AUTO VISCOSITY ADJUST™
MAKING SUSTAINABLE RESINS A REALITY FOR *ANY* MOLDER

Introduction

Injection molding is a technology commonly used for high-volume manufacturing of parts constructed of thermoplastic materials. When building an injection molding process, a wide variety of factors have an impact on what that process looks like. In many cases, these factors are static: part geometry, injection molding machine specifications, material type/family. However, there are also many possible dynamic factors: batch-to-batch material variation, color changes, cooling water temperatures and flow rates, environmental temperature and humidity, machine performance, etc. Typically, these dynamic factors are difficult to account for, hindering process robustness, and demanding constant manual adjustments to prevent or reduce scrap.

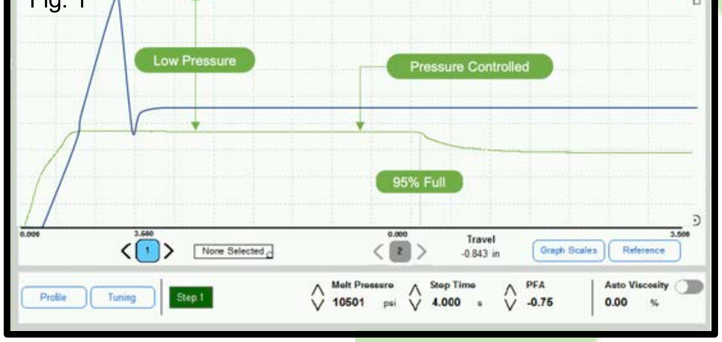
Throughout the injection molding industry, there is an expanding focus on combatting the negative effects caused by variable environmental factors and material properties. Unfortunately, one of the challenges of utilizing sustainable or recycled resins is the inherent, unpredictable variation experienced in both the material's viscosity and density. Utilizing these resins is less attractive to industries due to poor quality and scrap issues that are otherwise not experienced with virgin resins.

iMFLUX Auto Viscosity Adjust™ (AVA) makes processing sustainable materials not only easier, but it can manage the inherent material variation automatically. This technological breakthrough makes utilizing sustainable resins more attractive to the entire injection molding industry, rather than the fraction of the industry it currently penetrates.

Overcoming Process Variation

In a conventional molding process, plastic is injected into a mold at a fixed velocity to a predetermined transfer location based on screw position causing pressure to rise during fill as depicted by The Blue Curve™ in Fig. 1. In contrast, the iMFLUX process is injected at a low, constant pressure with velocity being a process output represented by **The Green Curve™** in Fig 1. Filling at a constant plastic pressure not only provides for significant quality improvements in the final product, but also inherently adapts velocity to meet changes in part geometry and material viscosity.

Fig. 1



The Blue Curve™ represents plastic pressure during the conventional injection molding process, while The Green Curve™ represents that same plastic pressure with the iMFLUX process.

Auto Viscosity Adjust™ (AVA) is a proprietary feature of iMFLUX's low constant pressure molding system, which enables the process to identify changes in the way that the material behaves, then compensate for those changes without user intervention.

The plastic pressure curve of a typical conventional molding process can be seen in The Blue Curve™ in Fig. 1. Conventional molding assumes that controlling the screw's velocity to a set transfer position guarantees a consistent fill time. However, the reliability of this method is heavily dependent on the stability of highly dynamic factors. Polymers are non-Newtonian, therefore, it is widely recognized that a material's shear rate during injection is highly impactful on the dimensions of the molded part(s). In a conventional injection molding process, shear rate is assumed to remain constant for each cycle. The compressibility of polymers contradicts the idea that constant screw velocity is indicative of constant flow front velocity.

Furthermore, Pressure-Volume-Temperature (PVT) graphs indicate that melt density varies with subtle changes in pressure and temperature. A greater understanding of this relationship has led a growing number of manufacturers to implement in-mold sensors, used to better identify flow front position to reliably transfer into the pack/hold phase. Although this greatly improves the inconsistencies involved with transferring by screw position, it cannot compensate for the inconsistent flow front velocity. This can be seen in the varying fill times while using an in-mold sensor.

Fig. 2

Increased viscosity increases time to fill

AVA increases Driving Pressure to achieve same fill time (from 8.24% to 69.04% in example shown)

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iMFLUX Auto Viscosity Adjust™ (AVA) addresses these issues. The technology works by monitoring fill time and correcting deviations with necessary changes to the melt pressure setpoint (Fig. 2). This is further assisted by iMFLUX's constant pressure molding method. The absence of pressure fluctuations allows for greater consistency of the melt density throughout injection. The target result is a molded part with far less stress concentrations, better weight distribution, uniform shrinkage, and a drastic decrease in part-to-part variability.

These claims were tested through a direct comparison between a conventional molding process and an iMFLUX enabled process with AVA. The proper setup methods were used for both processes, utilizing a rheology curve, gate seal study, cooling time study, range finding, and design of experiment. Final process setpoints were selected based on dimensional accuracy and process robustness (location within the processing window). Cycle time was equivalent between the two processes, and both process setup procedures were performed with a high-quality, virgin ABS (CP Pryme A100).

Each process was subjected to a material change midway through a 3-hour production run, without any changes being made to the process parameters. The production runs began with the same ABS material used in the initial setup procedures. The material was then changed to a post-consumer recycled, "utility" grade ABS (CP Pryme A300). Parts were collected throughout the 3-hour run, and their quality data was compared using measurements from 7 critical dimensions.

<u>Dynamic Material Viscosity Compensation</u>
It is well observed that fill rate and pressure directly represent shear rate and shear stress of the material, respectively. Through these observations, viscosity can be accurately measured and compensated for by monitoring and adjusting both parameters.

The iMFLUX process maintains a constant, true plastic pressure, measured directly at the nozzle via a melt pressure transducer. Velocity is an output of the iMFLUX process and is directly influenced by the gate, runner, and part geometry. Thicker nominal wall sections will allow for faster machine fill speeds vs. thinner nominal wall sections – the velocity is essentially profiled directly to the part geometry. For the first time, the mold and material are managing the process in a true, closed-loop control every 1.2 milliseconds.

AVA measures the time to achieve a specific cavity pressure (utilizing a pressure transducer installed in the mold) or a specific distance the melt volume has travelled (not just screw travel). iMFLUX proprietary algorithms calculate how much the viscosity has shifted and adjust the appropriate driving pressure change to ensure the fill time remains the same. The process is autonomously managed. Fig. 2 represents how the pressure is modified based on the viscosity changes recognized.

<u>Dimensional Variation Improvement</u>
Flow front speed and melt uniformity are two driving factors in shrinkage and stress within a plastic part – making a large impact on dimensional outcome.

Table 1

Dimension	Conventional Std. Dev.	iMFLUX w/ AVA Std Dev	% Improved
Tensile 1 Length*	0.0681	0.0101	85.17%
Tensile 1 Thickness A	0.0801	0.0552	31.09%
Tensile 1 Thickness B	0.0113	0.0111	01.77%
Circle Diameter*	0.0307	0.0097	68.40%
Tensile 2 Width A	0.0040	0.0026	35.00%
Tensile 2 Width B	0.0020	0.0018	10.00%
Tensile 2 Width C	0.0052	0.0019	63.46%

*2-sample Standard Deviation Test Results Shown (Fig. 3 & Fig. 4)

Fig. 3

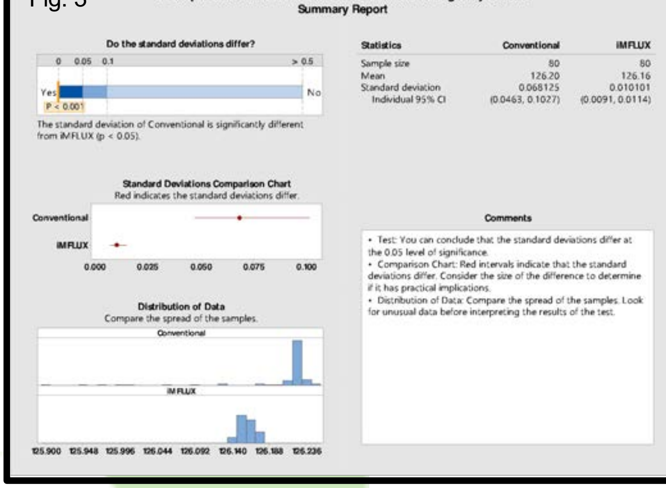
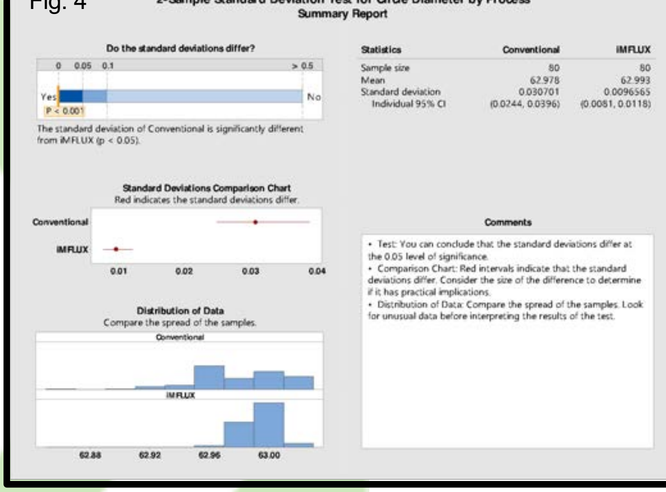


Fig. 4



It is understood that control over both factors drastically increases the capability of a process. Using AVA to perform the necessary, automated adjustments, the process was able to maintain control over a range of critical dimensions, despite shifts in material viscosity (Table 1).

<u>Material Quality's Impact on Visual Defects</u>
Many visual defects are directly related to the rheology, flow rate, and pressure and temperature gradient of the injected material as it flows through the mold. These defects include: short shots, flash, flow lines, sinks, burns, orange peel, stress whitening, gas traps, etc.

Fluctuations in material viscosity have a large impact on each of the factors listed above, and therefore the aesthetic quality of the finished product. Keeping these factors consistent, shot-to-shot, is traditionally highly dependent on the quality and batch uniformity of said material. For example, CP Pryme A300 caused short shots in some of the conventional samples. Viscosity shifts were far less impactful and short shots were eliminated with iMFLUX AVA.

<u>Conclusion</u>
iMFLUX provides the opportunity to process bio-resins, post-consumer and post-industrial recycle, and other renewable materials previously challenging, or even impractical, in a conventional molding process. With the ability to run at significantly lower pressures and compensate for any material changes in real time, sustainable resins can be utilized in a far greater capacity than they currently are and can make them a reality rather than a liability for *<u>any</u>* injection molding manufacturer.