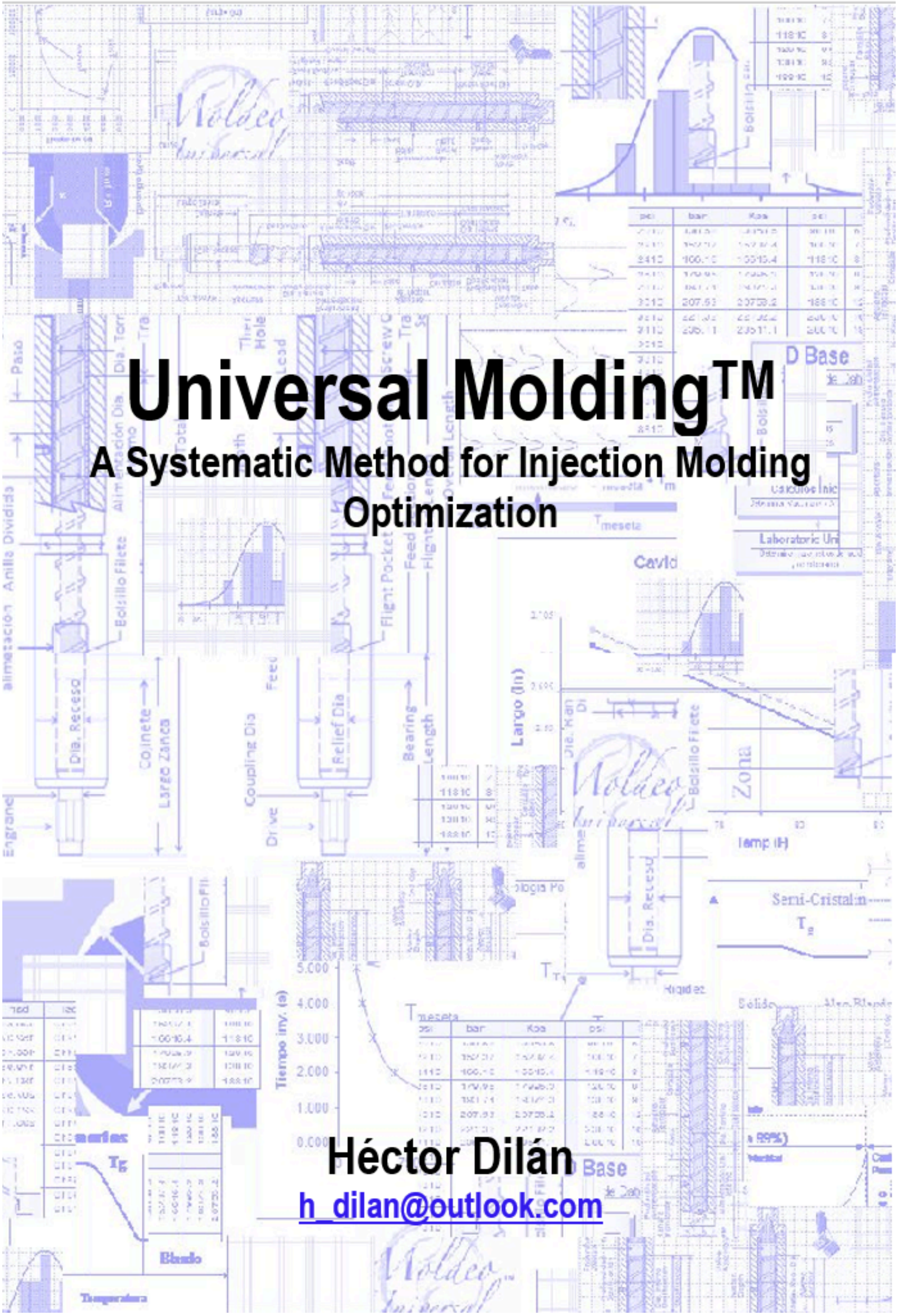

Universal Molding™

A Systematic Method for Injection Molding Optimization

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Dedication

I dedicate this book to my wife, Susan, for being the pillar that strengthens every day of my life, for helping me with the editing and for lending me family time to write this book.

Special Thanks

This book was written thanks to the motivation of friends from the plastic industry. Some of those friends and collaborators are Luis de Jesús, Carlos López, Iván Baigés, Gregorio Vélez, Runny Hernández, William Torres, Wally Cruz and Félix Colón. My friends, thank you for the collaboration and for sharing your knowledge with me.

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Preface

Injection molding was, for many years, a space occupied by the experienced masters of the plastics industry. Fortunately, today there are several techniques that accelerate learning and mastery of injection molding.

We have experimented with numerous molders of all calibers. Among us we have never found two that use identical molding techniques. Not only are the molding techniques different, but language, order of execution, definitions, parameter usage, equipment identification, procedures, and communication are not equal. These are the reasons that motivate the writing of this book.

Universal Molding™ (abbreviated ***MU™***) aims to unify molding styles, use valid process definitions, use Universal language, and standardize clear and representative procedures for all stages of injection molding.

This book is not limited to just newcomers to the industry; it is also recommended for experienced molders who wish to standardize and increase the number of competent molders in their sector. ***Universal Molding™: Systematic Injection Molding Optimization Method*** (***MU™***) is for anyone who wants to learn systematically and effectively about injection molding. ***MU™*** guides the molder to determine the Universal parameters characteristic of the mold, regardless of the injection machine used. There is a concern that affects a minority in the plastic industry, artificial intelligence. We see it as a tool that will help address the lack of standardization and empirical approaches in process parameter optimization. The integration of artificial intelligence in ***MU™*** considers the fundamental principles of standardization, rapid learning, efficient processes, and significant benefits. We must all strive to improve, accept, and learn new methodologies and technologies that strengthen continuous growth.

Prologue

What is the definition of an “optimal” injection polymer molding process? In reality, we do not establish an optimal process, but instead define an optimal operational window around the values of certain molding parameters that an optimization laboratory leads us to establish and define as 'nominal'. Using the tools provided by the internet we can find countless definitions and/or methods on what is an optimal process, how to establish it, and even how to monitor it. These definitions, in short, establish that an optimal polymer molding process is "*the result of a particular combination of molding parameter values... inside an operational window... able to consistently produce a plastic part that meets all cosmetic, dimensional and functional design requirements... in the shortest machine time possible*." This, for any combination of raw material, mold design and molding cell (i.e. injection machine, dryer, temperature controls, etc.). Similarly, that optimal process *cannot be* if it goes against the ability of the mold, or even the molding machine, in order to repeat the same cycle of behavior infinitely.

The author of the book has devoted much of his professional life to systematically identifying two things. First, how to establish that optimal operational window in a molding process; and second, how to make that optimal process window for any combination of raw material, mold and molding equipment the same regardless of who runs it or where the optimization lab is performed. That is why ***“Universal”*** is in the title of this book. It is the intention of the author, with the tools presented in this, his book, to make the Process Engineer able to identify the minimum requirements with which each of the equipment and utilities that make up the molding cell must meet. Once the equipment is successfully selected, it provides the tools for the selected equipment to become the foundation on which, in a complete way, the Process Engineer can develop the laboratory and establish the design experiments that will shape that combination of 'nominal' parameters around which will define the limits of that optimal operation window being validated. This....*in the shortest machine time possible*.

Felix Colón Ortiz
Injection Molding Process & Tooling Engineering Professional

I. Introduction

- **What is *Universal Molding^{TM} (MU^{TM})*?**
- **Fundamentals of the Injection Molding Process**

In this section we want the readers to familiarize themselves with the terminology, emphasizing those parameters that are most significant to the process and establishing the language used in this book.

What is *Universal Molding™*?

Universal Molding™ (MU™) is an injection molding process optimization discipline. It was developed with the collaboration of the Caribbean plastic industry and the academia (professor and students) from the University of Puerto Rico, Mayagüez Campus (UPR RUM).

MU™ is a *discipline* that emphasizes the maximization of resources and focuses on the quality of the product, utilizing process optimization methods proven by means of organized and scientifically backed molding techniques. This tecno-scientific background increases efficiency, decreases product cost, and shortens manufacturing cycles.

MU™ is a *common language* used by molders to eliminate terminology confusion. The equipment is labelled with a language that represents their capacities. It is this language of ***Universal*** process parameters that simplifies the transference of processes between machines. It is a language that defines a product and its utilization.

MU™ is an *organizing committee* (or ***Universal*** committee). It is a chosen group that promotes that discipline. It is a ***Universal*** committee represented by all departments of the ***Universal*** factory. It is represented by the Production, Quality Control, Equipment Maintenance, Mold Maintenance, Engineering and Sales departments.

MU™ is an *endless discipline* that never ceases to grow or improve. The ***Universal*** committee has the responsibility to evaluate and unanimously adopt procedures that improve the existing ones.

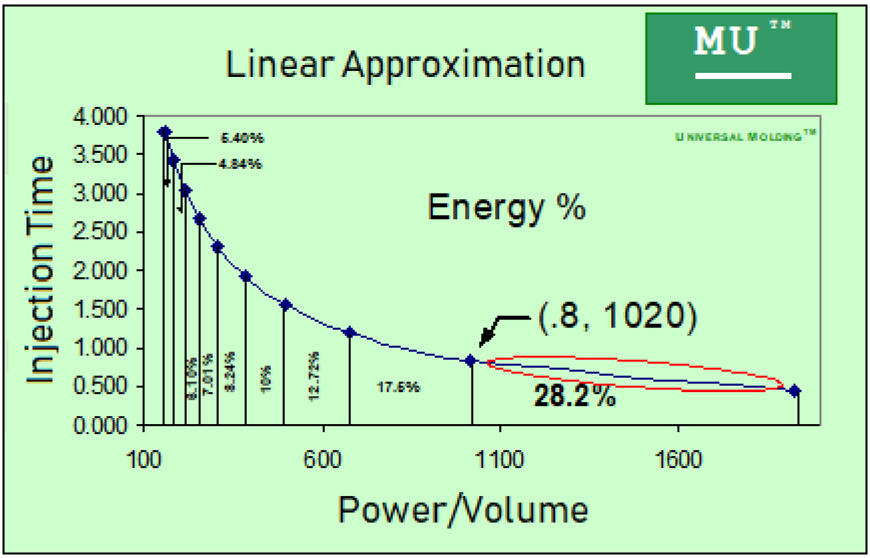
MU™ *is based on precise and representative process procedures.* At each stage, a procedure is followed to determine the parameters, either through linear equations or, in many cases, with a nonlinear component generated by artificial intelligence (AI).

MU™ is *maximizing the utilization* of the machinery. It is determining the appropriate equipment and its optimal process parameters.

Some of the techniques used are:

1- Injection machine rheology. This is an effective, proven technique used to determine injection time. Using a graph, it shows the effect of the injection time versus energy per unit of volume.

In the following graph, the area below the curve demonstrates the percentage of energy consumed for each decrement in injection time.



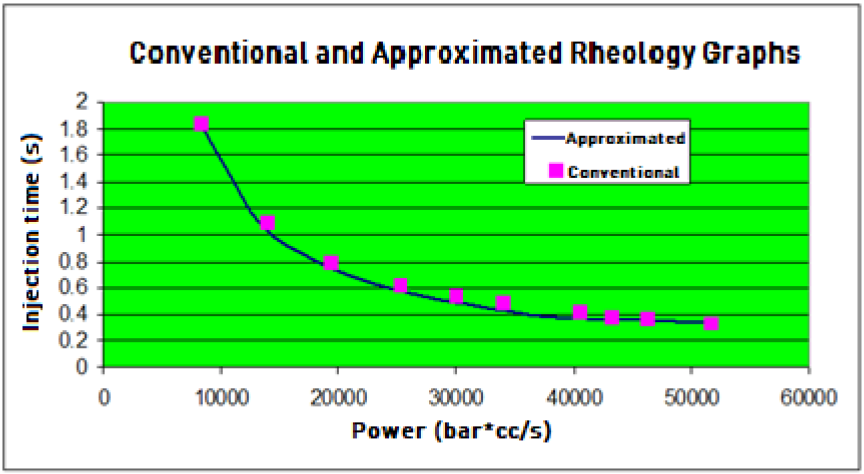
I-1. Injection molding machine rheology graph

Note that the power consumption increases as the injection time decreases. This graph shows that the power required at higher injection rates is considerably high, or the power consumed by the injection unit is more significant at lower injection times. The idea is to select an injection time in the zone in which the time stops contributing with an increase in power.

Later we will explain how to develop and utilize this injection molding rheology graph.

2- Approximated rheology. Developing a rheology laboratory with an injection machine consumes time and resources. With approximated rheology, a mathematical prediction technique, the laboratory can be achieved in less than a third of the time.

The following graph of injection time versus power by volume compares the two methods: conventional machine rheology and the approximated method.



I-2. Conventional and approximated rheology graph

Both methods conceptually function in the same way. The difference is that using the approximated method consumes less time and resources.

Again, the development of these graphs will be explained in later chapters.

Fundamentals of the Injection Molding Process

The basic stages of the injection molding process are:

- injection
- changeover or transfer
- hold
- gate freeze
- cooling
- recovery

Each stage has a function and a specific result. Understand each one of these stages thoroughly since their descriptions will be continually referenced.

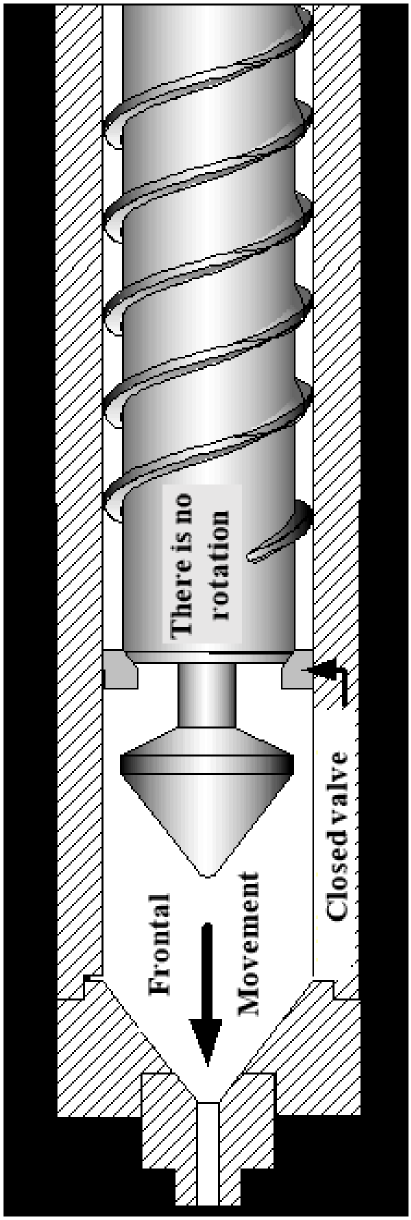
Injection - In this stage the mold cavities and runner are filled close to 95% of their total volume, and the screw acts like a piston that transfers melt from the injection unit to the mold. Here is where you program a velocity or injection flow rate that guarantees the best melt properties. These properties could be parts without burns, no flowlines, no degradation, minimal stress concentration, etc. When the hot melt enters the mold, it is met with cold walls and rapidly densifies until it solidifies. The slow fill increases densification or viscosity and, consequently, it could make filling the mold difficult and may even cause the melt to solidify prematurely before the mold has been filled. In this stage the injection time, as well as the injection pressure, are results and not control parameters. Do not confuse these with *injection pressure limit* or with *injection time limit*, which are limits that are programmed to protect the tooling and the equipment. This stage is known as the injection speed control stage.

Transfer (changeover) – This is what determines the end of the injection stage. Once the injection unit has filled the mold **close to 95%**, the injection stage ends, and the hold stage begins. The injection unit comes with a linear encoder that measures the injection screw displacement, which is how the injection unit knows when the melt is close to filling 95% of the mold. Avoid trying to fill the mold 100% in the injection stage. Let's see some of the reasons why:

- It could cause flash on the molded parts. What stops the screw is the melt in front of the injection unit; trying to stop at exactly 100% without opening the mold would be difficult.
- At a high speed, trying to fill a mold to 100% could create a bounceback effect on the screw. Plastic melt is compressible and during injection it is placed under pressure. This pressurized melt can act like a compressed spring, pushing the injection backwards and causing a suckback effect that pulls back part of the melt that was injected.
- Another reason that it should not be done is because of material shrinkage. Melt occupies more space than solidified material.

Once the melt enters the mold it will cool, gradually shrinking and leaving space for more material.

Note: Some molds present an extreme difficulty in filling, for example, nylon ties which are long and thin, or micro-molding applications with narrow and awkward spaces for filling. In these cases, a filling percentage higher than 95% may be required.



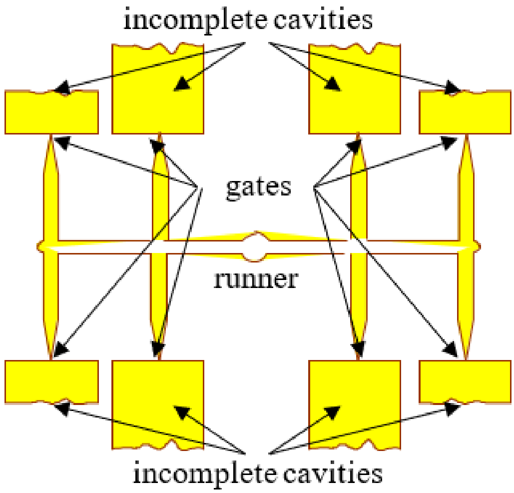
During the injection stage the screw acts like a piston injecting a fluid. The melt is maintained at the front of the screw and the valve keeps the melt from returning to the screw. The displacement of the screw begins at the recovery position and will continue until the changeover to hold.

I-3. The injection stage

Hold - In this stage the screw continues to move like a piston, forcing more melt into the cavities until it fills the portion that was not filled in the injection stage. Without opening the mold, the injection unit compresses the melt, packing more material into the mold until the cavities are completely filled. Here the molder adjusts the compacting pressure.

During this stage we achieve the proper weight for the molded parts, or what we ***Universal*** Molders call *mass dimensions*. The mass dimensions are those that are a function only of the quantity of material and should not be confused with the dimensions that are due to the effect of material shrinkage. Shrinkage is controlled during the cooling stage. As indicated previously, during the hold stage we only control the mass dimensions, the dimensions that are a function of the quantity of material.

Gate Freeze – During the hold stage, the parts are pressurized until the material in the gates solidifies, creating a seal that keeps the melt inside the cavities. Let's look at the spaces that the plastic occupies in the mold.



I-4. The spaces that the plastic occupies in the mold

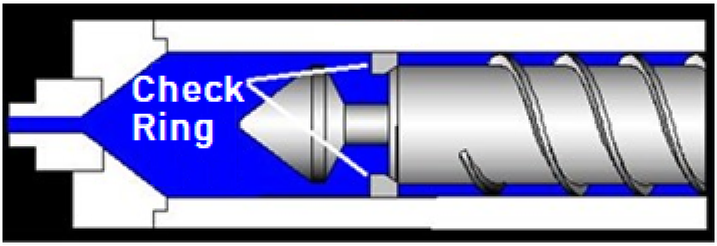
A gate is a small opening through which the melt enters the cavities. The melt enters the mold through a sprue and travels through the runner until it reaches the cavity gates. The melt is forced through the narrow openings of the gates until the cavities are filled. The plastic is held inside the cavities until the gates solidify. It is important to understand:

- If you remove the hold pressure prematurely, the melt will return to the runner and even to the injection unit.
- If the hold time is more than required, the molder will end up "molding runners".

In some molds with hot runners, the melt never solidifies and is integrated as part of the filling for the next parts. The goal of this type of mold is to reduce the waste of material from the sprue. However, even in this case, the gates on the cavities must solidify before releasing the hold pressure.

In other molds, in addition to having hot runners, valves are integrated into the gates. These gate valves remain open during filling and close once the holding is complete.

The screw acts as a piston thanks to the check ring that floats between the screw and the screw tip. During injection, this check ring moves against the screw, creating a seal and keeping the melt from returning to the screw.



I-5. The check ring

During injection, the pressure in front of the check ring is greater than the pressure on the screw side, causing the check ring to move against the screw to create a seal.

There exist some screws that do not have a check ring. Rigid PVC material is very sensitive to the friction of the melt against the check ring, and it is common to see that this type of system does not use any check ring. Instead, these screws come equipped with an anti-rotation mechanism so that they will not turn as a consequence of excessive melt pressure.

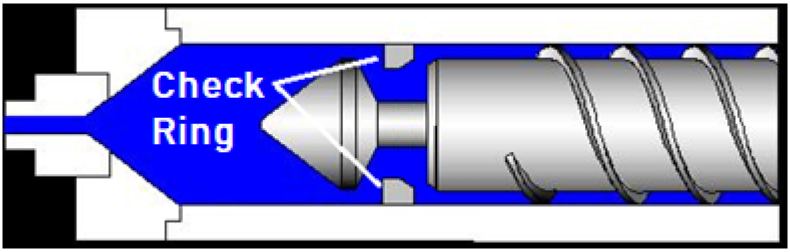
Cooling – In this stage, heat is removed from the parts, until they can be easily demolded with acceptable thermal dimensions. Thermal dimensions are dimensions that are a function of shrinkage and not of the quantity of packed mass. The molecules of thermoplastic melt are in continuous movement; as they cool, they look for conformity and accommodate themselves to occupy less space. The objective is to paralyze the molecular activity and manipulate this shrinkage to our advantage.

This means:

- Cold molds and extended cooling times result in parts with thicker walls.
- Hot molds and short cooling times result in parts with thinner walls.

Thermal dimensions and some mechanical properties are a function of how quickly the heat is being removed from the parts. These mechanical properties could include rigidity, translucence, crystallinity, etc. Later on, we will explain how thermal dimensions are a function of cooling time and mold temperature.

Recovery - In this stage, the screw reloads material for the next shot. The main goal of this stage is to produce a homogeneous melt. During recovery the check ring moves away from the screw, which allows the melt to flow to the front of the screw as the screw turns.



I-6. Position of the check ring during recovery

The melt that accumulates in front of the screw is what pushes the screw backwards.

Recovery occurs at the same time as the cooling stage. Under normal circumstances recovery ends before the cooling stage ends and, if the cooling stage ends first, permission to open the mold is denied by the machine's controls. Under these circumstances, where the permission to open the mold has been denied and if no alarms exit that would cause the process to stop, the cooling time will be extended, altering the thermal dimensions.

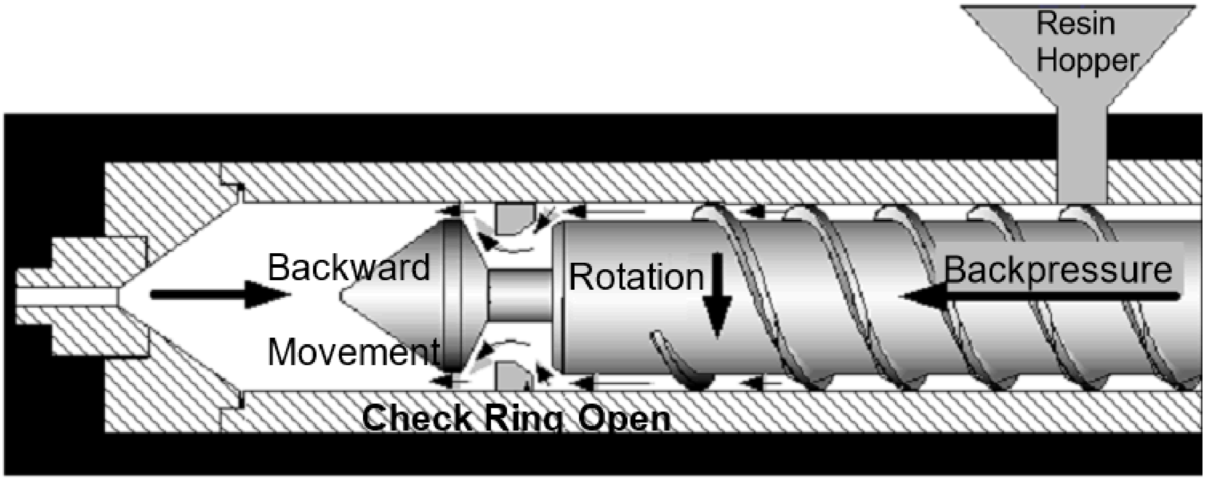
Imagine what would happen if the mold opened during the recovery stage. The melt would drool into the mold. During recovery, the plastic is pressurized and the mechanism that holds the melt in place is the filled mold. As a rule, recovery should end close to a second before cooling. Permission to open the mold during recovery can only occur if the injection unit has been equipped with a valve on the nozzle.

It is important to know that the injection unit utilizes two sources of heat to melt the plastic: the heating bands on the barrel and friction. Generally, 50% of the heat comes from the heater bands and the remaining 50% comes from the friction of the plastic moving inside the barrel.

Later we will discuss in more detail the parameters that govern recovery, which are recovery speed, recovery position, backpressure, decompression and melt temperature.

Mold Movement – During this stage we demold the parts. Once the cooling stage has ended, the sequence is: the mold opens, if cores exist they will disarm in order to liberate the parts, the parts are ejected, the cores are relocated into the mold, the mold begins to close, the mold protection system is activated and, if the mold protection does not detect any issues, the injection machine reaches full closure force, and a new cycle begins.

I-7. The recovery stage



In the recovery stage the screw rotates, moving the melt to the front of the barrel. The check ring moves, allowing the flow of melt. That melt accumulation in the front is responsible for pushing the screw backwards. The backpressure opposes the free movement of the screw, resulting in shear friction on the material, which, in turn, generates heat and contributes to the melting process.