Hot Runner Manifold, nozzle and gate design considerations for successful molding of semi-crystalline polymers

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Abstract

These days the demand for maximizing productivity is higher than ever before. One way to reduce cycle time and avoid regrind operations is to use a hot runner system. The question that frequently arises is when to use hot runner molds with crystalline polymers. The answer depends on many factors, and particularly on the part quality needs, eg mechanical performance, surface aspect. By looking at the behavior and the needs of semi-crystalline polymers, such as POM, PA, PPA, PET, PBT and LCP we will highlight some key factors to look at when choosing a well adapted hot runner system.

This is not an intention to recommend any trademark or system, the intent is to aid customers and mold makers with selecting the most appropriate hot runner system to maximize product quality and yield.

Status

Hot runner molds provide advantages vs. cold runner systems, among which the obvious ones are: less material to plastify leading to shorter cycles and no (or minimum) regrind. On the other hand, hot runner molds add complexity and costs. They often require maintenance and skilled molding operators.

Hot Runner Direct gating versus cold sub-runners

When designing a hot runner mold for semi-crystalline polymers, it should be kept in mind that direct gating via hot runner is more demanding with these types of polymers vs. amorphous ones. The difference is explained by the softening and melting behavior of these two types of polymers. An amorphous material exhibits a gradual softening behavior above Tg from the solid state to the liquid state. (temperature and viscosity.)

This behavior provides wide temperature domains for thermoforming (“T”), for blow molding (“BM”) and finally for injection molding (“IM”) as shown in figure 1.

Opposite to amorphous grades, the Tg of semi-crystalline polymers have usually a limited or negligible effect on the structure, which remains solid above Tg.

At the melt temperature Tm, semi-crystalline polymers melt sharply and become liquid (curve “C”).

This behavior of semi-crystalline materials requires special attention to:

- Drooling around the gate, which potentially can be responsible for bad surface aspect and deformation.
- Plugging of the gates by solidified material, plugs which will be pushed into the cavities, with consequent problems of surface defects and lower mechanical performances.

The critical objective is to allow the part to freeze at the gate outlet and remain molten at the gate inlet over a distance which represents a fraction of a millimetre. This requirement is exceedingly difficult to accomplish with direct gated parts using hot tip hot runner systems.

The use of a hot runner combined with cold sub-runners will achieve this goal, also contributing to a more robust process (Figure 2). The cold slug trap in front of the hot nozzle will catch any frozen or degraded material.

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**Fig. 1 – Modulus vs Temperature**

**Fig. 2 – Typical layout of a combination of Hot Nozzle with cold sub runners**
Key criteria for selecting a Hot Runner System

The following is a summary of typical weaknesses observed in Hot Runner System which require improvement:

- Dead spots (1)
  - In hot manifold flow channel
  - At tip of heated nozzle
- High heat loss
- Inappropriate temperature controls (including thermocouple location)
- Gate & channel dimension not allowing insufficient Flow & Hold Pressure Time
- Ease of maintenance (purging, heating system.)
- Poorly trained operators

(1) Areas with infinite hold-up time

Dead Zone or Hold-up Spots in manifolds

Channel Corners in the Hot Manifold could be a concern as they may result in a pressure drop in the channel but more dramatically in the «dead zone» if not properly designed. Hot Runner manufacturers offer a wide range of flow optimized geometries in corners to avoid Hold-up spots.

Dead Zone or Hold-up Spots of internally heated torpedo system (direct gating)

The dead zone on the far side of the torpedo may cause polymer stagnation and degradation. (Fig. 4a).

Dead Zone or Hold-up Spots in valve gate (direct gating)

Valve gate design requires special attention relative to the inherent dead zone present on the far side of the pin where polymer can stagnate (Fig. 4b).

Gate freeze-off in valve gate system with fast freezing polymers. (direct gating)

In order to achieve good dimensional control and/or obtain good surface appearance, the ‘optimum’ SFT required to obtain (or get close to) freeze-off across the wall section of the part will very often also result in freeze-off of the material in the gate itself (in front of the retracted valve pin). Many valve-gate systems cannot deliver sufficient pressure to force the closing of the valve pin against this (semi-) frozen mass of material, and in fact, cannot push this solidified mass of material into the (semi-)solidified part. The end result is a ‘puck’ of frozen material that stands proud of the surface of the part, sometimes by as much as several millimeters.

The only solution is to significantly reduce SFT so that the part wall, and material in front of the retracted valve pin is still semi-molten, which then allows for the valve pin to push this material into the part upon closing. When forced to do this, problems become apparent with the part (dimensional issues, poor surface, etc.).

It's a no-win situation unless the molder is made aware of this potential issue and agrees that a gate projection is acceptable.
« Dead Zone » or «Hold-up spots» in nozzles (direct gating)

Same challenges also apply to the nozzle tips where a fully streamlined design is mandatory to avoid degradation possibly leading to surface aspect problems and brittleness. Optimized streamlining reduces the necessary time when changing material color. (Fig. 7)

Gate tip design, where molten plastic is insulating the tip, should be avoided (see below Fig. 6).

To limit restriction and consequent pressure drops, externally heated hot nozzles are preferred versus Internally heated (Fig. 5) and heat conductive nozzles (not shown).

Side-gating systems on the vertical part wall (direct gating – special case)

By design the part shears away from the hot edge-gate during ejection, potentially leaving a semi-frozen slug in the gate orifice. This slug either gets injected with the next shot (creating a surface defect) or freezes-off completely, resulting in a plugged gate and subsequent risks of short shots and potential flash in other (open) cavities.

Several suppliers have raised the awareness of molders that these designs are NOT suitable for semi-crystalline resins.

Combination of Hot runner with cold runner

Gate freeze-off in Hot Runner Systems is less predictable than with a cold runner approach. It is one reason why it is recommended to use them in combination with cold sub-runners:

Open nozzle
Preferred for glass reinforced materials

Mini torpedo in open nozzle

Dimensions of cold sub-runners

Cold runners and gate designs should follow the guidelines for semi-crystalline dimensional recommendations. Gate dimension, «D», must be at least half of the part thickness (« T »).

The inscribed diameter «D» of the tunnel next to the gate must be at least 1,2 x the part thickness. The gate shown on the right side in Fig. 9 is not recommended for crystalline materials.

This is because such conical gate sections crystallise before the «pack-out» of the part has been completed. This results in low mechanical performance and uncontrolled shrinkage.

For parts made of DuPont™ Delrin® acetal resin, the runners next to the gate must have at least an inscribed diameter equal to the part thickness «T» + 1 mm in order to have the best physical properties.
System temperature control

Inappropriate layout of the heating system can lead to over heating (i.e if hot sprue is not properly insulated or the position of the thermocouple is not correct). Further more, contact between the hot runner system and the mold should be minimized in order to limit heat losses that are the main cause for poor temperature distribution (Fig. 10).

Thermocouple should be located near the tip of the nozzle (Fig. 11).

Fig. 11 – Ideal Thermocouple position

Temperature control of the cavity

Another challenge with a direct hot runner nozzle is the consequent non-uniformity of the cavity wall temperature created by the very close location of the nozzle.

An indirect gating system using a combination of a hot nozzle with cold runners is a good solution when cavity temperature uniformity is mandatory for dimensional consistency.

Fig. 12 – Uniformity of wall cavity temperature

Fig. 13 – Non-uniformity of wall cavity temperature

Semi-crystalline require well selected hot runner technology to take advantage of productivity benefits