# Sprue Gating Recommendations for Sulfone Polymers

Udel® polysulfone (PSU), Veradel® polyethersulfone (PESU), Radel® polyphenylsulfone (PPSU), and Acudel® modified PPSU are high-temperature, amorphous thermoplastics manufactured by Solvay that are commonly used for injection molding. Because they are viscous materials and less shear thinning than semi-crystalline thermoplastics, they generate high levels of viscous heating when sheared though narrow flow passages.

Screw Design

Shearing and viscous heating of the polymer begins in the screw and barrel of the injection molding machine. A properly designed screw can minimize the thermal degradation of the polymer and reduce the accumulative effects of viscous heating.

The screw design recommended for sulfone polymers is shown in Figure 1. This design along with a free flow nozzle tip and a full taper nozzle tip (Figures 2 and 3) completes the screw and barrel components recommended for injection molding sulfone polymers.
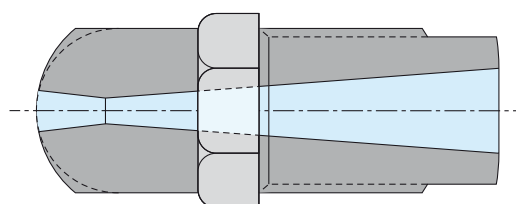
Figure 1: Screw design for injection molding
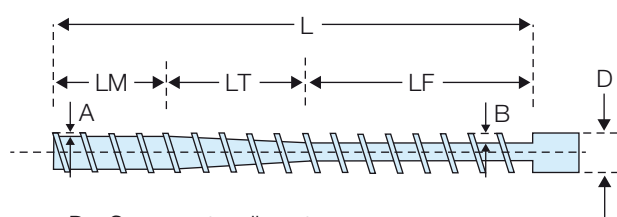
D = Screw outer diameter
L = Overall screw length   18 – 22 D
LF = Length of feed section   0.5 L
LT = Length of transition section   0.3 L
LM = Length of metering section   0.2 L
CR = Compression ratio   1.8 – 2.4 : 1
A = Metering depth
B = Feed depth (depends on screw diameter)

Figure 2: Free flow screw tip
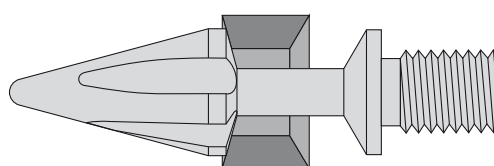
**Figure 3:** Full taper nozzle

Sprue Gate Design

The sprue bushing is designed to mate and seat with the spherical nozzle tip of the barrel and provides a flow path for the material from the nozzle to the part or runner system. A sprue gate is typically used in molding large single-cavity parts that are symmetric about a center axis. The sprue gate is machined through the center axis of the sprue bushing.

Geometry of the sprue gate is determined by three dimensions: sprue length, sprue "O" diameter, and the included draft angle or sprue base diameter.

The sprue "O" diameter mates with the orifice of the nozzle and is typically 1/32 inches larger than the diameter of the nozzle tip. If the "O" diameter were equal or smaller than the nozzle tip diameter, it would create an undercut with the mating nozzle surface and generate added force to pull the sprue or cause the sprue to stick in the sprue bushing. When a sprue sticks, the "O" diameter of the sprue is hit to dislodge the sprue. Because of this impact, the "O" diameter needs to be inspected frequently to ensure proper sealing with the nozzle and reshaped if any damage is detected.

Figure 4: Draft angles differ between inch and metric sprue bushings

½ taper per foot included angle

1° included angle

Inch sprue bushing

Metric sprue bushing
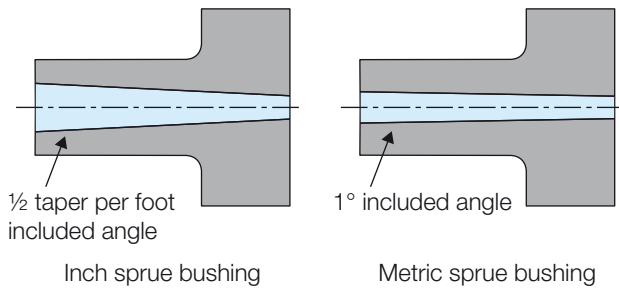
For most sprue bushings, the dimensions that need to be specified are the "O" dimension and the length of the sprue bushing. The typical taper angle for commercial sprue bushing is ½ taper per foot included angle. This means that the base diameter will be 0.5 inches bigger than the "O" diameter at a distance of 12 inches. This is equivalent to an included angle of 2.38 degrees. For the metric sprue bushing, the typical taper angle is 1 degree, which is about half that of the inch sprue bushing (Figure 4). The standard taper angle is adequate for most applications; however, for applications where shear heating needs to be minimized, the taper angle can be modified. As the taper angle deceases the force required to pull the sprue out of the sprue bushing increases.

For taper angles greater than 2.4 degrees, the "O" diameter becomes restrictive relative to the base diameter. For longer sprues, the taper angle has a dramatic effect on base diameter (Table 1). The taper angle needs to be kept to a minimum in order to keep the base diameter at a manageable thickness for faster cycle times and minimal shrinkage voids.

Table 1: Effect of increasing included taper angle on base diameter

Included Taper Angle [degrees]	"O" Diameter [inches]	Sprue Length [inches]	Base Diameter [inches]
2.4	9/32	1.5	0.343
3.0	9/32	1.5	0.360
4.0	9/32	1.5	0.385
2.4	9/32	3.0	0.405
3.0	9/32	3.0	0.438
4.0	9/32	3.0	0.490

Decreasing the included taper angle minimizes the size of the base diameter (Table 2). However, the drag on the sprue increases due to the lower draft angle, which may cause sprues to stick or break during mold opening. The higher drag forces associated with the lower taper angle can be reduced by using the following modifications:

- Draw polishing the sprue
- Plating sprue with a lubricous coating
- Cooling the sprue bushing

Draw polishing removes the radial machining marks from the sprue gate surface and orients the polishing marks in the direction of extraction. Plating the sprue gate will reduce the frictional forces between the wall and the

sprue surface. Adding a cooling circuit around the sprue minimizes the temperature increase of the polymer and allows for more sprue shrinkage and greater retraction of the polymer from the wall of the sprue bushing. The lower temperature also increases the strength of the polymer making it less likely to break when the mold opens and the sprue is extracted.

**Table 2:** Effect of decreasing included taper angle on base diameter

Included Taper Angle [degrees]	"O" Diameter [inches]	Sprue Length [inches]	Base Diameter [inches]
2.4	9/32	1.5	0.343
2.0	9/32	1.5	0.333
1.0	9/32	1.5	0.307
2.4	9/32	3.0	0.405
2.0	9/32	3.0	0.386
1.0	9/32	3.0	0.333

A cooling circuit is more forgiving for amorphous resins like sulfone polymers. Unlike semi-crystalline polymers, sulfone polymers do not have a distinct melting point. Therefore, their viscous nature and non-shear thinning characteristic generates more heat as shear rates increase, making a cooling circuit for sprue bushings a beneficial modification.

The cooling circuit also minimizes the formation of shrinkage voids. Voids can form in the sprue and are typically located in the thickest area, the base of the sprue. Voids that form at the base of the sprue adjacent to the part surface will leave a hole/divot when the sprue is removed. If the void forms in another area of the sprue, it can weaken the sprue and cause intermittent sprue breakage, which leads to cycle interruptions and scrap parts.

After the mold and sprue bushing reaches thermal equilibrium, voids will likely migrate to the base of the sprue because it is the thickest section and the tool surface temperature is the hottest just under the sprue gate. The shrink void can move up and down the sprue, but will most likely reside in the base of the sprue once the process equilibrates (Figure 4).

Figure 4: Void formation in sprue before

Before equilibrium

At equilibrium
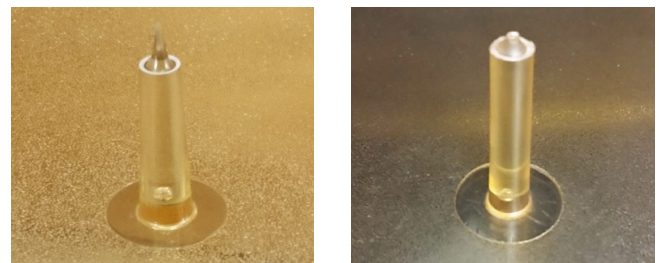
A cooling circuit in the tool just under the gate will keep the shrink void off the tool surface. Adding a BiCu insert on the core surface just below the sprue in combination with the cooling circuit should ensure that voids are formed in the sprue and not on the part surface.

Typical Method for Sprue Gate Selection

Sprue gate dimensions are typically selected using general guidelines. The base diameter is about 1.5 to 2 times the wall thickness. The "O" diameter is selected based on the typical diameter of the mating nozzle tip. For a nominal cost, a custom sprue gate can be machined with specific "O" and base diameters.

For inch-sized sprue bushings, the standard "O" diameters are 5/32, 7/32, 9/32 and 11/32 inches. They mate with respective nozzle tip sizes of 4/32, 6/32, 8/32 and 10/32 inches. Selecting the "O" diameter and length dimension will fix the total specification of the sprue bushing, including the base diameter since the taper angle is fixed at 2.38 degrees.

For faster cycle times, use the smallest feasible sprue gate. The process used to determine a sprue gate size is shown below:

Part dimensions:

- 12 × 12 × 4-inch deep pan
- 0.110 inch wall thickness
- Sprue length = 3 inches

Selecting a 9/32-inch "O" diameter fixes the base diameter to 0.405". The base diameter is extremely thick relative to the 0.110" part thickness. A more appropriate base diameter is 0.200–0.300 inches. A 5/32-inch "O" diameter will produce a 0.281-inch base diameter and a 3/32-inch "O" diameter will produce a base diameter of 0.209. Since each of these fit the recommended the base diameter to wall thickness ratio, 1.5 to 2 x wall thickness, and the criteria for a fast cycle time, it's reasonable to start with the 5/32-inch sprue bushing. The largest mating nozzle tip for this "O" diameter is a 4/32-inch (1/8-inch) orifice.

For this size pan, the volume of material is 36.36 in^3 and the part weighs 1.7 lbs. The typical injection time for filling a part without short shots and flow ripples would be about 3–4 seconds. A 3.5 second injection time corresponds to volumetric flow rate of 10.3 in^3/sec. The estimated shear rate in the sprue gate for this process can be calculated from the flow through a pipe using the formulation below:

$$\text{Shear rate} = 32Q/\pi D^3$$

Q = volumetric flow rate
D = diameter of the smallest orifice (0.125")

In this example, the calculated shear rate = $(32 \times 10.3)/(\pi \times 0.125^3) = 53{,}743$ s^{-1}. Because the maximum shear rate recommended by MoldFlow® for most amorphous resins is 50,000 s^{-1}, the calculated shear rate of 53,743 s^{-1} indicate that the process would be hampered with streaking, gate blush and other signs of material degradation associated with the excessive shear rate.

One possible solution is to buy the next larger size sprue bushing. The 7/32-inch sprue bushing matches with a 6/32-inch nozzle tip. The calculated shear rate is 15,915 s^{-1} and the associated base diameter is 0.310 inches. Other options would be either to use the standard 5/32-inch sprue bushing and ream out the "O" dimension to 7/32 inches or to purchase a custom sprue bushing where the "O" diameter and base diameter are specified based on the part size and expected volumetric flow rate. Either alternative will help minimize the shear heating and cycle time.

If a more precise calculation of sprue gate design is required, flow simulations can be used to assist customers in specifying the best sprue gate for their application. Using the physical and rheological properties of these flow simulators, an accurate assessment of the shear rate and temperature distribution can be obtained to provide a robust sprue gate configuration (i.e., a gate configuration with the "O" diameter large enough to reduce shear heating, the proper draft angle for easy release, and a minimal base diameter for faster cycle times). These dimensions will be calculated based on sprue length and volumetric throughput.

The information required to evaluate a sprue gate includes:

- CAD model of the part
- Processing information (mold and melt temperatures)
- Volumetric flow rate
- Injection pressure limit of molding machine
- Length of sprue
- Typical "O" dimension limitations for the injection molding machine

With this information, it is possible to determine the best sprue gate configuration based on the shear rate and temperature profiles from a flow analysis.

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