Design of the desktop vapor polisher with acetone vapor absorption mechanism

Kaiwen Xu, Tao Xi1 and Chunrong Liu
School of Design, Shanghai Jiao Tong University, Shanghai, China

1 E-mail: torchx@sjtu.edu.cn

Abstract. Acrylonitrile butadiene styrene (ABS) parts fabricated by fused deposition modeling (FDM) usually have high surface roughness due to the stair-step effect. The vapor smoothing method gives ABS parts a smooth and shiny appearance. However, the organic solvents used for vapor smoothing such as acetone could be toxic to operators. This paper proposed the design of a desktop vapor polisher with acetone vapor absorption mechanism. It prevents acetone vapor from leaking into the outside environment during the smoothing process in a technically feasible and economical way by using water. The polisher also includes other innovations such as the modular design and induction heating method. The benefits of the design include environmental friendly, economy saving, energy saving and user friendly. Finally, a full-scale model has been made to illustrate the layout of the design, and verification experiments have been done with a miniature prototype.

1. Introduction
3D Printing recently started to be marketed for home use [1]. The fused deposition modeling (FDM) technique is being widely used in personal desktop 3D printers, due to the advantages such as variety of compact size, available materials, low cost, and easy operation [2-4]. The FDM technique has also shown its potential for fabricating final function parts [2]. However, parts fabricated by FDM process usually have high surface roughness due to the stair-step effect [4, 5]. Various surface finishing techniques have been developed to improve the surface quality of FDM fabricated parts. These techniques can be classified into two categories, the pre-processing techniques and the post-processing techniques. The post-processing techniques do finishing work after the model was printed, which can also be classified into two categories, the mechanical finishing techniques and the chemical finishing techniques, based on the principle of the processing methods as it shows in their names [6]. Vapor smoothing is one of the chemical finishing techniques and will be focused on in this study.

1.1. Vapor smoothing
Vapor smoothing is an advanced finishing process developed by Stratasys Inc. where hot vapor of organic solvents such as acetone vapor reacts with the surface of FDM fabricated parts [7]. Figure 1 shows the 5 steps of the vapor smoothing process [8, 9]:

Step 1: The initial acrylonitrile butadiene styrene (ABS) parts with high surface roughness;
Step 2: The surfaces of ABS parts react with acetone vapor;
Step 3: Materials on the surface were in a semi-molten state;
Step 4: Materials dissolved by acetone vapor flowed into the voids between layers, and the surface of ABS parts turned flat;
Step 5: After the surface of ABS parts were solidified, the smoothing process was completed.

![Figure 1](image_url)

**Figure 1.** Illustration of the vapor smoothing process [8, 9].

The vapor smoothing method gives FDM fabricated parts a smooth and shiny appearance [10], and it is effective for parts with complex shapes [3]. However, the organic solvents such as acetone could be toxic to operators [11]. Operator’s eyes, nose, mouth and skin exposed to acetone vapor may get harmed. Acetone is also flammable and mixtures of acetone vapor with air could be explosive [12]. So it is important to set a ‘wall’ between the acetone vapor and the operator during the vapor smoothing process.

1.2. Vapor polisher

In this paper, vapor polisher is defined as the systems, devices or products that being used for the vapor smoothing process.

Stratasys Inc. has introduced a smoothing station for vapor smoothing process [13]. But the Stratasys smoothing station is too large and expensive for personal use. There are also several desktop vapor polishers on the market. These products use stainless containers as the chamber. Operators add the acetone solution into the chamber, and then put ABS parts on the platform which is above the liquid level. Next, the container will be heated by the underneath electric heating plate, to make acetone vaporized. During the heating period, acetone vapor was continuously generated and mixed with the air inside the container. As the volume of the inner gas increases, acetone vapor may leak into the outside environment, which may do harm to the operator.

Some device, such as Polysher made by Polymaker [14], is smoothing parts by spraying solvent atomization to the surface. Polysher uses alcohol as the solvent, which is safer than acetone. However, Polysher is not suitable for ABS parts because ABS can’t be dissolved by alcohol. The material that can be polished using Polysher is called PolySmooth PVB (Polyvinyl Butyral).

Other non-product polishers, most of which are personal-built polishing systems, can also do polish works very well [8, 15]. But these systems have the acetone vapor leaking problem as well.

1.3. Research purposes

There have been several works investigating the impact to FDM fabricated ABS parts from vapor smoothing, including the analysis of mechanical strength [16], dimensional accuracy [2], surface roughness [17], and thermos-mechanical properties [3]. But there are very few studies about the vapor polisher or polishing system. Kuo and Mao proposed a surface polishing system for FDM parts, introducing the hardware setup of the system and flowchart of the polishing process. The result shows that the polishing process is clean, and the mechanical properties of ABS parts can be improved with the shape complexity not being affected [8, 15]. However, the ergonomic design of the vapor polisher has not been studied in detail.

As the market of desktop 3D printers increases, there is an urgent demand to develop desktop vapor polishers [8]. The purpose of this research is to develop a desktop vapor polisher, which is accessible and suitable for home use. The design is focusing on preventing acetone vapor leaking problem and enhancing the user experience.

2. Basic construction of the desktop vapor polisher

Figure 2 shows the basic construction of a desktop vapor polisher. The system can be classified into four groups: the chamber, the heating element, the cooling element and the control system.
Figure 2. The basic construction of the desktop vapor polisher.

The chamber provides the room where hot vapor of organic solvents reacts with the surface of ABS parts. The chamber is composed of a container with a portable lid on the top. Inside the chamber there are acetone solutions, a platform, and ABS parts that being placed on the top of the platform. The container acts as the wall of the chamber, separating the reacting room from the outside environment. To make access into the chamber, a portable lid is on the top of the container. The container should be transparent so that the operator could monitor the smoothing process from outside. Acetone is a colorless, mobile, flammable liquid with a boiling temperature of 56°C [17]. The acetone solution is mostly used for smoothing ABS parts because of relatively low toxicity and low cost [15]. The platform is where ABS parts being put on. It’s usually made of stiff and stable materials such as stainless steel. The level of the platform should be set above the level of the acetone solution.

The heating element converts electric power to thermal energy, heating up and vaporizing the acetone solution at the bottom of the chamber.

The cooling element, usually a cooling fan is used to cool the chamber temperature and reduce surface solidification time of the smoothing parts [15]. The cooling fan could either be internal or external. Natural cooling is acceptable but much slower.

The control system includes electronics such as the ON/OFF switch, the temperature controller and the time controller. A control panel is set as the interface between the operator and the system.

3. Design and implement of the acetone vapor absorption mechanism

During the smoothing process, the acetone vapor will be continuously generated thus increase the inner air pressure. Due to the air pressure difference between the inside chamber and the outside environment, the additional acetone vapor may leak into the outside environment from the chamber and do harm to the operator. Targeted on this problem, an acetone vapor absorption mechanism was proposed. The mechanism prevents the acetone vapor from leaking into the outside environment and balance the air pressure between inside and outside during the smoothing process.

3.1. Fundamental design of the acetone vapor absorption mechanism

The mechanism is using water as the absorbent, which is a technically feasible and economically attractive method according to the former research [18]. The idea came from a simple gas absorption system used in chemical experiments. The system is illustrated in Figure 3. (A) to (F) in Figure 3 shows the acetone vapor absorption process.

(A) The acetone vapor was generated and mixed with air inside the chamber.
(B) Due to the pressure differential, the acetone vapor and air entered into the pipe at top.
(C) The acetone vapor and air were transported through the pipe.
(D) To enter into the outside environment, the acetone vapor and air must pass through the water.
The acetone vapor was dissolved in water. The inverted funnel prevents back suction of water and provides a large surface for absorption.

The output is fresh air without acetone vapor.

Figure 3. The illustration of acetone vapor absorption process.

3.2. Implementing the acetone vapor absorption mechanism

The acetone vapor absorption mechanism proposed in this paper is a variant design based on the system showed in Figure 3. The whole system is integrated within the lid, which includes the handle, the cover, and the plate. The handle is designed for handling the lid. There is the water level indicator at the middle of the handle, which is designed for indicating the water level (water should be added to this level). The ring-shaped cover acts as the funnel. The plate acts as the beaker. There are holes on the side wall of the plate, and there is a small gap between the container and the sidewall of the plate. The gap and holes act as the pipe which provides transportation of the acetone vapor and air. The bottom of the plate has an intrados which is designed for refluxing and recycling the acetone vapor. The water in the plate also acts as the cooling element for the refluxing.

Figure 4 is the cutaway drawing of the acetone vapor absorption mechanism. (A) to (F) in Figure 4 shows the absorption process which is on the same principle as it illustrated in Figure 3.

(A) The acetone vapor was generated and mixed with air inside the chamber.

(B) Due to the pressure differential, the acetone vapor and air entered into the gap between the container and the sidewall of the plate.

(C) The acetone vapor and air passed through the gap and holes on the sidewall of the plate.

(D) The cover blocked the way to the outside. To enter into the outside environment, the acetone vapor and air must pass through the water in the plate since.

(E) The acetone vapor was dissolved in water, while the cover prevents back suction of water and provides a large surface for absorption.

(F) The output is fresh air without acetone vapor.

(G) Meanwhile, most of the acetone vapor cooled down and condensed into liquids after reaching the bottom of the plate. The acetone liquids then flew back to the container and got recycled.

Figure 4. The variant design of the acetone vapor absorption mechanism integrated with lid.
4. Design of the desktop vapor polisher

4.1. The composition of the desktop vapor polisher
The complete desktop vapor polisher as a product was designed using CAD software and a full-scale model of the polisher has been made. Figure 5 shows the illustration of the desktop vapor polisher. Figure 6 is the picture of the full-scale model of the product. The modular design approach was adopted in the design of the desktop vapor polisher. The product can be separated into two modules: the chamber module and the heating module.

![Figure 5. The illustration of the desktop vapor polisher.](image1)

![Figure 6. The full-scale model of the desktop vapor polisher.](image2)

4.1.1. The chamber module. The chamber module contains the lid, the container, the platform and the metal sheet. The lid integrating the acetone absorption mechanism has been introduced in the previous session. The platform is a thin metal disc with a pair of arms and several legs. The arms are designed for carrying. The legs are designed for supporting the disc making it above the liquid level of acetone solution. The container is a cylinder made of hard borosilicate glass. To improve the stability of the container, there is a bulge at the bottom center of the container. A ring-shaped metal sheet is at the bottom of the container. The metal sheet is made of ferrous stainless steel, which generates heat in the dynamic magnetic field created by the induction cooktop. The heat induced in the metal sheet is conducted to the acetone solution around it, heating it up and vaporizing it.

4.1.2. The heating module. An induction cooktop is designed as the heating element. There is a coil of wire inside the induction cooktop. When the cooktop works, the current in the coil creates a dynamic magnetic field, which heating up the metal sheet in the container.

4.2. The desktop vapor polisher workflow
Figure 7 illustrates the desktop vapor polisher workflow. The polisher works as the following 8 steps:

Step 1: Prepare the desktop vapor polisher, ABS parts, and acetone solution. Put the container on the induction cooktop. Put in the metal sheet. Then add some acetone solution into the container.

Step 2: Set ABS parts on the platform. Put a piece of aluminum foil under the ABS parts.
Step 3: Add water into the lid until the water level reaches the indicator.
Step 4: Put the lid onto the top of the container. The cover of the lid made of silica gel will prevent acetone vapor leaking into the outside environment from the gap between the cover and the container.
Step 5: Plug in the power plug of the induction cooktop. Set up the heating temperature and heating time with the control panel of the cooktop. Press Start button to start heating and smoothing.
Step 6: The induction cooktop works, heating up the acetone solution to the boiling point. The generated acetone vapor will be filling up the container and smoothing ABS parts automatically. The extra generated vapor will be absorbed by water in the lid. Wait until the time is up, or press “Stop” button to stop heating at any time.
Step 7: When heating stopped, cool down the temperature of the chamber and remove the lid.
Step 8: Take out the ABS parts with platform and put them at a well ventilated place for some time.
Step 9: When smoothing work finished, unplug the induction heater. Clean the chamber module.

Figure 7. The desktop vapor polisher workflow.

4.3. Prototype experiment
A miniature prototype with an acetone absorption mechanism has been made to verify the design. There are two main questions: how well the smoothing system works, and how well the acetone vapor absorption system works. Figure 8 shows the miniature prototype at work.

Figure 8. The prototype which was smoothing an ABS part.
Figure 9. ABS parts before and after vapor smoothing process with the prototype.
Smoothing experiments were taken twice and the results are as follows:

1. The prototype did smoothing work well. The surface of the ABS parts became smooth and shiny after the smoothing process. Figure 9 shows the ABS parts before and after vapor smoothing process with the prototype.
2. No acetone smell was detected during the smoothing process.
3. Some acetone smell was detected when adding acetone solution into the container since acetone volatiles at normal temperature.
4. More acetone smell was detected when taking out the ABS parts after the smoothing process.
5. A piece of aluminum foil is necessary, without which the bottom of an ABS part was over melted in the first experiment.

4.4. Design innovations

4.4.1. The acetone vapor absorption mechanism. The major innovation of this design is the acetone vapor absorption mechanism. It prevents acetone vapor from leaking into the air and guarantees the safety of the operator. The air pressure between inside chamber and outside environment is balanced with this mechanism. The mechanism is integrated with the lid as one unit, which makes it easy to operate. The lid also acts as the cooling method which is useful for refluxing and recycling the acetone vapor.

4.4.2. The modular design and the induction heating method. The polisher is using induction heating method instead of using the electric heating plate. The induction heating method is safer and increases the heating efficiency. The modular design also makes it easier for cleaning since the chamber module contains no electronics.

5. Summary

In this paper, the design of a desktop vapor polisher with acetone vapor absorption mechanism was proposed. The benefits of the design include environmental friendly, economy saving, energy saving and user friendly. Compared with traditional vapor polishers, the major innovation of the design is the acetone vapor absorption mechanism. The mechanism prevents acetone vapor from leaking into the outside environment in a technically feasible and economical way by using water. The acetone vapor is being kept inside the chamber so operators would not be harmed by it during the smoothing process. The design also includes other innovations such as the modular design and the induction heating method. The modular design makes it easier for cleaning since the chamber module contains no electronics.

Finally, a full-scale model has been made to illustrate the layout of the design, and verification experiments have been done with a miniature prototype. The results of the prototype experiment show that both the smoothing system and the acetone vapor absorption system work well. In the future, a full-scaled and fully-functional prototype of the desktop vapor polisher should be made and more precise measurements should be taken with that. Future works will also be focusing on the optimum design of the desktop vapor polisher, including the research about reducing acetone volatilization before and after the smoothing process.

References

[1] Turbovich Z, Das A K, Avital I and Mazor G 2016 Personal 3D-Printing: A Remapping of the Relationship between Product Designers, Products and Users Proceedings of NordDesign 2016 (Trondheim, Norway: ResearchGate) pp 12-21
[2] Garg A, Bhattacharya A and Batish A 2016 On Surface Finish and Dimensional Accuracy of FDM Parts after Cold Vapor Treatment Advanced Manufacturing Processes 31 522-9
[3] SungUk Z, Jonghyeuk H, HyunWook K and ByoungChul S 2017 Thermo-mechanical properties of ABS parts fabricated by fused deposition modeling and vapor smoothing 18th
[4] Gajdos I, SpisaK E, KashkaK L and Krasinskyi V 2015 Surface Finish Techniques for FDM Parts Materials Science Forum 818 45-8

[5] Singh J, Singh R and Singh H 2017 Investigations for improving the surface finish of FDM based ABS replicas by chemical vapor smoothing process: a case study Assembly Automation 37 13-21

[6] Chohan J S and Singh R 2017 Pre and post processing techniques to improve surface characteristics of FDM parts: a state of art review and future applications Rapid Prototyping Journal 23 495-513

[7] Chohan J S, Singh R, Boparai K S, Penna R and Fraternali F 2017 Dimensional accuracy analysis of coupled fused deposition modeling and vapour smoothing operations for biomedical applications Composites Part B Engineering 117 138-49

[8] Kuo C C and Mao R C 2016 Development of a Precision Surface Polishing System for Parts Fabricated by Fused Deposition Modeling Advanced Manufacturing Processes 31 1113-8

[9] Jin Y, Yi W, Bing Z and Liu Z 2017 Modeling of the chemical finishing process for polylactic acid parts in fused deposition modeling and investigation of its tensile properties Journal of Materials Processing Technology 240 233-9

[10] Gao H, Kaweesa D V, Moore J and Meisel N A 2017 Investigating the Impact of Acetone Vapor Smoothing on the Strength and Elongation of Printed ABS Parts JOM 69 580-5

[11] Trieu Khoa N and Bong Kee L 2018 Post-processing of FDM parts to improve surface and thermal properties Rapid Prototyping Journal 24 1091-100

[12] Wilson W K and Forshee B 1959 Preservation of Documents by Lamination

[13] Singh R, Singh S, Singh I P, Fabbrocino F and Fraternali F 2017 Investigation for surface finish improvement of FDM parts by vapor smoothing process Composites Part B: Engineering 111 228-34

[14] Zhou L 2018 A Comparative Analysis of 3D Printers and Printing Materials for Art Designers in China

[15] Kuo C C, Chen C M and Chang S X 2016 Polishing mechanism for ABS parts fabricated by additive manufacturing International Journal of Advanced Manufacturing Technology 91 1-7

[16] Garg A, Bhattacharya A and Batish A 2017 Chemical vapor treatment of ABS parts built by FDM: Analysis of surface finish and mechanical strength International Journal of Advanced Manufacturing Technology 89 2175-91

[17] Lalehpour A, Janeteas C and Barari A 2017 Surface roughness of FDM parts after post-processing with acetone vapor bath smoothing process International Journal of Advanced Manufacturing Technology 95 1-16

[18] Máráki E, Lenti B, Vatai G and Békássy Molnár E 2001 Clean technology for acetone absorption and recovery Separation and purification technology 22 377-82