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Dryer Residence Time Calculator

Many resins require drying prior to molding to remove either surface moisture or absorbed moisture from the pellets. In order to calculate residence time in the dryer we must calculate the dryer weight capacity. A given dryer has an internal volume, but will hold different weights of resin depending on that resin's bulk density.

First we must gather the knowns so as to calculate the unknowns:

Knowns:
Dryer hopper is 5.7 cu feet of capacity.
We can weigh a sample or consult the resin supplier to determine the resin's bulk density; in this example it will be 40 lbs/ft$^3$.
The molding cycle is 28.5 seconds and the shot size is 188.4 gr.

We must first determine the molding press throughput rate or total pounds per hour processed.

\[
\frac{3600 \text{ sec}}{hr} \times \frac{188.4 \text{ gr}}{\text{shot}} \times \frac{1 \text{ lb}}{453.6 \text{ gr}} = Y
\]

\[
\frac{126.32 \text{ hr}}{hr} \times \frac{188.4 \text{ gr}}{\text{shot}} \times \frac{1 \text{ lb}}{453.6 \text{ gr}} = Y
\]

\[
52.47 \frac{\text{lb}}{hr} = Y
\]

We convert 5.7 ft$^3$ dryer capacity to pounds:

\[
5.7 \text{ ft}^3 \times 40 \frac{\text{lb}}{\text{ft}^3} = 228 \text{ lbs}
\]

We can now divide 228 lbs by 52.47 lbs/hr to get dryer residence time in hours:

\[
\frac{228 \text{ lbs}}{52.47 \frac{\text{lb}}{hr}} = Y
\]

\[
4.35 \text{ hrs} = Y
\]

It is useful to reexamine the above calculation to review how we cancel units. Sometimes it is easy to forget the units, but this can result in incorrect conversions and incorrect answers if we do not perform all necessary steps to make units come out right. If the units are wrong we will have a numerical answer that is wrong for the intended calculation.
Barrel Residence Time Calculator

The barrel residence time may be critical so as to avoid thermal degradation of the molding resin. Residence times can be too short and too long, but too long is the more common problem. In our example below we have a hot runner mold; thus, the hot runner system volume (internally heated passage ways) in the mold is an extension of the barrel with regards to residence time at processing temperatures.

First we must gather the knowns so as to calculate the unknowns:

Knowns:
Barrel rated capacity is 16.5 oz of GP styrene (1.06 gr/cc). Our resin is polycarbonate with cold density or sp gr of 1.20 gr/cc. Molding cycle time is 28.5 seconds and shot weight is 188.4 grams. Hot runner supplier tells us the melt channel's volume is 88 cm³.

We convert the 88 cm³ to styrene grams as shown:

88 cm³ x 1.06 gr/cm³ = 93.28 gr

We convert the 16.5 oz to grams as shown:

16.5 oz x \(\frac{1 lb}{16 oz}\) x \(\frac{453.6 gr}{1 lb}\)

= 467.8 gr GP styrene

The sum of these two calculations equals 561.1 grams (GP styrene); this is the value we will use for the barrel capacity (plus HR manifold).

We perform the following calculation (note: sp gr is specific gravity):

\[
3600 \frac{\text{sec}}{\text{hr}} \times \frac{188.4 \text{ gr}}{\text{shot}} \times \frac{1 \text{ lb}}{453.6 \text{ gr}} = Y
\]

\[
\frac{126.32 \text{ hr}}{\text{hr}} \times \frac{188.4 \text{ gr}}{453.6} = Y
\]

\[
52.47 \frac{\text{lbs}}{\text{hr}} = Y
\]
We are using the rules for proportions to calculate the barrel shot capacity (barrel only) with resin of different density - different specific gravity.

Note: A 16.5 oz barrel of styrene holds 18.68 oz of polycarbonate (18.68 oz = 529.58 grams):

\[
\frac{1.06 \text{ gr}}{1.20 \text{ cm}^3} = \frac{467.8}{Y}
\]

\[
\frac{1.06 Y}{1.20} = 467.8
\]

\[
Y = \frac{467.8 \times 1.20}{1.06}
\]

\[
Y = 529.58
\]

**Hydraulic Speed Calculator**

Calculation of cylinder extend & retract time (unscrewing core coupled with rack & pinion system in mold). This is a common scenario to accomplish the unscrewing action on cores for a closure mold. If the bore size is 2 inches; rod size 1 inch and the stroke is 20 inches and our available core circuit oil volume is 12 gal/min:
We divide the distance by the speed to get the time required. Hints to determine what should be on top vs bottom of fraction:

1. These units will cancel to get seconds on top as they should be.
2. If we think about the numbers and realize that we are going 20 inches and we can only go 14.7 inches per second - it must take longer than 1 sec to get there!
retract speed = \frac{12 \text{ Gal/min}}{2.3562 \text{ in}^2} = \frac{2772.2 \text{ in}^3}{2.3562 \text{ in}^2} = 1176.55 \text{ in/min} \times \frac{1 \text{ min}}{60 \text{ sec}} = 19.61 \text{ in/sec}

retract speed = \frac{20 \text{ in}}{19.61 \text{ in/sec}} = 1.02 \text{ sec}

1.02 \text{ sec} + 1.36 \text{ sec} = 2.38 \text{ sec total extend + retract time}

Projected Area Calculator

Only face shown at bottom of page is considered projected area for purposes of calculating clamp tonnage (area in X-Y plane or axis).

Formed by a mechanical slide (shown on earlier pages). This technically does add small amount to equivalent projected area.
Injection Moulding Calculations

Clamp Tonnage and Cavity Pressure Calculator

The principle of pressure amplification also acts on the mold cavities. If we are running the screw and injection unit at 750 psi hydraulic we would get 750 x 14.52 or 10,890 psi leaving the nozzle and entering the mold. This force per
area (pounds per square inch) acts on the projected area of the cavities to yield some amount of force in pounds trying to separate the mold halves. The clamp tonnage works to keep the mold closed. The projected area is only the 2D area of molded part surfaces in the X and Y directions only - do not count sidewall area in the Z direction (part depth . . . in this example the Z axis/direction is in line with the screw).

Example:

\[
4 \text{ cavs} \times 13.6 \text{ in}^2 \times 5 \text{ tons/in}^2 = 272 \text{ tons}
\]

Note: This pressure amplification does ignore pressure drop which could be as much as 50%. The actual pressure varies at each location along the flow length - constantly being reduced by pressure drop in system. More sophisticated mold filling analysis software is needed to accurately quantify the average pressure in mold. If our equation shows ample tonnage working against full cavity pressure, we know we are conservative which insures success.

Not shown above is one additional system of pressure amplification in the clamp mechanism which generates the 300 tons of clamp force. As mentioned, 300 tons is 600,000 pounds. If the typical system hydraulic pressure is 2000 psi, we can calculate the clamp cylinder diameter to be 19.54 inches as shown at left. Note: This would apply to a hydraulic clamp system; toggle systems use a smaller cylinder plus other forms of mechanical advantage in the form of lever arms & linkages.
**Injection Speed and Fill Rate**

We can calculate the injection speed using the formula below (machine pump is given at 55 GPM):

\[
\text{Piston speed} = \frac{\text{oil volume}}{\text{piston area}}
\]

Note: These units will not reduce to a speed such as in/min or in/sec; thus, we must change the GPM on top to some other volume such as in³/min...we must always keep track of the units!

\[
\begin{align*}
\text{Piston speed} &= \frac{55 \text{ Gal}}{\text{min}} \times \frac{1 \text{ ft}^3}{7.48 \text{ gal}} \times \frac{1728 \text{ in}^3}{1 \text{ ft}^3} = 12,705.9 \text{ in}^3 \text{ min} \\
\text{Piston speed} &= \frac{12,705.9 \text{ in}^3}{44.18 \text{ in}^2} = 287.6 \text{ in} \text{ min} \\
\text{Piston speed} &= 287.6 \text{ in} \text{ min} \times \frac{1 \text{ min}}{60 \text{ sec}} = 4.8 \text{ in} \text{ sec}
\end{align*}
\]

We calculate the volumetric injection rate (not injection speed) as follows:
If our part is polypropylene with a melt density of 0.70 gr/cm³ (0.90 cold density) and weighs 22.26 grams (same 4 cavity part described on previous page); we can calculate the fastest possible fill time:

4 x 22.26 grams = 89.04 grams = shot weight

\[
\frac{89.04 \text{ grams}}{0.70 \frac{\text{gr}}{\text{cm}^3}} = 127.2 \text{ cm}^3 \quad \text{= volume of shot (melt)}
\]

\[
\frac{127.2 \text{ cm}^3}{239.42 \frac{\text{gr}}{\text{cm}^3}} = 0.53 \text{ sec} = \text{fastest fill time possible}
\]

**Utilization Calculator**

Overall utilization comes from calculating the following efficiencies; then multiply all components together for net affect:

- cycle eff = std cycle ÷ actual cycle
- cavity eff = actual running cavitation ÷ full cavitation
- machine eff = actual run time ÷ machine scheduled
- scrap eff = 1 minus the molding scrap rate

It is important to understand that the overall efficiency is a product of all four of the above, for example:
There are some plants which like to use 90-95% as an efficiency or utilization value for pricing and scheduling the molding departments capacity. This may be too aggressive and can result in molding output deficiencies relative to plan as well as financial losses. As shown above, it is very easy to fall short of 90% overall efficiency. To accomplish 90%, the following scenario is needed:

**Example:**

\[0.97 \times 0.97 \times 0.98 \times 0.98 = 0.904\]

The 89% used in our pricing model from previous pages came from this utilization table:

<table>
<thead>
<tr>
<th>Cycle Efficiency</th>
<th>97.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrap &amp; Rejects</td>
<td>3.00%</td>
</tr>
<tr>
<td>Blocked Cavities</td>
<td>3.00%</td>
</tr>
<tr>
<td>Downtime</td>
<td>3.00%</td>
</tr>
<tr>
<td>Overal Utilization</td>
<td>88.53%</td>
</tr>
</tbody>
</table>

Another way to demonstrate these numbers is the following calculation:

\[
\frac{24.25 \text{ sec}}{25 \text{ sec}} \times (1 - 3\%) \times \frac{15.52 \text{ cav}}{16 \text{ cav}} \times \frac{116.4 \text{ hours}}{120 \text{ hours}} = \text{OA eff %}
\]

\[0.97 \times 0.97 \times 0.97 \times 0.97 = 88.53\%

When viewed as the equation above, it can be seen just how good we must be to accomplish 88.53% utilization.

**Thermal Expansion Calculator**

The following formula is used to calculate thermal expansion:

\[\delta_t = \alpha (\Delta T)L\]

Where the symbols mean the following:
Example: The leader pins on a mold are 18.75 inches apart. The "A" half is heated from 70° F room temperature to 185° F and to 165° F on the ejector half; if the moldbase is steel, use $6.6 \times 10^{-6}$ or 6.6 X 0.000001 as the coefficient of thermal expansion or use table if specific steel is known.

The expansion between leader pins centers is calculated as follows:

$$\delta_t = 6.6 \times 0.000001 \times (165 - 70) \times 18.75$$

$$\delta_t = 0.0000066 \times 95 \times 18.75$$

$$\delta_t = 0.0117 \text{ inches}$$

The bushing holes in "A" half will expand even more at 0.01423 inches since they are in hotter plates (185° instead of 165° F). This 0.0025 inch differential in leader pin to bushing spacing is about the maximum that can be tolerated unless the bushing holes are worn.

Note also that the shut height of this mold is 11.751 inches. This will grow to be 11.759 inches (0.008 inches increase).

$$\delta_t = 6.6 \times 10^{-6} \times (185 - 70) \times 4.563 + 6.6 \times 10^{-6} \times (165 - 70) \times 7.188$$

$$\delta_t = 0.0000066 \times 115 \times 4.563 + 0.0000066 \times 95 \times 7.188$$

$$\delta_t = 0.003463 + 0.004507 \text{ inches} = 0.008 \text{ inches}$$
This increase may be enough to throw off the mold protection setup if set very close; thus, requiring the clamp lockup position to be readjusted after temperature equilibrium is established. Note that the mold is located in press by the locating ring which is 3.99 inches for this mold. This is the center of the mold. Thermal expansion will occur about this center line. This is why the optimum location for taper locks (or straight locks) is at the centers of the four sides (3, 6, 9 & 12 o’clock positions). These locations are unaffected by thermal expansion about the mold’s center line.
### THERMAL EXPANSION COEFFICIENTS

\[ \mu = \text{micro.} \ldots \text{multiply } \times 0.000001; \ u \text{ in/in from } 68^\circ \text{F to} \]

<table>
<thead>
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<th>TYPE</th>
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<th>400° F</th>
<th>800° F</th>
</tr>
</thead>
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</tr>
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<td>7.0</td>
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</tr>
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<td>6.2</td>
<td>6.9</td>
<td>7.1</td>
</tr>
<tr>
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<td>5.8</td>
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<td>6.1</td>
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</tr>
<tr>
<td>M3</td>
<td></td>
<td></td>
<td>6.4</td>
</tr>
</tbody>
</table>
### Cavity Dimension Calculator

The tall round part below is made from polypropylene with a specified nominal shrink rate of 0.018 inches/inch (1.8%). This shrink rate is for shrinkage in the flow direction; the shrinkage in the transverse flow direction is only about 0.012 inches per inch (transverse is 90° to flow direction). If we want to calculate the cavity dimension required to accomplish the 3.7500 part length, we would calculate as follows:
Do Not Use: 3.7500 x 1.018 = 3.8175

The previous line is a common incorrect method to size cavities.

\[
\text{cavity} = \frac{\text{finished part length}}{1 - \text{shrink rate}} = \frac{3.7500}{1 - 0.018} \\
\text{cavity} = \frac{3.7500}{0.982} \\
\text{cavity} = 3.8187 \text{ inches}
\]

As you can see, if we use the wrong method of calculation, our answer can be off by 0.0012 inches!

If this part were made from polyetherimide or other resin molded at very hot mold temperatures we might also need to calculate the thermal expansion. If mold temp was 300°F, then steel thermal expansion would add 0.0055 inches of part length as follows:

\[
3.75 \\
x \ 0.0000064 \\
x \ 230 \\
= 0.0055 \text{ inches}
\]

In this example the steel was H 13; thus, we used 6.4 \times 10^{-6} for thermal expansion.

We can calculate the cavity diameter at the 0.375 ID location in a similar manner as length above, but we should use a different shrink value since the shrinkage will be a function of the transverse flow direction shrinkage. Our calculation would yield 0.3795 inches.

---

**CALCULATING ACTUAL SHRINKAGE**
If the part tolerances were very tight and critical; the preferred method of establishing the shrinkage would be to build a one to four cavity unit tool or prototype tool to accurately establish the actual shrink rates. This would be especially important if multiple high cavitation molds were going to be built so as to avoid costly rework on later molds.

Cavity dimensions determined from previous page are noted in parenthesis; we also must calculate cavity ID at bottom based on 0.25 degree angle used. Shrink calculations are as follows:

\[
\text{shrink} = \frac{(\text{cav dim} - \text{part dim})}{\text{cav dim}} = \frac{(0.3795 - 0.3756)}{0.3795} = \frac{0.0039}{0.3795} \\
\text{shrink} = 0.0039 \frac{\text{in}}{0.3795} \\
\text{shrink} = 0.0103 \frac{\text{in}}{\text{in}} \text{ at top of part}
\]
As can be seen there is more diametric shrink at end of fill than start of fill; this is due to pressure drop -- less packing means more shrink. Both diameters have less shrink rate than length shrink rate, since diametric shrink is a function of transverse flow direction shrinkage.