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## **DYNAMIC TEMPERATURE CONTROL INFLUENCE ON PRESSURE DURING INJECTION MOLDING OF PLASTIC PARTS TO IMPROVE PART QUALITY**

**Abstract:** *The plastics industry is continuously demanding for plastic parts with higher quality and improved mechanical properties. To meet these demands, companies depending on efficient and reliable flow simulation software. These simulation tools are valuable in optimizing the process parameters to obtain a plastic part with improved surface quality. This work studies the flow behavior on a plastic part with non-trivial model features, such as, holes, ribs, thin walls and zones with different thickness, using various injection point locations and different mold temperatures, under dynamic temperature control. Results have shown significant influence on the final process parameters, such as the injection pressure. A mold temperature increase from 40°C to 160°C and then to 200°C, promoted by an external system heating the mold surface, resulted on reductions of 36% and then another 42% of the injection pressure, respectively. This will have a very positive effect on the surface quality of the part as well as potentially eliminating several aesthetic defects.*

**Keywords:** *Injection molding; Surface quality; Flow simulation; Numerical simulation; Dynamic temperature control; Quality optimization*

### **1. Introduction**

The plastics industry, in particular the automotive, aeronautics, and medical devices sectors, can be extremely demanding in the production of thin, lightweight, high dimensional precision and optimum surface quality parts, in order to satisfy client requirements, while having to ensure the production of parts that meet stringent mechanical performance specifications (Xiao & Huang, 2014; Chen et al., 2011; Wang et al., 2010).

Surface quality is a critical feature in many products, and examples of parts that require excellent surface quality are found in every industry process, such as injection molding of plastics and milling of metals (Chen et al.,

2011; Dedić et al., 2017).

In metals, in addition to optimization through the use of modeling and simulation tools (Dedić et al., 2017), the improvement of part quality has been tackled also through the optimization of the production process, including Lean Six Sigma approaches (Klochkov et al., 2019).

In the case of plastics, the most widely used technology for this class of materials, conventional injection molding technology (CIM), has its own process limitations that often hinder satisfying all the requirements mentioned before. Additional operations and external process steps, such as painting, are often needed to ensure excellent aesthetic properties on molded parts (Xiao & Huang, 2014; Wang et al., 2011b).

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This need to improve the injection process and, at the same time, ensure the production of parts with high aesthetic and mechanical precision, has led to the development of alternative, often termed ‘unconventional’, molding technologies (Chen et al., 2012).

One such innovative molding technology is known as RHCM (Rapid Heating Cycle Molding) or RTCM (Rapid Thermal Cycling Molding). The capability of controlling dynamically the mold temperature, changing the heating and cooling stages of the injection molding cycle, is what distinguishes this non-conventional technology from the traditional injection process (Xiao & Huang, 2014; Wang et al., 2011b; Wang et al., 2013; Huang et al., 2011).

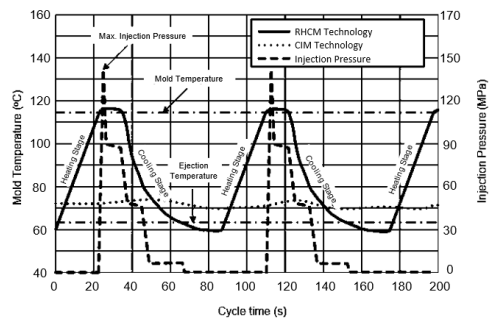
In terms of the injection process, this alternative technology has the main benefit of improving part surface quality and decreasing the injection pressure needed to fill the cavity. Common surface defects present on plastic parts molded by CIM technology, such as sink marks, welding lines, residual stresses, warpage, and others, are not expected with RHCM technology. These aspects will lead to an important enhancement on aesthetic properties of the molded parts, such as higher gloss, while simultaneously improving dimensional accuracy (Wang et al., 2010; Wang et al., 2013; Huang et al., 2011; Wang et al., 2011a; Macedo et al., 2019).

A fast mold heating is also essential to ensure a good reproducibility of all part properties, high productivity, low operating costs and to completely fill any cross-sectional thin wall parts (Wang, 2010; Wang et al., 2011a).

RHCM or RTCM technology consists on a pre-heating of the mold cavity until its surface reaches a temperature higher than the polymer glass transition temperature ( $T_g$ ), before the molding cycle starts and maintaining such high temperature during the filling and packing stages. On this technology, a long flow length results when the molten thermoplastic enters in contact with the “hot” mold walls.

In terms of cycle, this unconventional technology, as expected, presents a heating stage before the filling step (figure 1). So, after filling stage is finished, high mold temperature is maintained until the packing phase is complete. Then, the mold is rapidly cooled until the required part ejection temperature is reached. A fast cooling is needed to prevent a too long cycle molding. However, accurate control of this parameter is vital, or it can lead to defects on the molded part surface and affect, consequently, its mechanical properties (Wang et al., 2010; Wang et al., 2013; Wang et al., 2009; Shayfull et al., 2013).

Figure 1 shows how much injection pressure is affected by mold temperature increase, along the cycle molding, for both technologies. A dynamic temperature control system (Zhao et al., 2011) was applied and tested on a LCD TV panel mold in order to study and evaluate the thermic efficiency of an electric heating system and a water flow cooling.



**Figure 1.** RHCM (1) and CIM (2) cycle molding. Adapted from (Zhao et al., 2011).

Based on numerical simulation methodology, authors decided to develop two different RHCM mold structures and analyze their thermic efficiency on mold cavity surface, during the heating stage of the cycle molding. Simulation results exhibited a high heating efficiency promoted by the RHCM electric heating system, promptly increasing the mold temperature and avoiding a needless increase of the cycle molding time. In terms of molded

part surface appearance, the results showed an largely improvement on part surface gloss and elimination of surface marks, such as flow marks, usually seen on conventional technology (Zhao et al., 2011).

Wang et al. (2009), revealed that the mold temperature's increase above the polymer glass transition temperature reduces, drastically, different kinds of defects on molded plastic parts, for instance, welding lines, short shot, residual stresses, sink marks, and others. They go further and, through their study where a dynamic temperature control system (high temperature steam) was proposed and designed, observed a successfully elimination of such defects, as well as a surface gloss improvement of an injected LCD panel. Therefore, additional operations, previously required, are no longer needed, so the part can be directly used upon molding.

Guilong et al. (2010), conclude exactly the same as Wang et al. (2009) with their own experimental study. They observed the elimination of the weld line and the improvement of molded part surface gloss by using a hot steam system to heat mold cavity. However, the total cycle molding time needed to process one plastic part was too high comparing with the conventional technology, circa 72s (Guilong et al., 2010). The different dynamic temperature control systems developed reported in the literature have proved to be very useful and efficient in mold temperature control, improving the part's surface appearance, its mechanical performance, sometimes, without a noticeable increase in the traditional cycle time. The same experiments have revealed also the main benefits that this technology can give to the injection process, such as, reduction on injection pressures needed to fill the mold cavity, lower injection speeds, less difficulty to process thin-wall parts, etc.

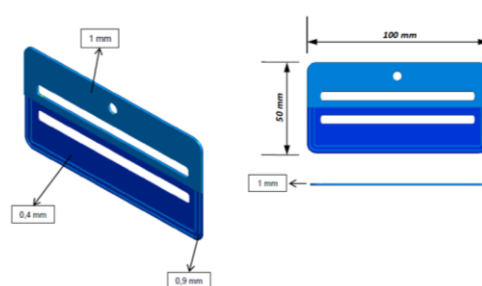
In the present work, models were designed on a simulation software for traditional and unconventional injection approaches. An existing temperature dynamic control system,

composed by electric heating rods, was applied to the unconventional model, to improve the final injection process parameters, such as the maximum injection pressure. The main goal of this numerical study is to predict and analyze how a significant mold temperature increase can drastically influence the final process outcome.

## 2. Experimental procedure

### 2.1. Numerical model of the part - geometry design

The geometry defined for this study, as well as its dimensions, is presented in figure 2. The plastic part has some aesthetic details that can easily lead to critical defects on part final appearance and the final process parameters. The plastic part has a planar shape with some particularities such as: different thickness throughout the part, thin walls, ribs and holes, which can lead to typical defects seen on injected parts, such as weld lines, warpage, shrinkage, or sink marks. The selection of such geometry was based on the research team's academic and industrial knowledge which explain how these defects usually result from the injection process of part with this kind of specifications.



**Figure 2.** Plastic part numerical model geometry and dimensions.

The requirements that this numerical study aims to achieve are: obtain a final part with A type class surface, high gloss, high aesthetic properties, reduce warpage and the weld

lines, and enhance the injection process by decreasing the injection pressure.

A CAD/CAE tool was used to draw the part geometry and define the intended dimensions, before exporting the model to the numerical software, capable of designing the mold base for the simulation study.

## 2.2. Mold-base Numerical Model Design – Case studies 1 and 2

This stage is focused on the design of the mold base, by using a design tool from the software Moldex3D®, before starting the flow simulation analysis. This subsequent analysis will allow us to predict and analyze the molten material flow throughout the mold cavity and the final process parameters. The first model developed is based on a traditional mold used for CIM (Conventional Injection Molding), which has only a water cooling system formed by cooling channels (blue rods) and used to maintain the mold temperature constant during the molding cycle. This conventional model was developed to understand how process parameters are affected by the injection of molten material at high temperatures in traditional (“cold”) mold conditions.

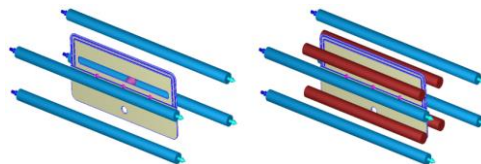
Figure 3 shows, on the left side, the traditional numerical model developed on Moldex3D® software design tool for the currently study. This model has 1 injection point, located on the part middle zone, and four cooling channels containing water flow.

The second model designed for this first case study is based on the introduction of a dynamic control temperature system on the mold (right side of figure 3). An electric rod heating system was incorporated on the traditional mold (red rods), with four heating rods between the mold cavity and the cooling channels. This configuration mimics an experimental setup by the team (where the electric rods actuation is managed by a digital controller system with thermocouples inside the mold to continuously monitor temperature near the cavity). This dynamic temperature

control system will be responsible for heating and maintaining the mold heated during the filling and packing stages until the cooling stage. For both numerical models, the injection point is located on the middle of the part, on the flat surface.

Also, three node sensors were designed and located on the part middle zone, in three different positions (pink points in figure 3). These sensors have the purpose of evaluating some specific process parameters, such as the injection pressure, flow rate, etc., on a specific region. Through the results measured on the node sensor located on the injection point zone, it is possible to predict the injection pressure vs time curve right in the moment when the molten material contacts for the first time the mold cavity. We must be sure the software makes all the numerical calculations on two or more symmetric mesh points at the same time, predicting on a reasonable and consistent way the final process parameters. This is why two other node sensors were placed symmetrically with respect to the part’s center on the x-axis, on both models.

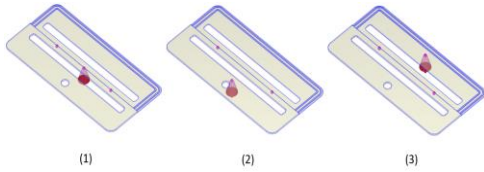
Those two numerical models were developed according to what it is intended on the first case study, i.e., identify how the dynamic temperature control system can affect the final injection process parameters.



**Figure 3.** Numerical models developed for case study 1 – Mold different temperature. Left - Conventional Technology; Right – Heating rod heating technology.

Another numerical model was developed to investigate the flow behavior of the molten material for different injection points, during the filling stage, using the same processing conditions. Two new injection points were selected for the case study 2, beyond the

traditional middle zone, specifically on the planar surface, on the thinner and thicker zone of the plastic part (see figure 4).



**Figure 4.** 3D CAD model of the three injection points selected for case study 2. 1) Part middle area; 2) Thicker part area; 3) Thinner part area.

Figure 4 shows the precise locations of the three injection points. The first one, on the figure's left side, represents the traditional model (1), the middle one shows the injection point on the thicker zone (2), and finally, on the right side of the figure, the injection point on the thinner zone of the part (3).

This case study intends to analyze how the injection pressure vs time curve is affected by the selection of different injection points placed on strategic zones and identify which one ensures better process parameters.

### 2.3. Processing Conditions - Case Studies 1 and 2

This section presents the experimental procedure followed on both studies and, mainly, the injection process conditions selected to run the simulations.

This experimental procedure aims to analyze and compare the flow results obtained from the filling stage, for each case. For the first case there are two different mold (cooling) structures, respectively designated as 'traditional' and 'reference' mold. The first one considers 40°C as mold temperature, common mold temperature for conventional injection molding process (CIM). A 160°C and a 200°C mold temperatures were selected for the second. Such high mold temperature is achieved by the calorific energy generated from the heating rods, located inside of the mold. A commercial Homopolymer

Polypropylene ("Mitsui Polypro J708UG") was selected for the simulation study. A 210°C injection temperature was selected, which is a common processing temperature for this thermoplastic material. Table 1 shows the main specifications of the selected Polypropylene. This specific material grade was chosen based on its MFI value, i.e., a low viscosity material, which is important to decrease high injection pressures needed to obtain the experimental study thin-wall part.

**Table 1.** Summary table with some specifications related to the selected material (Polypropylene).

Specification	Data
Generic name	PP
Supplier	PRIME
Commercial name	Prime Polypro J-708UG
MFI	MFI (230,2.16) = 45 g/10min
Melt Temp. range	180 - 260 (°C)
Mold Temp. range	40 - 70 (°C)
Ejection Temp.	100 (°C)

A 120°C and a 160°C mold temperatures were selected according to Tg (Glass transition temperature) of the selected Polypropylene grade (circa 100°C). This is intended to avoid the presence of the frozen layer and reduce the molten material resistance on mold walls, during the injection step. This phenomenon will lead to a decrease of transversal area of the channel and, probably, to an incomplete molding. For that reason, mold temperature should be higher than the thermoplastic Tg.

From this case study it will be possible to check how the different mold temperatures selected might affect the final processing settings. This study it is also important to check if a 200°C mold temperature increase is crucial to reduce significantly process parameters such as the injection pressure, or if a 160°C mold temperature is sufficient to obtain approximately similar process

parameters without an extra energy consumption.

Results obtained from the traditional model with follow conditions  $T_{inj}=210^{\circ}C$  and  $T_m=40^{\circ}C$ , and will be then compared with studies made with the model considering the introduction of a dynamic temperature control system. As mentioned before, the main purpose of these case studies is to understand better how the increase of mold temperature, above  $T_g$ , will influence not only the final process parameters, but also part final appearance.

All processing conditions defined for case study 1 are presented on table 2. However, for case study 2 - different injection points, only the first condition from **Error! Reference source not found.** was selected. For this study, a  $40^{\circ}C$  mold temperature and  $210^{\circ}C$  injection temperature were defined.

**Table 2.** Processing conditions used.

Condition	Temperature ( $^{\circ}C$ )	
	Melt	Mold
1	210	40
2		160
3		200

### 2.4. Process parameters input

The Moldex3D® software was used to consider the most important injection process parameters in a numerical simulation. Obviously, there are limitations to the computational approach, namely simplifications taken by the software. This is the biggest difference between the real and virtual process and, in some way, is often the limiting step for the industrial relevance of the software. Parameters such as the injection speed are calculated by the software through the limit injection time defined by user on process settings, and not controlled fully by the user as in a real injection equipment.

Table 3 shows the final process conditions used in the numerical simulations, for both cases. The software calculates automatically the filling time based on the total time needed

to fill the mold cavity. The final injection pressure needed to fill the mold cavity, will be drastically affected by the filling time selected. A lower filling time will lead to a rise of the injection speed as well as the injection pressure. For that reason, it was decided to increase the filling time assumed automatically by the software from 0,15s to 0,35s. To avoid any restriction in terms of injection pressure results, a 500MPa injection pressure is defined as the maximum value for the simulation. The same procedure was taken for the maximum packing pressure value.

**Table 3.** Final process parameters defined to start the simulation.

Stage	Parameters	Moldex3D (Theoretic)
Filling	Filling Time (s)	0.35
	Melt Temperature ( $^{\circ}C$ )	210
	Mold Temperature ( $^{\circ}C$ )	40/160/200
	Max. Injection Pressure (MPa)	500
	Dosage Volume ( $cm^3$ )	2.96
Packing	Packing Time (s)	3
	Max. Packing Pressure (MPa)	140
Cooling	Cooling Time (s)	10.6
	Ejection Temperature ( $^{\circ}C$ )	90

The numerical simulation results (process parameters) were then replicated in a real test using an industrial injection molding equipment. The main goal was to check how close (accurate) the numerical results are comparing to the experiment, in terms of final process settings and part aesthetic properties. The next chapter describes the results obtained from the numerical simulations studies, with an emphasis on an unexpected phenomenon that was consistently observed. A comparison is presented of all numerical studies and a possible explanation is provided for the unusual behavior observed in the injection pressure vs time curves.

### 3. Results and discussion

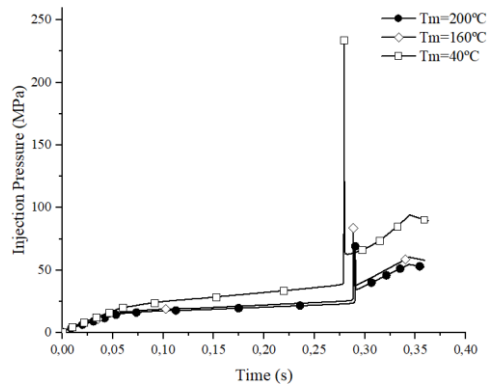
#### 3.1. Case Study 1 - Different mold temperature

In this case, injection pressure-filling time curves, at different mold temperatures, were analyzed and compared. On this study, simulation analysis was made according the following parameters: injection point located on the part's central zone and a 210°C injection temperature. This study's purpose is to predict the maximum injection pressure when the mold is "cold", i.e., at 40°C temperature (traditional mold temperature) and compare the results with the other two case studies. The remaining studies adopt a 160°C and 200°C mold temperature, respectively (uncommonly high mold temperatures in the injection molding process). A substantial injection pressure reduction is expected when the mold temperature is raised from 40°C to 160°C and then to 200°C, leading the molten material to a slower cooling, a lower flow resistance promoted by mold walls and, lastly, a decrease of the injection speed.

Figure 5 shows the injection pressure vs filling time curves for the three mold temperature cases. On the first 0.05s, the pressure curves present a slight increase, then, all curves remain nearly constant until 0.275s, while the molten material continuously fills the mold cavity.

For each situation, at about circa 80% of the complete part filling, a sudden pressure peak occurs on the graph. Such uncommon situation is normally known by "overshooting" and, as has already been reported, occurs when the previously pressure applied is no longer enough to fill the cavity. For all cases, the pressure peak always appears when the filling of the center and thickest zone of the plastic part is complete. It happens due to the highest flow resistance offered by the thin walls of the cavity on the thinner zone, which forces to a sudden increase of injection pressure ensuring a

complete cavity fill, over the filling time previously defined. Therefore, the total pressure applied by the equipment, even for "hot" mold case situations, is not enough to ensure to complete the molding cavity. So, this pressure peak is justified as a pressure booster needed to complete circa 98% of the part molding before the filling stage is over and the packing step begins. Instantly after the peak, a sudden injection pressure reduction occurs, reaching pressure values above those exhibited before the pressure peak occurrence (see figure 5). The only reasonable justification for this sudden decrease is that at that moment, the higher pressure needed to again advance the melt front in the more difficult thin region is no longer needed (and in fact, the high pressure peak can, possibly, result in undesired defects such as plastic burrs).



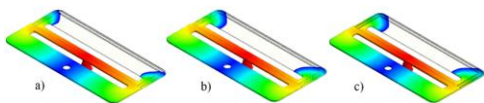
**Figure 5.** Time vs Injection pressure curves comparison between the three different mold temperatures.

From that moment on, the pressure will gradually increase, as would be expected, to ensure the 98% mold cavity filling, before the beginning of the packing stage.

As shown in figure 5, the maximum pressure value reached for the traditional case ( $T_m=40^\circ\text{C}$ ) is significantly higher than the other two cases. The large difference between the injection and mold temperature, leading to a much quicker solidification of the thermoplastic material in the moment it

contacts the mold “cold” walls, explains the pressure vs time curve. The molten material cools down as soon as it meets the mold inside walls. At the same time, a frozen layer is formed, reducing the cross-sectional area of the channel and growing the flow resistance.

This “overshoot” effect is normally responsible for raising severely the values of the injection pressure, in order to reduce different kinds of defects on plastic parts, such as, incomplete molding, warpage, flow marks, etc. figure 6 shows the flow analyses for the three case studies showing what happens to flow path and how much mold cavity is filled on the right moment when the pressure peaks arises, during the filling stage.



**Figure 6.** Precise moment when the pressure peak occurs for the three different mold temperatures-a)  $T_m=40^\circ\text{C}$ ; b)  $T_m=160^\circ\text{C}$ ; c)  $T_m=200^\circ\text{C}$ .

For case a), the molten material located on the thinner zone of the part, forms a shell, which will obviously reduce its cross-sectional area, due to fast cooling promoted by the mold “cold” walls. When the thicker and middle zones are complete, a peak pressure occurs to finish the cavity filling, boosting the molten polymer and breaking the formed shell and, therefore, continuing the cavity filling process. For this reason, we have a peak pressure which exceeds 200MPa for this case a), although after that moment, the pressure decreases significantly to values near to 60MPa, eventually reaching a final pressure slightly below the 100MPa, moments before the packing stage start.

For the  $160^\circ\text{C}$  and  $200^\circ\text{C}$  mold temperature case studies, the pressure "overshoot" values detected on injection pressure vs filling time curves are lower than those verified for a  $40^\circ\text{C}$  mold temperature. The formation of the frozen layer is not observed for these cases, due to “hot” mold temperature selected. So

then, thermoplastic material remains its molten state, during the filling stage due to mold high temperature, avoiding an early cooling. For that reason, the pressure boost calculated by the software should not be as high as the traditional case but must be enough to ensure a complete filling of the cavity.

For these last two cases, the injection pressure value exhibited on the peak never exceeded 100 MPa. The final maximum injection pressure values reached before the switching point, with and without the peak, are presented in Table 4.

**Table 4.** Maximum injection pressure for all cases, considering or not the peak pressure.

Max. Injection Pressure (MPa)	Mold Temperature		
	$40^\circ\text{C}$	$160^\circ\text{C}$	$200^\circ\text{C}$
Without Peak	94.0	60.4	54.6
At the Peak	233.8	83.7	69.2

### 3.2. Case study 2 - Different injection point location

Case study 2 compares the injection pressure vs filling time curves and the molten flow behavior for three different injection points, considering the following injection parameters:  $T_{inj}=210^\circ\text{C}$  and  $T_m=40^\circ\text{C}$ . Results obtained from the filling stage, for those three different injection points – center of the part (traditional model), thinner and thicker zone, were analyzed and compared.

Those results confirm, as expected, the shape of three different pressure curves over the filling time. According to the assigned injection point, different maximum injection pressure values were observed, as shown in figure 7.

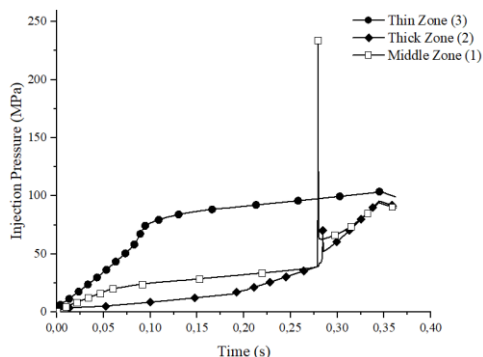
The traditional model curve shows, initially, a slight increase, then remains constant throughout the filling time, until approximately 0.28 seconds. The part's thinner and thicker zones are being filled simultaneously during this stage. However, the thicker zone is the first one to be filled, as expected, due to lower flow resistance offered by the geometry of the cavity. The opposite



situation is verified for the thinner zone. The flow speed noticed on this zone is significantly lower than the flow speed present on the thicker zone. This means that, in the thinner zone, the molten material faces a high flow resistance and higher shear rate promoted by mold walls.

As previously mentioned, when the molten material contacts for the first time the mold walls on the part thinner zone, the increase of the frozen layer dimension leads to a drastic reduce of the cross-sectional area of the channel, due to fast cooling and material viscosity increase. That rheological phenomenon is responsible for raising the flow resistance promoted by the mold's thin walls and induces the material's premature solidification. At the end, a sudden reduction of the injection speed and an incomplete molding are expected.

As soon as the thicker part is completed, the filling pressure value, calculated by the software to fill the cavity, is no longer enough to ensure the complete filling of the remain zones. At this time (0.28 seconds) the "overshoot" suddenly occurs, as it seen in figure 7. An increase above 200MPa of the injection pressure is detected. So, this "overshoot", previously discussed, resulted, in this specific case study, from part geometry features, such as different thickness and thin walls (thickness < 0.5mm).



**Figure 7.** Time vs Injection pressure curves comparison between the three-different injection points location.

The same "overshoot" occurrence is seen for the case 2 - injection point placed on thicker zone. It happens because both regions are filled at the same time, due to the fact of these have an equal thickness (0,4mm) and thus the software realizes that the peak pressure applied is enough to complete the remain cavity spaces.

However, the "overshoot" effect, identified in figure 7, is not as high as the one seen on case study 1 curve, presenting a 95.5MPa max. injection pressure value. Once the injection pressure peak is lower than the maximum pressure value, it is considered irrelevant, and can be ignored.

After the "overshoot", the pressure decreases instantly to higher pressure values than those exhibited before the peak occurrence, for the same reason mentioned in previously analyses. Then, to keep molten material flow and avoid its premature solidification, the injection pressure will be raised until the packing stage beginning.

Third and final case, the injection point placed in the part's thinner zone, shows a different curve behavior (figure 7) without the presence of the pressure "overshoot" during mold cavity filling. In fact, a significant increase of the injection pressure is visible in the injection pressure vs filling time curve until circa 0.1s.

Then, the injection pressure increases slightly until the end of the filling stage. When the cavity fill is 98% completed, the filling stage ends, and the packing stage is ready to start. In this precise moment, the injection pressure decreases, and the second pressure is applied to avoid part volumetric shrinkage.

It is important to notice that for cases 1 and 2, peak pressure values revealed by numerical simulation are considered merely indicative (exaggerated by the simplifications and assumptions of the simulation model) and not necessarily real values. These pressure peaks are determined by the software as needed to accomplish the simulation main requirement, i.e., to fill the mold cavity, which means that the maximum pressure value achieved is

expected to be lower in the real injection process. Moreover, the maximum injection pressure values visible in the graph are approximately similar, if we exclude peak pressure value. The final injection pressure results, for each case study, are presented in Table 5.

**Table 5.** Maximum injection pressure for all three cases, considering or not the peak pressure (note: overshoot is not present on case 3).

Max. Injection Pressure (MPa)	Injection Point Location		
	1	2	3
Without Peak	94.0	95.5	103.6
At the Peak	233.8	70.1	–

The “overshoot” effect was observed on all plots of the numerical simulation injection pressure, except for the case study where the injection point is located on thinner zone (which means the effective cross-section available for the melt front to advance can only increase when there is a change in the part thickness, and the cross-section will never decrease). The authors believe this occurrence is due to the software calculating that, under the conditions of a specific moment in time during filling, is no longer enough to ensure mold cavity fill (advancement of the flow front) at the user specified filling time. This means that the software calculates the total pressure needed, according to the final volume of the part and the filling time desired, to complete the cavity filling, and “boosts” the pressure accordingly (which is then no longer reflected on the packing stage). Nevertheless, it was possible to establish the effect on the mold temperature on the injection pressure, which was the purpose of the study.

#### 4. Concluding remarks

The dynamic temperature control technology was studied in this work using a numerical simulation flow software, and the resulting injection pressure vs filling time graphs were

evaluated according to different mold temperatures and different injection point locations.

Two mold structures, with and without the dynamic control temperature system, were designed to evaluate how mold pre-heating stage affects the final process parameters. The numerical analyses show, for case study 1, an increase of mold temperature from 40°C to 160°C and then to 200°C result on a 36% and 42% injection pressure reduction, respectively, i.e., an approximate 50% reduction of the maximum injection pressure is predictable when mold temperature is maintained higher than T<sub>g</sub>. For case study 2 – different injection points location, the lower maximum injection pressure value was obtained for the one located in part central zone (94MPa), disregarding the “overshoot” effect. In comparison with previous case, a 2% injection pressure increase is observed for the case study where the injection point is placed in the thicker zone.

From this, it was possible to verify the effect of the mold temperature on the injection pressure. An increase of the mold temperature during the injection phase will result in improved part quality (reducing or even eliminate defects such as weld lines or sink marks), and simultaneously improved aesthetic properties (e.g. increased surface gloss). This is also useful to produce thinner wall parts with ribs, maintain or increasing the part’s stiffness. In addition, as the required injection pressure decreases, consequently, the required machine clamping force will be lower. This positive effect is advantageous in industry because it decreases the cost of the injection process, by using lower capacity injection machines, and even reduces the mechanical requirements of the material used for the mold.

Thus, the use of dynamic temperature control can be an important approach for improving the quality of injection molded parts, whilst facilitating the production process. It is clear that this can be an important technology for the plastics industry, however, it still needs to

be further studied to enable its practical application.

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