Multi-Material Powder Print Head

Project Update

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August 12, 2011

Goals and Objectives

The goal of this quarter is to further improve the large scale multi-material powder print head developed for Big Red. The main objective is to finish setting up the flow rate control which was not finished last quarter. However, conclusions taken from last quarter's research have been considered in the Concept Generation section below.

However, the first goal is to get Big Red running.

Constraints

There are not many constraints for the print head itself. Big Red as a whole, however, must fit inside a van when disassembled. The budget is the entirety of the money received for the proposal as well as the money allotted for ME 495.

Concept Generation

Last quarter, several methods of flow rate control were implemented. The most promising results are highlighted in this section.

The first was the use of pulse width modulation. By changing the frequency of a square wave being applied to a vibrating motor, it was possible to change the volumetric flow rate. The results may be seen below in Figure 1 for two different motors.

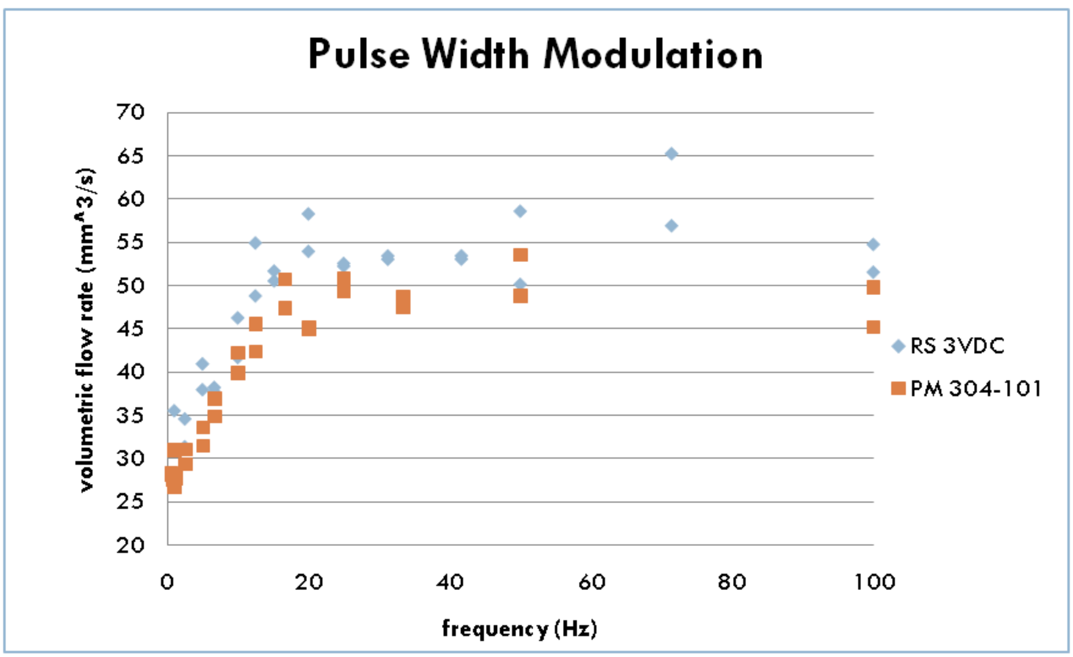

Figure 1. Flow rate control using pulse width modulation.

The results show an initial linear region between 0 and 20 Hz. However, one foreseeable issue with this method is that there appears to be a minimum achievable flow rate, a value of roughly 27 mm^3/s when using powdered salt as a build material. It would therefore be difficult to print a smooth concentration gradient that can go from entirely one material to another.

Another method of flow rate control was found to be through the variation of hole size. For the tests, the print head nozzles had to be changed manually. Figure 2 below shows the results of this method.

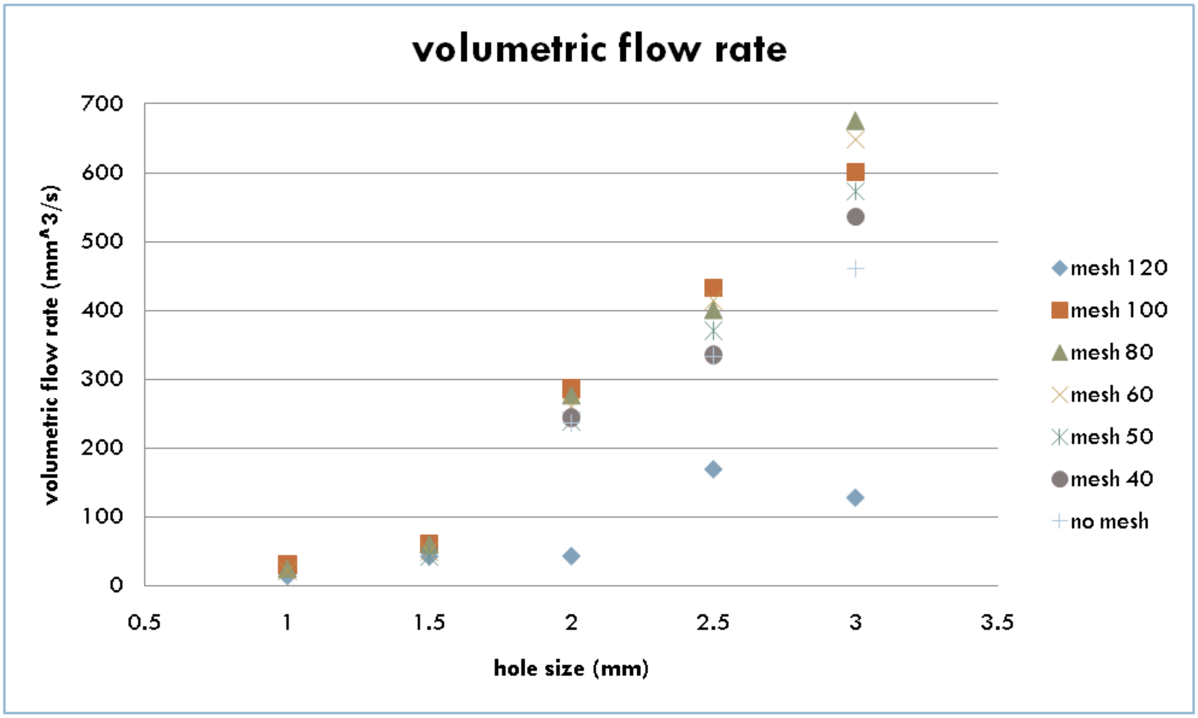

Figure 2. Volumetric flow rate as controlled by hole diameter.

From the results above, it can be seen that a very large range of flow rates is possible. However, the curve is not linear, which may prove difficult to account for when creating the flow rate control. Another issue with this method is that at larger hole sizes, powder tends to be more difficult to control. It becomes very sensitive to slight bumps, and it also has trouble ceasing flow when the vibrations are stopped.

One other method of flow rate control is the variation of hole density. It was not tested as extensively as the other two described above, but it was developed as a solution to the sensitivity issue with large hole sizes. Figure 3 below shows results for three different nozzles. The multi-hole nozzle had 11 holes, each around 1.2 mm in diameter.

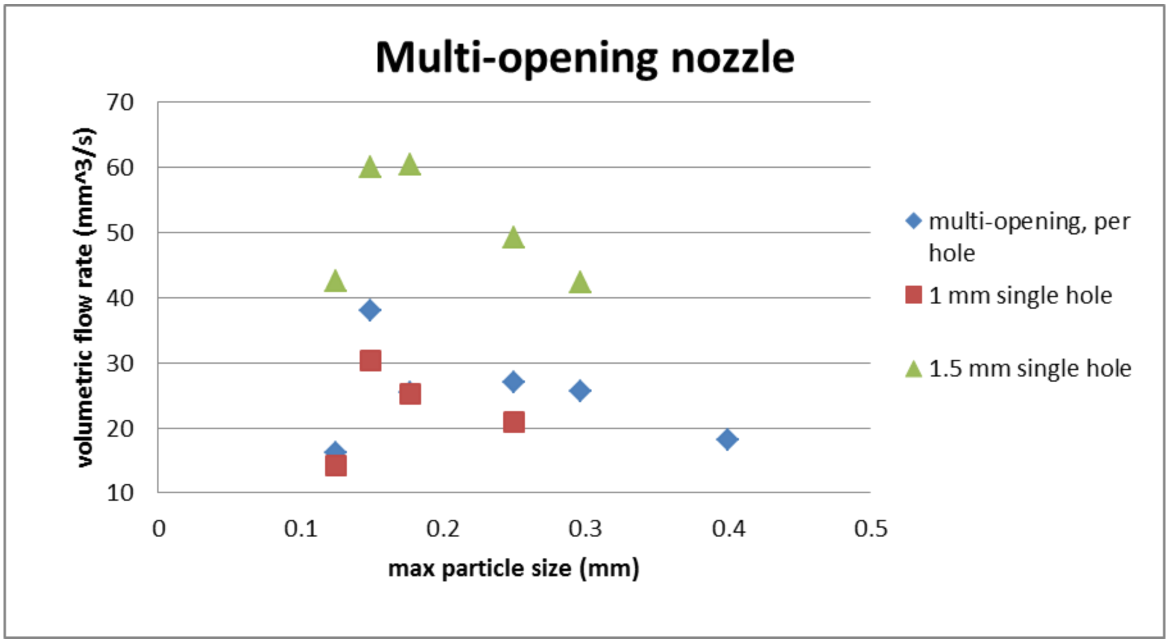

Figure 3. Effect of multiple holes per nozzle.

These results were as anticipated. One a per hole basis, the flow rate of the multi-opening nozzle was right between those of the 1 and 1.5 mms nozzles. It is anticipated that this method will have a linear scaling effect. A drawback of this method is that it would only be able to achieve a finite number of flow rates when using uniform hole diameters; however, it is possible that this method could be combined with hole size variation to produce a wider range.

During the early stages of concept generation, flow rate control using hole size variation was considered. The concept of using a mechanical iris was first researched. Several existing designs were looked at, and a paper one was constructed to obtain a better understanding of how it operated. [1]

Figure 4. Mechanical iris business card.

Although this was one possible solution, a much simpler one presented itself. Salt and pepper shakers have many different holes which allows for particles to be released without overflowing.

Conceptual Design

The initial proposed design for the hopper may be seen below in Figure 5.

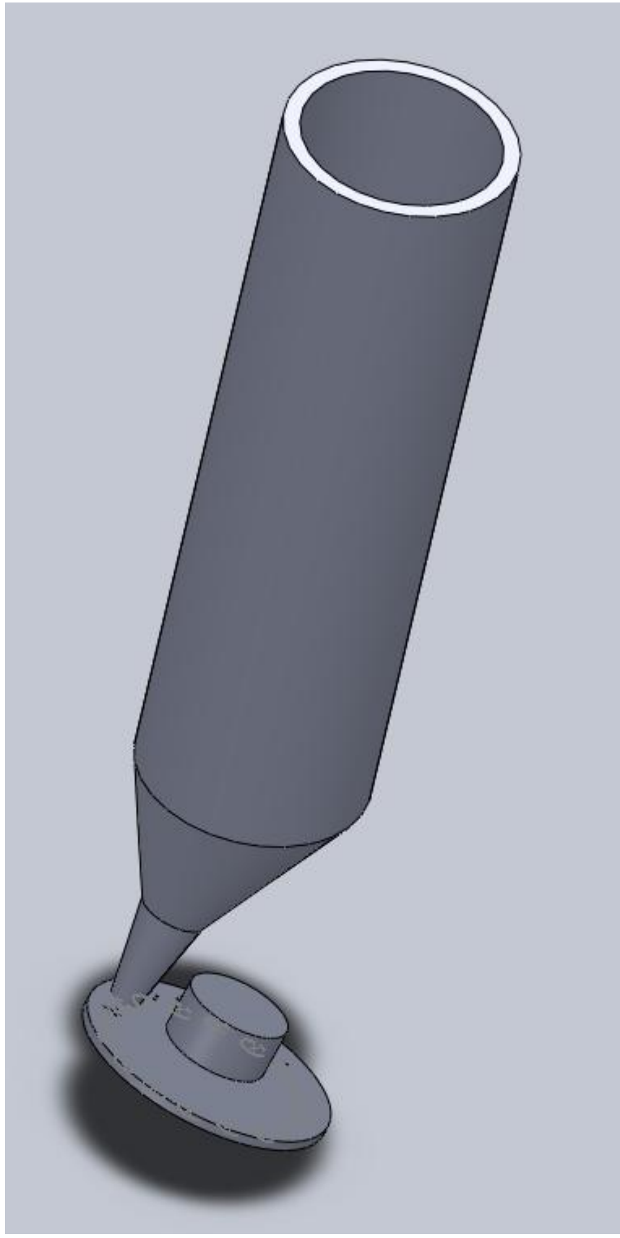

Figure 5. Proposed hopper design.

Several changes have been made from last quarter's design. The nozzle, for example, is now permanent and will not need to be changed. This will also allow for a permanent motor enclosure to be made and attached. The motor will have a constant voltage applied. The nozzle is now also angled to improve mixing between the two powder flows.

The flow rate will be controlled through the rotation of plate similar to the one seen below in Figure 6. It has 16 different settings, each of which correspond to a different hole density.

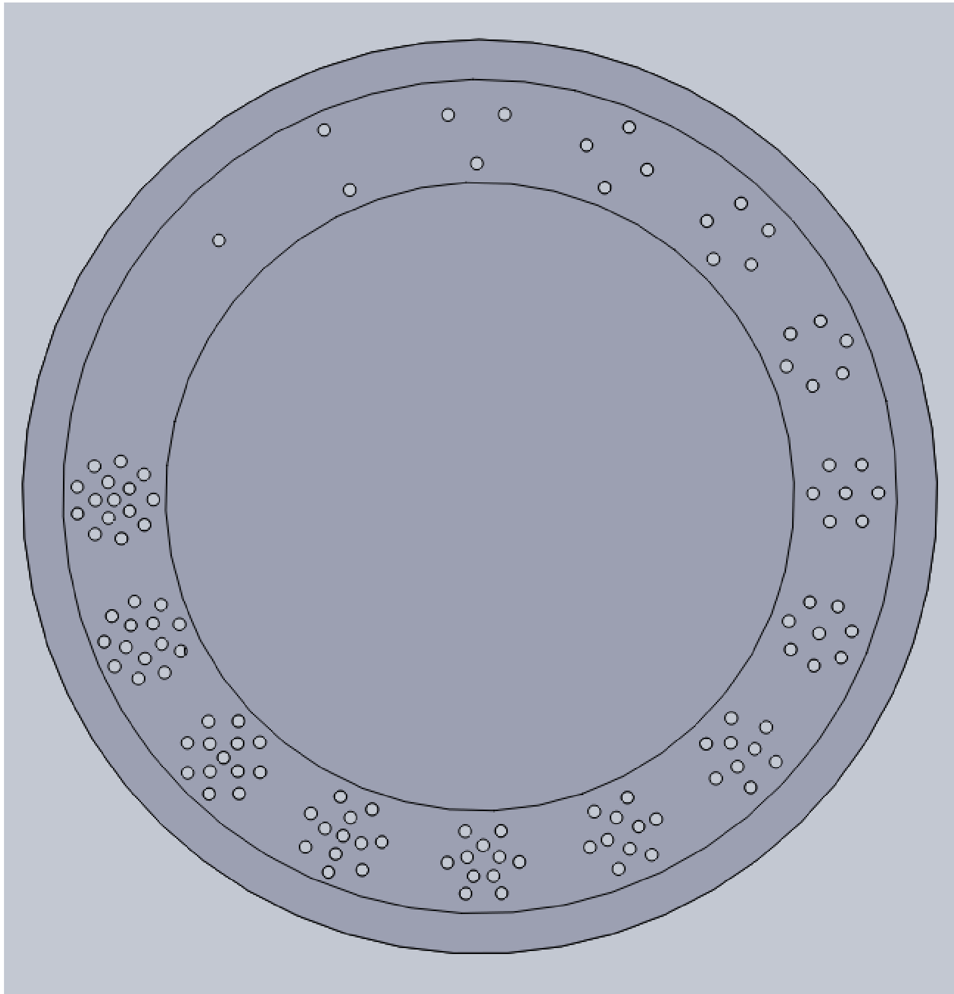

Figure 6. Flow rate control plate.

The print head will print according to color information provided by a 4-bit bitmap image. 4 bits allows for 16 different color intensities, which is also the reason why the plate in Figure 6 has 16 different hole settings. The print head will be run on an Arduino using open-source code altered from the low cost AdderFab printer. The AdderFab code only takes 1-bit color information, which is a black and white image. The capabilities of the code will be expanded to handle 4-bit information. The code also handles movement of the carriage, but since this will be done by Big Red's Dynatorch software, this portion will be eliminated. However, eventual synchronization between the print head and Big Red's carriage movement is important.

Figure 7 below shows the new hopper integrated with the old holder design. The new hopper shape was rejected in favor of the old design due to time constraints and the addition of a motor mount. In addition, the nozzles that are not angled can now be controlled with a single control plate.

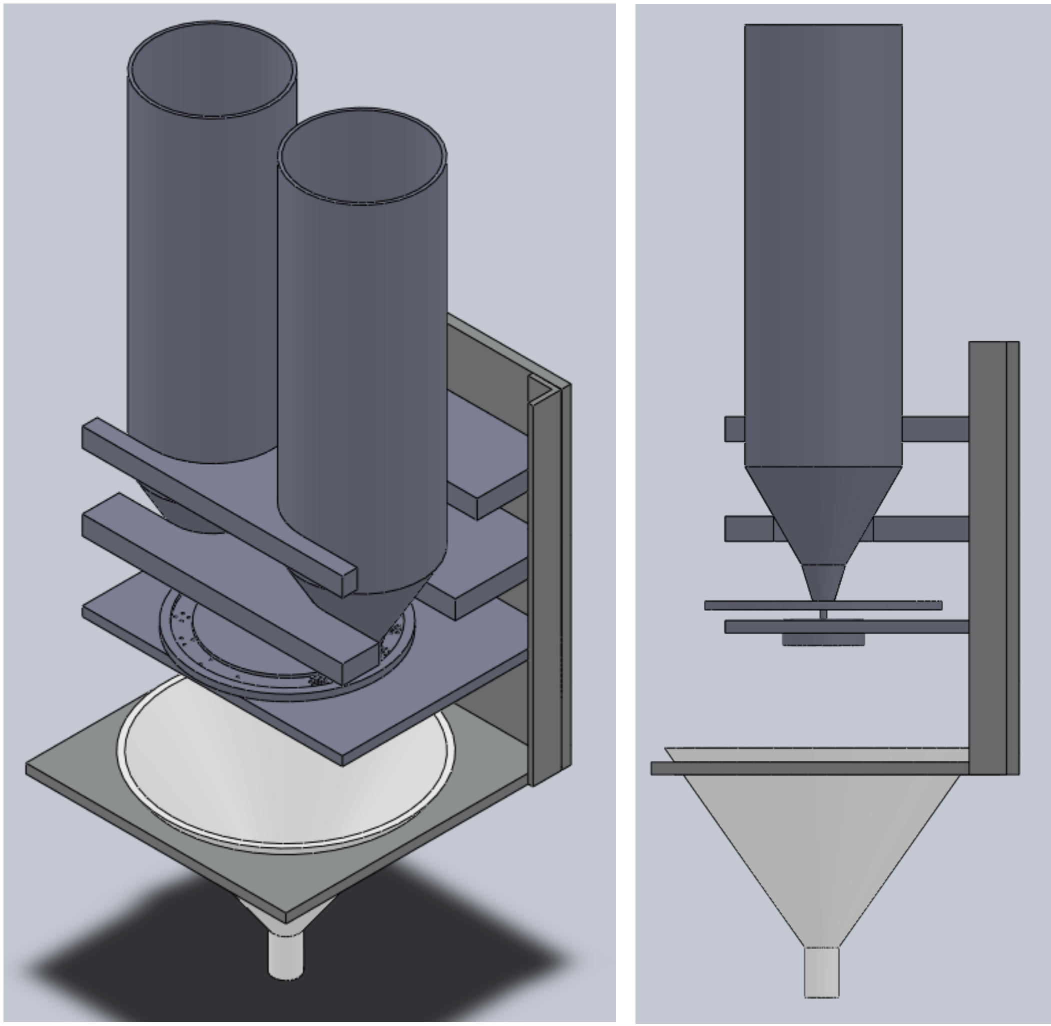

Figure 7. Powder print head assembly.

The middle plate has been moved up from the previous design to make room for an additional level to act as a motor mount. The bottom level can be seen below with the motor and control plate in Figure 8.

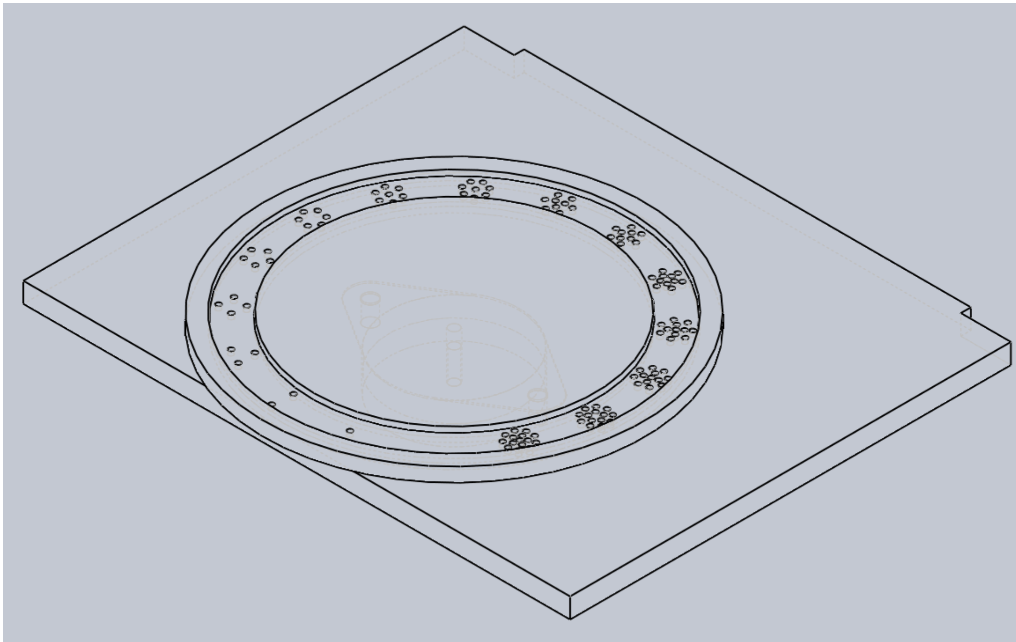

Figure 8. Flow rate control plate.

Figure 9 below shows a flow chart of how the print head will operate.

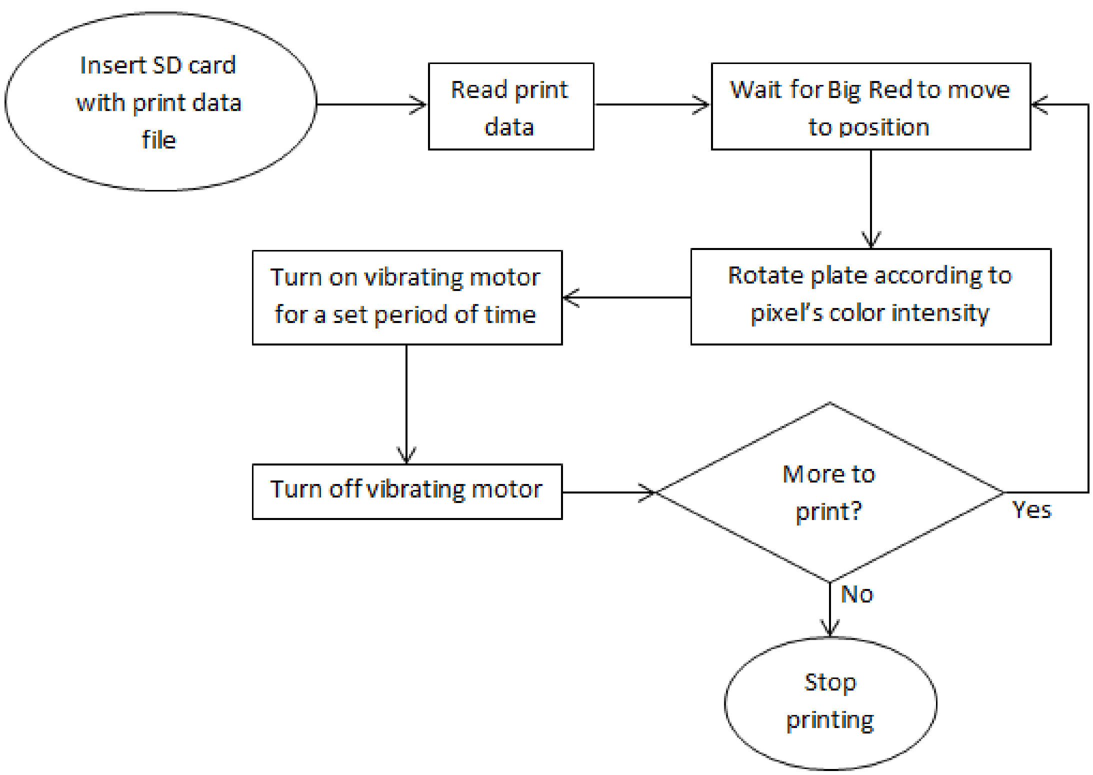

Figure 9. Flow chart of printing process.

Current Progress

The software and hardware components of the system have been completed. The preprocessor and firmware programs were taken from the AdderFab and modified for a 4-bit grayscale image. The flow chart for printing preparation may be seen below in Figure 10.

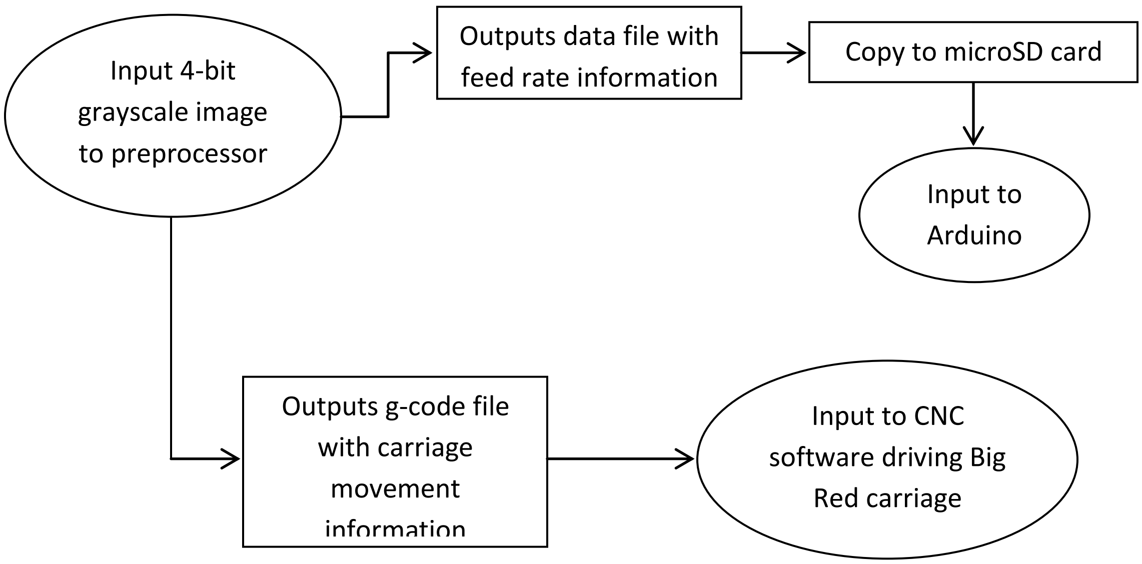

Figure 10. Flow chart of preparation process.

The preprocessor is run through Processing, an open source program that uses a language similar to C++. The firmware is uploaded to the Arduino, although some simple modifications to the code may be required depending on the model used.

Figure 11 below shows the hardware necessary to drive the flow rate controls. The cost list may be found below in Table 1.

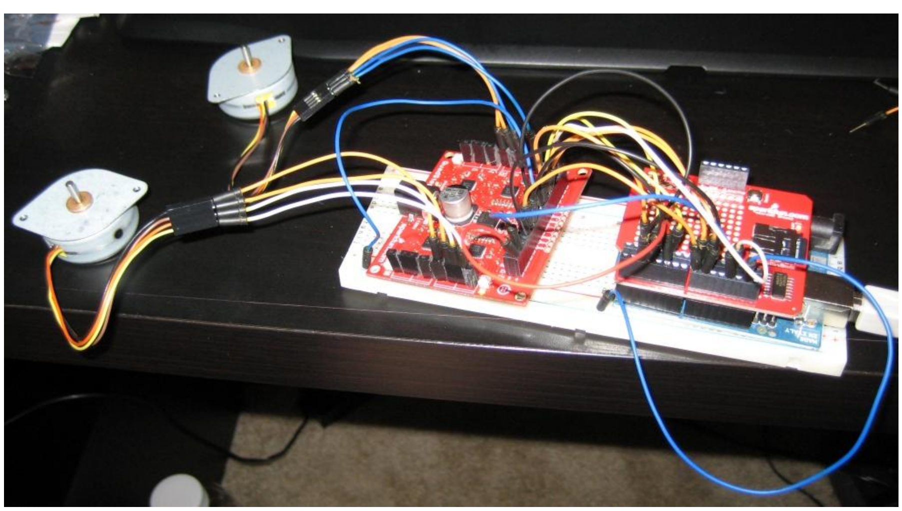

Figure 11. Flow rate control hardware.

Table 1. Hardware cost list.

Item	Purchased From	Units	Part Number	Cost
Arduino Uno	Metrix: Create Space	1	N/A	$40.00
microSD shield	SparkFun Electronics	1	DEV-09802	$14.95
Quadstepper Motor Driver Board	SparkFun Electronics	1	ROB-10507	$64.95
Small Stepper Motor	SparkFun Electronics	2	ROB-10551	$13.90
			Total Cost	$133.80

To create the flow rate control plate a mold was created of just the disc. The mold, made of OOMOO, can be seen below in Figure 12. Once the part was cast out of polyurethane, the holes shown in Figure 6 were drilled manually. In the future, this process could be sped up by inserting paper clips or pushpins into the mold to create the holes when casting.

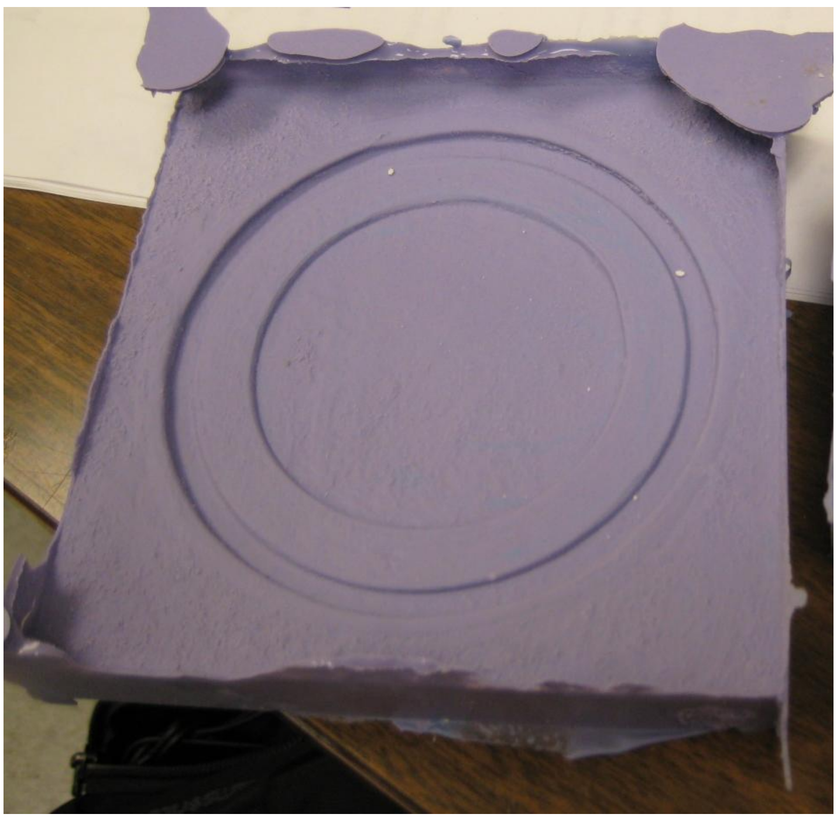

Figure 12. OOMOO mold of one side of control plate.

Figure 13 below shows the complete flow rate control setup without being mounted to the hopper. Note that the control plate on the left is directly printed out of Hydroperm while the right was the cast version. The direct print was later rejected due to its weight, brittleness, and relative ease of production compared to the cast plate. In the initial design phase, two plates were used, one for each container, but this has since been changed.

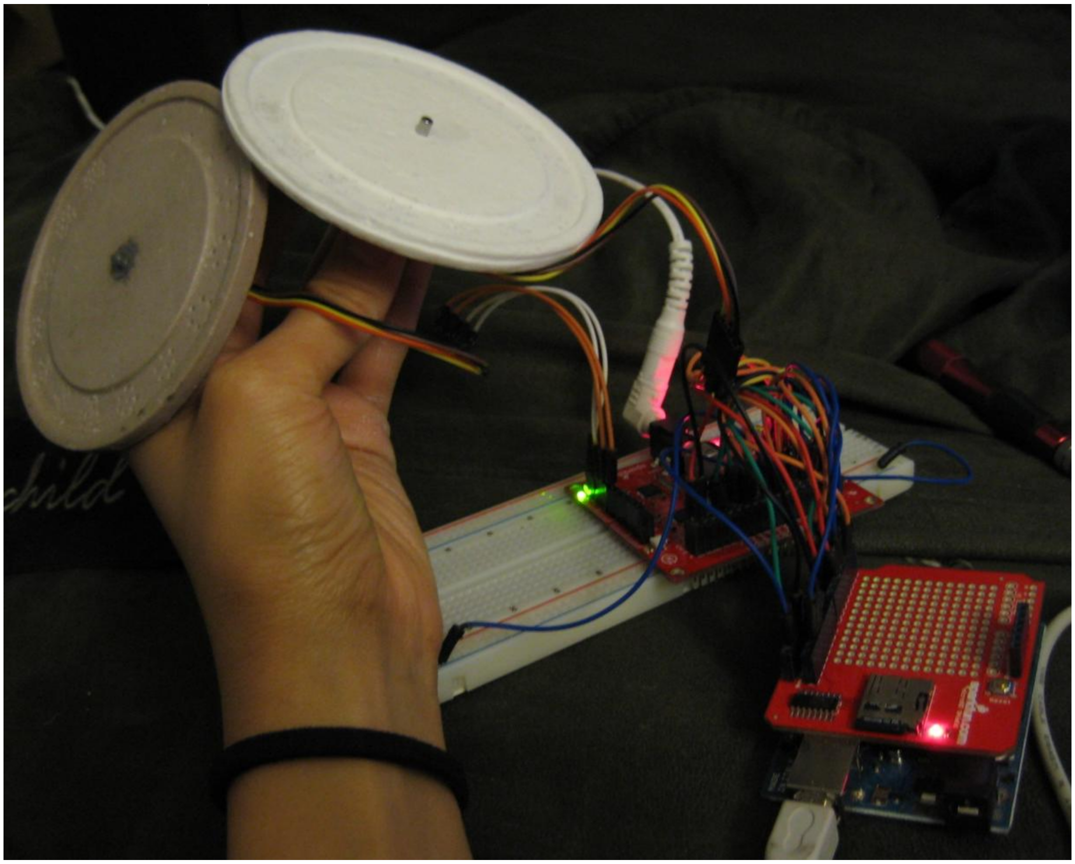

Figure 13. Complete hardware setup for flow rate control.

The results were tested and recorded on video. One screenshot can be seen below in Figure 14, although it is difficult to see in the image. There was difficulty producing continuous flow as the container often required additional force to be applied to maintain the flow. Another concern is that the flow rate is too low for a system as large as Big Red.

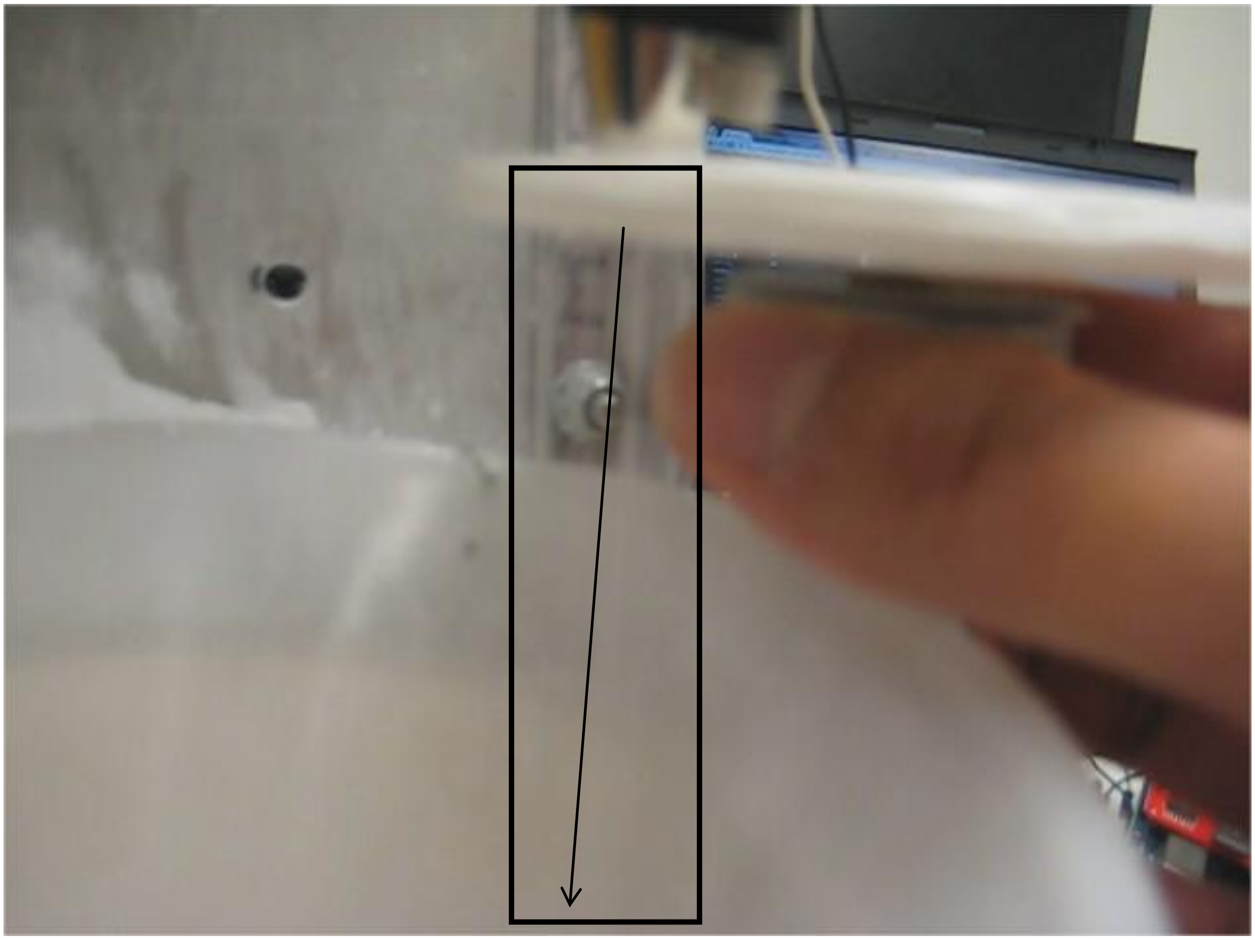

Figure 14. Screenshot of flow rate test.

The main issue seems to stem from the bottleneck effect which occurs at the end of the nozzle. It appears the powder becomes jammed in the holes and does not receiving enough momentum from the vibrating motor to move the powder through. This did not occur in prior tests when the nozzle was as pictured below in Figure 15.

Figure 15. Multiple hole nozzle.

This nozzle is different from the current design in several ways, and these variables should all be considered when proposing solutions. The current control plate is of a different material, thicker, and also detached from the nozzle. The polyurethane may have a greater damping effect on the vibrations, and the thicker plate also makes the holes longer and therefore more difficult for the powder to pass through. The detachment from nozzle also makes it more difficult for the plate to receive vibrations.

The nozzle in Figure 15 used hole sizes similar to those drilled into the control plate, so the diameter of holes themselves should not be an issue. Last quarter, a nozzle of 1 mm was also used successfully.

There are several proposed fixes, outlined below, for the current flow rate issue.

Solution 1: Increase hole size on plate.
The hole diameters, originally 3/64", were increased to 1/16" with little success. A minimum hole size necessary to produce steady flow has not determined, but note that the area of the nozzle opening limits the size.

Solution 2: Increase overall scale of the system.
This would allow for larger holes to be placed on the control plate, but the larger nozzle size is a concern for several reasons. The larger the hole, the more sensitive it becomes to vibrations. Small vibrations from the carriage movement could start the flow, and stopping it would also be more difficult. Also, as seen in Figure 2, flow rate tends to increase exponentially with hole diameter, which does not help the bottleneck effect.

However, the system could be very effective once a balance between nozzle and plate hole sizes is reached. A concern about the low flow rate was brought up during the final presentation, so a scale up could also resolve this issue.

Solution 3: Add draft to holes.
Adding draft to the holes may help the powder transition more smoothly and flow more readily.

Solution 4: Obtain better vibrating motors.
Applying more force to the nozzle may provide enough momentum for the powder to flow more readily through the holes.

This solution was one of the easiest to test. A 9V DC motor was pulled from an old inkjet printer, and an asymmetrical weight was added to the shaft to create vibrations. In this case, an offset was directly printed out of Hydroperm and attached with epoxy. The assembly may be seen below in Figure 16.

Figure 16. Motor with offset attached.

With this motor, unobstructed flow rate (flow without the control plate) was noticeably increased. It was also possible to produce constant flow when the control plate was used, but the flow rate was still very low for a system as large as Big Red. The amount of mass that was deposited after a minute was too low for a scale to read for a single hole, and the results for the 15 hole setting was only slightly heavier.

Figure 17 below shows the amount of powder collected for several hole densities. The bag labeled "Feed" on the far left is the unobstructed flow. Visually, it can be seen that the amount of powder deposited increases from the 1 hole test until roughly 9 holes. 9 through 15 look roughly similar, and this may be due to the overall 10 mm hole failing to cover all the smaller holes on the control plate.

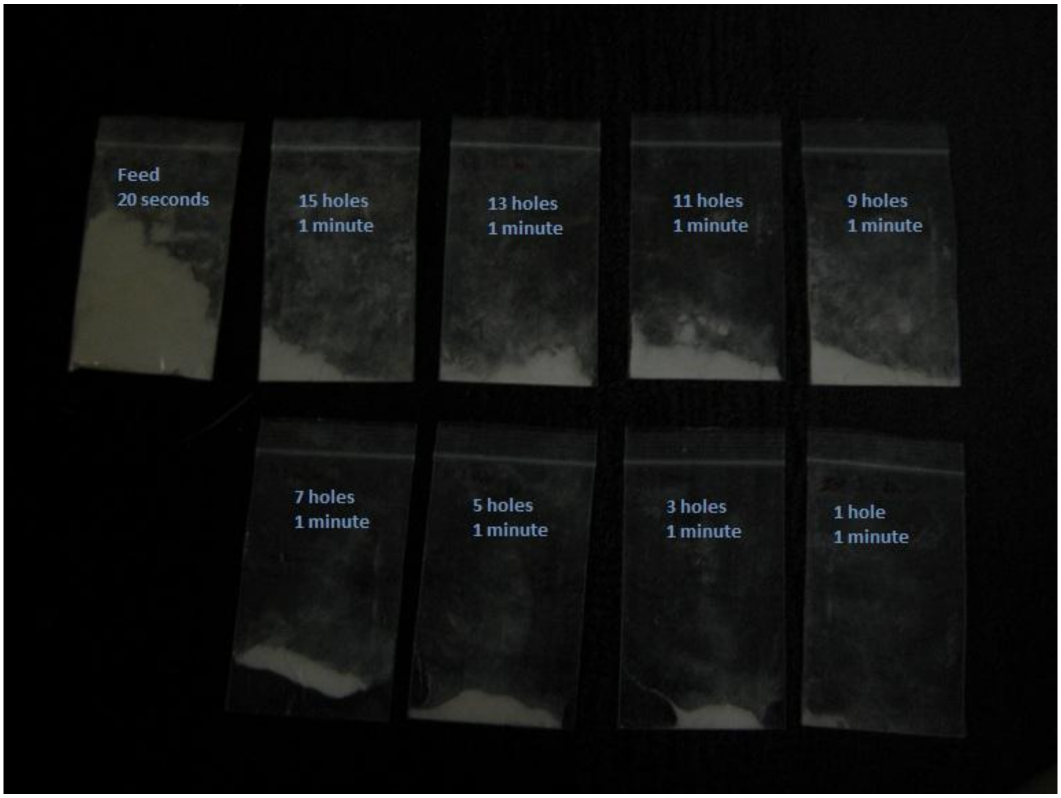

Figure 17. Powder deposited for different hole densities.

In addition, the overall hole diameter is only 10 mm, a factor which limits the track width when printing. It may be necessary to combine this solution of a stronger motor with solution #2, a complete scale up of the current system.

Since these motors run on 9V, additional equipment will be needed to power them. They will each require their own transistor and external power supply in addition to the Arduino.

Solution 5: Use an internal auger in place of a vibrating motor.
An auger could encourage a more even distribution of forces. Currently, the vibrating motor is mounted to one side of the nozzle. The auger could also provide greater momentum for the powder to flow through the control plate.

There are some concerns associated with this method however. The parts driving the auger must be kept outside of the hopper, or there may be issues with powder causing jams or malfunction. However, this means that the auger shaft will have to be relatively long and narrow.

Solution 6: Attach vibrating motor to mounting structure.
A strong vibrating motor could be used to shake the control plate itself. In this case, it may be useful to attach an industrial vibrator to the motor mounting plate.

Solution 7: Use a different material for the control plate.
It may work better to make the control plate out of a different material.

Solution 8: Convert system back to a single nozzle.
One idea proposed at the final presentation was to simple have a single hole and have color determined by the number of passes of each color. For example, when inputting a color intensity of 15, one color will be deposited in a single line through 15 passes while the other color will be deposited only once. The number of passes per line will always sum to 16. However, this system is very time-consuming, and it also does not promote even mixing.

Solution 9: Plate hole size variation.
Rather than having many holes, a single hole for each intensity could be used. Measurements in Figure 2 could be used to approximate the necessary hole size for a given flow rate. However, like the first solution, hole size is limited by the overall nozzle diameter, and the smaller hole sizes may continue to have deposition issues.

However, it is possible to estimate the hole size for a given flow rate. The data for volumetric flow rate as a function of hole size for ground salt, shown in Figure 2, has been fit to a parabolic curve below in Figure 18.

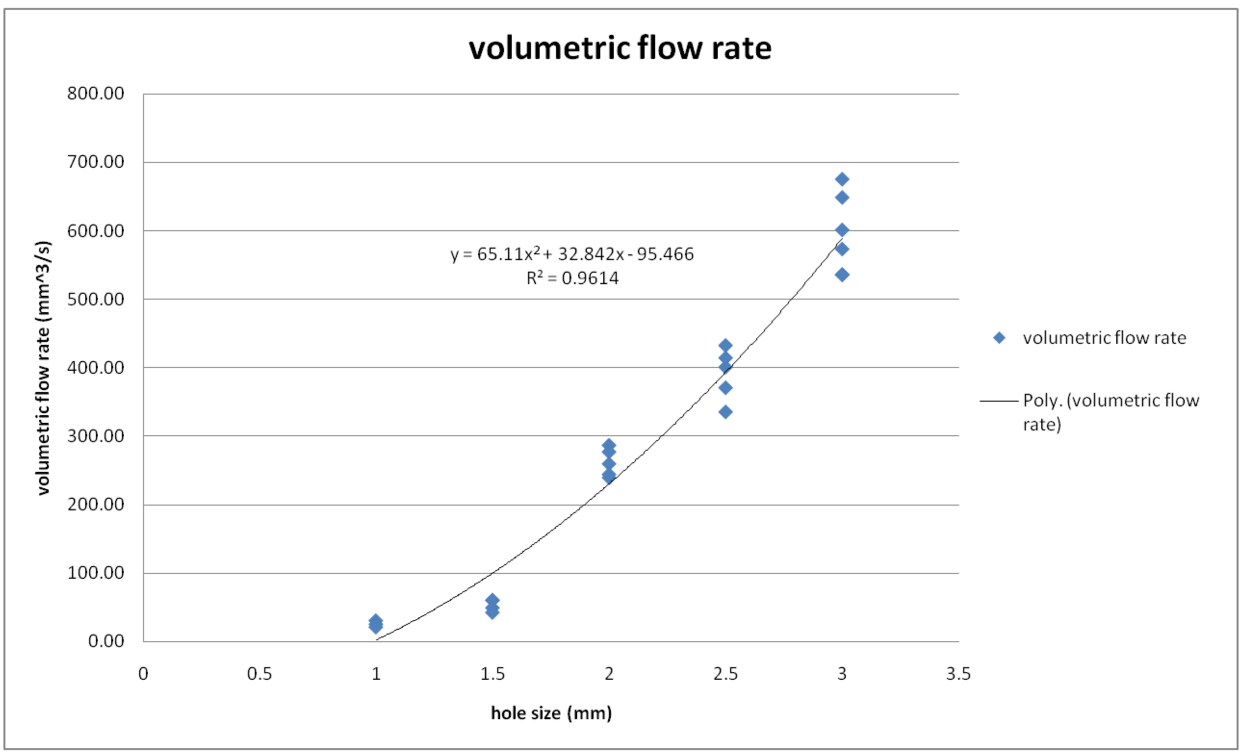

Figure 18. Volumetric flow rate as a function of hole size.

Using the equation displayed above, it would be possible to set *y* and solve for *x*, assuming that the behavior of these data points is applicable to both larger and smaller hole sizes.

Currently, the motor mounting plate pictured in Figure 8 has not been machined.

Future Work

The primary objective should be to obtain reasonable flow rates for Big Red. Several of the above solutions may be tried if they are determined feasible. Once this has been accomplished, synchronization between carriage movement and timing of deposition should be considered.

References

[1] clide. (2011, May 30). *Business Card 4 Leaf Version*. Retrieved from Thingiverse: http://www.thingiverse.com/thing:8944

[2] Lewis, Nicholas C. (2011, May 17). DIY Inkjet Printer. Retrieved from Thingiverse: http://www.thingiverse.com/thing:8542