ENTEC

MACHINE SIZING & PROCESS DEVELOPMENT

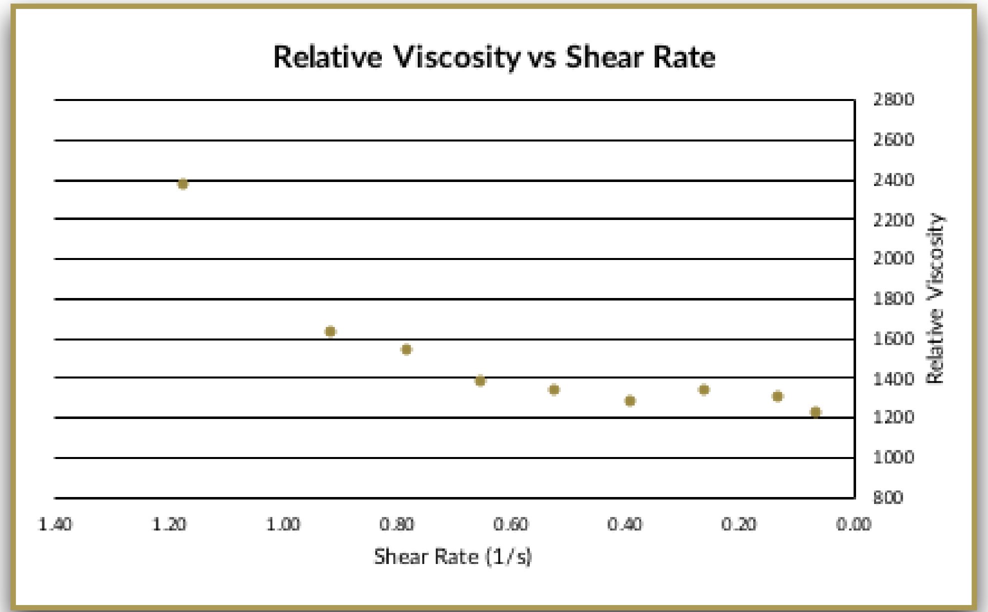
SHEAR RATE, RECOVERY SPEED, TEMPERATURE PROFILE

When launching new tools or transferring existing processes between molding machines it is critical to match shear rate, viscosity, and thermal performance in order to ensure a smooth transition. Running a few capability studies and confirming machine inputs/metrics can make or break a tool launch.

Viscosity Curve Generation

As shown in a previous technical overview, the shear rate vs relative viscosity curve can be utilized in order to determine the ideal injection speed to process a specific material. In the table/chart below, we provide an example of how to generate this curve. Running a fill only process at constant injection speed to ~90% full while incrementally adjusting speeds allows for the following data to be generated.

1ST STAGE FILL SPEED (in/s)	FILL TIME (s)	TRANSFER PRESSURE (psi)	SHEAR RATE (1/fill time)	RELATIVE VISCOSITY (pressure * fill time)
4.5	0.85	2800	1.18	2380
3.5	1.09	1500	0.92	1635
3	1.28	1200	0.78	1536
2.5	1.53	900	0.65	1377
2	1.91	700	0.52	1337
1.5	2.55	500	0.39	1275
1	3.83	350	0.26	1341
0.5	7.65	170	0.13	1301
0.25	15.3	80	0.07	1224



Ideally running along the "flat" region on the viscosity curve is ideal; this is where injection pressure varies <10% with respect to established fill time. Within the flat region, it is much less likely to develop a pressure limited process. Generally, shrinkage and part dimensions will be significantly more reproducible from shot to shot and quality defects will be minimized.

Shear Rate at Gate/Part Interface

Shear Rate through a round channel: $\dot{\gamma} = \frac{4Q}{\pi r^3}$ or $\dot{\gamma} = \frac{32Q}{\pi d^3}$

Shear Rate through a rectangular flow channel: $\dot{\gamma} = \frac{6Q}{wh^2}$

Where "$\dot{\gamma}$" is shear rate, "Q" is flow rate, "r" is radius of a round channel, "d" is the diameter of a round channel, "w" is width of a recatangular channel, and "h" is the heigh (or thickness) of the rectangular channel.

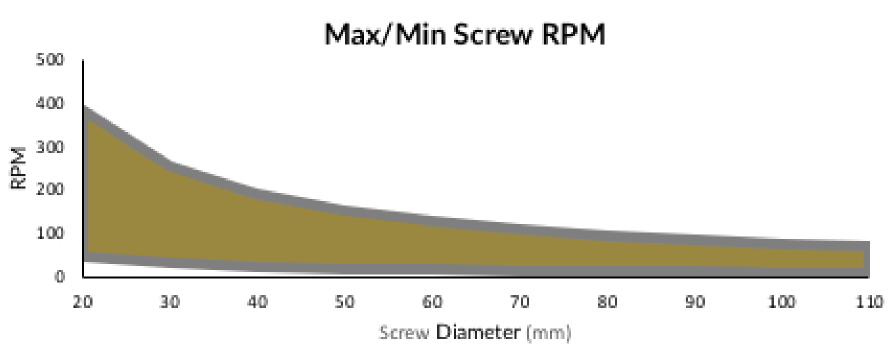
As developed on our recent technical overview, the first order approximation of shear rate through various orifices are shown above. This can be generalized when utilizing a multi-gate or hot runner system with multiple drops. We provide an example below showing the required inputs and equations to develop this value.

THEORETICAL SHEAR DEVELOPMENT		
Screw Size (mm)	30	Measurement
Screw Area (mm^2)	707	A = π * D ^ 2 / 4
Nozzle Tip (mm)	3	Measurement
Shear Rate (Nozzle tip)	13333	Shear = 32Q / π * d ^ 3
Injection Speed (mm/s)	50	Input
Shear Rate (1.25mm gate, 8 cavity)	23040	Shear = 32Q / (π * d ^ 3 * N) , where N is the number of gates

It should be noted that shear rate is linear with injection speed and quadratic with gate diameter. Reducing the diameter of a gate by a factor of 2 will ultimately increase the shear rate by a factor of 4. This will ultimately require increased injection pressure in order to push the material through the gate.

Recovery Speed

We generally recommend running a linear screw speed of 0.1 m/s to 0.3 m/s in order to convey consistent and homogenous melt to the process. This range of linear screw speed can be translated to RPM with the following chart/table.

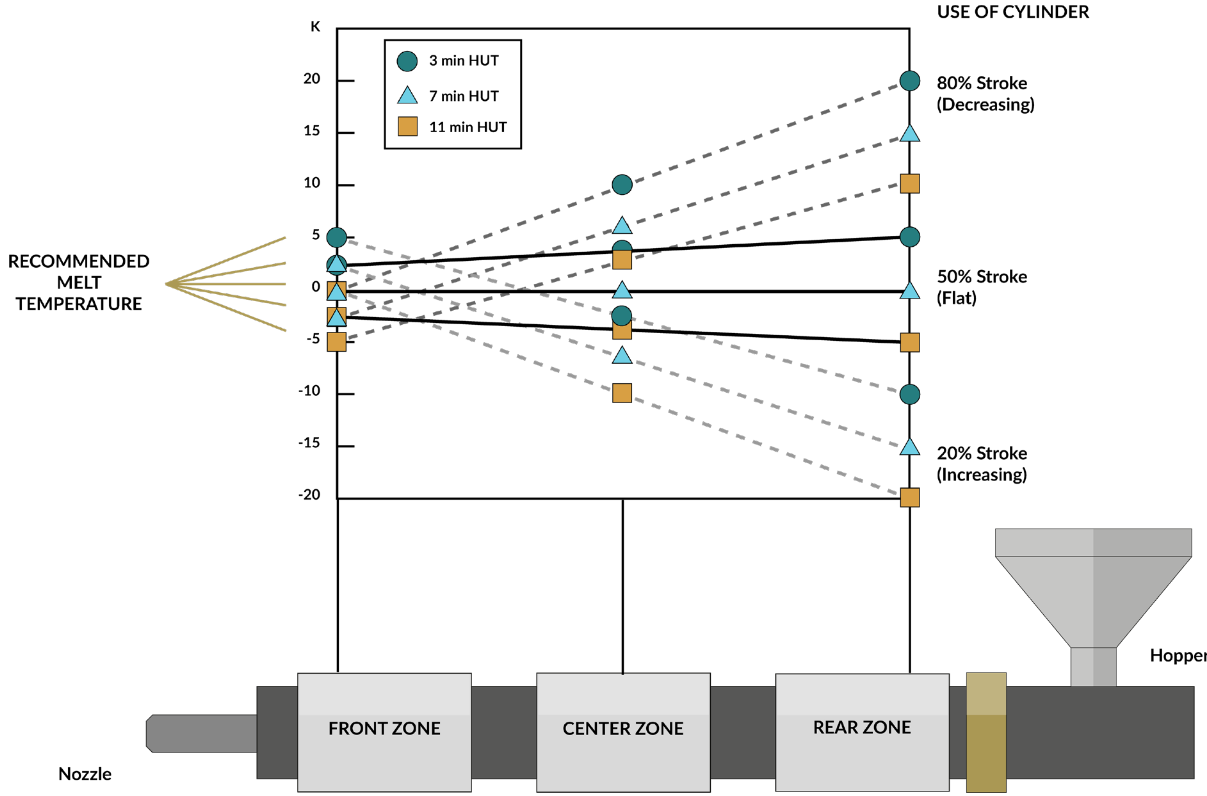


SCREW DIAMETER (mm)	LINEAR SPEED (0.05 RPM min)	(0.35 RPM max)
20	48	334
30	32	223
40	24	167
50	19	134
60	16	111
70	14	95
80	12	84
90	11	74
100	10	67
110	9	61

Running a screw speed less than the recommended value can lead to unmelts, inconsistent melt temperature, and surface defects (blisters, bubbles, cracks, etc.) If the linear speed is exceeded excessively, material can become degraded and result in heat splay, brittle parts, and other visual defects.

Barrel vs Melt Temperature

It should be noted that cylinder temperature and melt temperature are not always the same. Many processes are shear rate controlled with heat generation; moreover, barrel set points can often be overshot once the material enters the compression zone and shear rates are increased. In order to ensure a consistent melt temperature, we often recommend the following type of algorithm for determining barrel profile.



For the general rule of thumb, a flat profile generally only applies for the machines utilizing 40%-60% of their barrel capacity and running <11 minute residence times. If a process is utilizing <30% of the barrel, we generally consider a graduated profile. Additionally, it may become necessary to run a reverse or descending profile if more than 80% of the barrel is utilized each shot.

Process / Machine Transitioning

The following example was generated to show a mold that was transitioned from machine 1 to machine 2.

	MACHINE 1 PROCESS	MACHINE 2 PROCESS	IMPROVED MACHINE 2 PROCESS
Screw Size (mm)	30	70	70
Screw Area (mm^2)	707	3848	3848
Nozzle Tip (mm)	3	3	3
Injection Speed (mm/s)	50	50	10
Shear Rate (Nozzle tip)	13,333	72,593	14,519
Shear Rate (1.25mm gate, 8 cavity)	23,040	125,440	25,088
Recovery Speed (rpm)	90	90	40
Linear Screw Speed (m/s)	0.142	0.330	0.148
Cycle time	45	45	45
Barrel Capacity (grams)	600	3200	3200
Shot Weight	150	150	150
Utilization (%)	25%	5%	5%
Residence Time (min)	3	16	16
Heat Profile	Flat	Flat	Graduated Profile

Values in bold are standard to process 1 or to the corresponding machine. It is very common for process technicians and operations staff to reproduce the absolute values from machine 1 to machine 2. The injection speed, recovery RPM, barrel profile, and cycle time were transitioned form machine 1 to machine 2. As we note above, several thermodynamic and viscosity responses from the machine are significantly different. The shear rate through the nozzle tip and gates are well beyond the recommended high limits. At the higher shear rates with degraded material the parts had flash and burn marks. The increased barrel size would increase the volumetric flow of material and likely account for a majority of the shear related issues. We adjusted the process in order to more closely match the shear performance of machine 1; reducing injection speed, recovery rate, and adding a graduated profile improved part quality significantly.