VI. Molding from the Desk

- **Press Calculations**
- **Injection Unit Calculations**

Before proceeding with a molding lab, you should have determined several factors such as:

- clamping force
- space between tie-bars in the platen
- maximum and minimum opening of the mold
- nozzle tip and bushing
- transfer position to hold
- barrel temperature
- injection unit size
- backpressure
- recovery position
- intensification ratio

These initial calculations (Molding from the Desk) give you a starting point and save you time during startup. Avoid costly errors when determining these initial parameters.

Press Calculations

Your goal should be to identify your process' needs and address those needs with well-thought-out solutions. Because of this:

- Before molding, or making some adjustments to the injection machine, you should make some initial calculations.
- We call these initial calculations "Molding from the Desk".
- Remember that you are working with expensive equipment; do not rush the job.

This section will cover:

- clamping force fundamentals
- projected area
- thin wall calculation
- forces resulting from side action mechanisms
- three-plate molds
- stack molds
- platen spacing on machines with tie bars
- platen spacing on tie-bar-less machines
- minimum and maximum press openings
- ejector patterns

Clamping force fundamentals

There is a difference between the clamping force the press is capable of, and the force required to keep the mold closed. The melt that flows into the mold cavities enters at high pressure, and the press must generate the force necessary to contain that pressure.

Force is usually measured in US tons (2000 lbf) or metric tons in kilo-Newtons (kN).

US ton = **8.90 kilo-Newtons (kN)**
metric ton = US ton x 1.10 = **9.81 kilo-Newtons (kN)**

We can determine the clamping force with the following equation:

Force = pressure x area

Melt pressure varies with the type of material. For example, each material has a pressure factor measured in units of force/area.

Some of these pressure factors are:

Material	US ton/in²		kN/cm²	
Polypropylene	1.5	3.5	2.1	4.8
High density polyethylene	1.5	2.5	2.1	3.5
Low density polyethylene	1.0	2.0	1.4	2.8
Nylon 66	3.0	5.0	4.1	6.9
Polycarbonate	3.0	5.0	4.1	6.9
Flexible PVC	1.5	2.5	2.1	3.5
Rigid PVC	2.0	3.0	2.8	4.1
Polystyrene	2.0	4.0	2.8	5.5

VI-1. Table of pressure factors for some materials

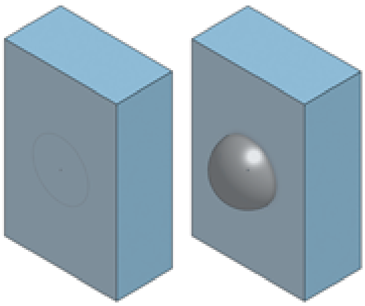
The table is a reference only; corroborate each resin's specifications with its manufacturer.

Projected area

The projected area is the plane or surface that you would see in the mold's partition, or parting line. For example:

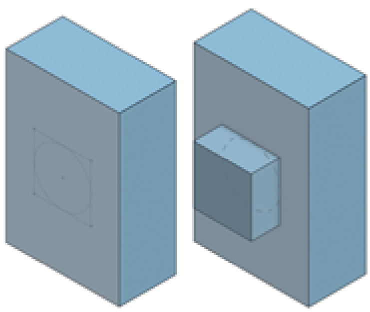
- A sphere's parting line would look like a circular plane, and the area would be equal to:

$$\text{diameter}^2 \times 3.1416 / 4$$



VI-2. Projected area of a sphere

- A cube's parting line would look like a square or rectangular plane. The area would be the length multiplied by width.



VI-3. Projected area of a cube

- In a cup, the largest diameter is at the mold partition. The area would be equal to:

$$\text{largest diameter}^2 \times 3.1416 / 4$$

VI-4. Projected area of a cup

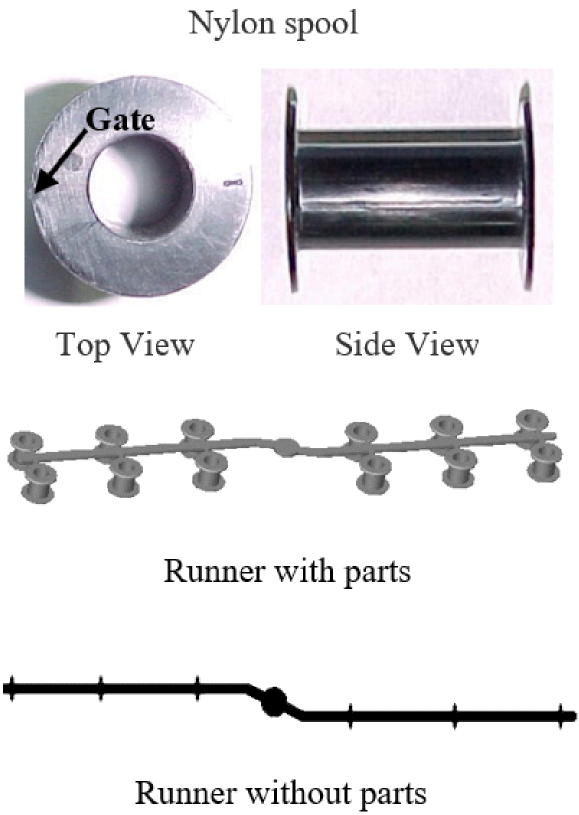
It's simple; if the projected area increases, the required clamping force will also increase. During the determination of a projected area, ignore the depth of the cavity.

There are several aspects to consider when determining the clamping force:

- the material and its characteristics
- understanding how the melt flow fills the cavities
- projected area of all cavities
- projected area of the runner
- type of mold, three plates or stack mold
- springs in the mold partition that act against the clamping force
- sliders with side action that add load to the clamping force
- that the clamping force of the press should always be greater than the clamping force required by the mold

Do not set the clamping force to maximum; excessive force could damage the cavities over time, especially the vents. Remember that gases inside the cavities and runner are expelled through small openings during fill. These very small spaces, or vents, allow these gases to escape. If the clamping force is excessive, the vents could choke. When this happens, it makes it difficult for the gases to escape. Some of these gases come from the melt, and at high pressures these gases could combust, an action known as "dieseling". Molded parts will show a burn at the end of the fill, near where the choked vents are.

Example (courtesy of Peter Paul Electric):
Nylon spools are molded using a 12-cavity mold.



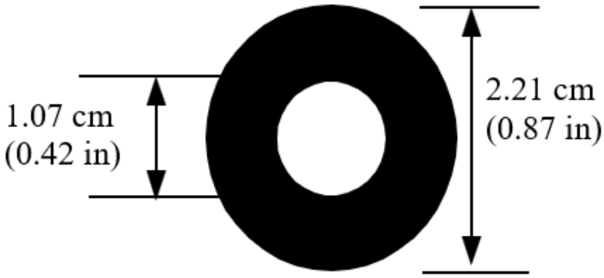
VI-5. Nylon spools and runners with and without parts

In this example the clamping force would be the result of:

- projected area of all cavities
- projected area of the runner
- slider action

The projected area corresponds to 12 circles with a hole in each center plus the area of the runner. The projected area of a circle with a hole in the center is calculated by subtracting the area of the minor (interior) diameter from the area of the major (exterior) diameter:

$$\text{Area of the parts} = \frac{D_{exterior}^2 - D_{interior}^2}{4}\pi$$



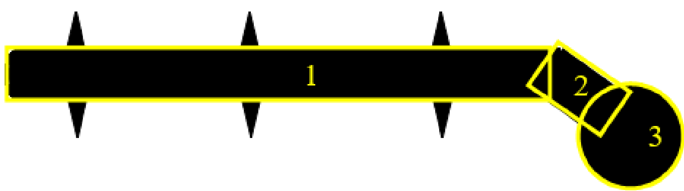
Area = $(2.21^2 - 1.07^2) \times 3.1416 / 4 =$ **2.94 cm² (0.46 in²)**

Projected area of the runner:

VI-6. Projected area of one of the 12 spools and its runner

The projected area of the runner can be simplified with a simple approximation using rectangles and a circle. Consider half of the runner composed of two rectangles (with area of length times width) and a circle (with area of diameter^2 x $\pi/4$).

The area of the runner would be the sum of four rectangles and a circle.



VI-7. Area of the runner

Projected area of the runner = 35.29 cm^2 (5.47 in^2)

Note that, for this approximation, the area where the gates are is not considered; we assume that amount is insignificant.

With irregular geometry, where the calculation of the area cannot be performed by conventional equations, graph paper is a good option. Trace or draw the component on the paper, counting the squares within the drawing (considering 1/2 and 1/3 squares if possible), then multiplying by the area of each square.

Another alternative would be to use the area function of a CAD program; for this you will need a drawing of the component in digital form.

Finally, add all the areas:

$$\begin{aligned}\text{Total area} &= \text{area of the runner} + (12 \text{ x spool area})\\ &= 35.29 + (12 \text{ x } 2.94) = \mathbf{71\ cm^2}\\ &= 5.47 + (12 \text{ x } 0.46) = \mathbf{11\ in^2}\end{aligned}$$

From resin manufacturer XYZ, a clamping force factor was obtained for nylon of 4.1 to 6.9 kN/cm^2 (3 to 5 USton/in^2).

If we use a pressure factor of 4.1 kN/cm^2 (3 USton/in^2), the required force is:

$$71\text{ cm}^2 \text{ x } 4.1\text{ kN/cm}^2 = \mathbf{291\ kN}$$
$$(11\text{ in}^2 \text{ x } 3\text{ ton/in}^2 = \mathbf{33\ USton})$$

If we use a pressure factor of 6.9 kN/cm^2 (5 USton/in^2), the required force is:

$$71\text{ cm}^2 \text{ x } 6.9\text{ kN/cm}^2 = \mathbf{490\ kN}$$
$$(11\text{ in}^2 \text{ x } 5\text{ ton/in}^2 = \mathbf{55\ USton})$$

You should be wondering; What pressure factor do we use, 4.1 or 6.9 kN/cm^2? The pressure factor will depend on the difficulty of filling the mold.

For example, if we consider that:
- thin walls will require higher fill pressures than thick walls
- a large fill travel will require more pressure than a short fill travel

The pressure factor will depend on a thin wall calculation, a value that considers the fill distance and the thickness of the spaces.

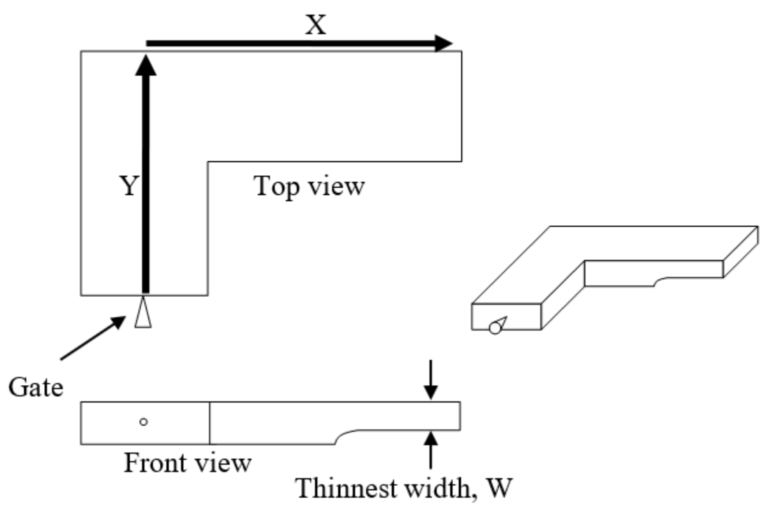
Thin wall calculation

A thin wall calculation is a factor that represents fill difficulty. This factor takes into consideration the distance that the melt must travel and how narrow those passages are. This factor is represented by the following equation:

$$Thin\ wall\ calculation = \frac{farthest\ flow\ path}{thinnest\ wall\ on\ the\ path}$$

- Thin wall calculation: a value that represents the fill difficulty; this difficulty increases when the value increases
- farthest flow path: the path of the flow from the gate to the farthest fill point
- thinnest wall on the path: the width of the thinnest wall on the farthest flow path

In the example below, there is an L-shaped part.

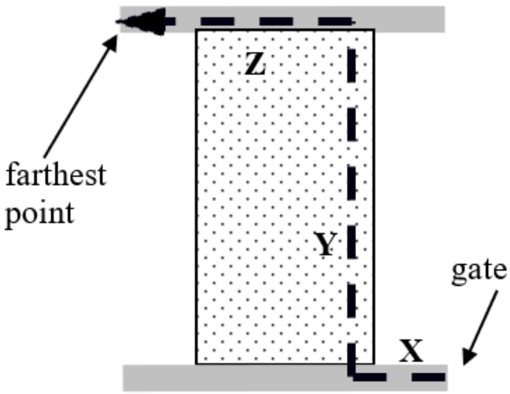


VI-8. Example of an L-shaped part

The farthest flow path can be approximated by the sum of X and Y. The thinnest wall of the path is W. So:

$$\text{Thin wall calculation} = (X + Y) / W$$

Let's continue with the spool’s thin wall calculation. The path from the gate to the selected farthest point is indicated by the dashed line.



VI-9. Flow path of a spool

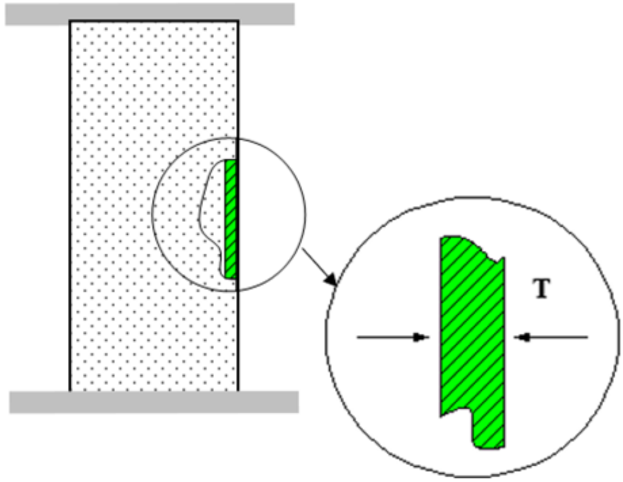
The farthest flow path would be the sum of X, Y, and Z.

You must be wondering, if the spool is a cylindrical part with a hole in the center, how can the path be represented linearly?

Good question, the melt will flow along the path of least restriction, and the path of Y is probably diagonal and around the circumference of the spool. If you have a numerical flow analysis program, excellent; use it. However, remember that we are molding from the desk; do not try to complicate your life with calculations that will not necessarily give you the best results.

$$\text{Farthest flow path} = X + Y + Z = \mathbf{50\ mm\ (1.97\ in)}$$

Now let's look at the thinnest wall from the path chosen in the illustrated drawing, where we find that the thinnest wall was found to be the central wall of the spool; and let’s call this thickness T.



VI-10. Thickness (T)

T = **1.22 mm (0.048 in)**

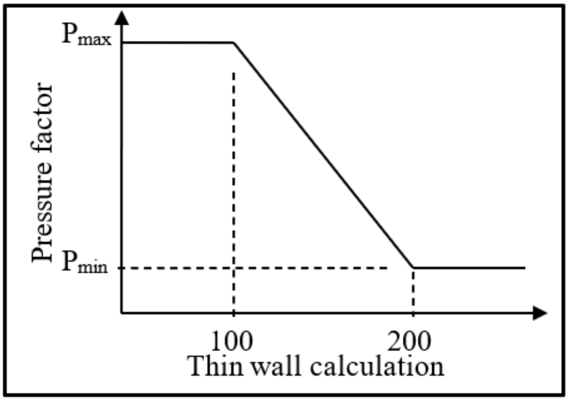
Select the thickness within the chosen path. Remember that there is a relationship between the flow path and the thickness of the walls. If you want, you can do several thin wall calculations with distinct paths. Once again select the thinnest wall within each chosen path; then use the largest value calculated as it will represent the worst condition.

Thin wall calculation (*TW*) of the spool = 50 mm /1.22 mm
= **41**

TW	Criteria
$\geq$200	Use the highest pressure factor. Force = (projected area) x (**highest** pressure factor)
$\leq$100	Use the smallest pressure factor. Force = (projected area) x (**smallest** pressure factor)
between 100 and 200	Interpolate between pressure factors. Force = (projected area) x (**interpolated** pressure factor)

VI-11. Table of thin wall criteria

The interpolated pressure factor is obtained with a linear interpolation.



VI-12. Linear interpolation of the pressure factor

$$Pressure\ factor\ = \frac{(TW - 100)*(P_{max} - P_{min})}{100} + P_{min}$$

With the spool example, we have a nylon pressure factor of 4.1 to 6.9 kN/cm^2 (3 to 5 $USton/in^2$) and a thin wall value of 41. According to the indicated criteria, if less than 100, we will use the minimum pressure factor, 4.1 kN/cm^2 (3 $USton/in^2$).

That means that the normal clamping force, as a result of the projected area and the pressure factor, is:

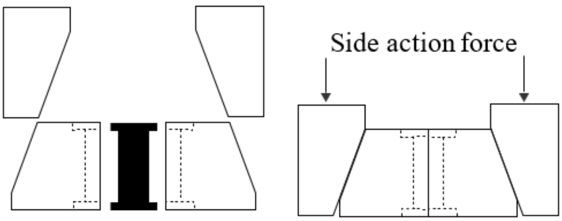
Normal force = pressure x area
= 71 cm^2 x 4.1 kN/cm^2 = **291 kN**
(=11 in^2 x 3 ton/in^2 = **33 USton**)

Forces resulting from side action mechanisms

One of the reasons for selecting the spool as an example is because it includes more than a simple force calculation due to the projected area in the partition of the mold. The clamping force can also be affected by forces resulting from mechanisms that act laterally.

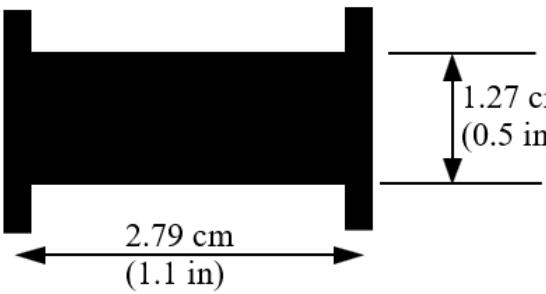
These mechanisms are part of the mold cavities and stay in position while the mold is closed. After the mold opens those mechanisms move, freeing the molded parts. These lateral forces are reflected in the clamping force, since it is the press that keeps these mechanisms in position.

Notice in the illustration how the cavity separates to free the molded part.



VI-13. Side action mechanisms (sliders) driven by clamping force

Each cavity is split in the middle by means of two sliders that will experience a force as a result of the melt pressure. This force will be the result of melt pressure (4.1 kN/cm^2) multiplied by the projected area in the cavity partition. With the area in the partition, we can assume that the extremities have an insignificant area, so our calculations will be based on the area of a rectangle.



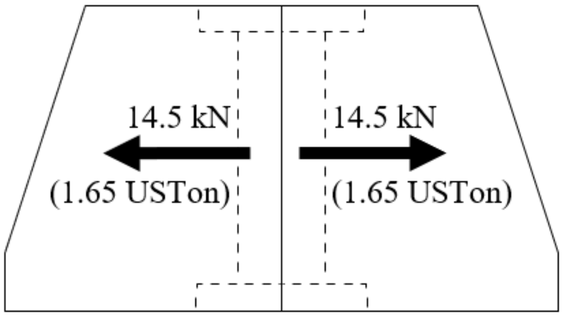
VI-14. Measurements to calculate the projected area

Lateral projected area =
1.27 cm x 2.79 cm = **3.54 cm^2**
(0.5 in x 1.1 in = **0.55 in^2**)

Then:

$$\text{Lateral force per slider} = \text{lateral projected area x pressure factor} =$$

$$3.54\ \text{mm}^2 \times 4.1\ \text{kN/cm}^2 = \mathbf{14.5\ kN\ /\ slider}$$
$$(0.55\ \text{in}^2 \times 3\ \text{USton/in}^2 = \mathbf{1.65\ USton\ /\ slider})$$



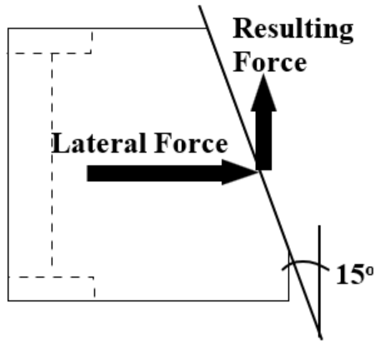
VI-15. Lateral force per slider

According to this number, each half of the cavity will see a force of 14.5 kN (1.65 USton) trying to move the sliders away.

Considering that there are 12 cavities and that each is kept closed by wedges, the total lateral effect could be determined by the following equation:

$$\text{Lateral force} = \text{force per slider x 2 sliders x 12 cavities}$$
$$= 14.5\ \text{kN} \times 2 \times 12 = \mathbf{348\ kN}$$
$$(1.65\ \text{USton} \times 2 \times 12 = \mathbf{40\ USton})$$

This number, 348 kN (40 USton), is the total force that the melt will exert laterally against the wedges.



VI-16. Resulting force

These wedges are manufactured with an angle, in this case 15°, and only a fraction of this lateral force will be seen in the direction of the closing of the wedges.

This resulting force in the direction of the press is determined by multiplying the lateral force by the tangent of the wedge's angle:

Force as a result of lateral action
= lateral force x tan (15°)
= 348 kN x 0.27 (40 USton x 0.27)
= **94 kN (10.8 ton)**

The total clamping force required for the mold would be the sum of the force resulting from the melt in the mold partition and the lateral action force of the cavities.

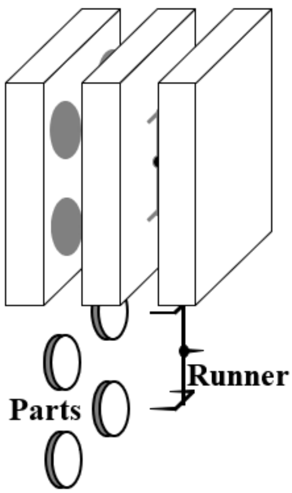
Final force = normal force +lateral action force
291 kN + 94 kN = **385 kN**
(33 USton + 10.8 USton = **43.8 USton**)

"Molding From the Desk" is an exercise that we must all perform before attempting to adjust the press; even if the mold maker recommends a clamping force, it should be corroborated.

The easiest, but not correct, thing to do would be to adjust the clamping force of the press to its maximum. Excessive force would eventually damage the mold by, for example, deforming the vents in the cavities. If the vents are blocked, then gases (air plus vapor from the same melt) inside the cavities could experience the dieseling effect, an explosion due to a combustion of gas at high pressures. The next time you find burn marks near the vents on the molded parts, verify the clamping force before attempting to repair the mold.

Other factors to consider are the springs. If your mold uses springs at the partition line and they are compressed when the mold is closed, add the force of each spring. The spring force factor can be obtained from the spring manufacturer.

Three-plate molds



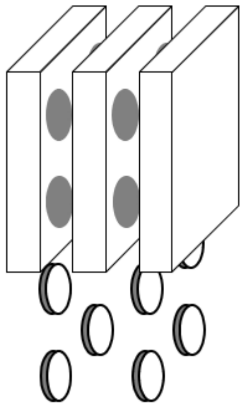
VI-17. Three-plate mold

This type of mold molds the parts and the runners in two distinct partitions. The mold is split into three, the parts are molded in one partition and the runner is formed in another. The purpose of this type of design is for molded parts, such as round parts, which need to be filled from the center.

Calculating the clamping force of a three-plate mold must be done twice, in the partition where the parts are molded and the partition where the runner is formed. Then, the largest of the two is selected. It is common for the force of the molded parts to be more than the force of the runner, but it is not true in 100% of the cases. Do the calculations and select the largest force.

Stack molds

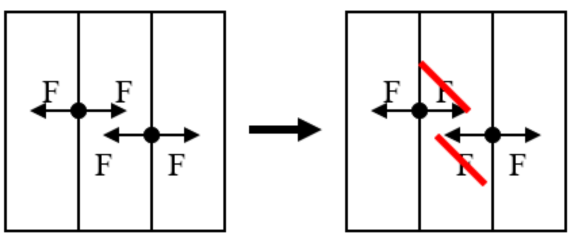
A stack mold has the same number of cavities in each partition side of the mold.



VI-18. Stack mold

If the same number of identical parts come out of each side, the clamping force on each side will be equal. Because of this, we only consider the clamping force of one side.

You must be wondering, why consider only one half instead of using both? That is what makes the stack design attractive, it produces twice the parts without needing twice the clamping force. Look at the illustration showing the force vectors.



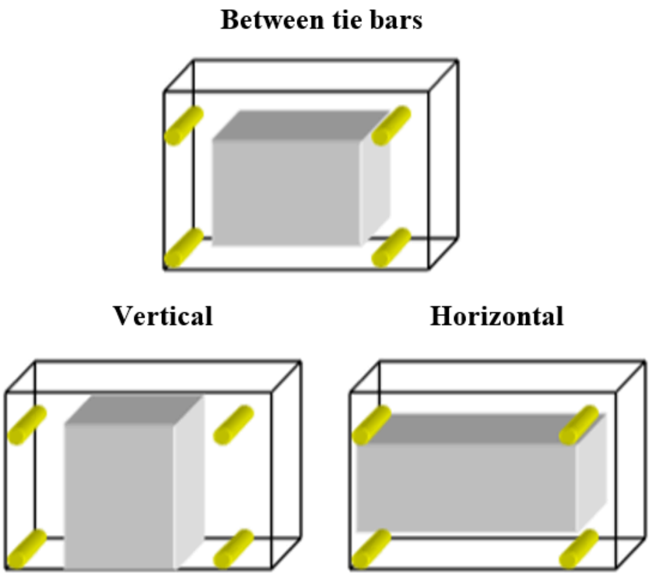
VI-19. Stack mold force vectors

Forces of equal magnitude in opposite directions will try to open each partition of the mold. The center vectors will cancel each other, resulting in the equivalent force of only one side.

In addition to the clamping force, you should verify that the mold fits properly in the press and that the ejector pattern of the press matches that of the mold.

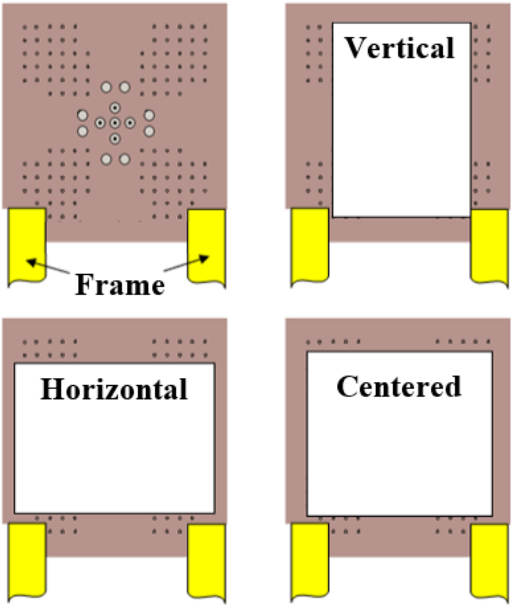
Platen spacing on machines with tie bars

If the press has tie bars, check that the mold fits in between them. It may fit inside the four tie bars, vertically between the bars, or horizontally between the bars.



VI-20. Platen spaces with tie bars

Platen spacing in tie-bar-less machines

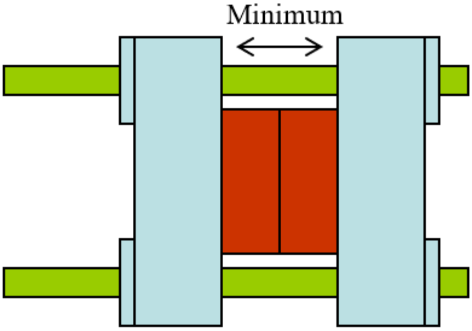


VI-21. Platen spaces on tie-bar-less machines

Tie-bar-less presses provide greater flexibility to accommodate the mold; even so, you must verify the available space.

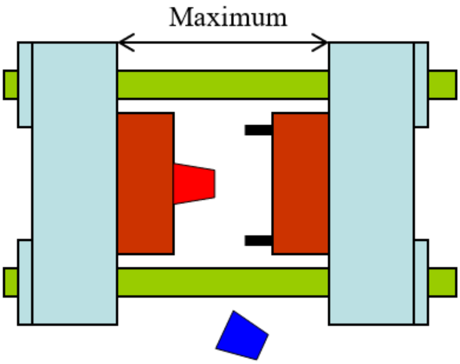
Minimum and maximum openings

Verify that the minimum press opening is enough to press the mold closed.



VI-22. Minimum press opening

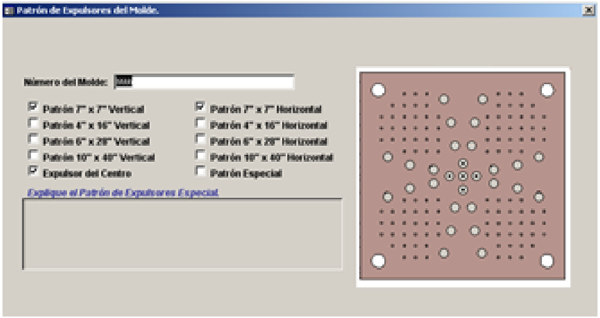
Also, verify that the mold opens enough so that the parts can be demolded.



VI-23. Maximum press opening

Ejector patterns

Verify that your machine has the ejector pattern required for the mold.



VI-24. Ejector pattern

Although most of these verifications appear to be simple and obvious, do your job and verify anyway. Those who have been present when a mold was transferred to the wrong press understand this advice, and those who have not witnessed it need to make the calculations to avoid it.

Questions

1) The chosen clamping force must be
   a. the maximum force that the press is capable of.
   b. the clamping force required by the mold.
   c. the maximum capacity of the hydraulic pump.

2) There is a 16-cavity mold that makes discs with a diameter of 0.5 inches. The projected area of each disc is 0.2 in^2. The projected area of the runner is 1 in^2. The thin wall calculation (*TW*) gives a value of 50. The material is polystyrene with a pressure factor of 1.5 to 3 ton/in^2.

2a) What is the total projected area?
   a. 16 cavities x 0.2 = 3.2 in^2
   b. 16 cavities x 0.2 + 1 from the runner = 4.2 in^2
   c. 0.2 in^2
   d. 1 in^2

2b) According to the thin wall calculation (*TW* = 50), the factor for polystyrene is
   a. 1.5 ton/in^2 since the *TW* is less than 100.
   b. 3 ton/in^2 since the *TW* is greater than 200.
   c. 2.5 ton/in^2 since the *TW* is between 100 and 200.

2c) For a factor of 1.5 ton/in^2, the calculated clamping force is
   a. 1.5 x 4.2 in^2 = 6.3 tons.
   b. 3 x 4.2 in^2 = 12.6 tons.
   c. 1.5 tons.

3) Excessive clamping force strangles a mold's vents. This can cause internal combustion since the gases do not find a place to escape. This is resolved by
   a. increasing the clamping force.
   b. enlarging the vents.
   c. cleaning the vents and increasing the clamping force.
   d. adjusting the press to the required clamping force and cleaning the vents.

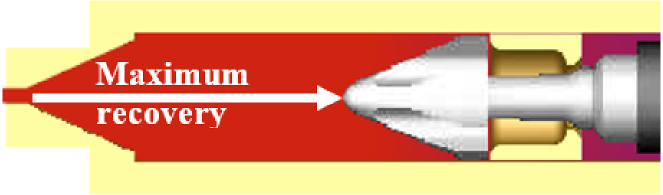
Injection Unit Calculations

In this section we will discuss:

- injection unit size
- nozzle tips and sprue bushings
- fountain flow effect
- density and specific density
- injection speed and injection flow
- barrel utilization
- recovery position
- residence time
- transfer position
- temperature profiles
- intensification ratio
- machine labeling

Injection unit size

The volume of the injection unit represents the maximum material capacity that the injection unit can charge during recovery.



VI-25. Maximum recovery

It is important to know that the recovery amount that the unit is capable of is greater than the amount required by the mold; in general, we say:

Maximum recovery > 30% more than what the mold requires

You may wonder why 30% more than what the mold requires. There are many reasons, such as: to guarantee a cushion after the hold stage, to compensate for the compressibility of the thermoplastic melt, to compensate for melt that returns to the other side of the check ring in the injection barrel, etc.

The factors that determine how much larger the barrel should be include:

- available recovery time
- whether the material is easy or difficult to melt
- whether the material degrades or resists long residence times in the barrel

The capacity of the injection unit is measured in volume, not by mass. If the size of the injection unit comes in mass units (ex: oz or g), you should know that it is generally based on the density of polystyrene (ρ = 0.94 g/cc or 0.54 oz/in^3).

Notes:

- Use volume values, not mass values, when specifying an injection unit.
- During your calculations, try to reach the specific density of the melt that is exposed to recovery temperature and pressure, not to ambient temperature and pressure.

Example:

Density of a polycarbonate, PC

= 0.95 g/cm^3 (melt)

= 1.2 g/cm^3 (solid)

= 1.04 g/cm^3 (plasticized)

Use the plasticized density, the density of the melt exposed to recovery conditions. Remember that thermoplastic melt is compressible. Some machine manufacturers call this recovery density the "discharge factor".

Example:
A polycarbonate with a plasticized density of 1.04 gr/cm^3 will fill a mold with a total weight, parts and runner, of 125 gr. According to the material manufacturer, barrel utilization should be between 45% and 60%. What would be the volumetric specifications of the barrel?

Injection volume required by the mold =
weight/density
= (125 g) / (1.04 g/cm^3) = **120.19 cm^3**

Utilization volume at 45% = 120.19 cm^3 / 0.45

$$= \mathbf{267.09\ cm^3}$$

The barrel should be less than 267.09 cm^3.

$$\text{Utilization volume at 60\%} = 120.19\ cm^3 / 0.6$$
$$= \mathbf{200.32\ cm^3}$$

The barrel should be more than 200.32 cm^3.

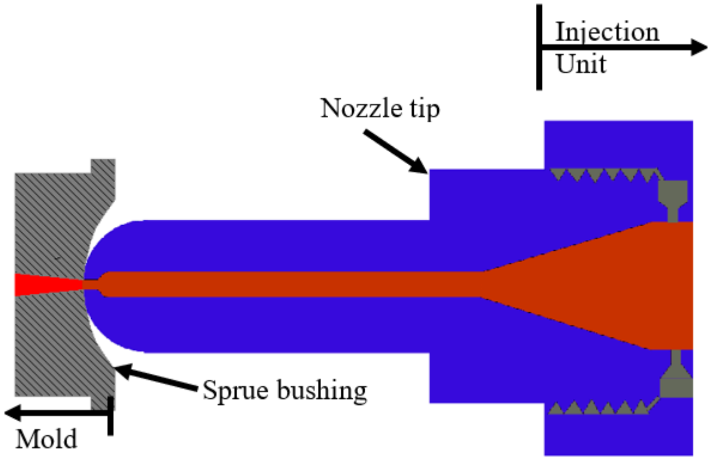
So, to meet the requirements of that PC, the volume of the injection unit should be between 200.32 cm^3 and 267.09 cm^3.

It is possible that you will not find the density of the material under the recovery conditions and will be forced to use a generic density or use density at ambient temperature and pressure.

Remember that you are working with thermoplastics, materials with properties that are functions of time, temperature, and pressure. If we add to this the large number of injection unit types, we can conclude that some calculation error will be present even with adequate density.

Nozzle tips and sprue bushings

The nozzle tip is installed in the injection unit, and the sprue bushing is installed in the mold. The injection unit generates the force required to keep them coupled together. If they separate while the mold fills, the melt could filter between them. As a rule, think of the nozzle tip as part of the mold.



VI-26. The nozzle tip and sprue bushing

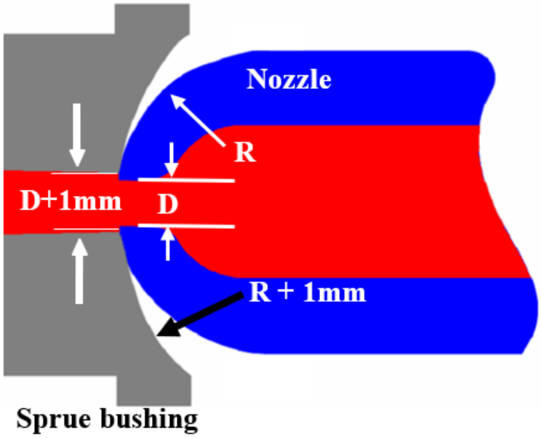
The nozzle tip is an important component, because of this the proper one should be selected and maintained at a specific temperature. This has more significant effects with semi-crystalline materials than with amorphous materials.

For example, with an amorphous material X, if the temperature is 50ºF above the required value, the nozzle could create a drooling effect and strings might be seen during the expulsion of the sprue. If the temperature is 50ºF under the required value, the nozzle could get stopped up or create cold slugs that could migrate to the mold.

Now, with a semi-crystalline material Y, if the temperature is only 5ºF over the required value, the nozzle could create the drooling effect, and strings might be seen during the expulsion of the sprue. If the temperature is only 5ºF under the required value, the nozzle could get plugged or create cold slugs that could migrate to the mold.

Diameter of holes and contact radii

Let's look at the diameter *D* and radius *R* of the nozzle tip in the illustration.

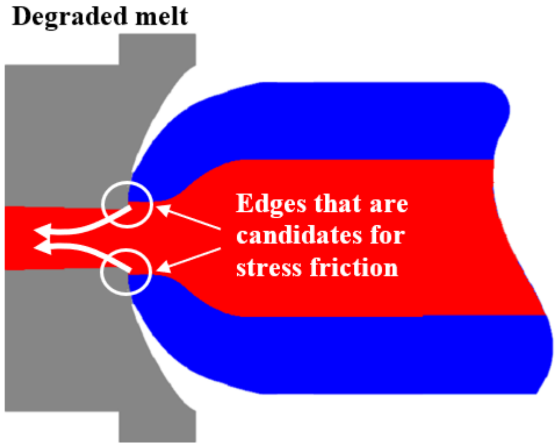


VI-27. Diameters and radii of the nozzle tip and sprue bushing

The diameter of the bushing's opening is 1 mm greater than diameter D of the opening of the nozzle tip. The contact radius of the bushing is 1 mm greater than radius R at the nozzle tip.

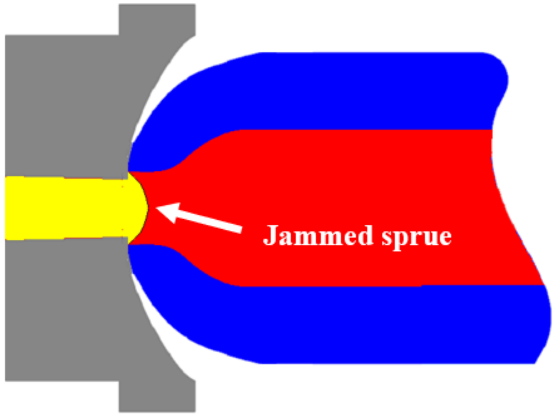
Before performing a ***Universal Molding***™ lab you should verify that the nozzle tip is properly sized. If it is incorrect, change it before starting.

Imagine what would happen if the diameter of the nozzle hole is larger than that of the bushing. A couple of defects could happen. One of them could be material degradation as a result of concentration of stress in the edges. That concentration of frictional stress would create degraded melt that could end up in the molded parts.



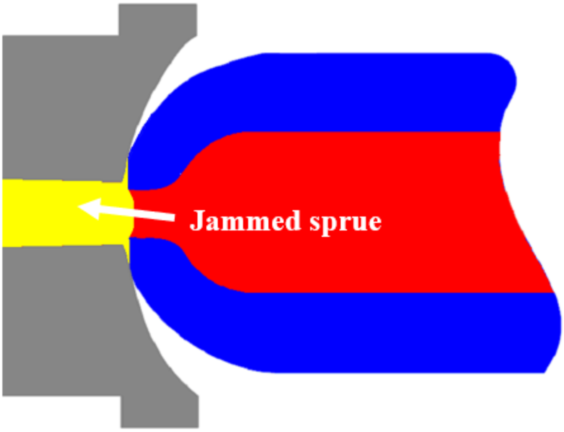
VI-28. Defect caused by stress concentration at the edge of the nozzle

Another defect seen in cold runner molds is that the sprue gets stuck in the nozzle. Remember that the sprue is part of the runner and should be ejected during demolding. In the example below, the sprue's solidified plastic has formed into the shape of a rivet head, which prevents it from ejecting.



VI-29. Defect caused by a sprue stuck in the nozzle

Now imagine what would happen if the radius of the nozzle tip is larger than that of the bushing. The melt could accumulate inside that gap and could cause the sprue to become stuck in place.



VI-30. Another defect caused by a sprue stuck in the nozzle

The sprue doesn’t always get stuck as a result of inadequate coupling between the bushing and the nozzle. Although it's often the case, it's not the only reason. For example, it sometimes gets stuck because the interior surface of the bushing was polished in a direction perpendicular to that of the sprue’s ejection. If that is the case, talk to the mold maintenance department and review the inner finish of the bushing.

This is why we prefer to say that the nozzle tip is part of the mold, even if it is installed in the injection unit. Some factories, when removing the mold for storage, also remove the nozzle and attach it to the mold.

Nozzle purge program

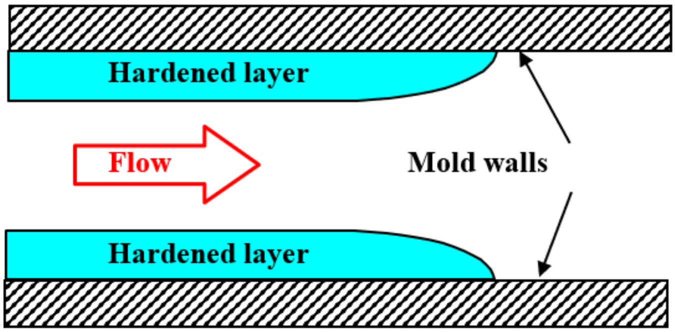
Some processes require special nozzle cleaning programs. This is seen more with molds for rigid PVC pipe joints. This material tends to be heat-sensitive and degrades easily. After each molding cycle, the injection unit pulls back, purging the small amount of plastic left in the nozzle.

This is done in order to remove any material remaining from the previous cycle. This purging would be used with single-cavity molds, usually large connectors. If the mold has multiple cavities, the degraded material will remain in the runner and will not need this program.

Never start a ***Universal Molding***™ lab without first installing the correct nozzle and sprue bushing combination.

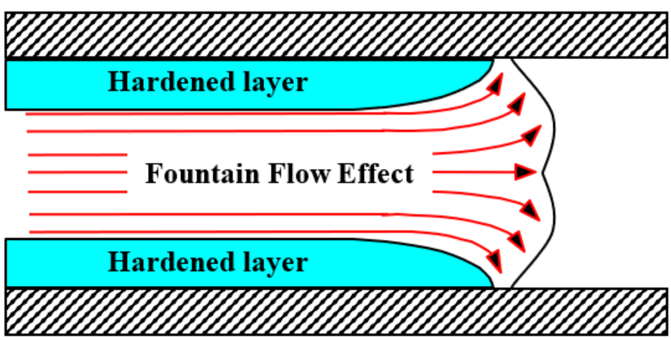
Fountain flow effect

The fountain flow effect describes the flow of a thermoplastic melt. Thermoplastic melt is compressible, opposes movement, and seeks to attach itself to the first static surface it finds. This opposition to flow is responsible for the fountain flow effect. Imagine melt flowing between the walls of a mold. The melt close to the metal surface of the mold will try to grab onto it and to any material already attached to that surface. That material in contact with the cold metal will create a layer of hardened material.



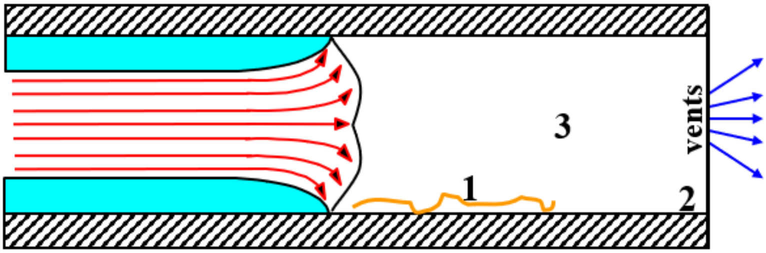
VI-31. Thermoplastic melt flow in a mold

The tendency would be to flow through the center in search of the opportunity to grab onto the first available static surface. It is this behavior that is responsible for the fountain flow effect that will be observed at the front of the melt flow. This means that the first melt that enters stays at the beginning of the mold.



VI-32. The fountain flow effect

Example: a piece of damp napkin is stuck to the surface of the cavity. The moisture is the only thing that is holding it. Once the mold closes, it is filled with melt in the indicated direction.



VI-33. Example of fountain flow effect using a piece of napkin

After filling, where will the paper napkin end up, position 1, 2, or 3?

It will stay perfectly flat on the surface where it was placed (position 1). Because of this effect, there is in-mold labeling technology.

Density and specific density

$$Density = \frac{mass}{volume}$$

$$Specific\ density = \frac{material\ density}{water\ density}$$

where the density of water is 1 **g/cm³** at room temperature and pressure.

Dividing cancels the units, so if you ever find a specific density without units assume it is in g/cm³. If you want to work with other units, find the density of water with the preferred units and multiply it by the specific density.

Injection speed and injection flow

Today it is common to see more molders using ***Universal*** parameters. They prefer these as these represent what the mold sees. A cavity represents a defined space or volume and is filled in an ideal time. From the mold's point of view, fill time is ***Universal*** and must be maintained. Imagine a scenario where you are forced to fill one less cavity in a mold, because the cavity was temporarily blocked for maintenance reasons. Apart from having to reduce the fill volume, you would also have to manipulate the injection speed to ensure the same injection time.

These days, it is common to see new machines provided with ***Universal*** parameters, such as injection flow instead of injection speed.

$$Injection\ speed = \frac{distance}{time}$$

$$Injection\ flow = \frac{volume}{time}$$

Injection flow (volume/time) is also ***Universal***. The relation between injection volume, area and screw diameter is:

Injection volume = (screw area) x (displacement)

$$Screw\ area = (screw\ diameter)^2 * \frac{\pi}{4}$$

We substitute in the flow equation and get:

Injection flow =

$$\frac{(screw\ diameter)^2 * \frac{\pi}{4} * (displacement)}{time}$$

or

$$= (screw\ diameter)^2 * \frac{\pi}{4} * (injection\ speed)$$

These are simple equations used by machine controllers to change from machine parameters to ***Universal***. If your machine is not able to work with ***Universal*** parameters, use these equations and make the determinations yourself.

Barrel utilization

Barrel utilization (*%U*) is a comparison between the maximum capacity of the injection unit and the capacity required to fill the mold.

$$\%U = \% \text{ of utilization}$$

$$\%U = \frac{(volume\ used)}{(volume\ the\ barrel\ is\ capable\ of)} * 100\%$$

Where:

volume used = the volume programmed to the mold's requirements
volume the barrel is capable of = the maximum recovery volume of the screw

Examples:

A barrel with a 35 mm screw, with a maximum recovery volume of 134 cm^3, needs to recover 62 cm^3. Since the machine's control is not ***Universal***, what would be its recovery displacement?

Knowing that:

$$Screw\ Area = (screw\ diameter)^2 * \frac{\pi}{4}$$

$$= (3.5\ cm)^2 * \frac{\pi}{4} = \mathbf{9.62\ cm^2}$$

Also, knowing that:

Injection volume = (screw area) x displacement
Displacement = (injection volume) / (screw area)

$$= (62\ cm^3) / (9.62\ cm^2) = \mathbf{6.44\ cm} \text{ or } \mathbf{64.4\ mm}$$

According to this calculation, the recovery displacement should be 64.4 mm (2.54 in).

How much would the percentage of utilization be?

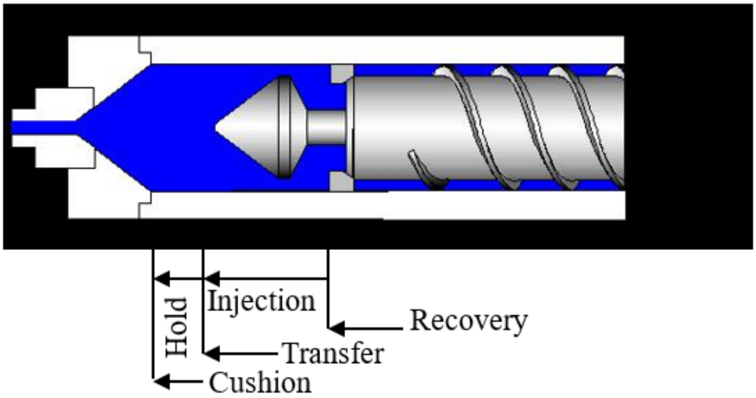
$$\%U = \frac{(volume\ used)}{(volume\ the\ barrel\ is\ capable\ of)} * 100\%$$

$$\%U = \frac{62cm^3}{134cm^3} * 100\% = 46\%$$

According to this calculation, the percentage of utilization is equal to 46%.

Are these recovery adjustment calculations reliable? They are a reference, since the final adjustment will be affected by the melt temperature, backpressure, leaks in the check ring, and the time it takes the check ring to seal.

Let's review:



VI-34. Fill positions

During recovery the screw rotates, forcing the melt to the front of the ring, pushing the screw back, and stopping when it reaches the desired recovery position. Once the signal giving permission to inject occurs, the screw will quickly inject until reaching the transfer position. Once the transfer position ends the hold stage begins; this is when the melt is compacted until the all the cavities are completely filled. The final position of the screw is called the cushion.

In the recovery stage we fill the barrel with a homogeneous melt. This normally happens during the cooling stage. The control parameters are recovery time (or velocity) and backpressure. The recovery time should never exceed the cooling time; this applies to injection units that are not provided with a shut-off valve in the nozzle.

Backpressure can be seen as a force that opposes free movement of the screw during recovery. With an increase in backpressure comes an increase in the amount of mass. Even if the recovery volume is the same, since the melt is compressible, the amount of material will increase. In addition, it increases mixing, friction, recovery time, and material degradation.

Backpressure has a significant effect on melt. Because of this, it should not be changed once it is optimized.

It is recommended keeping backpressure as low as possible. It should be increased only when more melting is required or when better mixing is needed. An initial/reference backpressure setting is 750 psi (5MPa) of plastic pressure. Remember that plastic pressure is the pressure that the melt sees.

Again, we emphasize that an increase in backpressure means an increase in recovery material as well.

Recovery position

The recovery position is the place the screw should reach in order to fill the mold. This is the result of combining the cushion, hold displacement, and injection displacement. In addition:

$$\text{Recovery position} = \text{transfer position} + \text{injection displacement}$$

In this equation the cushion is considered within the transfer position. The determination of the transfer position will be discussed later.

Combining the equations of weight, density, and volume we summarize:

$$Injection\ displacement = \frac{1.27W}{D^2}$$

$$Recovery\ position = transfer\ position + \frac{1.27W}{D^2}$$

Where:

ρ = the melt's specific density (g/cm^3)
W = weight of parts and runner (g)
D = diameter of the injection screw (cm)

This displacement is the distance between the recovery position and the transfer position. Note that this equation does not consider that, during injection, only about 95% of the mold is filled. This excess is ignored due to the fact that, during the injection stage, some material always sneaks to the other side of the check ring, whether during check ring closure or as a result of leaks between the check ring and the barrel.

It is imperative to clearly understand the effect of melt density during the determination of positions. During "molding from the desk", initial screw positions are established, which may change during the process optimization labs. The density value provided by the raw material supplier can vary by more than 20%, since thermoplastic melts are compressible, and their density is influenced by melt pressure and temperature. During recovery, parameters such as back pressure and barrel zone temperatures affect this density. Additionally, determining the recovery positions becomes complicated if part of the melt passes to the other side of the check ring during injection. For this reason, optimization labs determine what ***Universal*** molders call discharge density, to correct these positions.

Discharge density

Discharge density is more precise for determining the recovery positions, since it considers several factors:

- mass
- volume
- melt temperature
- back pressure
- melt leakage through the check ring during injection

This density is calculated in an existing process by measuring the injected volume and the total injected weight. The injected volume is determined using the equation of a cylinder:

$$\text{Volume} = \text{area x length}$$

Where:

$$Area = (screw\ diameter)^2 * \frac{\pi}{4}$$

$$\text{Length} = \text{recovery position} - \text{cushion position}$$

To obtain this data in an existing process:

- The recovery and cushion positions can be obtained by navigating through the control pages.
- The injection weight is determined by weighing the molded parts plus the runner (if one exists).
- Finally, the discharge density is calculated by dividing mass by volume:

$$\text{Discharge density} = \frac{total\ injection\ weight}{((screw\ diameter)^2\ x\ \pi/4)\ x\ (recovery\ position - cushion\ position)}$$

If the discharge density is known, the injection displacement equation would look like this:

$$Injection\ displacement_{95}\ XE\ "desplazamiento\ de\ inyección" = 95\% \frac{1.27}{{}_d}$$

$$\text{Recovery position} = transfer\ position + 95\% * \frac{1.27W}{{}_d D^2}$$

Where:

ρ_d = discharge density (g/cm³)
W = weight of the parts with the runner (g)
D = diameter of the injection screw (cm)

Example:

There is a process with a demolding weight (parts and runner) of 17.5 grams, with recovery and cushion positions of 50.3 mm and 4.5 mm respectively, and the injection unit has a 25 mm screw. What is the discharge density and the injection displacement$_{95}$?

Discharge density (g/cm^3) =

$$\frac{Shot\ weight}{[D^2\ x\ \pi/4]\ x\ [recovery\ position - cushion\ position]}$$

$$= \frac{17.5\ g}{\left[(2.5cm)^2\ x \frac{\pi}{4}\right] x [5.03cm - 0.45cm]} = \mathbf{0.78\ g/cm^3}$$

$$Injection\ displacement_{95} = 95\% \frac{1.27W}{\rho_d D^2}$$

$$= 0.95 \frac{1.27x17.5g}{0.78 \frac{g}{cm^3} x\ (2.5\ cm)^2} = 4.33\ \text{cm} = \mathbf{43.3\ mm}$$

Note:
If you know the discharge density, ρ_d, then:

$$\text{Recovery position} = \text{transfer position} + 95\% \frac{1.27W}{\rho_d D^2}$$

This is because the discharge density considers the melt leaks during injection.

Recovery speed

Recovery speed is a parameter that we need to determine during molding from the desk. Currently, it can be adjusted in two ways:

1. revolutions per minute (rpm)
2. tangential speed (mm/s), which represents the linear speed of the screw along its circumference.

The relationship between these two parameters is defined as follows:

tangential speed = rpm x circumference
circumference = 3.1416 x D
D = diameter of the injection screw (mm)

The recovery speed should be adjusted so that recovery is completed before the expected cooling time ends. As a general rule, recovery should occur within 90% of the total cooling time. However, this speed must be determined empirically during the process, as the determination of rpm or tangential speed alone are not sufficient to ensure that the recovery will finish before cooling.
A more useful approach could be to calculate the recovery flow, which refers to the volume of material plasticized per unit of time. If we know the required volume to fill the cavity and the estimated cooling time, we can calculate the flow required to complete recovery with a 10% margin before cooling, using the following formula:

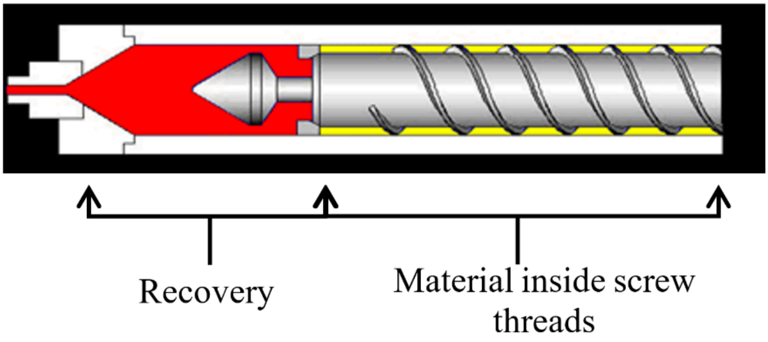
$$Recovery\ flow = \frac{recovery\ volume}{0.9\ x\ cooling\ time}$$

Unfortunately, many equipment manufacturers underestimate the importance of this parameter and do not incorporate it into their machine control systems.

Residence time

Residence time is defined as the time from which the material enters the injection unit to the time it is injected into the mold. In addition, if the mold includes hot runners, the time that the melt resides in the manifold should also be considered.

Another definition is that of the residence volume, the maximum amount of material that resides inside the barrel. Residence volume is greater than that of maximum recovery, since it also considers the volume of the material located between the screw threads.



VI-35. Residence volume

To determine the residence time, the volume of material residing in the screw threads, V_r, must be calculated. Determining the volume between the screw threads' complex geometry could be tricky. However, there is a simplified way to estimate V_r by assuming that it is 40% greater than the screw's maximum recovery capacity, V_{max}.

$$V_r = V_{max} \text{ x } 1.4$$

For example:

How much material lies in the screw threads of a 40mm barrel, which has a maximum injection capacity of 250.5 cc?

$$V_r = V_{max} \text{ x } 1.4 = 250.5 \text{ cc x } 1.4 = \mathbf{350.7\ cc}$$

Residence time T_r is measured in cycles and is determined by rounding to the next whole number of:

$$T_{\mathrm{r}} = 1.4V_{max}/V_{req}$$

Where:

V_{max} = maximum injection volume
V_{req} = volume required by the mold

The results of the equation for T_r is rounded to the next whole number, since decimals represent the fraction of uninjected melt that will reside in the barrel for an additional cycle, and not a fraction of a cycle.

The unit of residence time is cycles since we are molding from the desk and do not know the final duration of the cycle. Once molding is complete and we know the optimized cycle duration, it could be converted into seconds.

Another method with equal results is to use the % of utilization (*%U*).

$$T_r = 140 / \%U \text{ rounded to the next integer}$$

Where: $\%U = [V_{required} / V_{max}]100\%$

Example:
A 250.5cc barrel is used to mold two molds. One requires 150cc, the other 35cc. What would be residence T_r for each mold?

$T_r = 1.4V_{max}/V_{required}$	=	T_r (to the next whole num.)
1.4(250.5) / 150	2.3	**3 cycles**
1.4(250.5) / 35	10.02	**11 cycles**

VI-36. Table showing example of residence T_r

Or just use the following table:

%U	T_r (# of cycles)
1%	140
2%	70
3%	47
4%	35
5%	28
6%	24
7%	20
8%	18
9%	16
10%	14
11%	13
12%	12
13%	11
14% - 15%	10
16% - 17%	9
18% - 19%	8
20% - 23%	7
24% - 27%	6
28% - 34%	5
35% - 46%	4
47% - 69%	3
>70%	2

VI-37. Table of residence time, according to % of utilization

***%U* based on industry type**	**Min**	**Max**
General Molding	10%	80%
Precision	20%	65%
Optical Applications	20%	80%
High Speed	15%	40%
Reinforced with Fibers	20%	65%
Rigid PVC	20%	85%

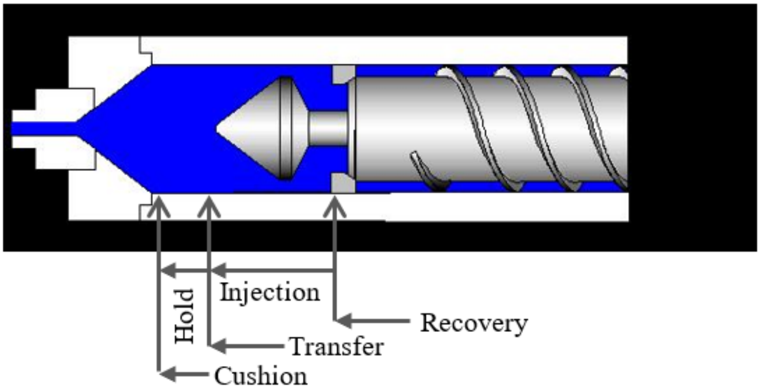
VI-38. Table showing % of utilization according to industry type

Examples:

- The high-speed industry typically has limited recovery times. Consequently, it will require a low *%U* (between 15% to 40%), or what would be equal to, for example, high melt residence (4 to 10 cycles), so that the plastic has enough time to melt.
- The heat-sensitive materials industry, such as those which use rigid PVC, demands a high *%U*, or in other words, low residence times, to avoid material degradation.
- If the *%U* is very low you could have trouble controlling the cushion, as it would not have enough injection displacement to close the screw's check ring.

Transfer position

The transfer position is the position where the injection ends and hold begins. Remember that transfer is a screw position that corresponds to about 95% of the mold filled with compressible melt.



VI-39. Transfer position

Important facts:

- If the transfer position is too premature, the screw could create the bounceback effect.
- If the transfer position occurs too late, the screw can reach the end of the barrel, or rather zero cushion, and could create short pieces.

- What stops the screw after transfer is the melt in front of the check ring.
- From the barrel's point of view, the transfer position is reached when the injection volume is close to 95%. From the mold's point of view, at the instant at which the transfer position is reached, the volume that the melt occupies in the mold is less than what was injected. Remember that melt is compressible and will gradually expand.

After examining dozens of processes, interviewing multiple molders, and reviewing several manuals of various injection machines, the criteria used to determine transfer position was obtained through experimentation.

With machines under 400 metric tons

% of Utilization	35% or less	65% or higher	between 35% and 65%
Transfer	6 mm (0.25 in)	12 mm (0.5 in)	Interpolate

With machines larger than 400 metric tons

% of Utilization	35% or less	65% or higher	between 35% and 65%
Transfer	12 mm (0.5 in)	25 mm (1.0 in)	Interpolate

VI-40. Tables showing transfer position criteria

Once the transfer position has been obtained, convert it to volume (***Universal*** unit).

$$\text{Transfer volume} = \text{transfer position x screw area} = \text{transfer position x (screw diameter}^2 \text{ x } 3.142 / 4)$$

The change must occur so that the screw's final position is greater than zero and less than the transfer position.

In the event of a defective mold requiring a transfer position other than the calculated one:

- if it is economically viable, repair the mold.
- if it is not, you will have to make the necessary changes and document them.

Examples:

1. A mold installed in a 160-ton press requires a fill volume of 120cc, and the barrel can be filled up to 160cc.

   Percentage of utilization = (120/160) x 100% = **75%**

   Since the % of utilization is greater than 65% and the press is less than 400 tons, the calculated transfer position would be 12mm.

2. A mold uses 50% of a barrel in a 200-ton press. To obtain the transfer position, you would have to interpolate between 6 and 12mm.

3. The recommended transfer position for a mold that uses 30% of the barrel would be 6 mm if the press is less than 400 tons and 12 mm if it is greater than 400 tons.

Summary

The screw positions are determined using the following:

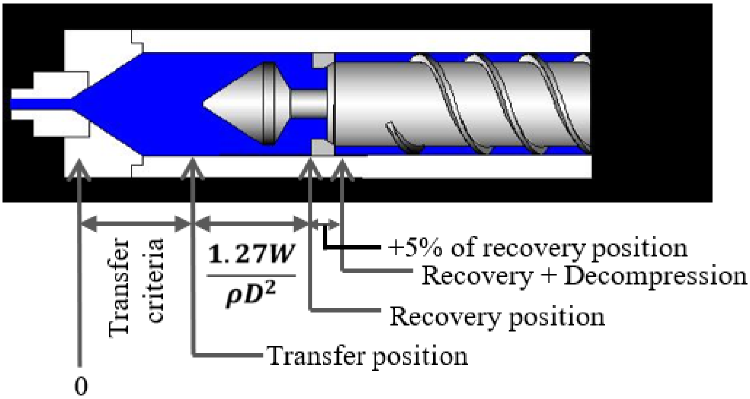
$$\text{Transfer position} = \text{use the } \%U \text{ criteria}$$

$$\text{Recovery position} = \text{transfer position} + \frac{1.27W}{\rho D^2}$$

or if discharge density is known, then use:

$$\text{Recovery position} = \text{transfer position} + 0.95\frac{1.27W}{\rho_d D^2}$$

$$\text{Recovery + Decompression} = \text{add 5\% of recovery position}$$



VI-41. Screw positions

Remember that you are molding from the desk, determining values that will be verified once the ***Universal Molding™*** *lab* is performed.

Temperature profiles

When we talk about temperature profiles, we mean the heat zones of the barrel. Heat zones are front, central, and rear.

VI-42. The barrel's heat zones

Each of these temperatures measures the steel temperature.
The main objective is to determine the temperatures before starting production to ensure optimal recovery and obtain the most significant temperature: that of the melt.

Resin suppliers typically recommend temperature ranges (upper and lower limits) for each barrel and melt zone.

To establish these temperatures, we consider three criteria:
1. **Thin wall (*TW*)**:
The thin wall represents the filling difficulty. It is calculated as:

PF = (farthest flow distance) / (thinnest wall in that flow path)

2. **Percentage of Utilization (*%U*)**:
This compares the maximum barrel capacity with the capacity required to fill the mold:

$$\%U = (\text{volume used / barrel capacity}) \times 100\%$$

3. **Cycle Duration:**
This is the time between demolding parts. Long cycles are common in overmolding processes, where the cycle extends due to the removal of molded parts and the placement of a new insert, which prolongs the residence time of the melt in the barrel and the hot runner.

The most common criterion is as follows:

- If $\%U \leq 35\%$, use the lower limit for each zone.
- If $\%U \geq 65\%$, use the upper limit for each zone.
- If $35\% < \%U < 65\%$, interpolate between the limits.

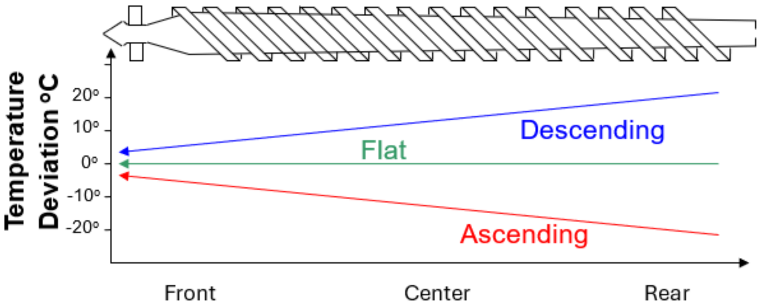
It is crucial to remember that the melt temperature is the most significant. If $PF \leq 100$, the melt temperature depends solely on *%U*. If $PF \geq 200$, the melt temperature is increased to compensate for filling difficulty. If the cycle extends due to part removal and insert placement, it will be necessary to reduce the temperature to correct excessive melt residence.

Examples:

- Low *%U* ($\leq 35\%$): molding caps.
- High thin wall (*PF*) (≥ 200): molding tie wraps, which are thin and extremely long parts.
- Long cycles: In the case of molding parts with more than one resin, such as toothbrushes where the handle is made of polystyrene with sections containing an elastomer, cycles can extend during automatic switching between the different components.

In conclusion, we must be cautious when determining barrel zone temperatures, always prioritizing the melt temperature.

The temperature profile is typically recommended by the material manufacturer. There are three basic temperature profiles: descending, ascending, and flat.



VI-43. Temperature profiles

The vertical coordinate corresponds to the temperature deviation, while the horizontal coordinate corresponds to the heat zones.

Ascending profile - Temperatures go from low to high, and this profile is regularly used in situations where the residence time of the plastic is extremely high (% of utilization less than 30%), so that it avoids premature or extended heating of the material.

Descending profile – Temperatures go from high to low, and this profile is recommended for materials with additives and hard-to-melt materials. It is also recommended in operations where residence time is small, with a % of utilization greater than 65%.

Flat Profile – Here all temperatures are set the same. This could be used with materials with no fillings or additives, in which the residence time is moderate.

Remember that this is a reference, consult with your resin supplier for the most suitable profile for your material. Another source of information could be the screw and barrel supplier. For example, barrier screws are commonly used with highly semi-crystalline materials, and a descending profile would be recommended.

Because of the high variety of screw types and sizes, it is typical for most manufacturers to provide temperature ranges for each heat zone.

During the process of molding from the desk, we predefine the temperatures for each heat zone. We consider the factors mentioned earlier, as well as material peculiarities. This includes aspects such as additives, friction sensitivity, melt difficulty, and sensitivity to high residence times.

Important:

- Thermocouples in the barrel's temperature zones read the temperatures of the metal.
- The most significant temperature is the temperature of the melt.
- Verify the temperatures with the resin supplier or the screw and barrel manufacturer.

Procedure for measuring melt temperature

1. Verify that the process has operated normally for at least ten cycles.
2. Preheat the measuring instrument to 25°C below the desired temperature. Digital mini-blowers are an economical option for preheating.
3. Stop the process (e.g., switch to semi-automatic mode). Once the mold opens, retract the injection unit and purge the melt. You can do this on a removable surface for easier access.
4. Adjust the instrument to maintain the temperature's peak value. This eliminates subjectivity when searching for the melt stabilization temperature.
5. Submerge the instrument into the melt and stir it. When you notice the temperature starting to decrease, remove the instrument and note the peak temperature obtained.

Note:

- Use safety equipment such as uniforms, gloves, and goggles.
- Adapt this protocol to your processes to ensure that everyone measures melt temperature in the same manner.

Back pressure

Back pressure is applied to counteract the free movement of the screw during recovery, thereby generating additional pressure on the molten material. This increase in pressure manifests as friction, which, in turn, produces heat. As a result, the heater bands experience less demand since the friction significantly contributes to material heating. However, it is crucial to moderate back pressure, as excessive friction can lead to thermal degradation of the resin in certain materials.

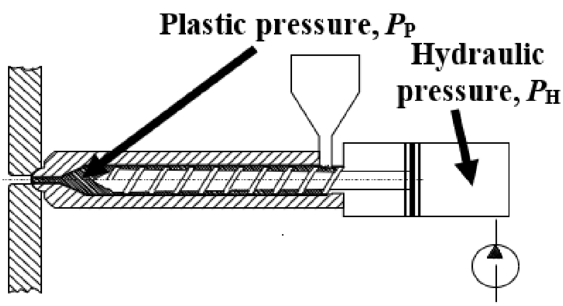
It's essential to exercise judgment because future changes in back pressure have multiple consequences. For example, when increased:

1. **Improved mixing**: Increasing back pressure can enhance the homogenization of additives in the melt.
2. **Degradation and breakage**: Sensitive materials may degrade, and fibers can break due to increased friction and heat.
3. **Equipment wear**: Higher back pressure can accelerate wear on the screw and barrel.
4. **Heat contribution**: With more back pressure, friction generates additional heat, potentially reducing the reliance of the heat from heater bands.
5. **Increased melt mass**: Molten thermoplastics are compressible; therefore, higher back pressure allows recovery of more material within the same volume. In other words, more material will be transferred to the mold during the injection stage.

Understanding these effects is crucial because adjustments to back pressure can have significant implications.

Intensification ratio (*R_i*)

It is imperative that the relationship between hydraulic pressure and plastic pressure be understood. Plastic pressure is intensified to a ratio of about 10 times the hydraulic pressure.



VI-44. Intensification ratio

The intensification ratio (R_i) represents the relationship between hydraulic pressure (P_H) and plastic pressure (P_P).

$$R_i = P_P / P_H$$

Other definitions are:

$$R_i = \frac{P_P}{P_H} = \frac{A_H}{A_P} = \frac{D_H^2}{D_P^2}$$

Where:

A_H = area of the hydraulic piston
A_P = area of the injection barrel
D_H = diameter of the hydraulic piston
D_P = diameter of the injection barrel

Important: Before molding, or making any adjustments to the injection machine, initial calculations must be done.

Machine labeling

Label your equipment with values that represent their capacities. This concept facilitates the understanding and use of your ***Universal*** factory.

Molding machine:

- maximum clamping force (US-ton, metric-ton, kN, ...)
- injection unit capacity (in^3, cm^3, liters, ...)
- maximum opening (in, mm, cm, ...)
- minimum opening (in, mm, cm, ...)
- space between tie-bars, horizontal (in, mm, cm, ...)
- space between tie-bars, vertical (in, mm, cm, ...)
- pattern of the ejectors on the platen (ex. 2x16in horizontal)

Dryer:

- air flow (CFM, liters/min, m^3/min, ...)
- drying hopper volume (ft^3, liters, m^3, ...)

Water circulator:

- water flow (gpm @ psi, liters/min @ kPa, ...)

Questions

1) The nozzle hole is
   a. greater than the diameter of the sprue bushing hole,
   b. less than the diameter of the sprue bushing hole.
   c. equal to the diameter of the sprue bushing hole.

2) The contact radius of the nozzle is
   a. less than the contact radius of the sprue bushing.
   b. greater than the contact radius of the sprue bushing.
   c. same as the contact radius of the sprue bushing.

3) A material that degrades easily will be injected with a barrel larger than recommended. Since there is no smaller injection unit, what would be the recommended profile?
   a. ascending
   b. descending or flat

4) It is known that a fast process one that is less than 6 seconds. For a fast process with a material that does not degrade easily, it is recommended to use
   a. a descending or flat profile with a larger barrel than normal.
   b. an ascending profile with a barrel utilization of 70%.
   c. a flat profile with 70% utilization.

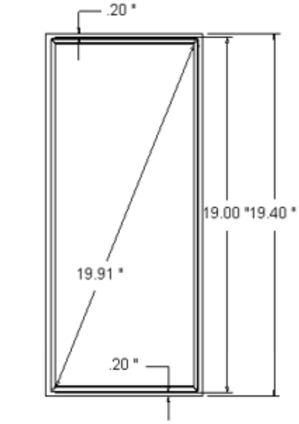
5) What would be the recommended transfer position, from injection to hold, for a mold that uses 50% of the barrel in a 150-ton press?
   a. Interpolating would give us a number between 6 and 12mm.
   b. A number less than 6mm
   c. A number greater than 12mm
   d. 6mm

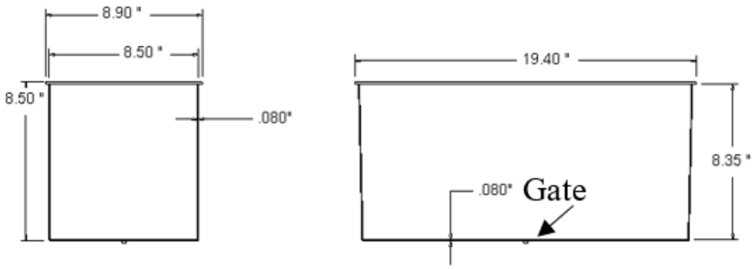
6) What would be the recommended transfer-to-hold position for a mold that uses 30% of the barrel?
   a. Interpolating would give us a number between 6 and 12mm.
   b. 12mm if the press is less than 400 metric tons
   c. 6mm if the press is less than 400 metric tons, and 12mm if it is greater than 400 metric tons
   d. 6mm

7) What would be the recommended transfer position for a mold that uses 50% of the barrel in a 150-ton press?
   a. Interpolating would give us a number between 6 and 12mm.
   b. A number less than 6mm
   c. A number greater than 12mm
   d. 6mm

8) ABS, with density of 0.97 g/cc plasticized at 270ºC and 50 bars, will fill a mold with a total weight of 147 gr. The ABS manufacturer recommends a barrel utilization between 40 and 60%. What would be the most appropriate barrel?
   a. 147gr/(0.97gr/cc)
   b. 147gr/(0.97gr/cc) x 52%
   c. 147gr/(0.97gr/cc) x 40%
   d. between 147gr/(0.97gr/cc)/60% and 147gr/(0.97gr/cc)/40%

9) Molding from the desk, a refrigerator drawer made of high impact polystyrene, in a single cavity mold with a hot sprue bushing, with:
   - total shot weight = 1100 gr
   - 500-USton injection machine with a 90mm injection unit ($2480cm^3$).
   - material is high impact polystyrene (PS) with a density of 0.92 gr/cc.
   - PS cooling factor = 50lb/hr/ton of cooling
   - total expected cycle = 50 seconds
   - estimated cooling time = 15 seconds
   - drying data: 100% virgin
     drying time = 2 hours at 190ºF
     bulk density = $35lb/ft^3$
     flow factor = 0.75 cfm/(lb/hr)
   - clamping force factor = from 1.5 to 2.5 $USton/in^2$





9a. Determine the projected area in in^2.
9b. Determine the thin wall value and force factor.
9c. Determine the required clamping force.
9d. Determine the total material consumption in lb/hr.
9e. Determine the volume required by the part in cm^3.
9f. Determine the percentage of utilization of the barrel, *%U*.
9g. Determine the cooling tons.
9h. Determine the water required from the chiller in gpm, assuming a Delta of 3ºF.
9i. Determine the transfer position.
9j. Determine the recovery position.
9k. Recommend a plastic backpressure in psi.
9l. Recommend a decompression.
9m. What is the temperature, in ºF, of the recommended melt?
9n. Recommend a temperature profile for the heat zones of the barrel.
9o. Determine the residence time in cycles and seconds.
9p. Determine the volume of the drying hopper.

9q. Determine the flow required for the dryer in cfm.

10) A process demolds with a total weight (parts plus runner) of 18 grams, with a recovery position of 54.3mm, a cushion of 5mm, a transfer of 6mm, and an injection unit with a 25mm screw. What is the discharge density (ρ_d), the injection displacement$_{95}$, and the recovery position?

a. $\rho_d = \dfrac{18\,g}{\left[(2.5cm)^2\, x\frac{\pi}{4}\right] x[54.3cm - 0.5cm]}$

Injection displacement$_{95}$ = $\dfrac{1.27x18g}{\rho_d\, x\,(2.5\,cm)^2}$

Recovery position = 6mm + 0.95 x injection displacement$_{95}$

b. $\rho_d = \dfrac{18\,g}{\left[(2.5cm)^2\, x\frac{\pi}{4}\right] x[54.3cm - 0.5cm]}$

Injection displacement$_{95}$ = 0.95 x ρ_d

Recovery position = 6mm + 0.95 x ρ_d

c. $\rho_d = \dfrac{18\,g}{\left[(2.5cm)^2\, x\frac{\pi}{4}\right] x[54.3cm - 0.5cm]}$

Injection displacement$_{95}$ = $0.95\dfrac{1.27x18g}{\rho_d\, x\,(2.5\,cm)^2}$

Recovery position = 6mm + injection displacement$_{95}$