WHITE PAPER

Transforming FDM Post-Printing Support Removal with Volumetric Velocity Dispersion

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CONTENTS

I. INTRODUCTION

For good reason, Fused Deposition Modeling, or FDM™, is a top print technology choice. From 3D printing enthusiasts to large scale production facilities, FDM adds value as a reliable, versatile, and cost-effective option that can provide near injection-molded surface quality with the right finishing solution. The simplicity of the technology is where many of the benefits of FDM are derived. While there are methods to mitigate labor costs in the additive manufacturing process, one unavoidable cost is material.

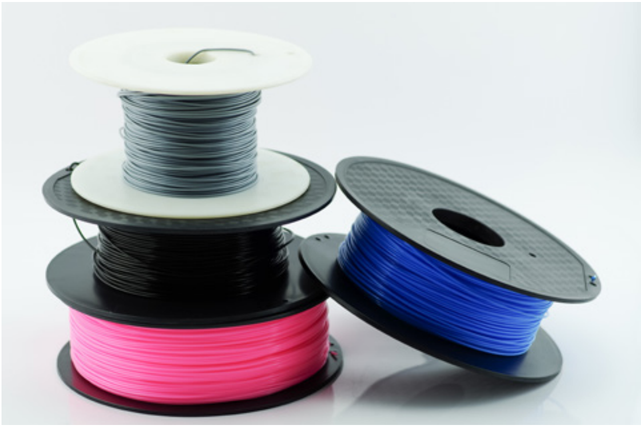


Figure 1: FDM Material Spools

In the case of FDM, the material used is a filament. The polymer manufacturing process used to produce these filaments, single screw extrusion, is a proven process that has been around since the 1950's that offers much flexibility. Additives and pigmentation can be added to the raw resin prior to extrusion for a wide range of practical material options. The extrusion is spun onto a spool, akin to a fishing line, and this is the form in which it is loaded into the FDM printer. The concept behind the print technology is also quite simplistic, relatively speaking. The material is fed through the print head where it is melted to temperatures upwards of 450F and extruded layer by layer, ranging from 0.005" to 0.010", as the build platform lowers accordingly. Although with the deposition process, one challenge can be complex geometries.

To simplify, imagine trying to conduct this extrusion process manually with a hot glue gun. If the goal is to make a gear - pretty straightforward. But what about an hourglass? Or a small turbine blade? With more complex geometries like thin walls, overhangs, or internal channels, the FDM concept required a solution as it cannot print on air. This is why support structures were developed. Some processes such as stereolithography (SLA) use the same material throughout the entire print, requiring a manual break-away process. However, industrial FDM printers utilize two print heads and can print an additional material on for most builds: a soluble support material. Instead of pliers and hand tools, the objective is to leverage a chemical reaction to dissolve the supports.

The recommended process involves mixing a caustic chemical solution and finding a conventional circulation or ultrasonic tank to pair it with. From there, the support removal process could involve submerging the part for hours and then allowing it to dry for proper post-processing. While more comprehensive submersive solutions exist, as additive manufacturing scales to production levels, post-print cycle time and manual labor becomes a growing concern. With more complex and detailed geometries, not only does the volume of support material increase, it also inherently becomes more fragile and difficult to access. A solution that autonomously removes soluble support from complex parts while dramatically reducing cycle time, both support removal and dry time, adds significant value to the FDM printing solution.

II. THE DEFAULT RESPONSE FOR FDM SUPPORT REMOVAL

With common FDM build materials such as ABS, ASA, Nylon 12 and PC, a handful of soluble material options are used with the intention of improving the support removal process. There are four common soluble support materials that FDM technology uses: SR-20, SR-30, SR-100, and SR-110. Here is a comparison of each below:

Soluble Support Material	Popular Build Materials	Characteristics
SR-20	ABS family	Expands more than SR-30. Discolors chemical solution quicker than SR-30.
SR-30	ASA	More shatter resistant than SR-20. Dissolves over 2X as fast as SR-20.
SR-100	Polycarbonate	Manual removal of some support material may be required. Faster expansion rate than SR-110.
SR-110	Nylon 12	Limited usability - Nylon only

Table 2.1

As mentioned above, a submersible tank is the industry recommended method to remove these soluble supports. However with conventional tanks, including ultrasonic baths, it is not as simple as dropping the part into a tank and walking away; there are preparation steps and risks involved. First, the chemical solution is not typically pre-mixed. With that, there are safety hazards from potential powder inhalation or splashing of the concentrate. This is also a concern as the solution evaporates. To top off the tank and reclaim the efficacy of the solution, the ratio of concentrate becomes unclear. As a result, the user will drain the tank and start the mixing process again. This maintenance cycle time can range from 30 to 90 minutes to complete. After the chemistry is mixed, it has to reach proper temperature ranging from 120F to 185F. The proper temperature is dictated by the type of support material, and geometry may play a role as well. If the tank temperature travels above the recommended setting, there is a high probability that the part will be damaged, most likely from warpage.Temperature runouts are a real possibility, especially if ultrasonics are involved.

In addition, each support material has the potential to expand. In a conventional flow tank, some parts will want to float. Parts not fully submerged may lead to uneven expansion of the support material, and/or part cracking. Conversely, some parts will want to sink. If not properly circulated there still remains a risk of uneven exposure to temperature or ultrasonic levels resulting in cracking, yet again. Another concern in a basic circulation tank is the limitations and risk associated with running multiple parts simultaneously. Parts can collide with the each other or with the boundaries of the tank. This is a relatively low risk, but depending on the geometries in combination with previously highlighted buoyancy issues, any avoided collisions are beneficial.

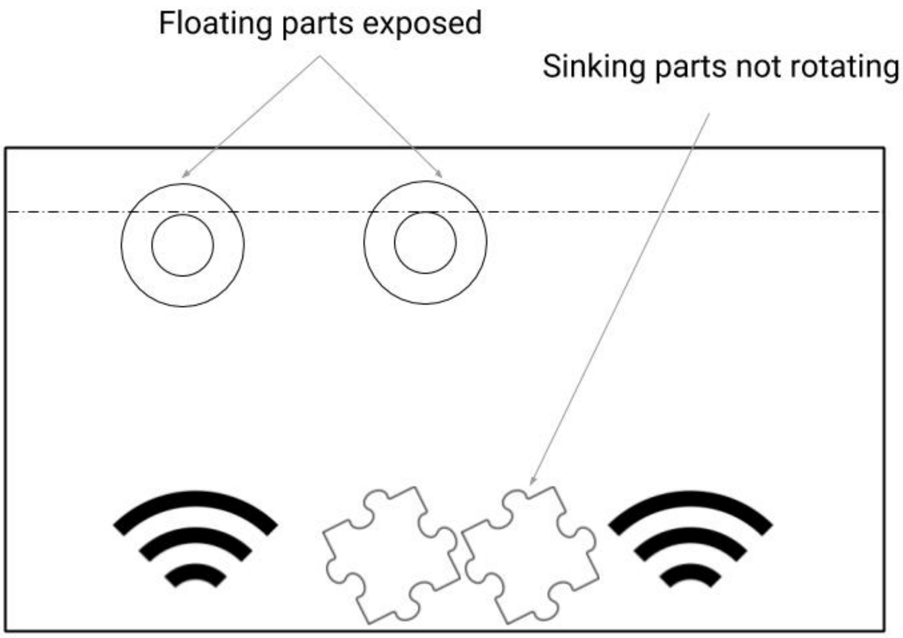


Figure 2: Buoyancy issues preventing even support removal, leading to potential cracking or warpage.

Another challenge to overcome with dunk tanks is the dry time once the cycle is complete. After submerging the FDM part in a solution for hours, the build material is going to take on some of that solution. In order to properly process a polymer, whether it be surface finishing, coating or dyeing, the part should be dry for an optimal result. The table below shows cycle times for two FDM parts using SR-30 submerged in an ultrasonic bath.

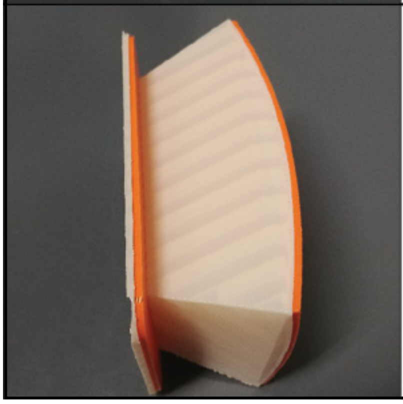
Part	Popular Build Materials	Submersion Cycle Support Removal & Dry Time
	The SR-30 material is throughout the inner channel of the spiral. There is an airway to allow detergent into the channel, maximizing exposed surface area.	10 hrs submersion
	The SR-30 material is in white. It is underneath the 'umbrella' as well as the base of the part.	3 hrs submersion

Table 2.2: Before post-printing pictures of FDM parts with support material intact.

To summarize, submerging a part in a conventional or ultrasonic tank increases the risk of the following:

- Additional chemical exposure
- Improper ratios of chemical solution
- Temperature regulation and warping
- Potential bumping or settling in batches
- Uneven expansion and cracking
- Extended dry times

There are some submersion technologies that incorporate software, mitigating or even eliminating these challenges. However, the ability to remove this soluble support material without having to submerge the part adds tremendous value.

III. AN INTRODUCTION TO VOLUMETRIC VELOCITY DISPERSION

Basic submersion, relying heavily on a chemical rate of removal (cRoR) is one method to tackle the soluble support removal problem. A conventional tank may work for blocks and basic geometries, but for complex designs and features it is clear that there is an opportunity to improve upon its shortcomings. PostProcess Technologies (PPT) has developed an alternative technology for soluble support removal: Volumetric Velocity Dispersion (VVD). This software-driven technology uses a series of high volume and flow jet streams spraying bidirectionally, coupled with perpendicular linear motion for mechanically assisted support removal. Breaking down the characteristics of each element of the acronym helps describe this system further.

Volumetric: Proprietary PPT detergent is circulated at a rate of up to 150 gallons per minute (GPM) while maintaining low pressure, around 35 PSI.

Velocity: High speed flow optimizes the Rate of Removal (RoR), leveraging steady mechanical force to dispose of support material as it weakens.

Dispersion: Jetted agitation engulfs the part with an optimized droplet size through two rack manifolds with linear control for targeted coverage.

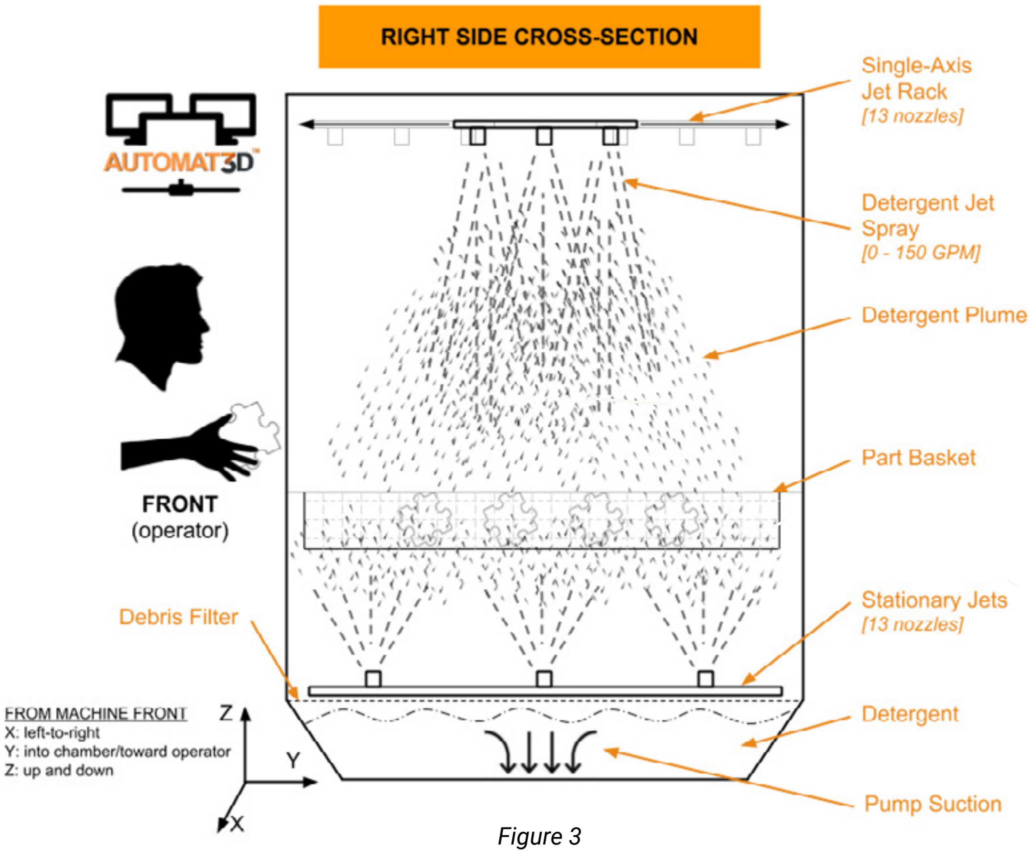


Figure 3

Figure 3 highlights the main components inside the the chamber of the DECI, one of PostProcess' VVD systems. Because of the high-volume (150 GPM), low-pressure system (35 PSI), parts feel a powerful yet gentle, all-encompassing flow of detergent that also keeps the part in place. Once applied, the part experiences a constant force which reduces the risk of damaging parts. One result of the bi-directional jetting action is the part remains stationary and avoids any potential collisions that a circulation tank may subject parts to. With the DECI's envelope size of 18" x 18" X 18", the part tray can comfortably fit 10 of the orange parts shown in Table 2.2.

In addition, parts are not being saturated in a solution where ultrasonics can generate excessive heat, leading to quick warpage if not controlled correctly. Regardless of the technology, minimizing unnecessary exposure to the elements, i.e. ultrasonics, through a reduction in cycle time can also reduce risks. Of course this also has major workflow benefits, eliminating what many users experience as their bottleneck in their additive manufacturing value stream: post-printing. Below is a cycle time comparison between a legacy submersion system and one of PPT's VVD machines, the DECI. The cycle time represents unattended time to completely remove the support material. The only operator interaction was placing and removing the part from the system and turning the machine on.

Part	Submersion Cycle Time	VVD Cycle Time	VVD Cycle Time Improvement
	10 hrs submersion	3 hrs VVD	70%
	3 hrs submersion	2 hrs VVD	33%

Table 2.3: After post-printing pictures of FDM parts with support material removed.

The cycle time improvement is clear. Table 2.3 shows a 70% reduction in cycle time for the spiral part, and a 33% cycle time in the orange umbrella part. While geometry dependent, the VVD technology sees on average a 70% cycle time reduction in FDM support removal when compared to a traditional submersion system. How? The increase in the mechanical rate of removal (mRoR) through the jetting system allows the VVD technology to continually push support material away. This creates an optimal cRoR as the detergent continually works on a fresh surface, unimpeded by support material that has not yet fallen away. Think about removing hardened food from cookware. Soaking the dish helps loosen the food that has adhered (i.e. support removal in a standard submersion tank), but there are multiple wipe and rinse steps required to continually expose that which is still bonded. VVD loosens and wipes simultaneously and continually. As soon as the material loosens from the work of the detergent, the VVD technology instantly removes it and continues to erode the remaining exposed support material. In layman's terms, what a sink is to a dishwasher, a dunk tank is to PostProcess' VVD solutions.

What is also impressive is the varying geometries that the VVD technology can effectively remove support material from. A misconception is that a submersion tank is the only way to ensure the fluid can reach all support material surfaces. With properly designed support structures that maximize the exposed surface area, from swirling internal channels to thin walls, the VVD technology provides calculated force and coverage without damage. In addition, the system is absent of chemical mixing by an operator. For an initial fill, the VVD technology connects to a standard garden hose and auto-doses in PPT's proprietary detergent concentrate to reach and maintain a proper pH level with communication from the AUTOMAT3D™ software. During the cycle, the software and intelligent sensors will monitor and maintain outputs such as temperature to keep the chemical in the optimal operating range. For sake of experiment, the data in Table 2.3 was collected with an out-of-the-box Agitation Algorithm from PPT. Each part's algorithm can be configured at the machine to optimize the cycle time further

III. CONCLUSION

Although ultrasonic and circulation tanks are the default response to the soluble FDM support removal problem, it is clear there is an alternative worth considering. The Volumetric Velocity Dispersion technology surpasses a conventional tank by deploying a different form of mechanical energy that has shown to speed up FDM support removal cycle times up to 70% or greater. This is accomplished while reducing risk of warpage and cracking, and speeding up dry times. PostProcess Technologies offers two VVD solutions, the DECI and BASE, to accommodate increasing throughput allowing any operation to scale. When soaking is not doing the work, VVD will.

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