to 80% of the fill (parts and runner), the parts could fill more than 80% with fast fillings.

Remember that at the end of the injection, transfer position, the screw is being stopped by the plastic in front of the check ring. The screw, just like the plastic, will continue to travel with its own kinetic energy. In other words, the melt will continue to fill the mold until it consumes all that energy in the form of speed. That is why the higher the injection speed the higher the energy at transfer and, consequently, the higher the fill volume.

Continue determining the minimum injection time.

f) Write down the maximum pressure and the maximum speed obtained.

V_{max} = Maximum speed (machine parameter)
PH_{max} = Maximum hydraulic pressure (machine parameter)

If you are working with Universal parameters, it will be:

F_{max} = Maximum flow (Universal parameter)
PP_{max} = Maximum plastic pressure (Universal parameter)

Summary of the steps:

a) Adjust the transfer position to hold.
b) Turn off the hold stage so that it does not interfere with the determination of the injection time.
c) Adjust the injection unit to produce parts that are 20% incomplete.

Recovery position =
Transfer position + 80% of injection displacement

d) Find the minimum injection time and maximum injection speed for the mold being used.
e) Although the parts will be incomplete, verify they are free of defects due to degradation.
f) Write down the maximum pressure and the maximum speed obtained.

V_{max} = Maximum speed or F_{max} = Maximum flow
PH_{Max} = Maximum hydraulic pressure or

$$PP_{Max} = \text{Maximum plastic pressure}$$

Notes:

- If any equipment limitation or defect arises, evaluate the situation, and if the limitation requires a modification or a simple change of equipment, do so. However, if the modification or change is not feasible, you will have to carry out the laboratory with what you have.
- The programmed injection speed might not be reached by the injection unit; verify that it does.
- This lab is performed with the hold stage off. You could do this by adjusting the hold pressure or time to zero.
- In order to avoid damage to the mold and the machine, this laboratory is carried out by adjusting the injection unit to produce parts that are 20% incomplete.
- The weight of the parts increases with an increase in speed or injection flow.

Laboratory II. Determination of Injection Time and Injection Speed

a) Set the injection speed or speeds to 95% of $V_{max,}$ the maximum speed found, and call it $V_{95.}$

$$V_{95} = 0.95 \text{ x } V_{max}$$

Use only one fill speed. Previous chapters explained that, if the recovery and transfer positions are adjusted correctly, most molds can be filled with a single injection speed. Family molds, with cavities of different volumes and distinct geometries, may require more than one speed. Now, most molds can be filled with a single injection speed; do not use a speed profile if you don't need it.

b) Adjust the limit pressure equal to P_{max}.

c) Using the V_{95} speed, adjust the recovery position so that the mold (parts and runners) fills to about 95% of its total weight.

The adjusted limit pressure is likely to be reached, even though P_{Max} was achieved with an incomplete fill of 80% of the mold. Continually verify that the pressure limit is **never** reached; keep it 5% to 10% above the maximum fill pressure.

Notes:

- Do not try to maximize the fill during the injection stage; only guarantee about 95%. Trying to get to the maximum can result in problems with flash and screw bounceback.
- Be sure to produce parts without flash.
- Ensure that the pressure during injection remains at least 5% lower than the set limit pressure.

d) Without changing the transfer position and continuing with the hold stage off (hold time = 0 or hold pressure = 0), create a rheology table with different injection speeds.

Remember that this laboratory can be performed:

- With machine rheology by power or with viscosity.
- With complete or approximated rheology.

We Universal molders prefer and recommend approximated rheology by power, since the equations represent the evaluated effects.

Include in the header:

- For machine parameters: injection speed, fill time, hydraulic transfer pressure and plastic transfer pressure.
- For rheology by power: flow and power.
- For conventional rheology: shear rate and viscosity. Remember to write the corresponding units.

Machine Parameters				Rheo. by Power		Rheo. with Viscosity	
Speed (mm/s)	T_{inj} (s)	$P_{hydraulic}$ (bar)	$P_{plastic}$ (bar)	Flow (bar*cc/s)	Power (bar*c/s)	Sh. Rate (1/s)	Viscosity (bar*s)

VIII-5. Rheology table headers

With rheology by power, use the following equations:

$$\text{Average injection flow} = \frac{\text{Injection volume}}{\text{Injection time}}$$

$$\text{Injection volume} = \text{Screw area } (D^{2\pi/4}) \times \text{Injection displacement}$$

$$\text{Peak power} = \left\{ \begin{array}{c} \text{Average injection} \\ \text{flow} \end{array} \right\} \times \left\{ \begin{array}{c} \text{Plastic pressure} \\ \text{during transfer} \end{array} \right\}$$

$$\text{Plastic pressure} = \text{Hydraulic pressure} \times \text{Intensification ratio}$$

Each of these equations was explained in detail in the “Machine Rheology” chapter.

With approximated rheology by power, carry out the laboratory with the first and last lines. The first speed will be equal to 95% of the maximum speed found in the previous lab.

$$V_{95} = 0.95 \times V_{max}$$

The second and last speed will be equal to 10% of the V_{95} speed.

$$0.1 \times V_{95}$$

Speed (mm/s)	**T_{inj} (s)**	**$P_{hydraulic}$ (bar)**	**$P_{plastic}$ (bar)**	**Flow (cc/s)**	**Power (bar*cc/s)**
V_{95}					
$0.1V_{95}$					

VIII-6. Table of approximated rheology by power

If you work with complete rheology, calculate and enter 10 descending speed values, the first equal to the V_{95} speed, and the next 9 in $0.1 \times V_{95}$ decrements.

Rheology by Power					
Speed (mm/s)	**T_{inj} (s)**	**$P_{hydraulic}$ (bar)**	**$P_{plastic}$ (bar)**	**Flow (cc/s)**	**Power (bar*cc/s)**
V_{95}					
$0.9 \times V_{95}$					
$0.8 \times V_{95}$					

0.7 x V_{95}					
0.6 x V_{95}					
0.5 x V_{95}					
0.4 x V_{95}					
0.3 x V_{95}					
0.2 x V_{95}					
0.1 x V_{95}					

VIII-7. Table showing conventional rheology by power

e) Without turning on the hold stage and without changing the transfer position, inject at the different injection speeds, taking readings of:
   - Maximum hydraulic pressure: Take the reading in the position where the injection ends. If the machine gives plastic pressure readings, then eliminate or leave the hydraulic pressure spaces blank.
   - Fill time: Take the reading of the time it takes from the start of injection to the transfer position.

f) Calculate and fill the table with its corresponding values. Remember that the maximum plastic pressure = $P_{hydraulic}$ x R_i. If the machine gives a plastic pressure reading, ignore this calculation or assume that $R_{i} = 1$.

Summary of the steps:

a) Adjust the injection speed or speeds to 95% of the maximum speed (V_{max}) that was found and call it V_{95}:

$$V_{95} = 0.95 \text{ x } V_{max}$$

b) Adjust the limit pressure equal to P_{max}.

c) Using the V_{95} speed, adjust the recovery position so that it fills the mold (parts and runner) to about 95% of its total weight. Ensure that the adjusted limit pressure is at least 5% higher than the maximum injection pressure.

d) Without changing the transfer position and continuing with the hold stage off, create a rheology chart at different injection speeds.

e) With the hold stage still turned off and without changing the transfer position, inject using the different injection speeds, taking readings of:

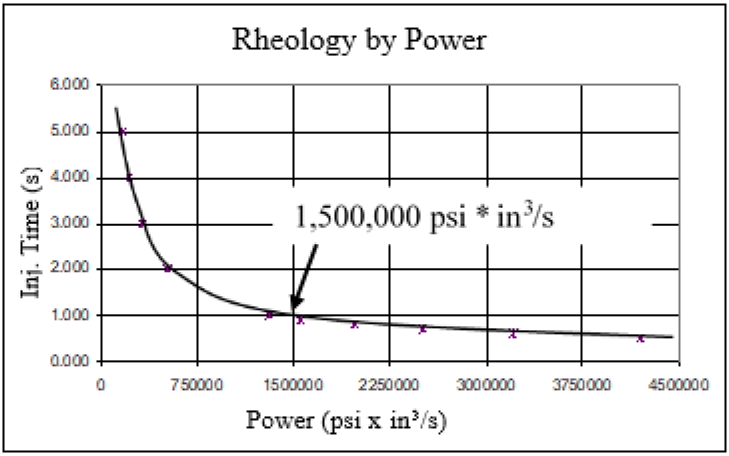
- Maximum hydraulic pressure: Take the reading in the position where injection ends. If the machine gives plastic pressure readings, then eliminate these spaces or leave them blank.
- Fill time: Take the reading of the time it takes from the start of injection to the transfer position.

f) Calculate and fill the table with its corresponding values. Remember that the maximum plastic pressure = $P_{hydraulic}$ x R_i. If the machine gives a plastic pressure reading, ignore this calculation or assume that $R_i = 1$.

Laboratory III. Rheology Graph and Determination of Ideal Injection Time and Speed

a) Using the rheology table already completed, make a rheology graph. If you work with rheology by power, your rheological table will look something like this:

Rheology by Power, R_i = 6.41, Vol = 273 in^3					
Speed (in/s)	**T_{inj} (s)**	**$P_{hydraulic}$ (psi)**	**$P_{plastic}$ (psi)**	**Flow (in^3/s)**	**Power (psi*in^3/s)**
3.2	0.50	1200	7692	546	4199832
2.9	0.60	1100	7051	455	3208205
2.6	0.70	1000	6410	390	2499900
2.3	0.80	900	5769	341	1968671
1.9	0.90	800	5128	303	1555493
1.6	1.00	750	4808	273	1312448
1.3	2.00	600	3846	137	524979
1.0	3.00	550	3526	91	320821
0.6	4.00	500	3205	68	218741
0.3	5.00	461	2955	55	161344



VIII-8. Example of a table and graph of conventional rheology by power

According to this graph, the power stops contributing significantly to the injection time after a power greater than 1,500,000 psi * in^3/s.

Laboratory IV. Approximated Graph

As explained in the previous chapter, developing an injection molding rheology laboratory consumes time and resources. With approximated rheology, a mathematical prediction technique, the laboratory can be performed in less than a third of the time.

In the previous example, we used velocity V_{95} and 10% of V_{95} to find the readings for injection time and pressure at the moment of transfer. If we work with rheology by power, you will notice that there is a relatively linear relationship between average injection flow and peak power of injection. Using the equation of a line, $Y = Y_o + MX$, where Y is the peak power, Y_o is the intercept in the coordinate of the peak power, M is the slope, and X is the average flow.

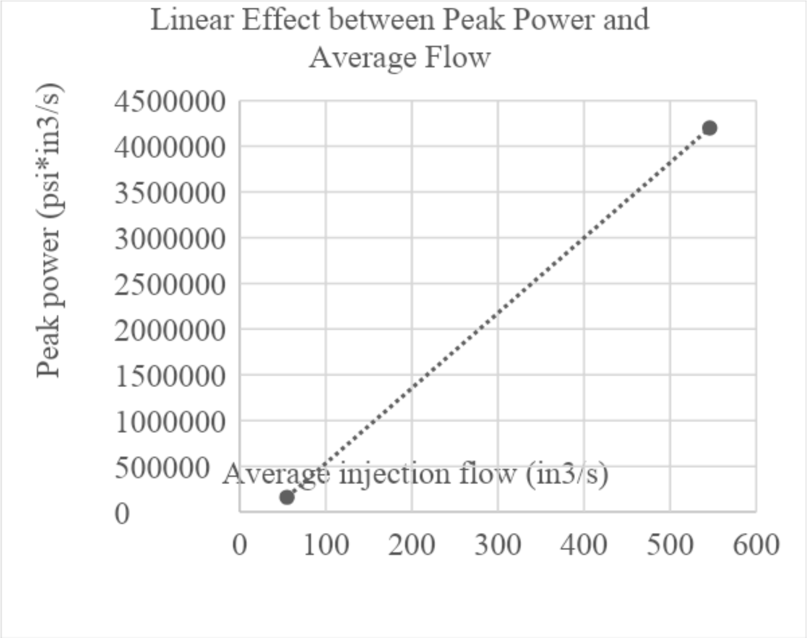
The value of these constants can be found with simple math or Excel.

Using the values of the fastest velocity and the slowest velocity from the previous example, we get:

Rheology by Power, $R_{i\,x}$ 6.41, Vol 273 in^3					
Speed (in/s)	**T_{inj} (s)**	**$P_{hydraulic}$ (psi)**	**$P_{plastic}$ (psi)**	**Flow (in^3/s)**	**Power ($psi*in^3/s$)**
3.2	0.50	1200	7692	546	4199832
0.3	5.00	461	2955	55	161344

VIII-9. Example of a table of approximated rheology by power

Using the Graphing Trendline tool in Excel, we find the linear equation between the maximum and minimum points.



VIII-10. Graph with linear trendline equation between peak power and average injection flow

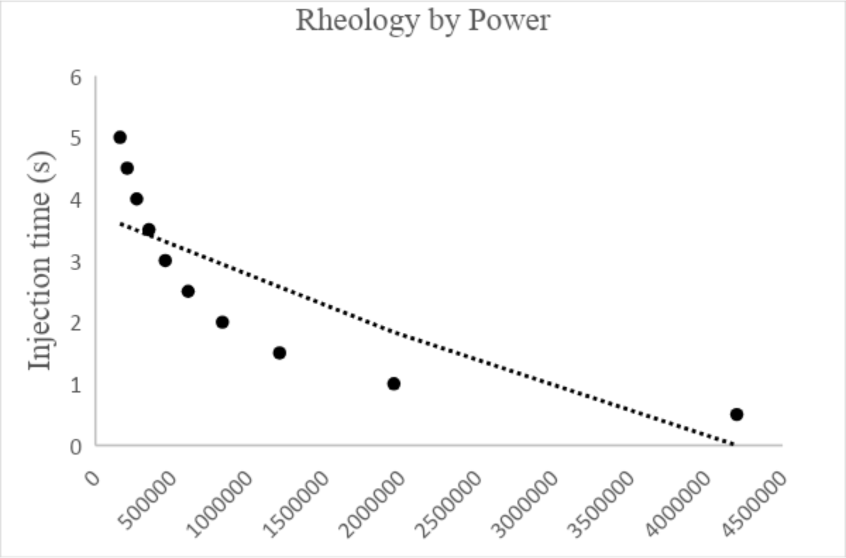
$$\text{Peak power} = 8225 \times (\text{Average flow}) - 291032$$

Knowing that the volume required by the mold is 273 in^3 and using the equation for average flow (required volume/injection time), we get:

$$\text{Average flow} = 273\ in^3 / \text{Injection time}$$

With these two equations, we can now approximate the intermediate values of the graph. With ten equidistant injection times, between the minimum and maximum injection times, we calculate their corresponding average flows and peak injection power.

$T_{injection}$ (s)	Flow (in^3/s)	Power ($psi*in^3/s$)
0.5	546.0	4199832
1	273.0	1954393
1.5	182.0	1205918
2	136.5	831681
2.5	109.2	607138
3	91.0	457443
3.5	78.0	350518
4	68.3	270324
4.5	60.7	207951
5	55	161344



VIII-11. Table and graph of approximated rheology by power

Laboratory V. Injection Time Prediction

In the chapter on machine rheology, it was established that the ideal injection time would depend on the type of industry.

Conventional molding industries:

$$\mathbf{T_{Intermediate}} = T_{min} + (T_{max} - T_{min}) / 18$$

Industries that mold sensitive materials:

$$\mathbf{T}_{\textbf{sensitive mat.}} = T_{min} + (T_{max} - T_{min}) / 12$$

Industries with a high volume of injection:

$$\mathbf{T}_{\textbf{fast}} = T_{min} + (T_{max} - T_{min}) / 36$$

In addition, $T_{plateau}$ was defined as a time when the contribution of power to the injection time begins to be insignificant.

$$\mathbf{T}_{\textbf{plateau}} = T_{min} + (T_{max} - T_{min}) / 9$$

Where:

$\mathbf{T}_{\textbf{min}}$ - Injection time corresponding to the maximum injection speed

$\mathbf{T}_{\textbf{max}}$ - Injection time corresponding to the minimum injection speed

Using the previous example, we find that $T_{min,}$ is 0.5 seconds, which corresponds to the speed of 3.2 in/s (V_{95}) and T_{max} is 5.0 seconds, which corresponds to the speed of 0.3 in/s (10% of V_{95}).

Rheology by Power, $R_{i\,x}$ 6.41, Vol 273 in^3					
Speed (in/s)	**T_{inj} (s)**	**$P_{hydraulic}$ (psi)**	**$P_{plastic}$ (psi)**	**Flow (in^3/s)**	**Power (psi*in^3/s)**
3.2	0.50	1200	7692	546	4199832
0.3	5.00	461	2955	55	161344

VIII-12. Table of approximated rheology by power

b) After identifying the industry type, select its corresponding equation, and replace the values of T_{min} and $T_{max,}$ in order to determine the ideal injection time.

$$\mathbf{T}_{\textbf{Intermediate}} = T_{min} + (T_{max} - T_{min}) / 18$$
$$= 0.5s + (5s - 0.5s) / 18 = 0.75 \text{ seconds}$$