only activates to increase the water temperature when the process requires it.

From an energy cost point of view, adding a heater appears to be inefficient, but that is not necessarily so. The heater only activates when needed. Let's say that during a mold startup it is necessary to increase 10ºC; it would take too much time to reach that operating temperature if we depended on the friction and heat of the mold. Another example, during a thermal dimension optimization lab, where various water temperatures must be evaluated to study their effects, we would have to wait too long between each temperature increment.

There are molds that need to be connected to more than one TCU. This could be to improve the demolding of the parts, to correct bending, to guarantee some mechanical characteristic of the molded part such as stopping the formation of crystals in a specific location of the molded product, etc.

There are other styles of TCUs:

- *Negative flow* - Using suction, negative water pressure is achieved in the mold, solving filtration problems.
- *Closed circuit* - This separates the mold water from the process water, in order to minimize deposits of contaminants and minerals in the mold.
- *With oil* - The transfer fluid is oil, which permits high temperature ranges, from 120ºC to 290ºC (~250ºF to 550ºF).
- *Built-in Chiller and TCU* – This does not require an external cooling source.

Each TCU provider offers multiple options. Consider:

- Mold purging, a device that allows you to empty the water from the mold, avoiding water spillage during mold change or maintenance.
- Protective devices, such as programmable pressure and temperature alarms.
- Alarms preset by the manufacturer, such as the system’s maximum operating temperature and minimum pressure allowed from its cooling source (chiller or tower). These alarms mainly protect your equipment.

It is important not to disable those alarms included by the manufacturer. For example, the minimum water pressure alarm coming from the cooling source, typically preset above 1 bar, prevents the pump from being damaged by cavitation.

It is also important that the temperature of the cooling source (chiller or tower) must be at least 5ºC (10ºF) cooler than the set temperature of the TCU. This is done to compensate for heat loss due to friction and heat coming from the mold; otherwise it may not be able to drop to the set temperature.

If the cooling tower provides water at 30ºC, connect it to TCUs that operate at 35ºC or more. Any mold that requires less than 35ºC must be connected to a chiller.

A significant benefit of TCUs is that regardless of what happens in the rest of the factory, the pump ensures a constant flow between the TCU and the mold. In other words, if the TCU did not exist and the cooling came directly from a centralized chiller, or was being shared with other processes, the mold would be subject to anything that was happening with that shared water pipe.

For example, consider three machines with similar molds that share a chiller. Under an ideal operation the chiller water flow is shared between the three machines.

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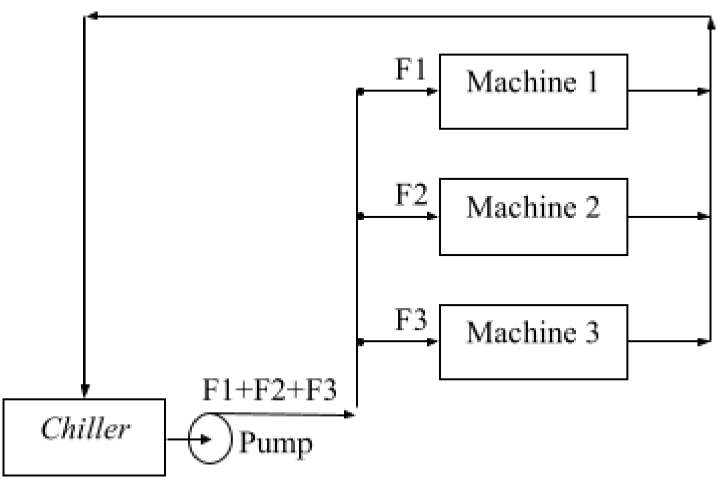
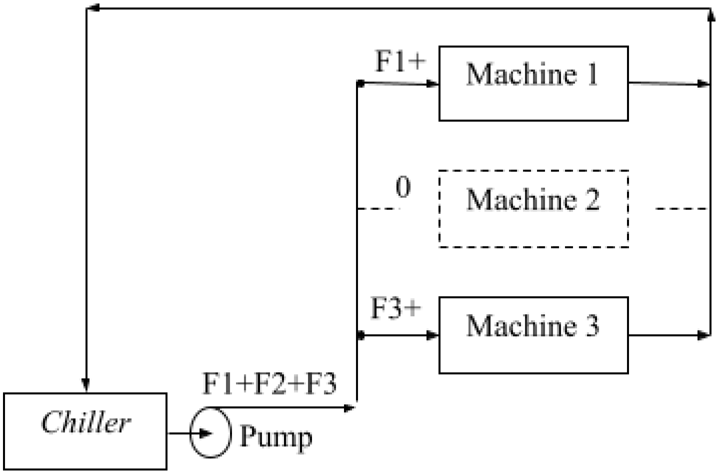


V-29. Three machines sharing a chiller

If one of the machines is stopped for mold maintenance, the flow of chilled water that previously reached three molds will be shared by only two molds.



V-30. Three machines sharing a chiller, with a stopped machine

This could consequently affect the thermal dimensions of the molded parts. In the same way, imagine that on a Monday, all the machines are started up after a weekend shutdown. Each time a machine is powered up, the ones that are already in operation will be affected, a pretty complicated scenario.

Summary:

- Some of the heat transmitted to the water, circulating between the TCU and the mold, comes from friction.
- Hose connections must be in parallel.
- Water flow should be turbulent.
- The Delta T of the water must be less than 2ºC (4ºF).
- The metal temperature of the cavities must be uniform, with a differential of less than 2ºC (4ºF).
- Pressure loss (Delta P) through the mold should be maintained.
- Temperature loss (Delta T) through the mold should be maintained.

- In centralized systems the TCU independently isolates the flow of water to the mold.
- The cooling source (chiller or tower) must be at least 5ºC (10ºF) cooler than the TCU's set temperature.

Questions

1) A mold requires water at a temperature of 32ºC, a chiller provides water at 12ºC (~55ºF) and a tower at 30ºF (~ 85ºF). Where should the TCU be connected?
   a. To a tower, because tower water must be at least 1ºC colder than the desired temperature.
   b. To a chiller since tower water is only 2ºC colder and is not 27ºC (32ºC –5ºC) as required.

2) For PA (nylon), how many cooling tons are needed for a consumption of 40 lb/hr?
   a. 2 cooling tons
   b. 1 cooling ton
   c. 1/2 cooling ton

3) A mold that creates nylon components consumes 275 grams per cycle, and the expected cycle is 9 seconds. How much is the consumption per hour?
   a. Material consumption = 275 g/hr
   b. Material consumption = (275/9) - 39 lb/hr
   c. Material consumption = (275g/9s) x (3600 s/hr) x (kg/1000g) = 110 kg/hr

4) The connections between the manifold and the mold are made
   a. in parallel, and the hoses are the same diameter as the mold connections.
   b. in series, and the hoses are a smaller diameter than the mold connections.

5) The temperature of the mold is equal to the water temperature.
   a. True. The temperature of the metal is somewhat cooler.
   b. False. The water and metal temperatures could be different.

6) A process using polypropylene (PP) needs 3.6 tons of chilled water at a Delta T of 2ºC (4ºF). What chiller water flow is needed?
   a. 24 x (3.6 chiller tons) / (4ºF)
   b. 30 x (3.6 chiller tons) / (4ºF)
   c. 24 x (3.6 chiller tons) / (2ºC)

7) A part bends after demolding. It is known that with distinct temperatures on the mold faces, this bending will be eliminated.

temperature side 1

temperature

side 2

The solution is to

a. set the temperature from side 1 greater than that of side 2.
b. set the temperature from side 2 greater than that of side 1.
c. set both temperatures the same.

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
- suitable nozzle tip and bushing
- transfer position to hold
- barrel temperature
- injection unit size
- backpressure
- recovery position
- intensification ratio

Initial calculations or "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 settings "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 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).

Metric ton = 1.10 x US tons
US ton = 8.90 Kilo-Newtons (kN)
Metric ton = 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/in^2		kN/cm^2	
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 force factors for some materials

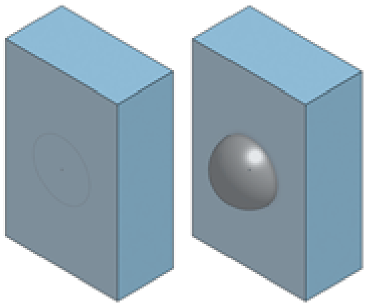
The table is a reference only; corroborate each resin's specifications with its manufacturer.

Projected area

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

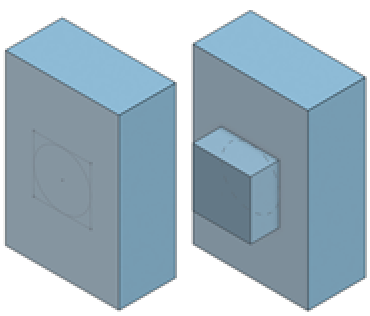
- A sphere's parting line would look like a circular plane, and the area would be equal to:

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



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

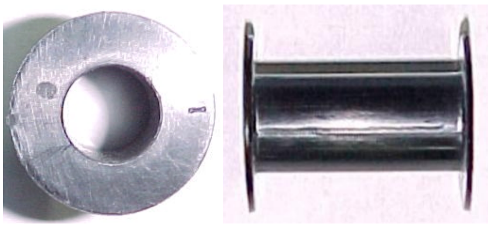
It's simple; if the projected area increases, the required clamping force will also increase. During projected area determination, ignore the depth of the cavity.

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
- 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 get choked. 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.



Top View   Side View

Runner with parts

Runner without parts

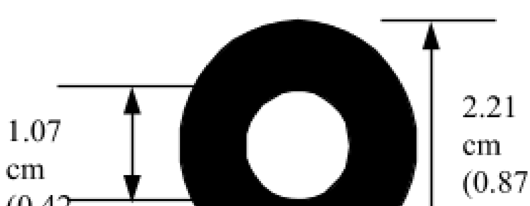
VI-5. Nylon spools and runners with and without parts

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

- Projected area of all cavities
- Projected area of the runner and
- 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:

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



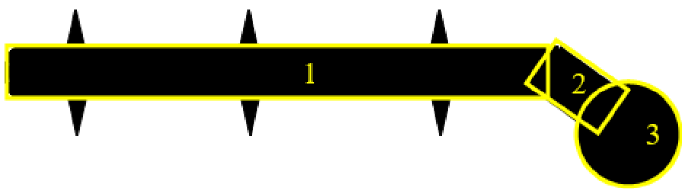
$$\text{Area} = (2.21^2 - 1.07^2) \times 3.1416 / 4 = \mathbf{2.94\ cm^2\ (0.46\ in^2)}$$

Projected area of the runner

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

$$\text{Projected area of the runner} = 35.29\ cm^2\ (5.47\ in^2)$$

Note that, for this approximation, the area where the runner branches to the gates 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:

$$\text{Total area} = \text{Area of the runner} + (12 \times \text{spool area})$$

$$= 35.29 + (12 \times 2.94) = \mathbf{71\ cm^2}$$
$$(= 5.47 + (12 \times 0.46) = \mathbf{11\ in^2})$$

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:

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

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

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

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

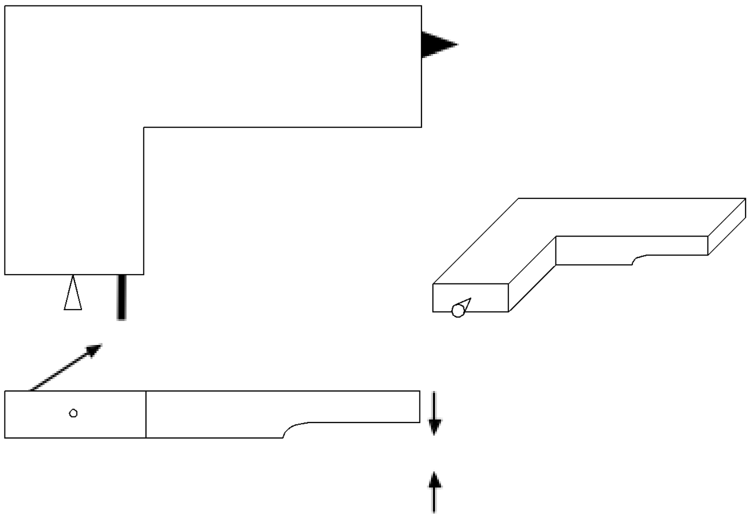
A thin wall calculation is a factor that represents fill difficulty. This factor takes into consideration the distance that the melt must travel and how narrow those passages are. This factor is represented by the following equation:

$$\text{Thin wall calculation} = \frac{\text{(Farthest flow path)}}{\text{(Thinnest wall on the path)}}$$

- 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.



Gate
Thinnest width, W
Y
X

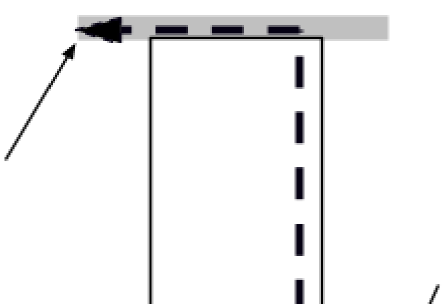
Top view
Front view

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.
gate



farthest point
X
Ynd

Z

VI-9. Flow path of a spool

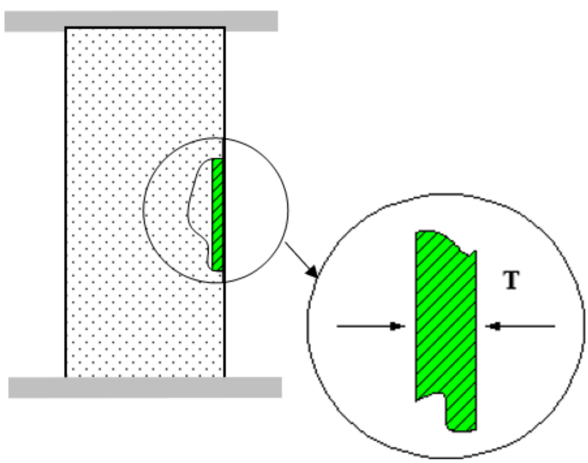
The farthest flow path would be the sum of X, Y, and Z.

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.

Farthest flow path = X + Y + Z = **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)**

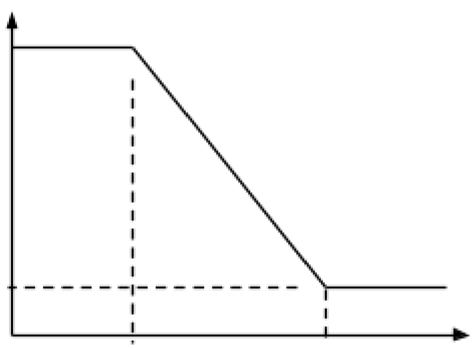
Select the thickness within the chosen path. Remember that there is a relationship between the flow path and the thickness of the walls. If you want, you can do several thin wall calculations with distinct paths. Once again select the thinnest wall within each chosen path; then use the largest value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

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

TW	Criteria
200 or more	Use the highest pressure factor. Force = (projected area) x **(highest** pressure factor)
100 or less	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.



Thin Wall Calculation
100
200

P_{Max}
P_{Min}
Pressure Factor

VI-12. Linear interpolation of the pressure factor

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

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).

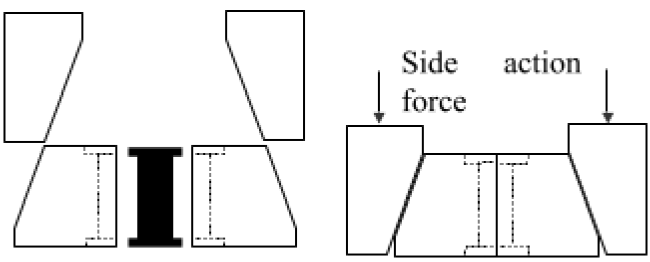
That means that the normal clamping force, as a result of the projected area and the pressure factor, is:

$$\text{Normal force} = \text{Pressure} \times \text{Area}$$
$$= 71\ cm^2 \times 4.1\ kN/cm^2 = \mathbf{291\ kN}$$
$$(= 11\ in^2 \times 3\ Ton/in^2 = \mathbf{33\ USTon})$$

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 because of the projected area in the partition of the mold. The clamping force can also be affected by forces resulting from mechanisms that act laterally.

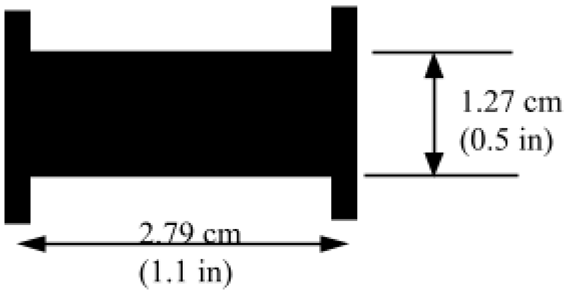
These mechanisms are part of the mold cavities and stay in position while the mold is closed. After the mold opens those mechanisms move, freeing the molded parts. These lateral forces influence the clamping force, since it is the press that keeps these mechanisms in position.

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.



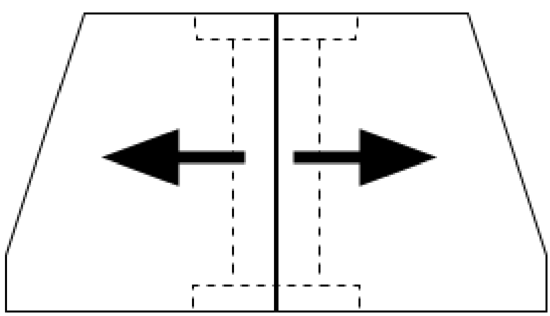
VI-14. Measurements to calculate the projected area

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:

Lateral force per slider =
Lateral projected area x Pressure factor

= 3.54 mm^2 x 4.1 kN/cm^2 = **14.5 kN / slider**
(0.55 in^2 x 3 USTon/in^2 = **1.65 USTon / slider)**



14.5 kN

(1.65 USTon)

14.5 kN

(1.65 USTon)

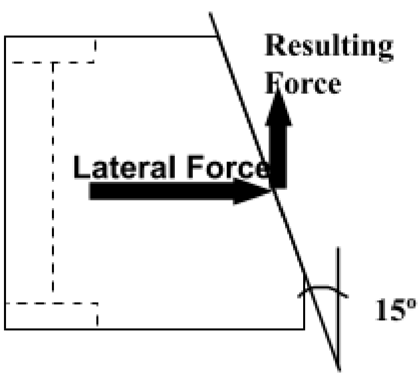
VI-15. Lateral force per slider

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 cavity is kept closed by wedges, the total lateral effect could be determined by the following equation:

Lateral force =
Force per slider x 2 sliders x 12 cavities
= 14.5 kN x 2 x 12 = **348 kN**
(1.65 USTon x 2 x 12 = **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 at an angle, in this case 15°, and only a fraction of this lateral force will be seen in the direction of the closing 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.

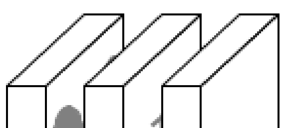
Final force = Normal force + Lateral action force
291 kN + 94 kN = **385 kN**
(33 USTon + 10.8 USTon = **43.8 USTon**)

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 cause 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 that 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



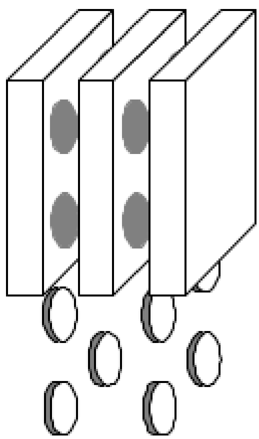
VI-17. Three-plate mold

This type of mold molds the parts and the runners with distinct mold plates. The mold is split into three, in one partition the parts are molded and in another partition the runner is formed. The purpose of this type of design is for when molded parts, such as round parts, 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

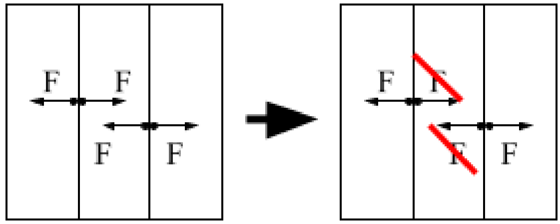
A stack mold has the same number of cavities in each partition side of the mold.



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.



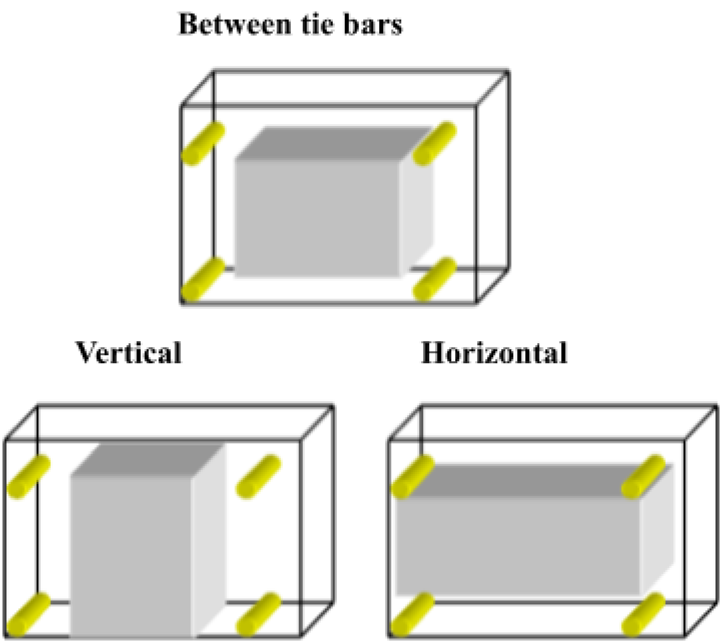
VI-19. Stack mold force vectors

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.

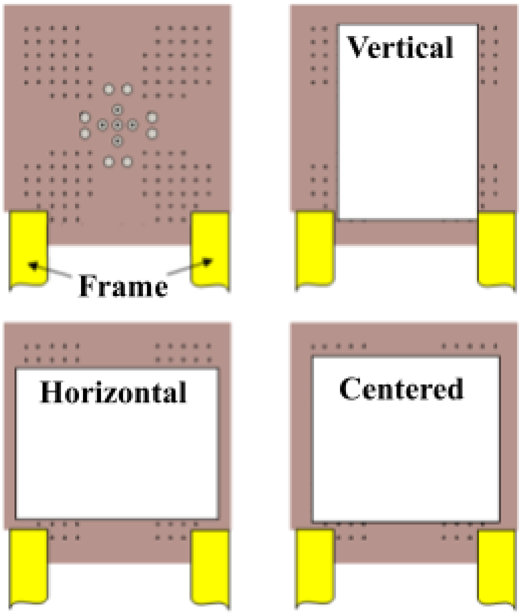
Platen spacing on machines with tie bars

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

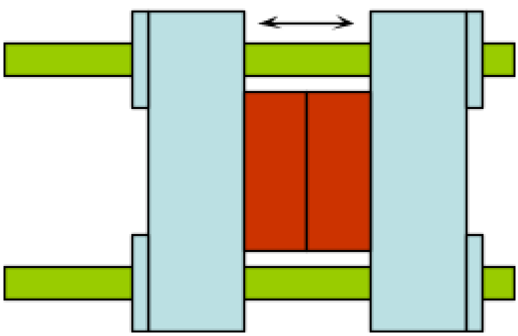


VI-21. Platen spaces on tie-bar-less machines

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

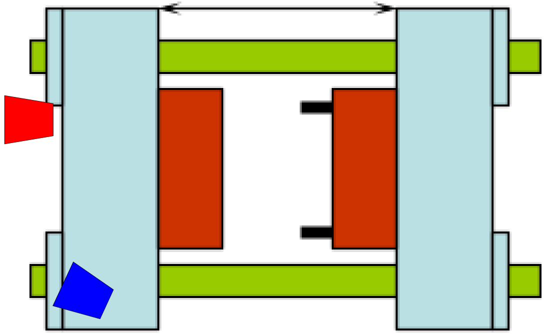


closed.

Minimum

VI-22. Minimum press opening

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



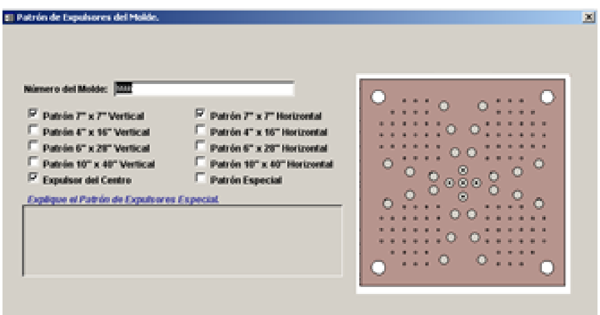
demolded.

Maximum

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. 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 spheres with a diameter of 0.5 inches. The projected area of each sphere is a circle of 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 to be used 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

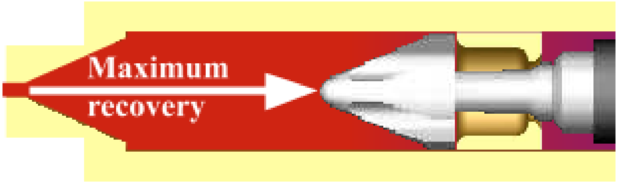
3) Excessive clamping force strangles a mold's vents. This can cause internal combustion since the gases do not find a place to escape. This is resolved by
   a. increasing the clamping force.
   b. enlarging the vents.
   c. cleaning the vents and increasing the clamping force.
   d. adjusting the press 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, or shot size, represents the maximum recovery amount of the injection unit.



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 and
- 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:

The 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
= **267.09 cm^3**

The barrel should be no larger than 267.09 cm^3.

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

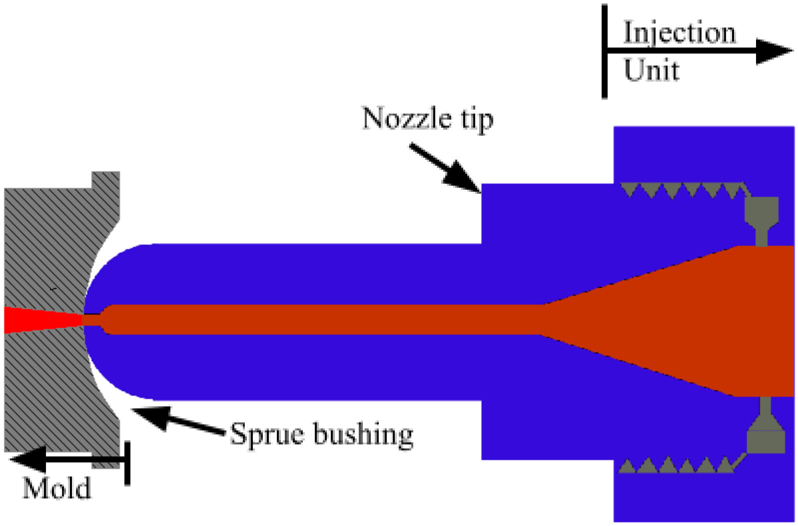
The barrel should be at least 200.32 cm^3.

So, to meet the requirements of that polycarbonate, 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

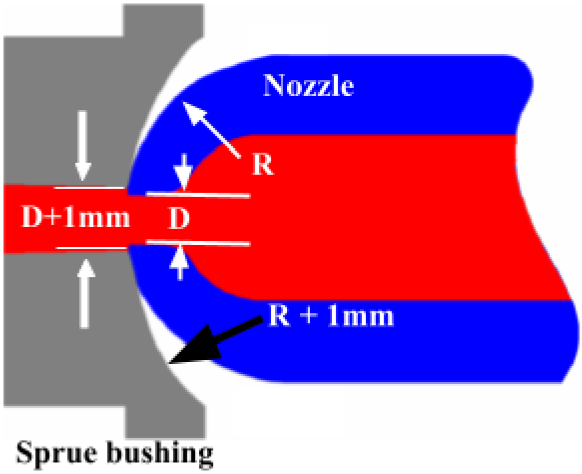
The nozzle tip is an important component, because of this the proper one should be selected and maintained at a specific temperature. This has more significant effects with semi-crystalline materials than with amorphous materials.

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**

illustration.

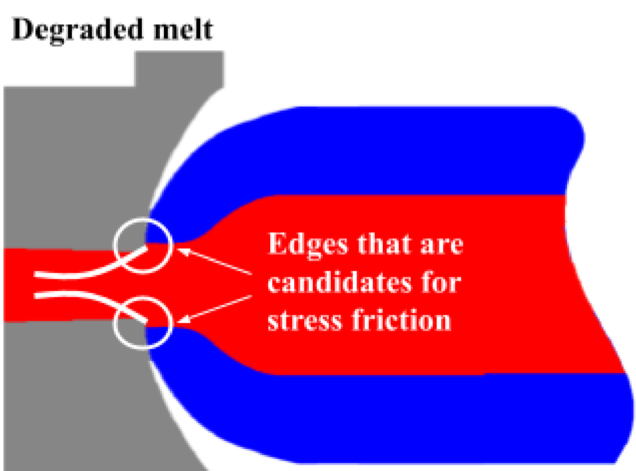


VI-27. Diameters and radii of the nozzle tip and sprue bushing

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.

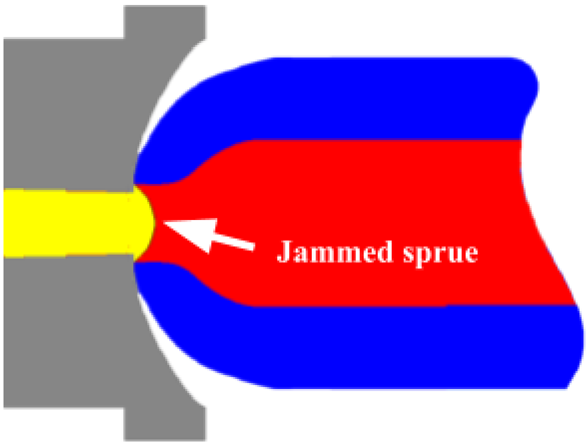
Before performing a ***Universal Molding***^{TM} lab you should verify that the nozzle tip is properly sized. If it is incorrect, change it before starting.

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 or burned melt that could end up in the molded parts.



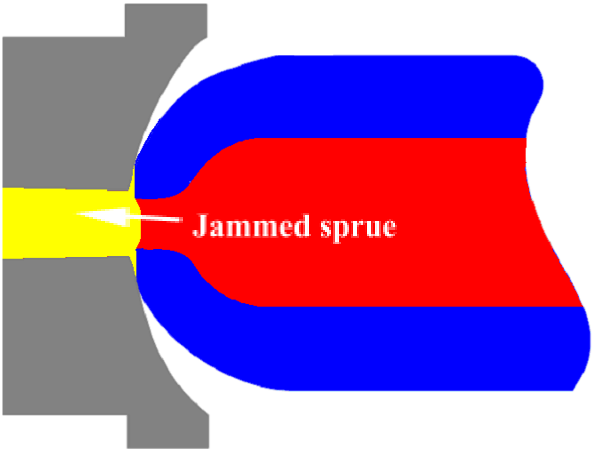
VI-28. Defect caused by stress concentration at the edge of the nozzle

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 would prevent it from ejecting.



VI-29. Defect caused by 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 the spaces and could cause the sprue to become stuck in place.



VI-30. Another defect caused by 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 opposite 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**

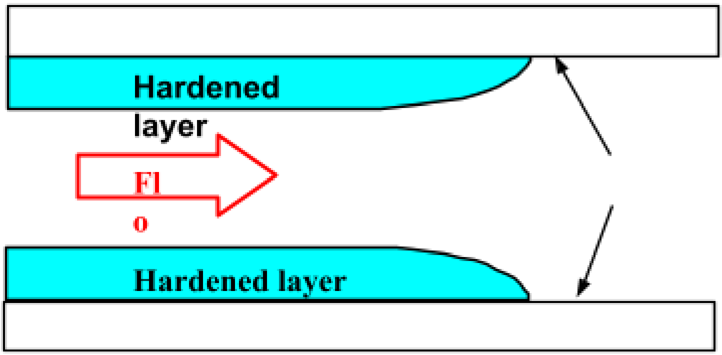
Some processes require special nozzle cleaning programs. This is seen more with molds for rigid PVC pipe joints. This material tends to be heat-sensitive and degrades easily. After each molding cycle, the injection unit pulls back, purging the small amount of plastic left in the nozzle.

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

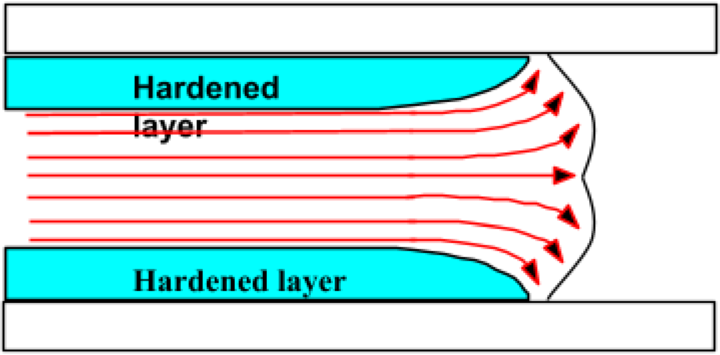
The fountain flow effect describes the flow of a thermoplastic melt. Thermoplastic melt is compressible, opposes movement, and seeks to stay on the first static surface it finds. This opposition to flow is responsible for the fountain flow effect. Imagine melt flowing between the walls of a mold. The 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.



Mold walls

VI-31. Thermoplastic melt flow in a mold

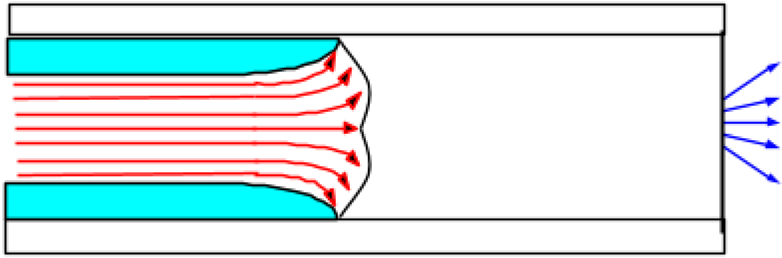
The tendency would be to flow through the center in search of the opportunity to grab onto the first available static surface. It is this behavior that is responsible for the fountain flow effect that will be observed at the front of the melt flow. This means that the first melt that enters stays at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



Fountain Flow Effect

VI-32. The fountain flow effect

Example: a piece of wet napkin is stuck to the surface of the cavity. Moisture is the only thing that holds it. Once the mold closes, it is filled with melt in the indicated direction.



vents

1

2

3

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

After filling, where will the paper napkin end, 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 = Weight (mass) / Volume

Specific density =
Material density / Water density

where the density of water is 1 **g/cm^3** at room temperature.

Dividing cancels the units, so if you ever find a specific density without units assume it is in g/cm^3. 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 are preferring these as these represent what the mold sees. A cavity represents a defined space or volume and is filled at a given 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 volume of filling, you would also have to manipulate the injection speed to ensure the same injection time.

It is also common to see new machines provided with Universal parameters, such as injection flow instead of injection speed.

Injection speed
= Displacement per unit of time
= Distance/time

Injection flow
= Volume per unit of time
= Volume/Time

Flow (Volume/Time) is also Universal. The relation between injection volume, area and screw diameter is:

Injection volume = (Screw area) x Displacement
and

$$\text{Screw Area} = (\text{Screw diameter})^2 \; 3.1416 / 4$$

We substitute in the flow equation to get:

$$\text{Injection flow} = [(\text{Screw diameter})^2 \; 3.1416 / 4] \times \text{Displacement} / \text{time}$$

and

$$\text{Injection flow} = [(\text{Screw diameter})^2 \; 3.1416 / 4] \times (\text{Injection speed})$$

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.

% of Utilization (U%)
=

Volume the barrel is capable of

where the volume the barrel is capable of is the maximum recovery position of the screw and the volume used is the programmed recovery position, according to the mold’s requirements.

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:

$$\text{Screw area} = (\text{Screw diameter})^2\ 3.1416 / 4$$
$$= (3.5\ \text{cm})^2\ 3.1416 / 4 = \mathbf{9.62\ cm^2}$$

Also, knowing that:

$$\text{Injection volume} = (\text{Screw area}) \times \text{Displacement}$$
$$\text{Displacement} = (\text{Injection volume}) / (\text{Screw area})$$
$$= (62\ \text{cm}^3) / (9.62\ \text{cm}^2) = \mathbf{6.44\ cm} \text{ or } \mathbf{64.4\ mm}$$

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

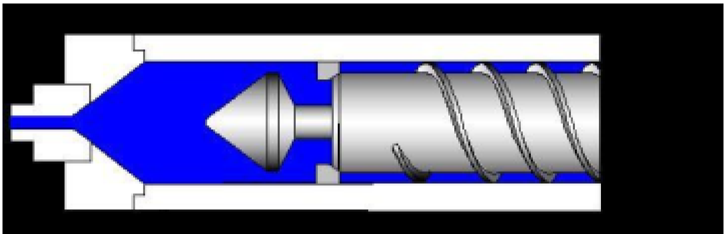
How much would the percentage of utilization be?

$$U\% = (\text{Volume used}) \times 100\% / (\text{Volume barrel is capable of})$$
$$= (62\ \text{cm}^2) \times 100\% / (134\ \text{cm}^3) = \mathbf{46\%}$$

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:



During recovery (or plasticizing) 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. The hold stage begins after the transfer position; 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 feels.

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

Recovery position

The recovery position is the place which 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:

Recovery position =
Transfer position + 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:

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

Where:

ρ = the melt's specific density (gr/cm^3)
W = weight of parts and runner (gr)
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.

Recovery speed
The recovery speed is measured in:

revolutions per minute (rpm)
or
tangential speed (mm/s)

Where:

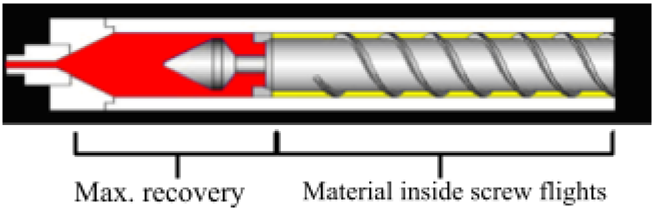
Tangential speed = rpm x Circumference
Circumference = 3.1416 x D
D = Diameter of the injection screw (mm)

It is adjusted so that the recovery ends before the expected cooling time. As a rule, recovery should occur before reaching 90% of the cooling time.

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 be considered.

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



VI-35. Residence of the material inside the screw flights

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 flights' complex geometry could be tricky; however, there is a simplified way to estimate V_r. To approximate V_r, assume 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 flights 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:

$$T_r = 1.4V_{max}/V_{req}$$

Where:

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