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Fax: +41 66 200588

Xintech Systems AG

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Fax: +41 1 8220903
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