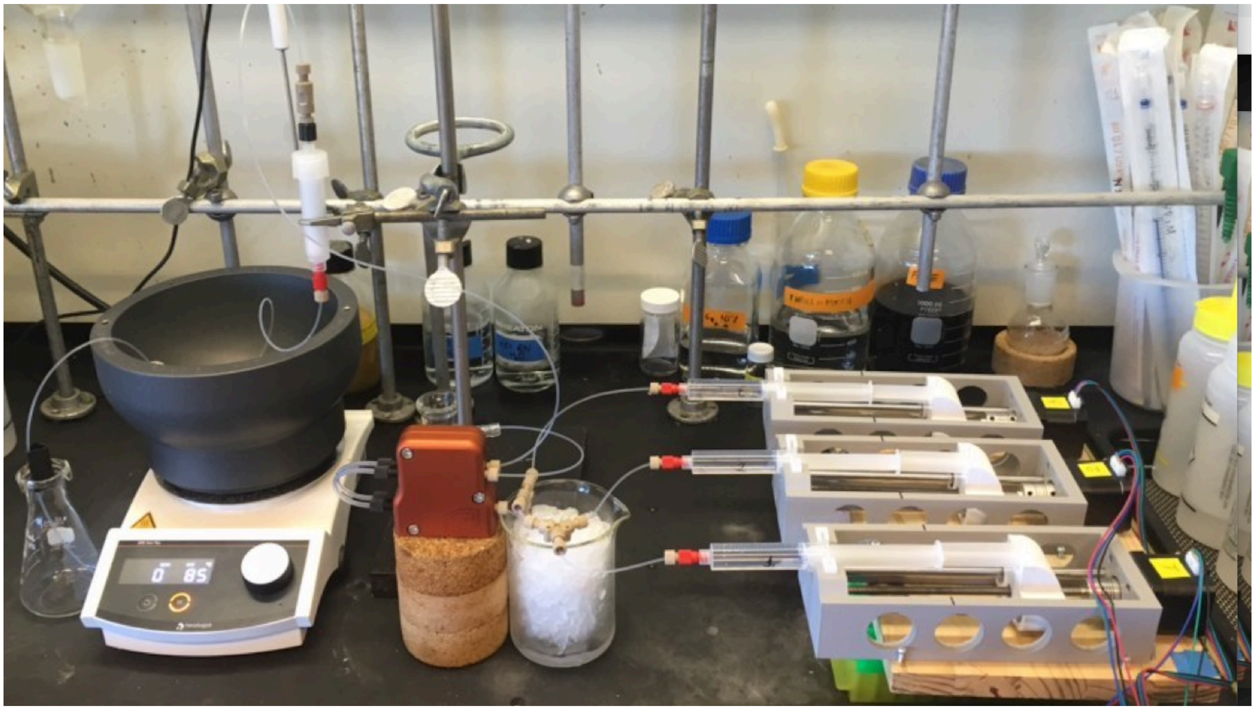
Designing a Flow System for Sustainable Chemistry



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Abstract

This project, sponsored by Dr. Haim Weizman of the Department of Chemistry and Biochemistry at UCSD, focuses on the development of a user-friendly, low-cost, and do-it-yourself (DIY) flow system. The sponsor's goal is to design a syringe pump system that is paired with an intuitive user interface to increase the prevalence of flow systems in undergraduate laboratories and to provide students with a positive user experience. The system consists of a syringe pusher actuated by a stepper motor which is controlled by an Arduino and receives input commands from the user. Major requirements for the system include a straightforward user interface, compact housing of the electronics, and a modular syringe pump. The system should be accompanied by simple assembly and operating instructions. [Design Approach]. [Results]. [Conclusion].

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Chapter 1: Project Description

Background:

The practice of synthesizing chemicals has relied on low technology equipment such as glass flasks and pipettes for decades. These practices are outdated in a world of modern technology and leave a great deal to be desired in terms of both safety and efficiency. Flow chemistry was invented in order to modernize and advance the practice of synthesizing chemicals. In flow chemistry reactions are conducted continuously as reagents are pumped through tubing and mix to form a product. Figure 1 presents a schematic diagram demonstrating the process of flow chemistry.

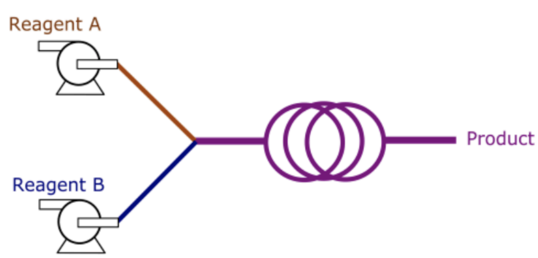

Figure 1. Flow chemistry schematic (Zaiput Flow Technologies).

Flow chemistry exhibits numerous benefits over traditional laboratory techniques. Reactions are safer due to the smaller volume of hazardous materials reacting at once, are more efficient due to the high surface area to volume ratio which increases the kinetics of the reactions, and exhibit better control because reactors can be kept at specific temperatures and pressures (Zaiput Flow Technologies). Additionally, flow chemistry is more environmentally friendly and has generated new ways to manufacture sustainable materials. However, one large downside of flow chemistry is it’s substantial price tag. Commercially available systems cost upwards of $20,000. Figure 2 displays a $20,000 chemistry flow system located in the Burkart Laboratory, UCSD. This high price point makes it such that this technology is largely unavailable to academic laboratories and undergraduate students.

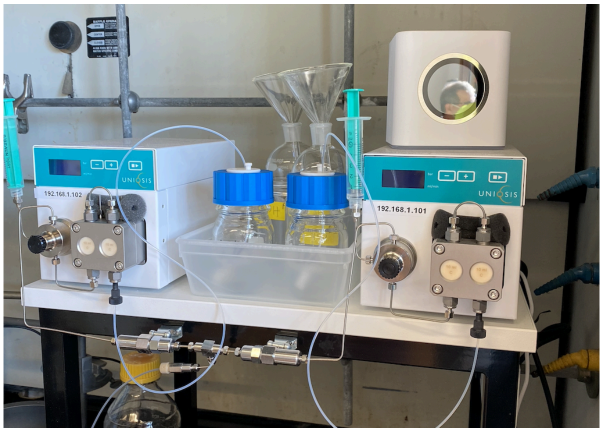

Figure 2. $20,000 flow chemistry system.

The sponsor of this project, Dr. Haim Weizman, a researcher and professor with the Department of Biochemistry and Chemistry, UCSD, hopes to make a chemistry flow system which is cost-effective and therefore accessible to undergraduate laboratories. With primary research interests of improving organic chemistry instruction at a college level and developing comprehensive laboratories to better train chemistry majors, Dr. Weizman hopes to see new cost-effective and user-friendly flow chemistry systems implemented in undergraduate laboratories in order to educate and inspire chemistry students.

Review of Existing Design Solutions:

Other researchers and professionals have likewise recognised the need for a cost-effective alternative to the costly commercially available flow systems. Therefore, various low-cost, DIY (Do It Yourself) flow chemistry systems have been developed. Namely, the Croatt Research Group at UNC, Greensboro has developed a DIY flow system which is open access and can be manufactured using only a 3D printer and parts ordered from Amazon. This system costs around $150 total - roughly a 100th of the cost of commercial systems. The system consists of a syringe pump actuated by a stepper motor which is controlled with an Arduino. Figure 3 displays a model of the Croatt Research Group's system.

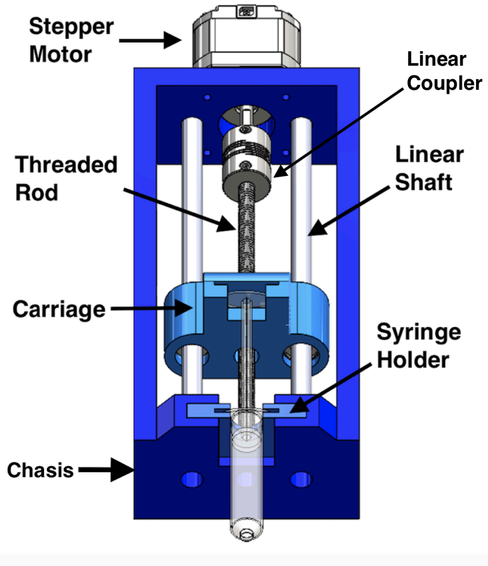

Figure 3. CAD model of Croatt Research Group's flow chemistry system.

The Croatt Research Group's system functions as a basic flow system, however, the overall user-friendliness of the system leaves something to be desired. A laptop must be connected to the Arduino in order to control the system. Since space is highly limited in many laboratories, having a laptop connected to the system poses an inconvenience. Additionally, the user input commands to the serial monitor on the laptop are not intuitive, especially considering that many chemistry students have limited experience with coding. Furthermore, the Croatt Research Group's system offers little in terms of wire management. As can be seen in Figure 4, many wires are needed to connect the components of the system, resulting in a large nest of wires. Having exposed and mismanaged wires is inconvenient and unsafe to have in a chemistry laboratory. Another issue with the system is that the steel threaded rod experiences corrosion after being left in the fume hood while reactions take place. The system fits syringes of size 1,3,5, and 10 mL. The syringe holder is specific to the size of syringe being used, so multiple differently sized syringe holders are required, along with steps to exchange them when a different syringe is used.

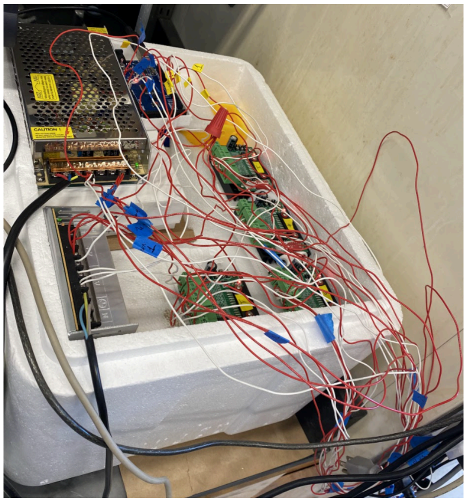

Figure 4. Arduinos and power supply used to run four flow systems simultaneously. Picture taken from the Burkart Laboratory, UCSD.

A second cost-effective solution to flow chemistry was created by engineer David Florian and published to his website Dr. D-Flo. This system is similarly open access, and can be created with a 3D printer and parts ordered from McMaster-Carr and Amazon for a total cost of $200. Also operated with a stepper motor and Arduino, the main external difference between this system and the Croatt Research Group's is the use of an aluminum rail as opposed to a fully 3D printed chassis. Figure 5 displays David Florian's syringe pump design as manufactured by the Burkart Laboratory, UCSD.

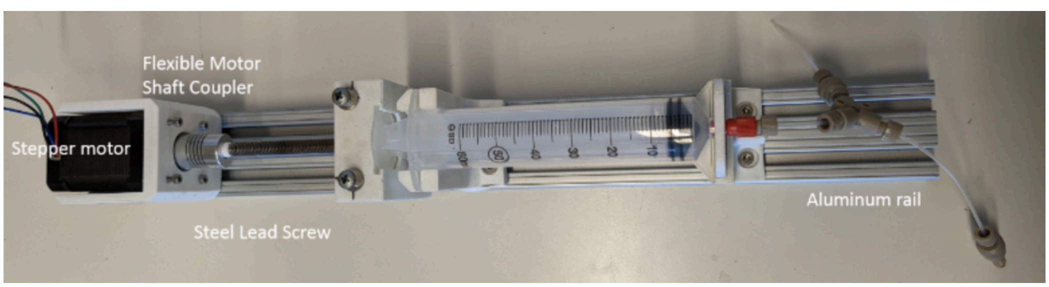

Figure 5. David Florian's syringe pump design.

This design presents the same issues as the Croatt Research Group's in terms of non-intuitive user-input commands, limited wire management solutions, and corrosion of the steel lead screw. Syringes of sizes ranging from 15 to 50 mL can be used with this system. However, changing the size of the syringe requires modifying the 3D printed syringe holders.

A much more expensive syringe pump system that was found during the research process is the Standard Infusion Only PHD Ultra Syringe Pumps. This system uses a mechanical driving mechanism that resembles the Croatt Group's mechanism as it features a lead screw that when rotated by a stepper motor pushes a carriage which then pushes the plunger of a syringe. This system also includes two low-friction guiding linear shafts for the carriage and a modular syringe holder design. This system represents the high end spectrum of syringe pump systems that at its price point offers a wider range of configurability. For example, this system is able to fit syringe sizes ranging from as large as 140 mL to as small as 0.5 μL which the system uses to achieve a maximum flow rate of 216 mL/min and a minimum flow rate of 1.5 pl/min from these syringe sizes, respectively.

Figure 6. PHD Ultra Syringe Pump from Harvard Apparatus

Statement of Requirements and Deliverables:

High Priority Objectives:

1. Implement a user-friendly user-interface to serve as a control panel.
2. Design a modular syringe pump that can fit various sizes of syringes (1,3,5,10 mL).
3. Enhance resistance to corrosion of threaded rod.

Second Priority Objectives:

4. Provide an alternative design for refilling the syringe that doesn’t rely on expensive check valves.

WOW Design Solution:

5. A system that can detect leaks and shut down the system when they occur.

Deliverables (to be completed):

1. Flow Chemistry System
    a. 2 complete syringe pumps
    b. Touchscreen user-interface

2. Documentation
    a. Manufacturing procedures
    b. Operation instructions
    c. Code files
    d. CAD (Computer Aided Design) files
    e. BOM

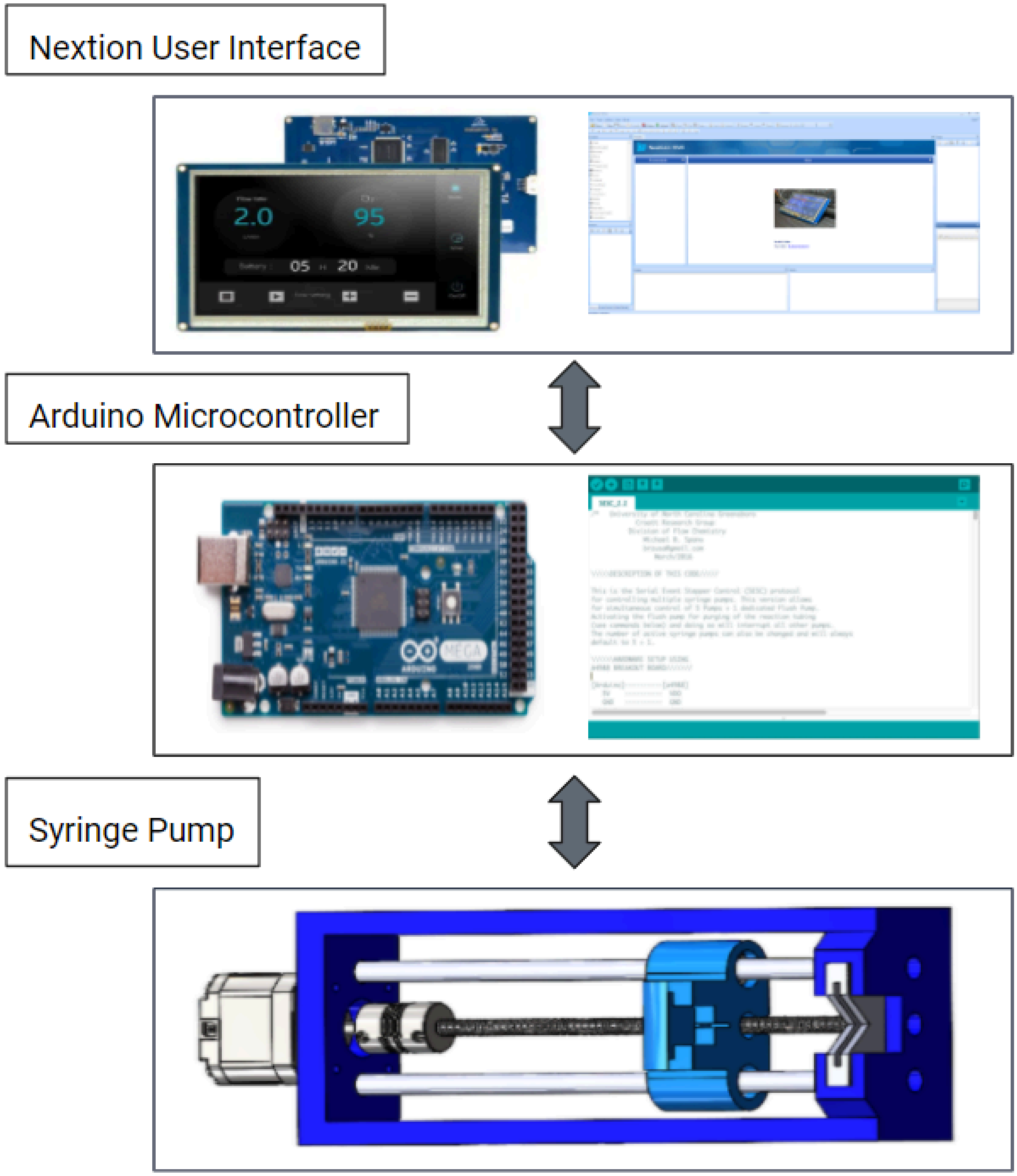

Figure 7. The main components of the syringe pump system include: Nextion 7” Basic Series, Arduino MEGA 2560, and the syringe pump.

Chapter 2: Description of Final Design Solution

Chapter 3: Design of Key Components

Chapter 4: Prototype Performance

Chapter 5: Design Recommendations and Conclusions

Impact on Society

Green chemistry (or sustainable chemistry) refers to the development of efficient chemical processes that reduce or can even eliminate the generation of hazardous substances[1]. It takes into consideration the environmental impact of every step in the process of chemical synthesis, from the waste created during the reaction to the lasting effects that the chemicals created will have on the environment. It also concerns safety, aiming to minimize potential hazards to laboratory personnel. As environmental concerns have come to a head over the past half-century, government, academia, and industry alike have begun to look towards green chemistry as a necessary scientific advancement in order to promote a more sustainable civilization[2]. Flow chemistry has made valuable contributions towards the practice of green chemistry. By allowing for strict control of reaction parameters, the efficiency of reactions is increased, waste is reduced, and safety is enhanced.

However, one important consideration when it comes to green chemistry initiatives is the economic impact of the processes being implemented. Governments, industries, and research

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[1] Environmental Protection Agency. (n.d.). *Basics of Green Chemistry*. EPA. Retrieved January 17, 2022, from https://www.epa.gov/greenchemistry/basics-green-chemistry#definition
[2] Vaccaro, L., Lanari, D., Marrocchi, A., & Strappaveccia, G. (2014). Flow approaches towards Sustainability. *Green Chem.*, *16*(8), 3680–3704. https://doi.org/10.1039/c4gc00410h

institutions desire both environmental and economic sustainability. Practices must therefore be cost effective in order to gain acceptance and widespread use. Currently, chemistry flow systems are prohibitively expensive and therefore largely impractical for large-scale implementation. By greatly reducing the price of flow systems, use of these systems will become more commonplace as institutions no longer have to choose environmental or economic sustainability over one another. This creates opportunity for a larger portion of chemical synthesis to be conducted in a sustainable manner.

Similar cost-effective flow systems have been developed, however these systems are non-intuitive and not user friendly. The user-friendly nature of this flow system will allow for increased prevalence of flow systems in undergraduate laboratories because students will not require significant training and expertise to operate the system. Therefore, a greater number of students will have the opportunity to conduct experiments using this equipment, leading to a workforce of adept chemists. Furthermore, by removing unnecessary obstacles associated with operating the system, students will be inspired rather than discouraged when using this flow system. This inspiration will encourage students to persevere through difficult courses, and enhance the retention of students from underrepresented groups in STEM fields.

Professional Responsibility

When designing the system, care was taken to account for the safety of the individuals operating the system. Therefore, an automated refill option has been included to minimize the handling of chemicals by allowing users to command the system to refill the syringes using the user interface. Without this option, the syringes must be detached from the system, refilled by hand, and repositioned within the syringe pump. This process may lead to accidental chemical spills and the chance of chemicals coming into contact with the operator's skin.

Replication of this design will lead to the creation of plastic waste. Most common types of 3D printing filament are classified as Type 7, or “Other” by the ASTM International Resin Identifier Codes[3]. Type 7 plastics are not recycled by most curbside municipal recycling programs. However, independent plastic recycling and processing companies exist which process plastics not typically handled by municipal recycling programs. It is also possible to melt down old 3D printed components and re-extrude them as usbale filament[4]. Additionally, PLA (Polylactic Acid), one of the most commonly used 3D printing filaments, is a biodegradable material which means that it can be broken down over time. As 3D printing gains popularity, there is discussion regarding the introduction of more comprehensive recycling codes in order to include common 3D printing filament polymers.[5]

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[3] *3D Print Recycling*. Iowa State University Computation and Construction Lab. (n.d.). Retrieved January 17, 2022, from https://ccl.design.iastate.edu/3d-print-recycling/#:~:text=One%20of%20the%20common%20types,typically%20processed%20by%20municipal%20programs.

[4] *3D Print Recycling*. Iowa State University Computation and Construction Lab. (n.d.). Retrieved January 17, 2022, from https://ccl.design.iastate.edu/3d-print-recycling/#:~:text=One%20of%20the%20common%20types,typically%20processed%20by%20municipal%20programs.

[5] Emily J. Hunt, Chenlong Zhang, Nick Anzalone, Joshua M. Pearce, Polymer recycling codes for distributed manufacturing with 3-D printers,Resources, Conservation and Recycling, Volume 97, 2015. Pages 24-30. ISSN 0921-3449. https://www.sciencedirect.com/science/article/pii/S0921344915000269.

Appendix: Preliminary Component Analyses

1. User Interfaces

An important component of the flow chemistry syringe pump system is a suitable user interface. As the system is to be used by students and even hobbyists, they do not necessarily have technical experience in electronics. As such, it is important for the system to have a user friendly interface that is non-intimidating, especially for those only just getting into flow chemistry as their focus is to learn chemistry, not to learn about electronics and programming.

Functional Requirements

This user interface is only meant to control the syringe pumps, so there are not that many functional requirements for its operation. Essentially, it just needs to reliably send and receive information to and from the system's microcontroller. There will need to be inputs for which pumps are on/off, the syringe size, the flow rate, and a start/stop input. Of course, the controls on the interface should be very user friendly.

User Interface Options

There are three general interface options for this system. The first would be a touchscreen display that connects to the microcontroller. Second, the system could just be hooked up to a switchboard with knobs, switches, and sliders to control the various inputs necessary to control the syringe pumps. There would be an LCD display here for the user to keep track of what their inputs were and what the system is currently outputting. Finally, the original flow chemistry system designed by the Croatt Research Group had an Android app for controlling the syringe pump (with a bluetooth dongle on the microcontroller to receive information from the app). The sponsor of this project would prefer to steer away from this control scheme as it is exclusive to only Android phone users and some people would not like having stuff pertaining to business on their personal phone. However, this is still an option, and to accommodate, an inexpensive Android phone can be purchased and hooked up to the system.

Touch Screen Interface

Two of the most common types of touchscreen technologies are resistive and capacitive touch screens. With resistive touch screens, there are two layers of material separated by a tiny gap. The resistance between the two sheets of material is measured at different points. "Pressing down upon the top sheet will change that resistance, and by comparing the measurement points it can be determined where the screen was pressed"("Touchscreen Display with Arduino"). These resistive touch screens are generally less expensive and can be operated with any touch input whether it be from finger, stylus, or while wearing gloves. However, they are more susceptible to scratches on the display. The display is also a bit dimmer due to the resistive overlay. Alternatively, there are capacitive touch screens that use the conductivity of the human body. When the glass is pressed with one's finger/body, the current changes and sensors can then tell where the screen was pressed("Touchscreen Display with Arduino"). As this sort of touchscreen depends on the conductivity of the body, it is not possible to operate with gloves or a stylus. They are more durable and brighter than resistive touchscreens, and allow for multi-touch sensing. However, they are not as precise and are more vulnerable to accidental touches.

Based on where this flow chemistry system is expected to be used, there will likely be gloves involved since chemists may deal with some dangerous chemicals. Thus, it would be a better idea to go with resistive touchscreens as they are operable while wearing gloves. Their display may be a little duller, but that is not much of a concern as the purpose of this touchscreen is just to send commands to the microcontroller. The touch screen is more susceptible to scratch damage, but if that ever happens, it can simply be replaced.

Figure 1. Mockup for touch screen interface.

Above is a mockup of what the user interface would look like with the touchscreen. All of the relevant inputs are there on screen to turn pumps on and off and set the pump direction, flow rate, and size. There is a progress bar on the right to display the current flow rate of the system. There may be up to six pumps that can be controlled by an Arduino, so there may be six pump settings, but only three are shown here for the mockup.

<u>Display with Switchboard</u>

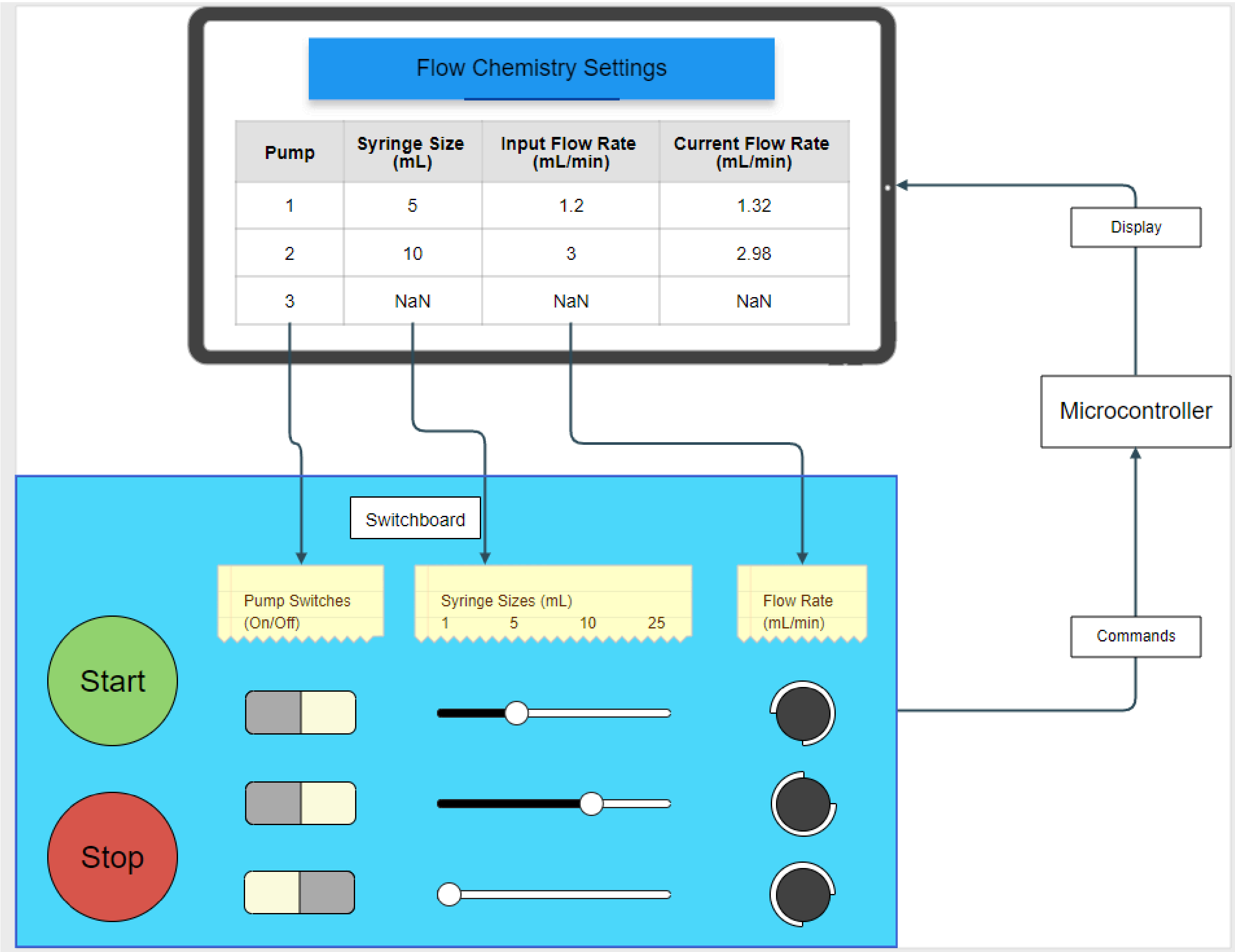

Figure 2. Mockup for display screen with switchboard interface

Instead of a touch screen, one can use a switchboard with knobs, switches, and sliders to control the inputs of the system. Such a system is depicted above. Switches turn pumps on and off, sliders can control the syringe size, and knobs can increment the flow rate. The display screen or another sort of screen display can display the current inputs and flow rate. There may be up to six pumps that can be controlled by an Arduino, so there may be six pump settings, but only three are shown here for the mockup.

Generally, display screens are pretty cheap, but they often come in small sizes. Common LCD displays for the Arduino come in sizes of 16 x 2, 16 x 4 and 20 x 4 characters("Using LCD Displays with Arduino"). However, the display may need to be bigger to accommodate all the information. Perhaps a solution here would be to buy multiple display screens to display all the information.

Bluetooth App

Finally, the other option would be to have a bluetooth app that controls the microcontroller. There was an app developed by the Croatt Research Group, but the link on their website no longer works, so it is necessary to contact the group for further information about it. Alternatively, a new app can be created with compatibility for more mobile devices. The app from the Croatt Research Group only works for Android, but this can be remedied with the development of a new mobile app. The user interface would look similar to the one presented in figure 1.

Summary

	Pros	Cons
Touch Screen	- intuitive -easy to use -can operate with gloves	-costly -susceptible to scratches -harder to troubleshoot -potential programming issues
Display + Switchboard	-easy to use -generally inexpensive -easy to troubleshoot -replaceable parts if one breaks	-lots of different parts -displays generally come in small sizes -knobs and such might break
Bluetooth App	-easy to use -intuitive	-very costly -potential programming issues -harder to troubleshoot -likely cannot operate with gloves (phones usually have capacitive touch screens)

Touch screens for the Arduino costs:

- Adafruit touch screen costs about $40 for a 5" display (resistive touch panel), comes with its own adafruit driver, presumably more expensive for 7" display but it is currently out of stock
  https://www.adafruit.com/product/1596

- Arduino touch screen shield 7" from BuyDisplay about $70 with the resistive touch panel https://www.buydisplay.com/7-inch-arduino-touch-screen-shield-ssd1963-library-for-mega-due

Display screen for Arduino costs:

- Adafruit LCD display (no touch screen) about $30 https://www.adafruit.com/product/1680
- Lots of different display screens at BuyDisplay, generally cost a bit over $10 for bigger displays, but will likely need more than one screen to display all data https://www.buydisplay.com/i2c-white-1-5-inch-oled-display-module-128x64-arduino-raspberry-pi

Android phone costs:

- One of the cheapest ones on Amazon was about $86 https://www.amazon.com/ZTE-Unlocked-T-Mobile-Straight-International/dp/B08D6XNKRC/ref=sr_1_11?keywords=Android%2BPhones&qid=1638852420&sr=8-11&th=1
- There are a couple of cheap Android phones at Best Buy and some other places, but the cheapest is around $180

Other Considerations

Some of the other considerations that came up while researching about the user interfaces was the possibility of using a Raspberry Pi instead of an Arduino to control the syringe pump. While this is not the interface that the user will be interacting with, it may be worthwhile looking at the advantages of using a Raspberry Pi as opposed to an Arduino. Another consideration is all of the wirings that go in between all of the electronics. An inexperienced user would be at a loss at how this connects to that and so on. Perhaps there is a wireless solution to this problem? Maybe the signals that the microcontroller sends can be wirelessly transmitted to a receiver where the stepper motor is to do away with all the convoluted cable connections.

References:

"Touchscreen Display with Arduino." *DroneBot Workshop*, 12 Aug. 2019, https://dronebotworkshop.com/touchscreen-arduino/. Accessed 6 Dec. 2021.

"Using LCD Displays with Arduino." *DroneBot Workshop*, 19 Mar. 2018, https://dronebotworkshop.com/lcd-displays-arduino/. Accessed 6 Dec. 2021.

2. Non-Corrosive Threaded Rods

Project Description: Designing a Flow System for Sustainable Chemistry

The objective of this project is to develop a flow chemistry system which is accessible and user friendly in order to be widely used in undergraduate research labs. In a flow chemistry system reactions are conducted continuously as reagents are pumped into the system via micro tubing and are mixed to form a product. Commercially available systems cost upwards of $20,000. The Croatt Research Group has developed a low cost, DIY flow system in order to achieve the objectives of this project. However, their system has a number of issues. One of these issues involves the threaded rod used to push the syringe-pushing carriage. This threaded rod is currently made of standard steel and experiences corrosion when kept under a chemistry fume hood with a mix of gases (the most corrosive being ozone) and sustained moisture. This corrosion inhibits the ability of the threaded rod to advance the carriage as intended. Therefore, additional consideration is needed to determine an alternative threaded rod which eliminates corrosion.

Research Process:

By searching the Thomas Register using key words “threaded rod” and “lead screw,” a large number of manufacturers and distributors resulted. This list was narrowed down by excluding custom manufacturers due to their higher price points and limited accessibility. From the remaining results, companies specializing in lead screws could be identified, such as Thomson and Helix Linear Technologies.

Helix Linear Technologies supplies lead screws, however, they are mainly restricted to series 300 stainless steel. While this was not very helpful in the search for various material options, Helix also provides anti-backlash lead screw nuts as well as accompanying design guides. When testing the flow chemistry system, we noticed significant backlash after the stepper motor reversed its direction. Therefore, information regarding anti-backlash lead screw nuts will be useful in future design considerations for the flow chemistry system.

Similar to Helix, Thomson does not offer a wide range of materials. However, their website includes design guides for lead screw usage. From these design guides, useful information was gathered such as the use of PTFE coatings in order to increase resistance to corrosion and decrease friction. With this new knowledge of PTFE coatings, companies/suppliers specializing in lubricants and coatings could be identified using the Thomas Register. After identifying CRC industries as a supplier of coatings and lubricants, contacting an application engineer revealed that PTFE coatings are best suited for plastic adhesion rather than metal. This engineer then suggested CRC’s Dry Mold Lube in order to provide superior corrosion resistance, decreased friction, and better results when adhering to a metal lead screw.

An additional company found using the Thomas Register was Paramount Fasteners. While this company primarily specializes in fasteners, they also offer lead screws made from a range of materials. In order to get an expert’s opinion on the most suitable material options to resist corrosion, an application engineer from this company was contacted. This conversation revealed stainless steel 316 to be the superior grade of stainless steel when it comes to resisting corrosion. For plastic options, he advised against nylon and suggested looking into PVC. After discussing pricing and shipping options, it became apparent that this company did not align with our project objective to build a low cost and accessible system.

Due to our project's budget and accessibility requirements, it is clear that specialty suppliers and manufacturers are not the best option. However, they were useful in providing engineering specific information and design guides. The products suggested and discovered throughout this research process were cross-referenced with products available from well known, highly accessible, and well priced suppliers such as Amazon and McMaster to ensure the components meet both the functional requirements and the overall project objectives.

1. Functional Requirements

1. Corrosion resistant to fumes (specifically ozone) and moisture present in fume hood. Fumes will vary according to the chemical reaction taking place.
2. Must transform rotary motion from the stepper motor into linear movement of the carriage.
3. Low Cost.
4. Easily Accessible.

2. Short Description of 3 component options

1. 316 Grade Stainless Steel Threaded Rod.

   316 Grade Stainless Steel is significantly more corrosion resistant than the standard steel threaded rod currently in use, and superior to 18-8 and 410 grade stainless steel rods in its resistance to corrosion. It has excellent resistance to chemicals and salt water. Additionally, it displays excellent resistance to corrosion resulting from ozone, which is a main factor causing corrosion in these chemistry flow systems. It can be noted that 316 stainless steel has paramagnetic properties. This is only an area of concern if there is an externally applied magnetic field in the vicinity of the flow system, and if the stepper motor relies on a magnetic encoder rather than an optical one. In this case, the externally applied magnetic field or the magnetic field induced in the rod may interfere with the encoder counts.

2. Solid-film Lubricant.

   A solid-film lubricant can add a layer of corrosion resistance to existing hardware. Specifically, the Dry Moly Lube (Molybdenum Disulfide), from CRC Industries is well suited for use on metal lead screws, will increase resistance to corrosion, and reduce friction. The frequency of reapplication depends on the tolerances between the lead screw and the nut, the amount of friction in the system, and the frequency and duration of use. This product is intended to withstand sufficient use before reapplication is required, and it is possible to go months without needing to reapply, depending on the system. An additional advantage of this product is its resistance to dirt and dust build up, which will keep the carriage running smoothly along the lead screw.

3. Polyvinyl Chloride (PVC) Threaded Rod.

   Another option when it comes to enhancing resistance to corrosion is PVC plastic. PVC is a plastic which is largely resistant to corrosion. PVC exhibits satisfactory resistance to ozone and many other common gases and chemicals found in chemistry experiments. Additionally, PVC has a friction coefficient comparable to that of 316 stainless steel. However, rigid PVC has a tensile strength of 32-64 MPa whereas stainless steel has a tensile strength of 480 MPz. In order to increase the strength of the PVC threaded rod, a thicker diameter may be required. The necessary diameter can be calculated using the column strength equation for a lead screw in compression. A thicker diameter will not be an issue design-wise, however, the cost of the threaded rod increases with diameter.

3. Summary table comparing the pros and cons of the different components found.

Options	Pros	Cons	Cost
1. Stainless steel 316	- Excellent resistance to chemicals, salt water, and ozone. - Easily accessible.	- May be slightly magnetic. - 4x the cost of medium strength steel.	McMaster 1/4"-20: $8.03 / 3ft
2. Dry Moly Lubricant	- Corrosion resistant. - Decreased friction. - Resistant to dirt and dust build up. - Requires less frequent application than other protective lubricants.	- Requires reapplication.	Amazon $10.42
3. Chemical Resistant PVC	- Satisfactory resistance to acids, alkalines, salt	- 7x the cost of medium strength steel.	McMaster 1/4"-20: $14.48 / 3 ft 5/16”-18: $16.20 / 3 ft

	solutions, alcohol, ozone, and others. - Nonconductive and nonmagnetic.	- Decreased strength may require an increased diameter, which increases the cost.	3/8"-16: $20.70 / 3 ft 1/2"-13: $24.42 / 3 ft

Conclusion:

316 Stainless Steel is the best option due to its excellent resistance to corrosion, affordable price, and wide availability.

4. List of References Used.

Databases:

- The Thomas Register.
- Google Scholar.

Key words:

- “threaded rod”
- “lead screw”
- “corrosion resistant”

Contacts:

- Application Engineer from Paramount Fasteners, Roy Hurst. (562) 903-7610.
- Application Engineer from CRC Industries, Ben (did not offer last name). (800) 521-3168.

Other Resources:

- Materials Ozone Resistance Chart. Oxidation Technologies, LLC. https://www.oxidationtech.com/blog/materials-ozone-resistance-chart/
- Chemical Performance of PVC.Vinidex by aliaxis. https://www.vinidex.com.au/app/uploads/pdf/Chemical-Performance-of-PVC.pdf?v=1638674869513
- Morgan Coates, Product Engineer. “Lead Screw Coatings.” Thomson Industries, Inc. Wood Dale, IL. https://www.thomsonlinear.com/downloads/articles/Lead_Screw_Coatings_taen.pdf
- Robert Lipsett, Engineering Manager. “Why Lead Screws are the Best Fit for Many Linear Motion Applications - and How to Rightly Apply Them.” Thomson Industries, Inc.

San Jose, CA.
https://www.thomsonlinear.com/downloads/articles/Lead_screws_QA_Application_Considerations_taen.pdf
- Nook, Christopher. "Selection of Anti-Backlash Nuts in Linear Motion Systems." Helix Linear Technologies.
https://www.helixlinear.com/blog/lead-screws/selection-of-anti-backlash-nuts-in-linear-motion-systems/
- "An Engineer's Guide to Lead Screw Selection." Helix Linear Technologies.
https://www.casa.co.nz/hardware/leadscrews/An_Engineers_Guide_to_Lead_Screw_Selection.pdf
- McMaster-Carr. https://www.mcmaster.com/
- Amazon. https://www.amazon.com/

3. Check Valves

The component chosen to research is the check valve, which is essential for controlling the flow of liquids or gasses in flow chemistry setups. Check valves are used in systems that require one-way flow such as continuous flow systems. The functional requirements of the system are that the check valve should protect the system from backflow, provide pressure relief, allow a constant flow rate, and prevent contamination from backflow.

Some secondary considerations were that the check valve should allow the syringes to be refilled, contain wetted materials that are non-corrosive to a wide range of chemicals, and offer low maintenance requirements.

The tubing used for the flow system will dictate which size check-valve will be used. Furthermore, the chemistry itself will influence what tubing size will be utilized. A tubing size of 1/16" outer diameter and 0.02-0.04" inner diameter is recommended for our application.

After browsing through catalogs from suppliers these are three check valves that meet the requirements:

- Check Valve Inline Non-Metallic 1/4-28
- Masterflex Inert Inline Inlet Check Valve
- Slim-Line In-Line Check Valve w/ 1/16" Ball Cartridge

Here is more information gathered from the webpage of each check valve option:

1) **Check Valve Inline Non-Metallic 1/4-28**

- This check valve is made of polyetheretherketone (PEEK) and perfluoroelastomer. It has a cracking pressure of 1 psi and a maximum pressure rating of 2000 psi.

2) Masterflex Inert Inline Outlet Check Valve

- The wetted materials in this check valve are PEEK and ethylene propylene diene monomer rubber (EPDM). It has a cracking pressure of 0.99 psi and a maximum pressure of 100 psi.

3) Slim-Line Inline Check Valve w/ 1/16" Ball Cartridge

- The wetted materials are 316 stainless steel, PEEK and ruby ball/sapphire seat. It has a cracking pressure of 1 psi and a maximum operating pressure of 18,000 psi.

Check Valve	Pros	Cons
Check Valve Inline Non-Metallic 1/4-28	● PEEK and Perfluoroelastomer: Made of chemical resistant materials ● Rated for up to 2000 psi ● Compatible w/ other PEEK tubing components	● Expensive ($117.80) ● Requires additional components for the 1/16 outer diameter tubing
Masterflex Inert Inline Outlet Check Valve	● Inert flow path which minimizes turbulence ● No metal components ● No maintenance required ● Lower cost ($59) ● Made of PEEK which is a corrosive resistant material	● Requires additional components which adds to its cost ● Only rated for up to 100 psi
Slim-Line Inline Check Valve w/ 1/16" Ball Cartridge	● Ruby and Sapphire Ball and Seat ● Ultra low internal volume ● Low resistance to flow ● Operates independent	● Expensive - $126.50 (or $168.30 w/ complete assembly) ● Also needs additional check valve for inlet

	of gravity ● Rated for up to 18000 psi	

Table 1. A summary table of the different types of check valves found.

Conclusion:

All these check valve options are for high precision flow chemistry operations and the chosen check valve to use will be reliant on the type of chemistry done. For our choice we want to go with the industry standard Check Valve Inline Non-metallic 1/4 - 28 because the PEEK material makes this excellent in terms of chemical resistance and its higher pressure rating of 2000 psi allows for use in chemical reactions which require high temperatures and pressure. Also, another reason for choosing this check valve specifically is that it is compatible with the tubing connectors and joint components, most of which are also made out of PEEK.

Summary:

Keywords - Check valve 1/16” tubing, High-performance liquid chromatography (HPLC) check valve, PEEK inline check valve

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4. Stepper Motors

Project Description

The sponsor project that my team is doing is a Chemistry Flow system. It focused on modernizing the synthesis of chemicals and reactants. This is done with micro tubing and syringes deposit the chemicals through these tubings.

Introduction and Functional Requirement

Component - Stepper Motor

The system works with a stepped motor that is connected to a threaded rod. As the motor rotates the rod screws through the mount attached to the syringe pushing the syringe down. The rate at which the stepper motor rotates and the torque it exerts determines the flow rate at which the chemicals are deposited.

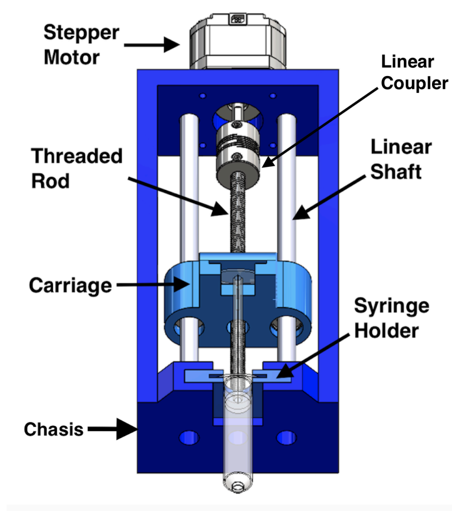

Fig 1. Chemistry Flow system

In figure 1, it is the complete assembly of the flow system and the stepper motor is labelled at the top of the system. I will be further analyzing the stepper motors that can be used for this function and doing research on the required outputs for the system.

Main Requirement

- The optimal stepper motor would be one that would provide maximum torque.

Component Description and Analysis

A stepper motor is a brushless, synchronous electric motor that converts digital pulses into mechanical shaft rotation.

There are **three** main types of stepper motors.

- Permanent magnetic Stepper
- Variable Reluctance Stepper
- Hybrid Synchronous Stepper

Operating Modes of Stepper Motors

Stepper motors have three operating modes, the Full Step, Half Step and the Micro Step. The full step takes 200 steps and has an angle of 1.8 degrees, the half step has 400 steps and a 0.9 degree step angle and the micro step has 51,200 distinctive steps and has an angle of 0.007 degrees.

Summary Table

Type of Stepper Motor	Resolution Angle	Torque
P.M Stepper	Low	Low
V.R Stepper	High	Low
Hybrid Stepper	High	High

From this table we can conclude that the optimal stepper motor to be used would be a Hybrid Stepper motor. However further research would determine whether it is the most cost effective and sustainable choice.

Operation Mode of the Stepper Motor	**Torque and resolution output summary**
Full Step	Exists in two models namely Single and Dual. Single phase provides less torque and control and is good as replacement use whereas Dual phase provides good torque however uses more power.
Half Step	Alternates single and dual phase operation. Compared with the full step drive, the motor's step angle resolution is doubled, and the motor runs more smoothly and quietly.
Micro Step	The microsteps are produced by proportioning the current in the two windings according to sine and cosine functions. This mode is only used where smoother motion or more resolution is required.

Conclusion

From these tables we can tentatively conclude that the most optimal stepper motor for the risk reduction and testing stage would be to use the Hybrid Motor ran on a Full step with a dual phase setup. However as it uses more power and is not the smoothest option, the Hybrid stepper motor ran on a Half step operating mode would be the most efficient step as the motor would run more smoothly with the resolution angles and also provide sufficient torque inorder to push the syringes at the respective flow rates requires.

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