Mechanical and Aerospace Engineering
650:468 – Design and Manufacturing II
650:488 – Aerospace Design II
Spring 2023

FINAL DESIGN REPORT

for

DISPENSING PUMP SPONSORED BY COLGATE-PALMOLIVE

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EXECUTIVE SUMMARY

Dispensing pumps are used daily for common personal care and beauty products such as toothpaste, soap, and lotion, to name a few. They easily dispense predetermined dosages every time a user applies a force to the pump. The goal of this project is to design and model a dispensing pump that tackles some of the most common issues of using pumps: clogging and runoff. Most pump mechanisms are the same and include similar components such as the body, actuator, closure, gasket, housing, and stem/piston/spring/ball. Our final design looks like a conventional hand pump but has unique features designed to make the user experience better and mitigate clogging and runoff issues. Incorporated into our design is a silicone membrane that is commonly used in condiment bottles, which will create a moisture barrier; ultimately, resolving both the clogging and runoff issues. The design was also inspired by a sink where the product leaves the nozzle through a hole on the underside instead of at the tip of the actuator. This placement creates a better user experience as the product does not shoot out horizontally at the consumer but rather downward toward their hand, surface, etc. Using Solidworks, we were able to draft a model of our pump and use that design in Comsol to test different viscosities, pressure, and many other parameters. After 3D printing our design and tweaking it to fit our needs, we tested the design to gather data that would prove it tackled the issues previously stated. With this design, we used ASTM standards to test and conclude which silicone membrane would be the best fit for our dispenser. We concluded that with consistent pump dosages and a satisfactory spray pattern, the silicone membrane best suited for the soap was the cross (+) design.

PROBLEM STATEMENT

Current dispensing pump designs are not efficient. Oftentimes there are issues with clogging, inconsistent dispensing amounts, cracking and rusting. As stated by Cision Pr Newswire, the dispensing pump market is predicted to reach a value of $12.31 billion by 2023. There has been an increase in demand due to the surge of health and hygiene awareness, making efficient designs a core marketing point. To address the needs of consumers and the recent surge in market demand, the goal of the new dispensing pump is to design a nozzle that can reduce these issues. Based on the problems laid out by Colgate Palmolive, the team is tasked to research the cause of these issues and design a solution.

The motivation behind this project is to develop a new dispensing pump that is not only more efficient but increases user friendliness. Consumers purchase products from companies like Colgate Palmolive because they want household essentials such as soap, toothpaste and lotions. Ideally the dispensing mechanism should complement the product, but many do not and reduce the user friendliness over time. For instance, lotion bottles often clog up after a few months of use because the nozzle is filled with hardened product, and the user ends up having to find other ways to get the lotion out. This takes away the ease of use from the product. Therefore, using current Colgate dispensing bottles as a guideline, a prototype that can address these issues will be developed.

Using other industries such as food and pharmaceutical for inspiration, the idea of implementing a silicone membrane is incorporated to reduce clogging as a result of drying and oxidation of the product. Similar to the Heinz ketchup bottle dispensing membrane, the new nozzle design will blend the basic dispensing pump with a membrane that can tackle the issue of product exposure to air. This issue is seen across a multitude of products in different industries so blending different solutions together with the team's ideas will generate a product that can address the prolonged difficulties and issues that consumers face. All in all, over the course of two semesters, the team will design and develop an improved dispensing pump that can address issues such as clogging, inconsistent dispensing amounts, cracking and rusting.

1. CONCEPTUAL DESIGN

The design aims to tackle the issue of clogging and leaking in the current dispensing pump, and one of the engineering goals is to address this problem. To solve the problem, the output profile of the dispense pump was modified to point downward, and a silicone membrane with a cross-pattern incision at the center was introduced. This membrane not only prevents liquids from leaking and clogging but also controls the stringiness effect. Additionally, the design takes sustainability into consideration, and therefore, the selection of silicone material was done with great care.

To complete the project, several measures were taken. Firstly, the problem statement was reviewed, and we searched for solutions in existing patents in the pharmaceutical industry, such as dispensers with anti-clogging closure caps, reversing trap container closures, and other related approaches. Concurrently, the team began drafting design concepts that could overcome the shortcomings of current pump designs. A CAD design model was created with two components: a nozzle and a screw cap, which were 3D printed on a standard printer. To fine-tune the pump design, standard silicone sheets with various thicknesses and slit patterns were tested. The selected silicone membrane had a thickness of 1/32 inches, which was observed to effectively address the design goal of preventing stringiness, leaking, and clogging. The testing results will be discussed in detail in the later part of this report.

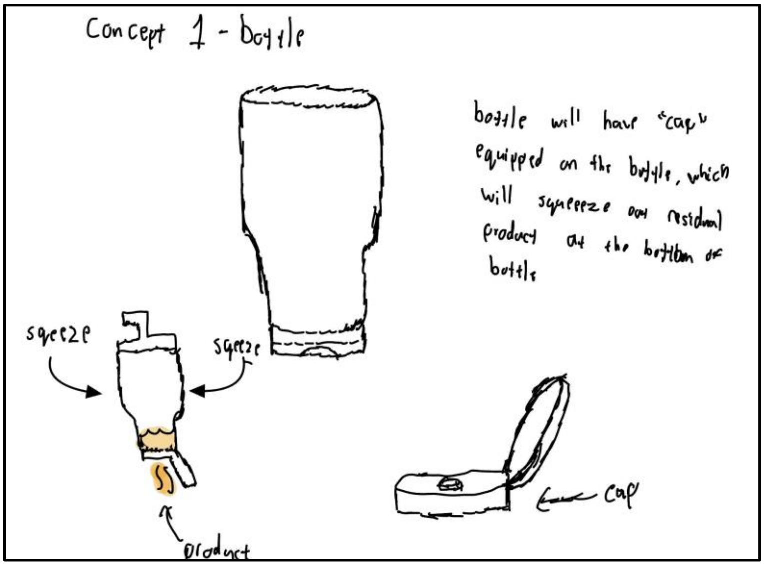


Figure 1 - Closure Cap Dispenser

Initially, we considered a design concept where the actuator was located at the top of the pump, and a cap was used to protect the dispensing mechanism between applications (as shown in figure 1). This design was intended to prevent clogging or drying of the dispensing nozzle, as the cap would provide a seal between actuations. However, this approach had certain drawbacks. It altered the existing ergonomics that average consumers were accustomed to when dispensing a solution, such as soap. Additionally, this design violated manufacturing standards, as it was not standardized, which would significantly increase the manufacturing cost.

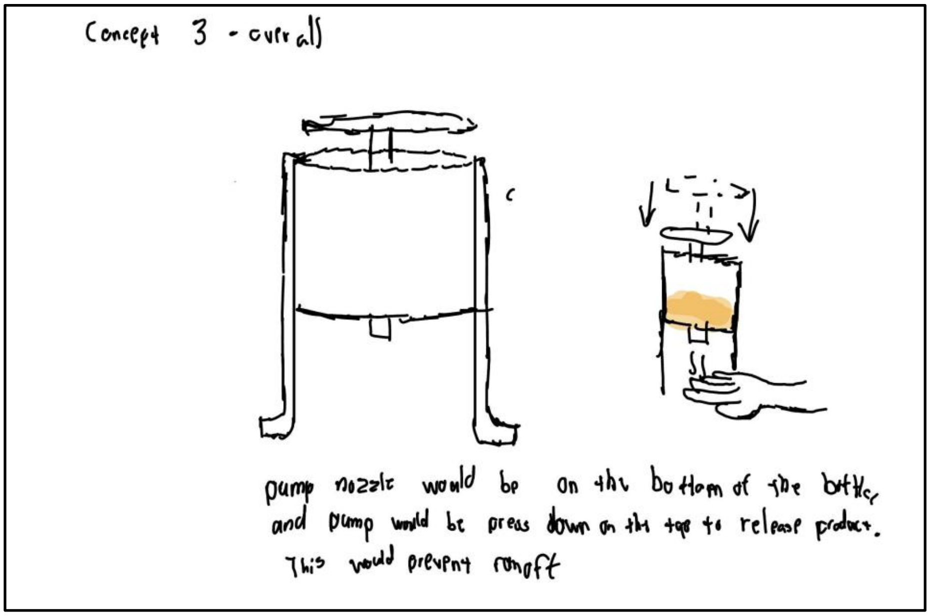


Figure 2 - Dispenser with Pedestal

The proposed pump design concept (as depicted in figure 2) featured a piston pump that did not require a tube. This design had the advantage of leaving no residual substance in the container after use, and it was ergonomically designed such that it only required one hand to actuate while the other hand could be kept underneath. However, a drawback of this pump design was that its manufacturing was not standardized, leading to an increase in the product cost.

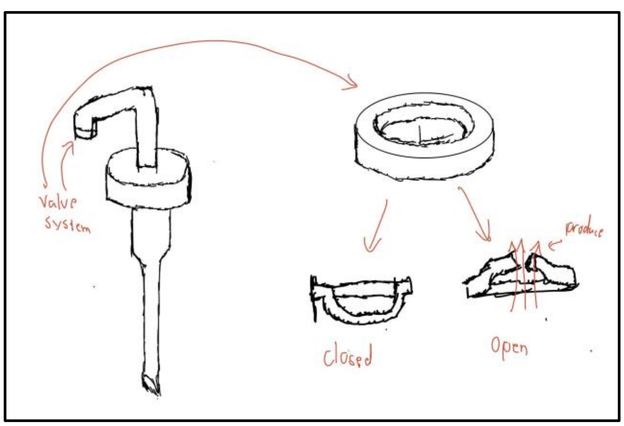


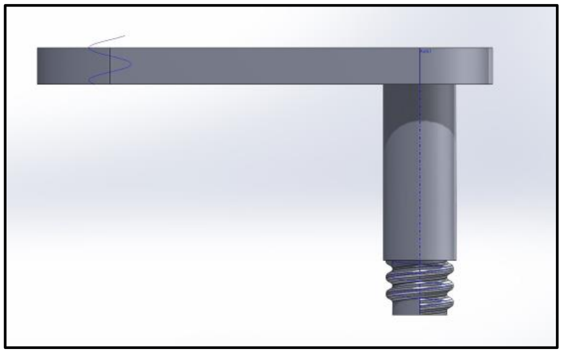
Figure 3 - Dispenser Pump with Introduced Silicone Membrane

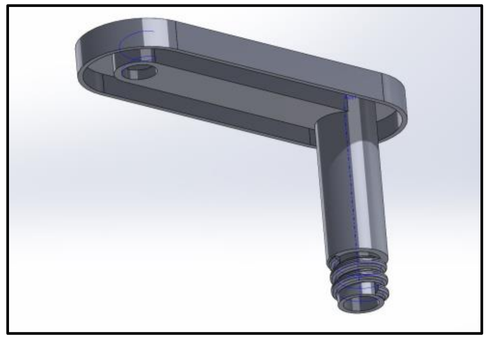
During our meeting with Mr. Simonovic, he recommended exploring solutions from other industries. Following his suggestion, we looked into a food industry solution that involved Aptar, a packaging manufacturing company, introducing a silicone membrane to address leakage issues (as shown in figure 3). We subsequently decided to enhance and incorporate a silicone membrane into our dispenser pump design, which we believed would resolve both the leakage and clogging issues. The membrane would close automatically after the substance had been dispensed. We considered various approaches to adapt the membrane, but Mr. Simonovic proposed a simple opening at the bottom of the dispenser nozzle and the introduction of a silicone film with slits, which would accomplish the same goal (Simonovic, 2022). The advantages of this pump design are that it does not disrupt the standard manufacturing process, does not increase the cost, and adheres to what the average consumer is accustomed to. Additionally, based on the testing conducted, it has preliminarily addressed the problem statement we were tasked with.

2. DETAILED DESIGN AND ANALYSIS

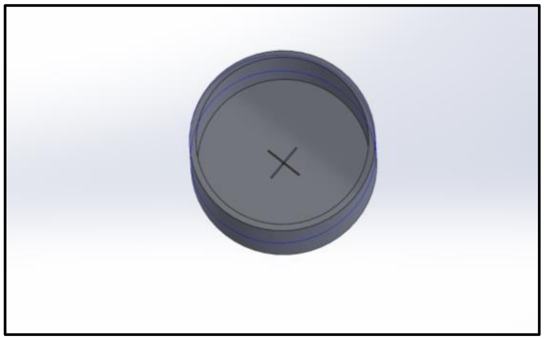
Design:

Figures 4 and 5 - Dispense Pump Head:





Figures 6 and 7 - Silicone Membrane Cap:



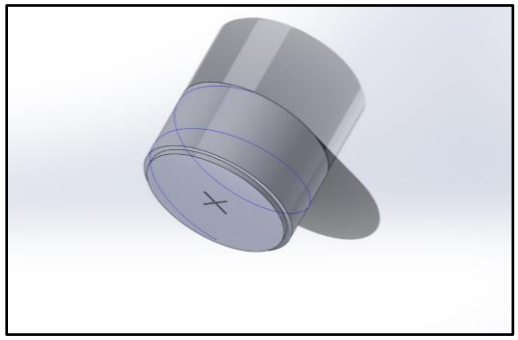
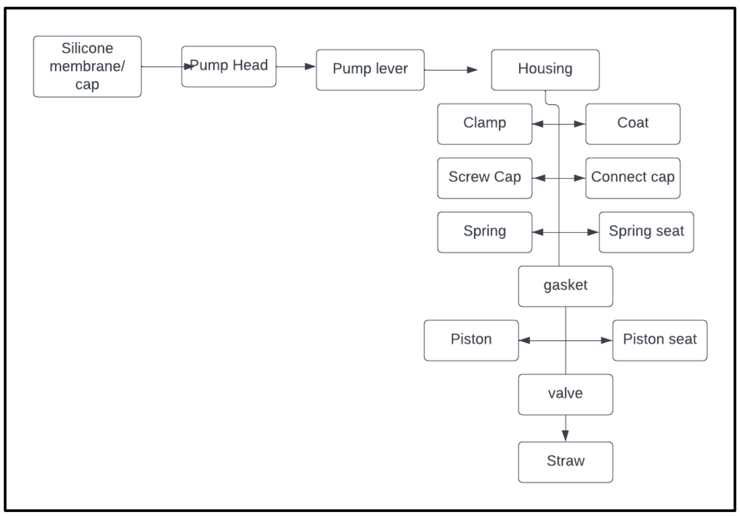


Figure 8 - Prototype Pump Design:
(shown to indicate container shape)

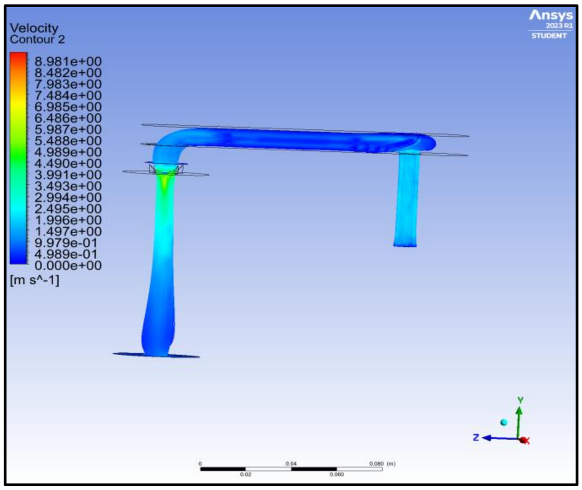
Figure 9- Pump Subsystem flow chart:



The subsystems include the pump mechanism, pump head and nozzle, and container. The components list of the aforementioned are; the pump head, silicone membrane, pump lever, clamp, gasket, piston, piston seat, straw, spring,coat, and housing. The pump mechanism dispenses product from the container up and into the sprout of the pump nozzle. The pump nozzle is the profile that the dispense pump flows through and out of. The silicone membrane attached to the pump nozzle hole will allow the dispense product to be released out and will suck back in the product that did not flow out during the dispense. The silicone membrane does a good job of limiting oxygen that hardens the product solution overtime and therefore causes clogging. As depicted in the CAD drawings, the pump head is flat with a hole underneath that will direct the flow of product downward. The CAD is still in the process of design. The housing for the pump is being redesigned. The housing contains the clamp, coat, screw cap, connect cap, spring pieces, gasket, piston pieces, valve and straw. In the CAD, it is shown that there are blue helix profiles on the membrane cap and pump hole. These helix profiles will be swept to make the silicone membrane cap screw into the pump hole. The way the dispense pump works is that after a consumer applies pressure to the pump head (by pushing the pump head downward), product in the container (housing) will be dispensed up and into the valve, where the product is then released into the dispense pump nozzle. The profile of the nozzle will cause the product to dispense down vertically. The silicone membrane cap attached to the pump head hole will allow the product to release out. Product that was not released completely would vacuum back in.

As previously mentioned, our defined objective for our project is to tackle Colgate-Palmolive's consumer issues for dispensing pump products, such as soap and lotion, which experience clogging, rusting, and inconsistent product pumped out that occurs after weeks of normal use of the company's product. Our solution to this problem is to; first, change the profile of the dispense pump nozzle to have an opening at the bottom instead of on the top and on the actuator so therefore the product is dispensed downward (direction perpendicular to the surface pump is on) instead of outward (direction parallel to the surface that the pump is on); second, to shorten the length of the dispense pump nozzle from the original design because it will work best with minimizing product that remains on the silicone membrane after dispense; and third and most importantly, to add silicone membrane to the nozzle opening. The way the design incorporates these changes are also important. To ensure testing could be as smooth as possible, a screw on "cap" or "ring" design is used to make it easy to replace the silicone membrane samples of different thicknesses against products with varying viscosities. To further elaborate, the hole where the product is released from in the pump will have a detachable cap that alternates different silicone samples.

Analysis



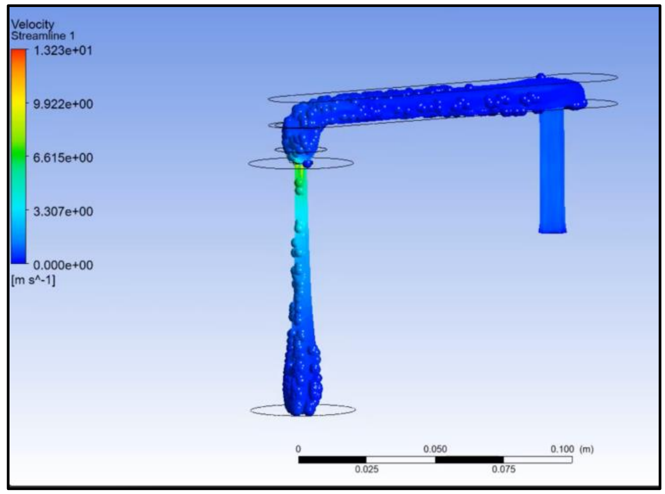


Figure 10: Velocity Streamline
Figure 11: Velocity Contour

Engineering analysis used in this design are the simulation software, Ansys, for theoretical testing, and real world testing with current Colgate pump designs in comparison to the redesign pump prototype. Changes from our first design concept to our current design were based on our conducted research on industry innovations that could be applied to improve our dispense pump. Simulation analysis was not used to influence our pump in the early stages of design modification. Material properties of polypropylene plastic and silicone, and fluid properties of water and fluids of more viscous properties are used to conduct analysis of the effect of the fluid on the pump. The simulation results for the redesigned pump, using a more viscous fluid than soap and a partially opened silicone membrane, exhibited promising outcomes. These assumptions were based on the current knowledge limitations of the simulation software. We observed the surface velocity and contour pressure changes as the fluid goes from the inside container to the pump nozzle. The simulation demonstrated that there was no apparent stringiness left between actuations when the pump was activated, and the fluid flowed along the flow path. However, the simulation is an ongoing process, and further models will be developed to analyze the performance of the redesigned pump when the silicone membrane is closed and different slit patterns and fluid parameters are introduced.

When we updated our design, we first made sure to scale the pump head big enough so that the silicone membrane cap test section would be an adequate scale to work smoothly with. We cut circles of silicone and made varying slit combinations to test which would work best with our pump head design. When performing testing on our design we used a food scale with measurement precision of 1 gram and 0.01 grams to measure the consistency of the product pumped. We altered our slit designs based on results we analyzed from our measurements. From testing we found that the cross slit produced the best dispense pattern and had the most efficiency for each dosage dispensed.

3. MANUFACTURING PROCESSES

The manufacturability and the consideration of materials that would make up our components was a crucial aspect of our overall design process this semester. The first step that we took in understanding what parts we wanted to incorporate as part of our design was to first understand what current part of the design process. During our visit with Barbara Porter at the Colgate-Palmolive facility in Piscataway, NJ, we were educated on the material specifications as well as the different pumps that they use. Specifically, Colgate-Palmolive uses mostly Polypropylene plastic within their atmospheric pumps. Other materials that are included are the stainless steel that the spring is composed of, as well as the valve check that is composed of glass. In different atmospheric pump variations, there may be additional plastics that are incorporated into the bottle/pump system.

One of the issues expressed by our sponsor Colgate-Palmolive involved sustainability. With the variety of materials that make up the dispensing pump system, some of which need to be separated from each other. The reason being is so that they could be properly recycled and reduce the environmental impact of each pump. Unfortunately, due to the way the pump is constructed and the behavior of consumers, the pump and bottle when thrown into an individual’s recycling bin cannot actually be recycled together. This leads to more of these bottles not being processed and thrown out in landfills, having an overall negative effect on the environment. We hope to tackle this issue through the use of only one particular plastic, which will reduce the overall carbon footprint of our product.

Another component that ties into the manufacturability of our design was the incorporation of the silicon membrane and valve component. When speaking to Mr. Milan during our manufacturability meeting, he spoke about finding a way to test the valve as a proof of concept to see if our design functions properly and pivot if needed. This allowed us to come up with the idea of scaling up our model by some portion. This in turn will make it easier for alterations to be made to the silicon membrane (i.e. number of slits, dimension of slits, slit geometry). Also, to aid in our testing, we plan on having each different “rings" that will each contain different membranes inside. These rings can be screwed on the exit of our actuator, and this will help with only needing to manufacture one pump system for testing instead of multiple pumps.

As you can see, taking into account the manufacturability of our product has had an impact on the final design we have. As stated previously, the implementation of the silicon membrane component drove our design from being “curved” to “flat”. Also, this made us take into account how the membrane would be attached. We opted to secure it by screwing it on as opposed to snapping it on. If we went with the latter, we predicted that the force/pressure on the valves as the product is being forced out may cause it to pop off. For further reference, the budget and parts list can be found in Appendix C.

4. TESTING

For testing, we used ASTM Standard D4336-18 : *Standard Practice for Determination of the Output Per Stroke of a Mechanical Pump Dispenser.* Standard D4336-18 covers the measurement of the mean quantity-by-weight of liquids dispensed from a mechanical pump dispenser with a consumer-type product on each actuation. This practice can be used to compare the output per stroke of different pump dispensers for the purpose of establishing dosage and use instructions for products of consumer usage. This is also suitable for establishing specifications for both the pump dispenser and the final package. To test our new design, we conducted eight rounds of testing. We tested the original Soft Soap dispenser provided by Colgate, our new design with the 6 different silicone membrane slit designs and our design without any silicone membrane. Below one can see the different silicone inserts we used for the test:

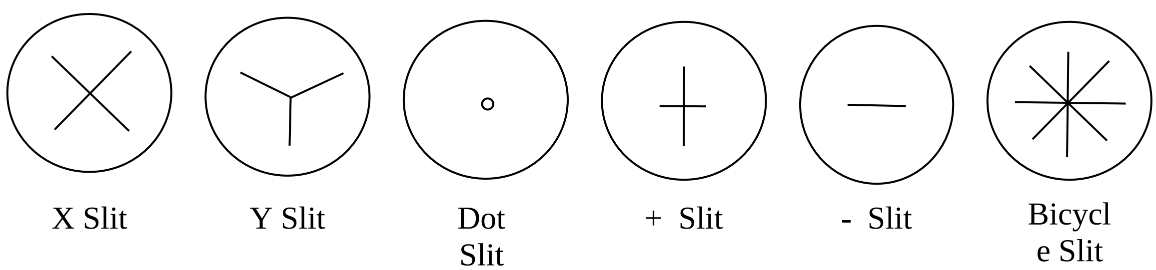
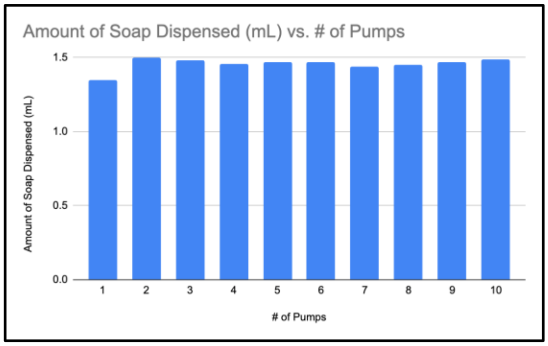


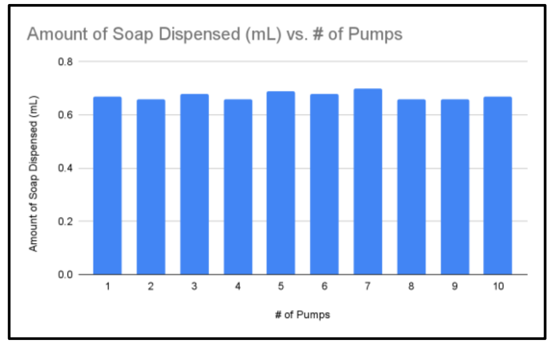
Figure 12- Silicone Slit Patterns

First, we selected an appropriate number of pump dispensers (8) at random for the precision and accuracy desired. Then for each round we filled the container with soap to 221 mL and secured the mechanical pump dispenser to the container. Then the pump dispenser was primed by actuating it until a full discharge of product occurred. Next for all eight rounds of resting, we actuated the pump dispenser ten times by hand and used a food scale to record the amount dispensed. The graphs below provide a visualization of how each design performed:

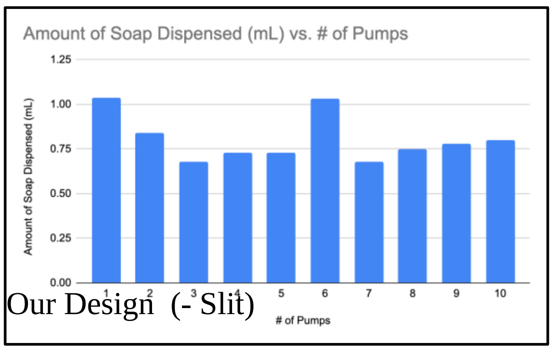
Original Soft Soap Dispenser:



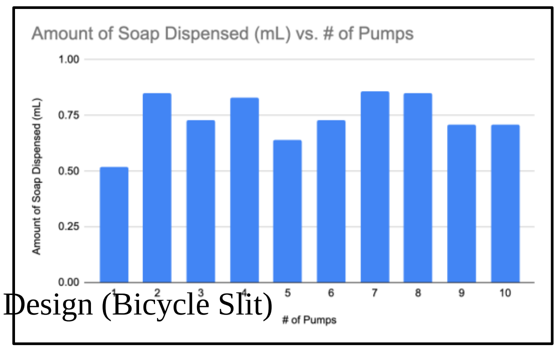
Our Design (+ Slit)



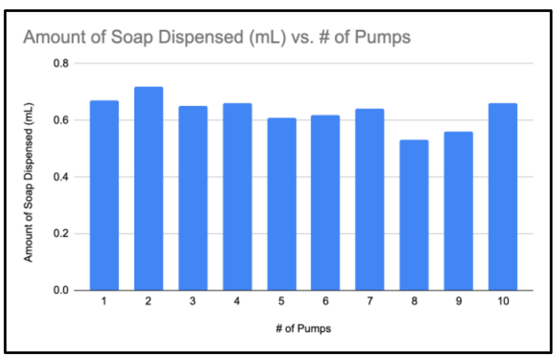
Our Design (Dot Slit)



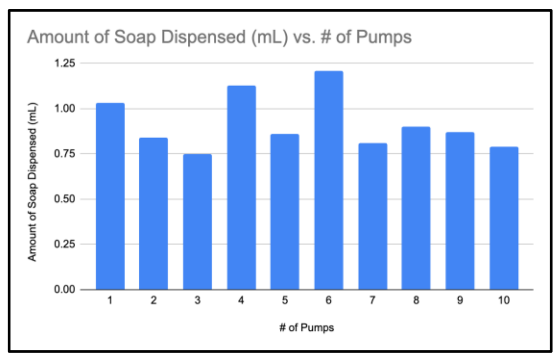
Our Design (X Slit)



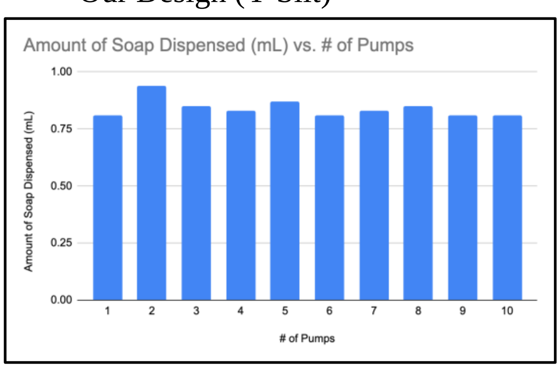
Our Design (- Slit)



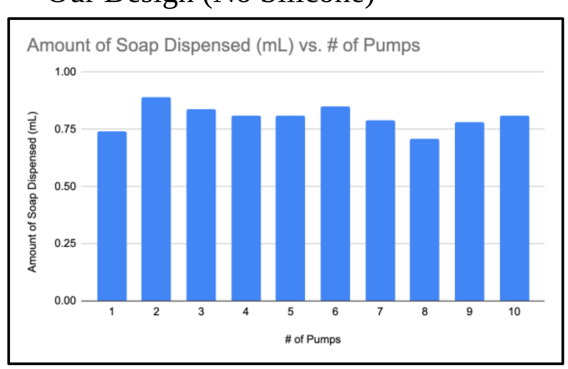
Our Design (Bicycle Slit)



Our Design (Y Slit)



Our Design (No Silicone)



As shown by the graphs above, the silicone slit that performed the most consistently was the cross (+) design. It dispensed an average of .673 mL of soap, the most being 0.70 mL and the least being 0.66 mL. The original Soft Soap design dispensed an average of 1.458 mL, the most being 1.50 mL and the least being 1.35 mL. While the original design dispensed about two times as much product as our design, both of them performed about the same in terms of consistency. However, a big difference that we did see while testing was the amount of stringiness between the two designs. The Soft Soap design had a lot of stringiness in between pumps while our team's design did not see much. Two major issues we wanted to solve were consistency and stringiness and through testing we believe our new design addresses these concerns. The silicone membrane reduces the amount of stringiness as anticipated and serves as a barrier to lessen the amount of oxidation and thus clogging. If the amount of soap needed to be dispensed has to be increased, it can be very easily solved by adjusting the dimensions of the slit.

Another testing standard we utilized is ASTM Standard D4041/D4041M: *Standard Practice for Determining Spray Patterns of Mechanical Pumps Dispensers*. This practice covers the determination of spray patterns of a mechanical pump dispenser. Standard D4041/D4041M was used to compare spray patterns of pumps with different actuators and liquids of varying viscosities. Essentially the spray pattern of each slit design, as described before, was compared to each other and to that of the Soft Soap pump. This practice helped us determine which liquid would be best suitable for the design of our pump and which silicone design worked the best.

To test we attached the pump head to a bottle with test liquid. We then secured a sheet of test paper to the table and primed the pump until a full pump load was obtained. We chose a spot on the table to place the pump (it was the same spot for each test). We then pumped once fully onto the test paper. We removed the paper and put it to the side to dry flat. If the spray pump was irregular, we would conduct the experiment again. We repeated this for the Soft Soap dispenser, our design with the 6 different silicone membrane slit designs and our design without any silicone membrane. Below are the spray patterns and measurements of the spray patterns diameter:

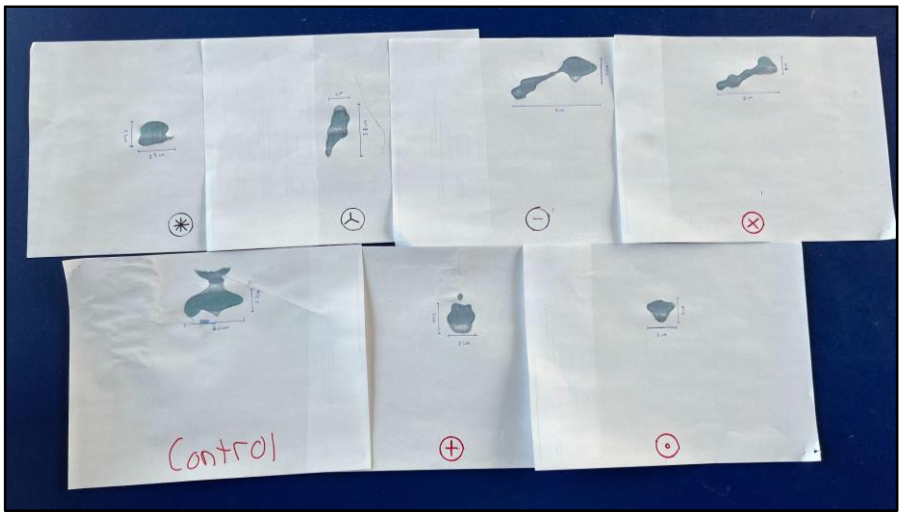


Figure 13- Spray Patterns

Analyzing the spray patterns, it can be seen that they are all different and represent how a user could receive the product once pumped. To ensure a good user experience, we chose a silicone membrane that not only dispensed a consistent dosage as previously stated in ASTM Standard D4336-18, but also had an acceptable spray pattern. In this case, we chose to base what would be deemed acceptable off of the control pump spray pattern. The spray pattern had a length of 5.6 cm and a width of 2.3 cm and using those measurements as bounds we were able to conclude that the best silicone design was the cross (+) slit with a length of 2 cm and a width of 3 cm.

5. CONCLUSION

Our innovative dispensing pump design comes with a new way of dispensing liquids. Instead of pumping through a nozzle we have created a pump that points downward. We have also added a piece of a silicone sheet where the liquids will be dispensed in order to eliminate clogging by reducing the amount of air that can dry up whatever liquid is being dispensed. Through our testing we tried out different patterns that we cut into the silicon. In total there were six silicon cut designs, those being an X, Cross, Dot, Minus, Y, and Bicycle slit designs. We loaded each of those silicone designs into the pump and tested to spray patterns to see which one would be the most user friendly. In the end we chose the cross as it provided a consistent spray pattern and was very similar to our colgate provided pumps. We then tested the output of the product to see how it compared to the colgate pumps. Again that cross was very consistent with the amount of product that it output. Although it wasn’t as much as the colgate pumps it was still enough to provide an adequate user experience and have some factor when it comes to sustainability as less product being used per interaction will allow bottles to be thrown away later than usual. In addition, if dosage needed to match Colgate, the fix to this would be to increase the holding chamber. Dosage held in housing would need to be bigger in order to dispense higher dosage. With our design we have the intention of having it be detachable as well as being able to remove the silicon piece and switch it out for a new one similar to how you only switch out the toothbrush head from an electric toothbrush. This was done in hopes of having users throw away bottles less frequently and only needing to replace the piece that is most likely to experience the issue. With a detachable design it’ll allow Colgate to make the pump head and silicon chamber to be manufactured with recyclable material to better assist with sustainability and being environmentally friendly. Our prototype is fully functioning using the assistance of a 3D printer, all that is necessary is to tweak some of the dimensions in order for the product to look more streamline. Our product has reached his goal of eliminating clogging, stringiness, and has plans to improve sustainability, and being environmentally friendly.

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Standard practice for determining spray patterns of mechanical pump dispensers. ASTM. (2017). Retrieved April 12, 2023, from https://www.astm.org/d4041_d4041m-05r17.html

Appendix A. PROJECT MANAGEMENT

At the beginning of the semester, our group planned how we should structure our deliverables. With the help of a Gantt chart, we were able to visualize our progress. Each week we would meet up to assign roles. In Figure A.1, we have our tasks for what we are calling Phase I and II of our project. The gray bars indicate the tasks that have been accomplished while the purple sections represent how much more progress needs to be made.

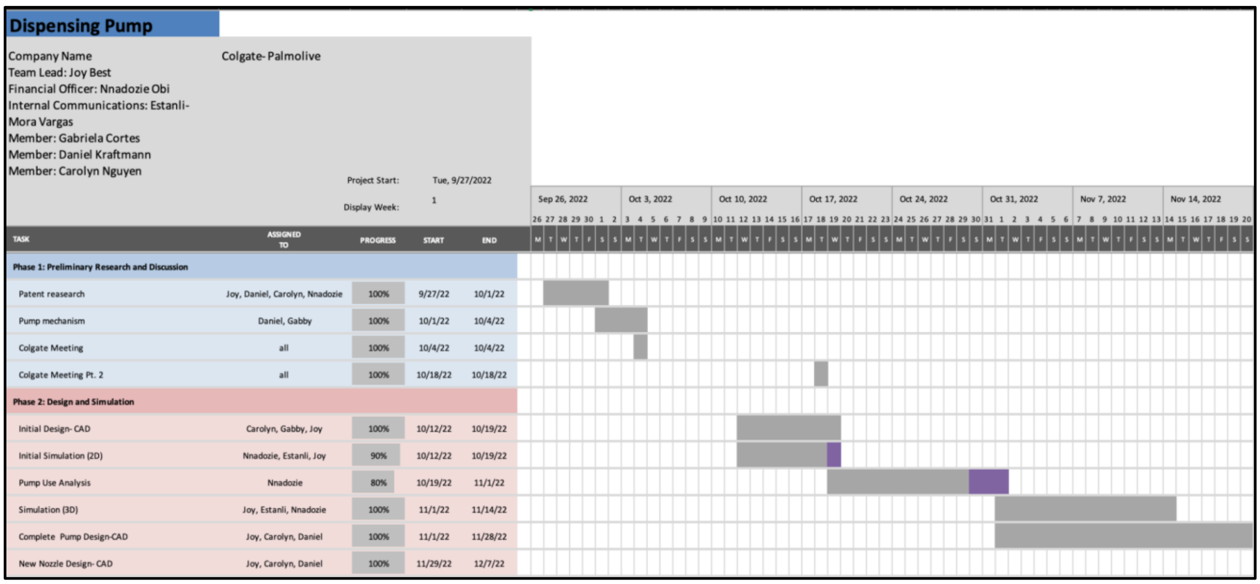

Figure A.1- Gantt Chart for Fall 2022

Phase I was our preliminary research and discussion phase where we had focused on doing research on pump patents and designs, different pump mechanisms, materials, and meeting with our sponsor, Colgate- Palmolive. During this phase we were able to find a silicone membrane used in the food industry- this was a critical point in our design process. Our only issue now was figuring out how we would physically incorporate it into our design. We attempted to contact Aptar, the company who produced the membrane, but had no luck. At this point we needed to do more research to fully incorporate the membrane to our initial design. This led us into phase II.

Phase II consisted of our pump design and simulation. Using Solidworks and Comsol we made initial designs and simulations. Our first design was a standard pump with the nozzle end pointing down. We still were unsure how to incorporate the membrane but after getting some input from our design specialist, Milan, we decided to do a redesign of the actuator. A trouble area we faced in this phase was our 3D simulation. From previous experience, we knew creating a 2D simulation would be easier and still help us achieve results. We then wanted to translate the same properties into a 3D simulation but ran into many errors that we could not troubleshoot. After struggling, we contacted a COMSOL specialist who was able to help us finalize a simulation for our design. Our simulation results were introduced in our report and on our final poster.

For the spring semester, Figure A.2 gives a detailed view of our progress leading up to this report and our final presentation being held on May 4th 2023.

Figure A.2- Gantt Chart for Spring 2023

Phase III began with printing our 3D model and continuing to tweak it until we were satisfied with the size and functionality of our product. Carolyn did the 3D printing and relayed any information to the rest of the group on how the design could be improved. Gabriela would tweak the CAD model to fix any issues we encountered during testing. Baseline testing was conducted by Joy, Gabriela, Estanli, Carolyn and Daniel where we used two standards to test for dosage dispensed and spray patterns. After running some tests, we encountered some issues with inconsistent results due to poor measuring tools. We reassessed and bought the proper tools to test. This led us to Phase IV: Fine Tuning and Showcase Preparation. During this phase, we did some final testing with the new measuring tools and began to prepare for the final showcase of our product. We finished our poster, recorded our promotional video, and wrote this final report. In the next coming days, our group will meet to prepare for our final presentation that will take place on May 4th 2023.

Appendix B. PARTS LIST & BUDGET

The project was funded by the Rutgers MAE Department as well as Colgate-Palmolive. Rutgers MAE Department provided the group with $650. Colgate Palmolive did not disclose the budget, but the project was able to be developed with the Rutgers MAE funding. The team also manufactured the product in house using the Makerspace so there was no additional cost to 3D print besides the material.

Vendor	Part Name/Description	Part ASIN/ Part Number	Quantity	Unit Price	Total Price
Amazon	Official 3D Printer Creality Ender 3 v2 Neo New Upgrade Version with CR-touch Auto Leveling 95% Pre-Installed Resume	B08FSTRZML	1	317.00	317.00

	Printing and Metal Extruder New Touch Screen 3 steps to assemble,220×220×250 mm				
	HATCHBOX 1.75mm Silver PLA 3D Printer Filament, 1 KG Spool, Dimensional Accuracy +/- 0.03 mm, 3D Printing Filament	B00MEZEEJ2	1	24.99	24.99
Amazon	HATCHBOX 1.75mm White PLA 3D Printer Filament, 1 KG Spool, Dimensional Accuracy +/- 0.03 mm, 3D Printing Filament	B00MEZEEJ2	2	24.99	49.98
Amazon	MATNIKS Food Grade Silicone Rubber Sheet 12x12-inch by 1/8 White - Duro Shore A65 High Temperature Heavy Duty for Gaskets DIY Food Covers Lids Sealing Material Supports Microwave Oven Protection	B088RMF99J	1	17.45	17.45
Amazon	Silicone Rubber Sheet, 50A 1/16 x 9 x 12", Food Grade, Made in the USA, No Adhesive Backing, High Temp Material for Gaskets Covers Lids Sealing	B08DDFQ9YM	1	11.99	11.99
Amazon	Silicone Rubber Sheet, 50A Durometer, 1/32 (.032) inch Thick x 9 x 12 (.8mm x 230mm x 305mm)Smooth Finish, No Adhesive Backing, Made in The USA	B0931SP1QT	1	11.99	11.99

Table B.1: Parts list and spending activities

Appendix C. DRAWINGS/ SIMULATION/CODES/DATA/DIAGRAMS

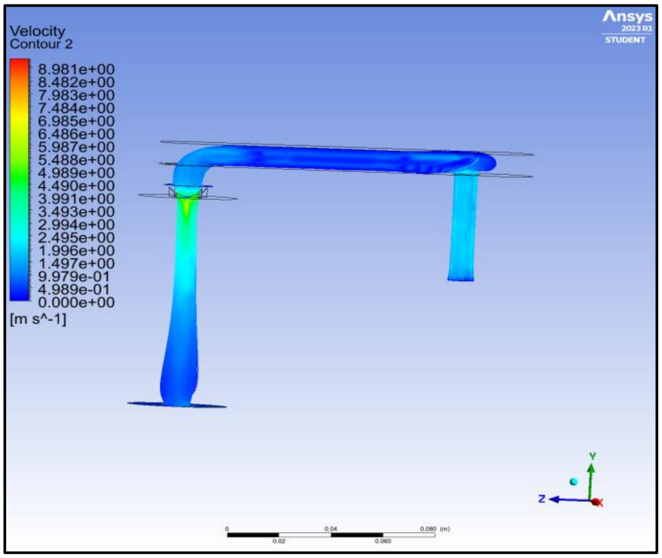

Figure C.1 Velocity Contour Plot

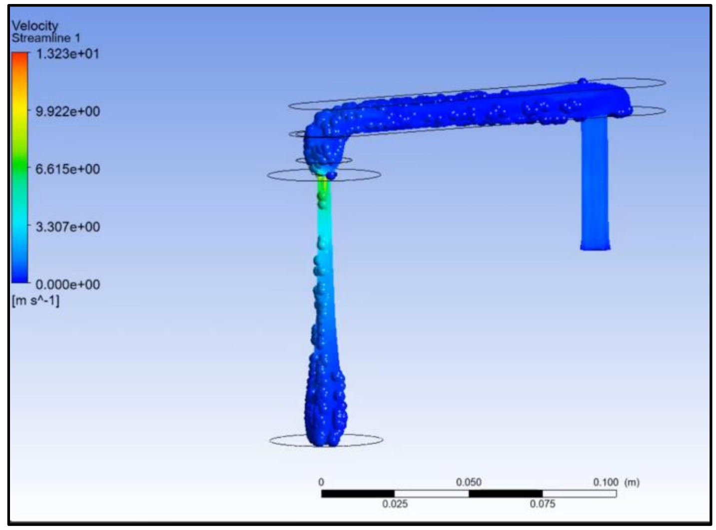

Figure C.2 Velocity Streamline

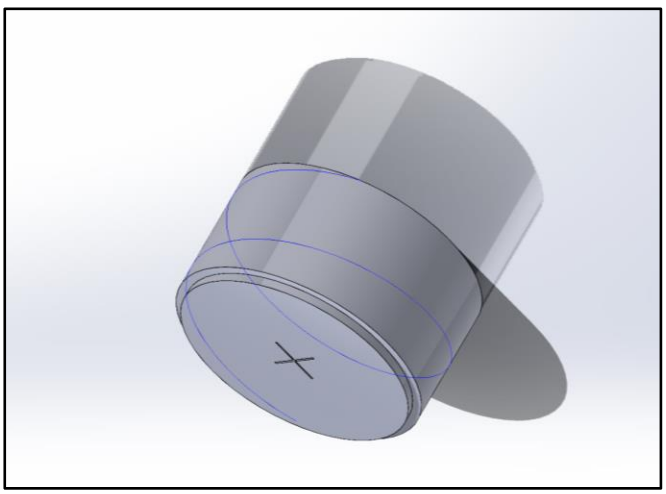

Figure C.3 Silicone Membrane

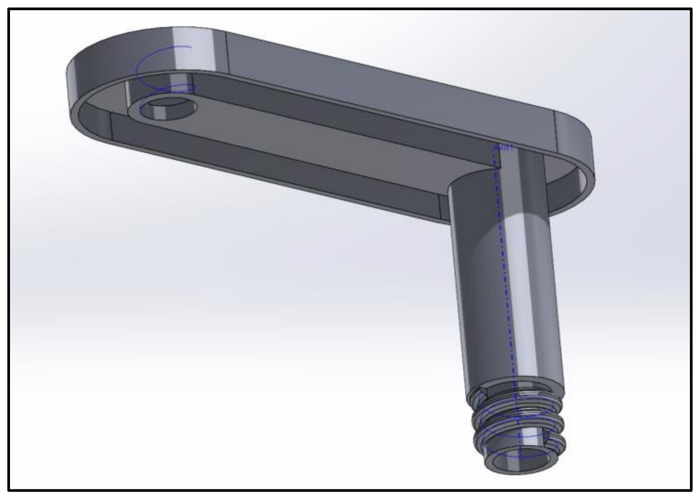

Figure C.4 Nozzle Design