NORTHERN ARIZONA UNIVERSITY

To: W.L. Gore & Associates, Inc.

From: Northern Arizona University Capstone Engineering Team

Subject: Portable Sanitization Chamber Project Proposal

Date: Friday, April 18, 2014

This document contains the final design for the portable sanitization chamber. Using a combined system of hydrogen peroxide and UV lights, several tests were performed and analyzed. From the results of the tests, the design and process of the product could be finalized. The attached document includes all research, concept generations, engineering analysis, and our final design.

The final design fits the cost constraint, including costs for research, materials, prototype, and testing. The total cost of materials for the final design is approximately $1,900, staying below the $3,000 limit.

If you have any questions or comments regarding the final design, costs, or anything contained within this document please contact our team via email.

Thank you.

Portable Sanitization Chamber

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Final Report

Document

Submitted towards partial fulfillment of the requirements for
Mechanical Engineering Design II – Spring 2014

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ABSTRACT

Sterilization and sanitization are very important processes that are used on a daily basis in the medical field. Sterilization of some equipment is not always necessary and equipment such as plastic tackle tool boxes or cleanroom notebooks often need to be cleaned, but cannot withstand the heat or soaking processes of commonly used sterilization technology. Ultraviolet light and hydrogen peroxide dry fogging are two techniques that don't use heat or liquid to sanitize the surface of materials. The ultraviolet light compliments the hydrogen peroxide fog by breaking the chemicals down to oxygen and water, making it safe for the user. This process will only take 10 minutes to complete, which is about as quick as an autoclave. By combining the processes into a chamber that is easily portable by one person, it is easy for a person to sanitize equipment quickly and easily.

1.0 Introduction

The problem in question is assessed in the following sections. Based on information given by the client, the project goal, objectives, constraints, and working environments are developed. Research in the field of interest is conducted and a Quality Function Deployment (QFD) chart is generated.

1.1 Client Introduction

W.L. Gore & Associates need a portable sanitization device that will decrease the bioburden levels of *Bacillus atrophaeus* past a certain threshold. Many devices today are used for sterilization, but that is not always what is needed in the medical field. W.L. Gore is looking for a device that is safe for all users, portable, reduces the level of bioburdens on various instruments and materials, cost efficient, and finishes the process in a certain time limit. This device would mainly be used in the medical field or in certain industries where sanitization is needed on a regular basis. The scope of the project described by W.L. Gore can be found in Appendix A.

1.2 Problem Description

The goal of the project is to develop a portable sanitization process that sanitizes bioburden amounts past acceptable levels. The design, testing, and manufacturing must not exceed $3,000 and the process must be safe to the user and environment under OSHA standards.

1.3 State of the Art Research

The Center for Disease Control released a manual of requirements for disinfection called, '*Guideline for Disinfection and Sterilization in Healthcare Facilities'.* This document covers all bases on how to sterilize different materials and spaces and what safety requirements should be met.

Current processes that can sanitize objects in such ways do exist. The most common of these is an autoclave. An autoclave works very much like a dishwasher. They are enclosed metal boxes that spray scalding hot water and or steam within them. Autoclaves are widely used in environments in which sanitization is needed such as: hospitals, dental offices, tattoo parlors, and operating rooms. Although effective, there are two major fallbacks of using autoclaves. Autoclaves cannot sanitize objects that are sensitive to water or heat. Further, autoclaves can take up to two hours to properly sanitize, which is longer than desired for this project.

Lasers are also used in current sanitization processes. They can kill a variety of harmful bacteria by setting the lasers at different wavelengths. Lasers are so powerful that they are used to sterilize open wounds during surgery. However, lasers are used to sanitize very small areas, and would not be effective at sanitizing objects larger than a few millimeters. Also, the types of lasers used in these situations can be both extremely expensive and dangerous.

The most current and innovative types of sanitization are using ultraviolet light and hydrogen peroxide fogging techniques. An article by Owens at The College of Charleston in South Carolina titled, '*High Dose Ultraviolet C Light Inactivates Spores Bacillus Atrophaeus and Bacillus Anthracis on Non reflective Surfaces'* details the effectiveness of ultraviolet light on the Bacillus spores.

There are a few companies that use hydrogen peroxide fogging to sterilize on small and medium size bases by utilizing smaller machines that sanitize one or two objects at a time and larger tanks that can sanitize entire rooms. This method of sanitization is particularly impressive because it disinfects all exposed surfaces, slides into crevices, and can penetrate some fabrics.

Both methods, ultraviolet light and vaporized hydrogen peroxide, are highly effective at killing bacteria and are currently in use in healthcare facilities. Additionally, these methods can be used on materials that cannot be introduced to water or heat.

The US National Library of Medicine has a number of articles on the effectiveness of a combined UV/H_2O_2 process on Bacillus spores. This special combination acts as a photocatalytic oxidizer and has been shown to inactivate even *Bacillus subtilis* spores, spores that are resistant to either method alone. An article by Braz in the Brazilian Journal of Chemical Engineering titled, '*Inactivation of Bacillus atrophaeus Spores in Healthcare Waste by UV Light Coupled with H_2O_2'* showed very impressive results. Inactivation percentages of 70-95% were found with an exposure time of 5-10 minutes with a UV/1% H_2O_2 solution.

2.0 Problem Formation

Descriptive requirements of the sanitizing device are provided by the W.L. Gore associates which can be broken down into project objectives. These objectives are derived from meetings and documents provided by the client. These objectives will show the main focuses of the project at hand.

Safety of the final design ties into the main focus: decreasing bioburden levels. These levels, along with the allowable exposure of certain substances that are deemed safe, will follow guidelines provided by the Occupational Safety and Health Administration (OSHA). Procedures and regulations for proper safety are quantified in their respective documentation, tabulated in concentration values.

The sanitization process requires an ability to function with a variety of objects and components of mixed materials and geometries. W.L. Gore provides examples of a tackle box (plastic), a notebook (sensitive), and hemostats (medical equipment). These examples emphasize a temperature range for heat sensitive materials and no impact for malleable material. The temperature range can be limited by annealing levels and melting points of materials which must remain below 70°C.

For the final product, the design must prove to be portable enough for the transportation of a single individual. The portability of the device in question can be defined as being able to fit through door frames and tight hallways while remaining under a weight threshold. Therefore, the maximum width shall be less than 3 feet and the maximum height less than 6 feet. Dimensions are estimated by comparing to common door sizes. The overall weight is limited by the average lifting of an individual and the weight limit allowable on free rotating wheels.

The expense of the product design follows the guidelines set by the budget provided. W.L. Gore is allowing a budget of $3,000 for research, presentation, and design prototyping. Estimations in need for research and presentations leave approximately $2,500 for the finalized design. This amount is more than affordable when compared to sterilization systems such as autoclaves, irradiation, and chemical processing.

Medical sanitizing requires a certain ease of use for the individuals running the device. Defining ease of use creates a criterion of characteristics as cycle time, process completion, and electrical comprehension. The cycle time must be kept within sixty minutes as this device will be sanitizing objects under immediate demand. To aid in process completion, the device should automatically end the process once sanitization is complete. All electrical components should be properly installed and allow for power through common wall outlets.

2.1 Working Environment

W.L. Gore will test sample strips with a known amount of *Bacillus atrophaeus* CFUs on the strip. After running the sanitization process, the strips will be analyzed to see how many CFUs are left on the strip. This data will determine if the process was successful or not.

Further testing must be done to ensure that the levels of hydrogen peroxide (H_2O_2) in the air are not above one part per million, in accordance with OSHA regulations. Hydrogen peroxide test strips will be placed one foot from the chamber in various directions and measure the levels of H_2O_2, to ensure user safety.

2.2 Constraints

In order to sanitize various materials with complex geometry, the sanitization chamber should comply with standard door sizes (limitation 3'x3'x6'). The total cycle time cannot exceed 60 minutes and cycle must end automatically. Ethylene oxide cannot be used as the source of the sanitization due to its harmful property to humans. To meet the portable requirement, the sanitization chamber should be transported and operated by one person easily.

2.3 Quality Function Deployment and House of Quality

The customer indicated that three main things were wanted in the product: safety, ease of use, and ability to clean various materials. The client broke down ease of use where they wanted the device to have a short cycle time that ends automatically and that it can be easily transported by one person. Using this criterion, a quality function deployment and house of quality were made. The team met together and rated the importance of each of the customer's wants and rated them on a scale of 1-5, five being the highest priority. The client especially stressed safety and the ability to sanitize the sample materials without damage to them. While the team is in early stages of research and brainstorming on what methods will be used to accomplish the goals of the project, a short list of engineering requirements were developed.

These include:

- Size – The overall dimensions of the product. This must be manageable by one person while also being able to easily fit through standard doors. This is the cross sectional area.

- Weight – The weight of the device. This could lead to lower portability or higher cost.
- Cost to produce – Prototyping needs to fit within budget. It should be noted that W.L. Gore is known for not compromising a product due to cost.
- OSHA standards – Standards set by the Occupational Safety and Health Administration. The device needs to meet the standards that apply to the design and process.
- Low operating temperature – This is required to be able to sanitize various materials which includes a polymer that has relatively low melting temperature.
- Cycle time – Client requested a low cycle time. The team noted that autoclaves can sterilize in 15-20 minutes and is looking for a similar time.
- Power source – This will become more important depending on the sanitization process chosen but the device will need a safe and reliable power source.
- Bioburden reduction – The main purpose of the device to reduce the bioburdens on the provided samples. This will be tested using a known amount of bioburdens and testing to see how much is left after one cycle.

The generated QFD matrix and House of Quality are shown below in Tables 2.1 and 2.2.

Table 2.1: QFD Matrix

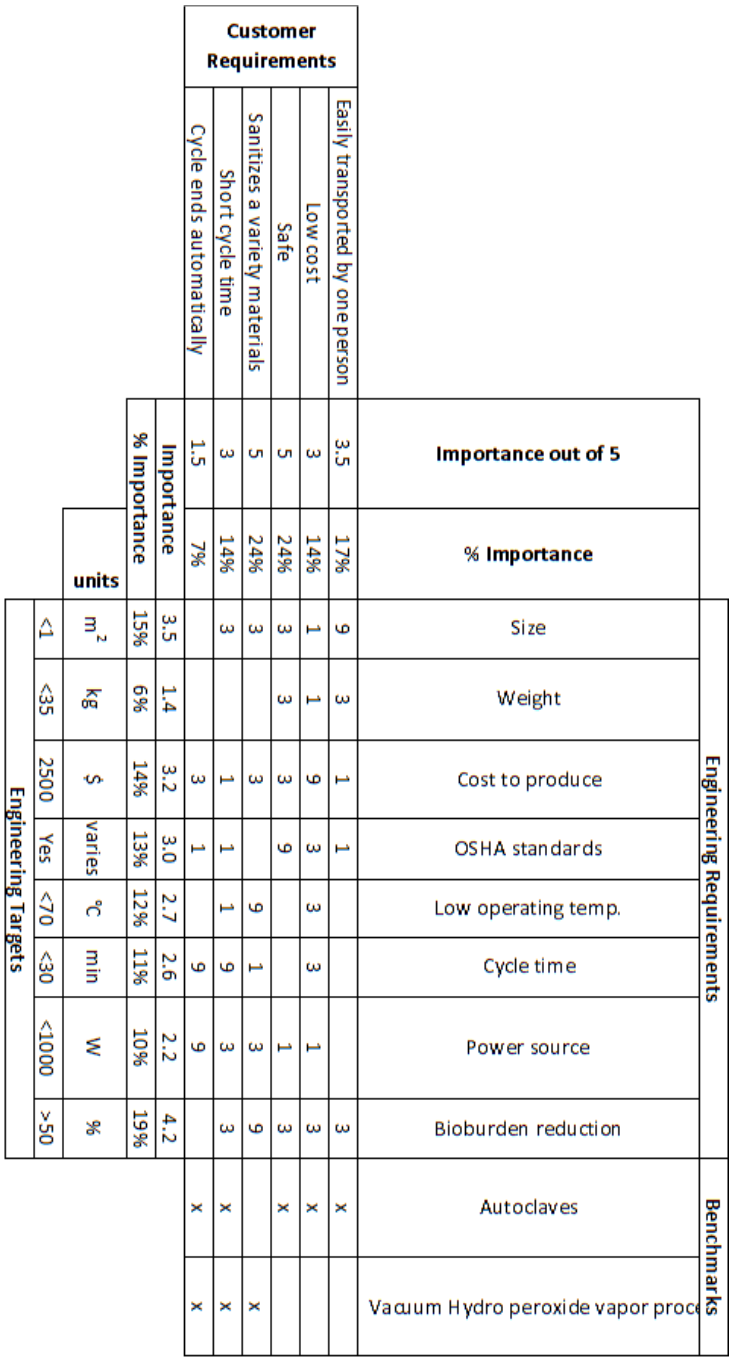
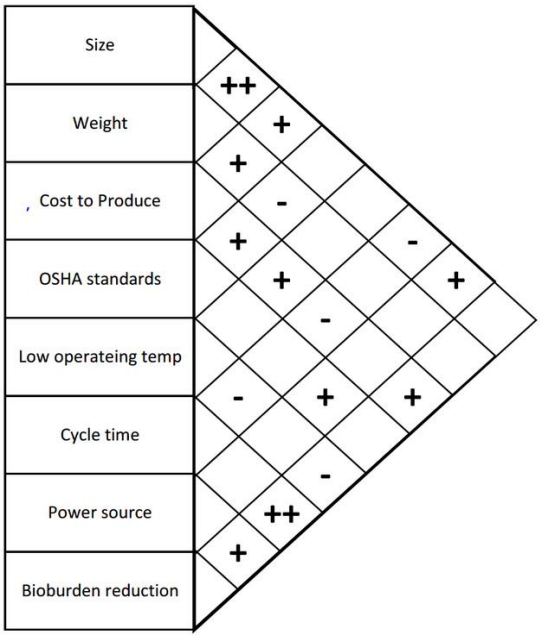


Table 2.2: House of Quality



The team discussed whether each of the customer requirements had a weak, medium, strong, or no correlation with the engineering requirements represented by 1, 3, 9, or 0 (blank) respectively. This creates a greater weight for those that are strongly correlated. Once this was done, the value was multiplied by the importance weight of the customer requirements and totaled for each engineering requirement. This leads the team to see that the most important design concern is finding a process that will lower the bioburden levels. The next important requirements are the size and cycle time with the cost staying within budget. Comparable processes or devices are the autoclave and a vacuum hydrogen peroxide vapor process. The autoclaves come in various sizes and are cheap. They sterilize in about 20 minutes but because of the steam process, they cannot be used due to potential damage to some of the items that the client provided. The vacuum hydrogen peroxide process is very quick, about 6 seconds to sterilize water bottles, but it is prohibitively expensive and not portable.

3.0 Proposed Design

The final chosen design for the portable sanitization chamber is a dual process involving vaporized hydrogen peroxide (H_2O_2)/ Ultraviolet light. Both individual methods are used in the medical and industrial fields to sterilize a variety of objects. By combining both processes, there are two active disinfection methods at work. Additionally, this two-step photocatalytic process of using H_2O_2 followed by UVGI light, also creates free hydroxyl radicals, OH-, that are strong oxidizing agents. These hydroxyl radicals lack an electron, making them highly unstable, reacting with the first chemical they come into contact with. Organic contaminants are degraded almost entirely by the radicals, creating safe byproducts such as water, carbon dioxide, and

various salts. These radicals degrade a variety of additional toxins such as: benzene, dichloroethylene, Freon 113, and various pesticides. The combined UV/ H_2O_2 process has been documented to successfully inactivate *Bacillus atrophaeus* spores.

3.1 Materials

The materials selected for the chamber were chosen based off of compatibility with H_2O_2. Due to the strength of the materials (Modulus of Elasticity), aluminum was chosen to be used for the overall enclosure. This will also include the door, handle, hinges, rack, and any other small connecting pieces.

For additional pieces, including the H_2O_2 solution container, tubing, and nozzle: PVC and PTFE will be used. Both PVC and PTFE are highly inert materials.

Eight UVGI light bulbs with a wavelength of 254 nm were chosen for the design in order to output enough UVGI light to sanitize the objects within the chamber, as well as degrade the H_2O_2 vapor to safe levels . The bulbs were chosen based off the time it takes to achieve a 2 log reduction for Bacillus spores.

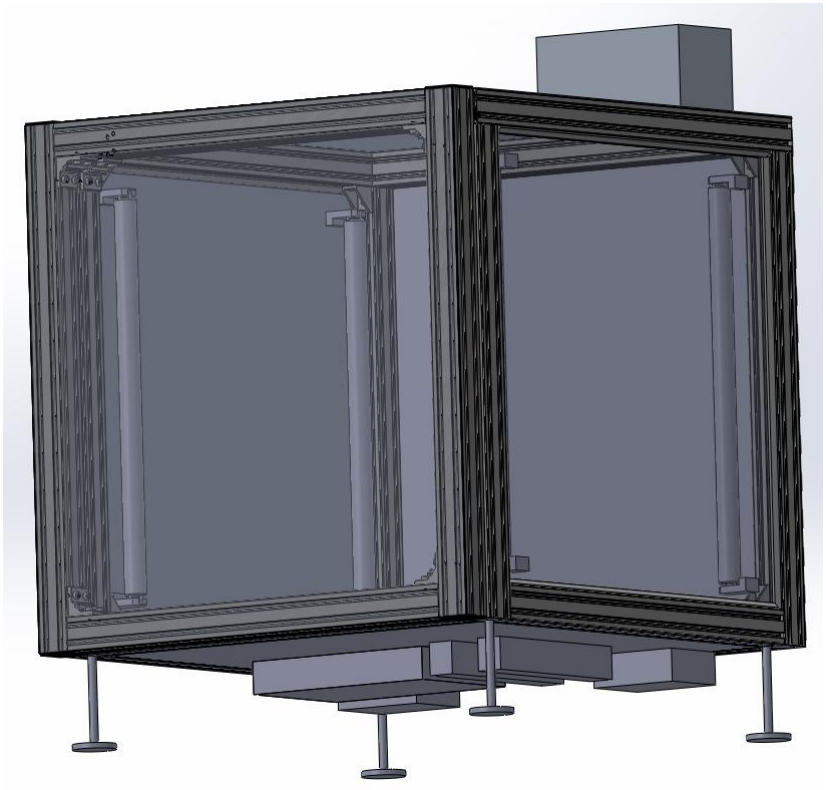


Figure 3.1: Prototype Model

The frame of the chamber is made of aluminum and was ordered from Misumi. It is 2 x 2 x 2 feet in size and has aluminum side panels. A fog machine was used to vaporize the hydrogen

peroxide and eight UV lights were added to the inside of the two side panels. The chamber has several features such as safety locks and a display system. The bottom of the chamber contains all the electrical components

4.0 Prototype Fabrication

The fabrication stages include assembling the chamber, developing the source code for the control system, and testing the fog machine.

4.1 Chamber Assembly

When assembling the chamber, it became apparent that certain components would need to be changed. One issue that needed to be addressed was that the chamber door would not fully close with the current sealant that was being used in the door. The sealant was too stiff and did not fit in the extrusions correctly. One idea to fix the problem was to buy stronger door clasps that could pull the door completely shut. But this could prove to be difficult for the user to use. Instead, a softer sealant was used, allowing the door to close and seal fully. Another problem was that some of the materials did not fit properly, such as screws and bolts. This was simply fixed by buying the correct size that was needed.

Figure 4.1: Fully Assembled Chamber

4.2 Control System

The control system was originally controlled by an Arduino Uno. Coding the Arduino proved to be difficult because there needed to be code for each component of the system in order for it to run properly. It soon became apparent that the Arduino Uno would not control the entire system because there were not enough ports to plug the wires in. An Arduino MEGA was used instead because it contains enough ports for the wires. The team also used liquid crystal display(LCD) and light-emitting diode (LED) to indicate each stage of the process inside the chamber.

A logic flow chart was made to guide the team during coding (Fig. 4.2). The fogger will not run unless the door is shut. After the door is shut, it will lock the door when the user starts the process by pressing the start button. Once the process is finished, the door will unlock and the system cannot restart until the door is opened and closed again.

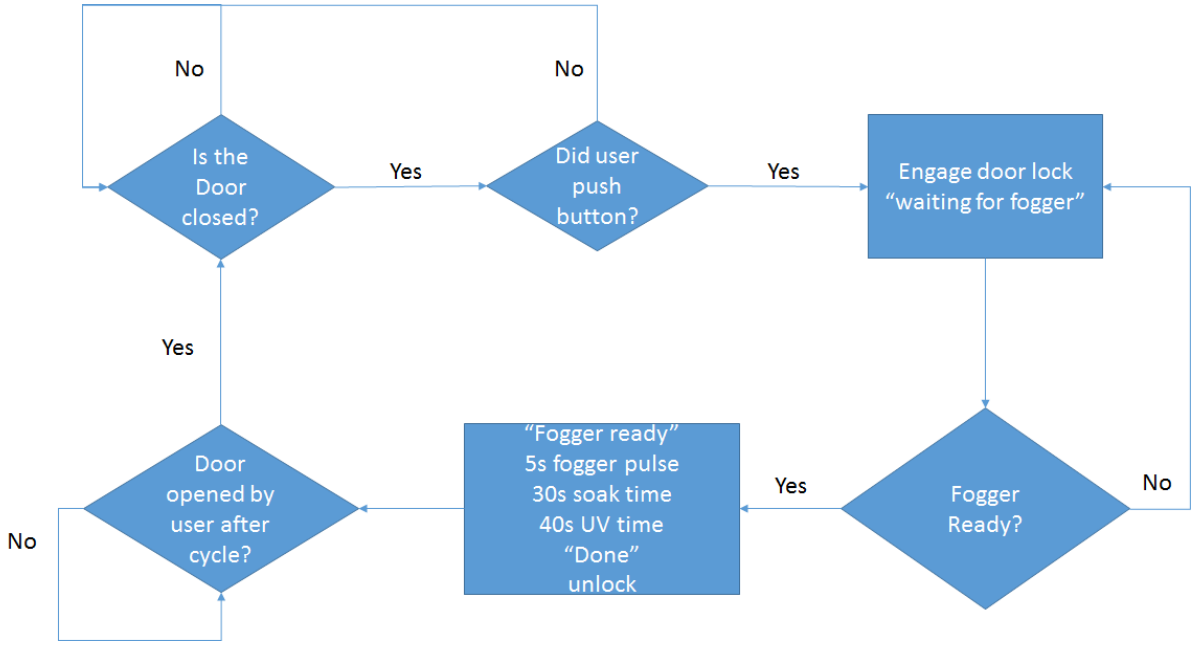


Figure 4.2: Logic flow chart

This logic flow was chosen because it was easy to code while still adding safety measures into the system. With more resources and time, the system would have more complicated code for greater flexibility for the end user.

4.3 Fog Machine

The fog machine was moved to the top of chamber to allow the hydrogen peroxide to fill the chamber more easily (Fig. 4.3). The fog machine is placed on a plastic base which is mounted onto the chamber to insulate it from the rest of the chamber. The team decided to use a light sensor (photocell) to sense the green (ready) light of the fog machine so that the control system knows the fogger is ready to run. This allows for fully automatic operation once the start button is pressed.

Figure 4.3: Fog Machine

4.4 Safety

The team used both a safety switch (Fig. 4.4) and a magnetic lock (Fig. 4.5) to make sure the entire system meets the safety requirement. For the safety switch, the logic reads low if the door is open, which means the user cannot run the process. For the magnetic lock, the user cannot open the door if the system is running.

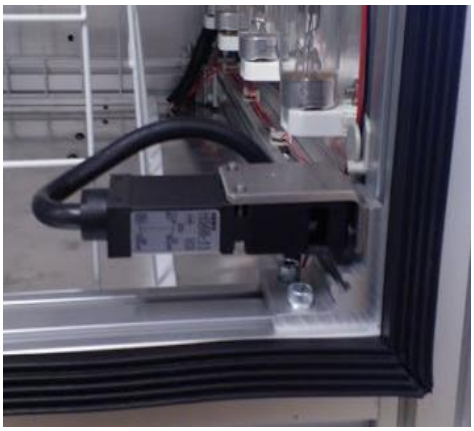


Figure 4.4: Door safety switch

Figure 4.5: Electromagnetic lock

The main safety mechanism in the system is the electromagnetic lock. This locks the door so that users cannot open the chamber mid-process. With more time and coding experience, an ideal cycle would include an integrated system to check that H_2O_2 levels are safe for the user after each run, keeping the door locked until safe. This would protect the user from faulty UV lights which are either not working at all or are in need of replacement.

The door safety switch is used so the process cannot be started while the door is open. In the future, the door safety switch would also be used to monitor the door at all times during the process in case the lock failed.

Figure 4.6: Emergency Stop Button

An emergency stop button (Fig. 4.6) was added just in case the machine needed to be completely powered off. The button can also be used as an on and off so the machine can stayed plugged into the wall.

5.0 Testing and Results

This section will discuss the optimization for testing as well as the testing and results.

5.1 Optimization

In order to optimize the process, two levels are taken into consideration. These levels consist of a minimum and maximum quantity. Ideally, four different factors would be taken into account. These factors include the intensity of the UV lights, how long the UV lights are set to run, the concentration of the hydrogen peroxide, and how long an object will be allowed to soak in the hydrogen peroxide. With four factors and two levels, this means that there would be sixteen different combinations of tests. Table 5.1 shows each factor with the corresponding minimum and maximum variables.

Table 5.1: Ideal Optimization

	Level	
Factor	Min	Max
A. UV Light Intensity	4 light bulbs	8 light bulbs
B. UV Light Run Time	1 minute	5 minutes
C. H_2O_2 Concentration	0.5 mg/L	3 mg/L
D. H_2O_2 Soak Time	30 seconds	5 minutes

Unfortunately, there was not enough test strips provided for all the necessary tests for full optimization. To accommodate the time limit and the amount of strips provided, the amount of variables tested was reduced to two. The UV light intensity was kept at a constant of four UV lights and the concentration of hydrogen peroxide was kept at a constant of 3.0 mg/L. With only two variables, the amount of testing combinations reduces to four. Table 5.2 shows the factors and the corresponding variables that were actually used for the testing.

Table 5.2: Actual Optimization

	Level	
Factor	Min	Max
A. UV Light Run Time	1 minute	5 minutes
B. H_2O_2 Soak Time	30 seconds	5 minutes

The final cycle that was chosen is based off of the results that were received from the actual optimization tests. The first three runs of tests were performed before optimization, so the concentration of the hydrogen peroxide was not kept as constant.

5.2 Testing

Two different sets of spore tests were run before the final spore testing. The first set of spores were tested on Sunday March 2, 2014. Three BI strips were sent by the client, W.L. Gore, each strip containing a specific amount of *Bacillus atrophaeus* spores. The first test was run with only the UV lights running. The strip was set inside of the chamber with the lights running for 5 minutes. The second two strips were tested with both vaporized hydrogen peroxide and UV lights at different time lengths. Run two and run three were tested at different concentrations of hydrogen peroxide. The second run had a concentration of 0.5 mg/L and the third run had a concentration of 3 mg/L. After testing, each strip was placed into a special container and mailed back to Gore for analysis. A process called serial dilution was used to count the number of active spores still present on each test strip. Results for the first round of testing are shown below in Table 5.3.

Table 5.3: Test Results from Round 1

Run	Components	Time	Concentration	Results
1	H_2O_2 UV lights	none 5 minutes	N/A 4 light bulbs	78%
2	H_2O_2 UV lights	30 seconds 5 minutes	0.5 mg/L 4 light bulbs	88%
3	H_2O_2 UV lights	30 seconds 5 minutes	3 mg/L 4 light bulbs	93%

The second set of spores were tested on Thursday March 27, 2014. Again, there were three BI strips containing a specific amount of *Bacillus atrophaeus* spores. The first test was run with 30 seconds of hydrogen peroxide fogging and 60 seconds UV lights. The second and third tests were run with 5 minutes of hydrogen peroxide followed by 1 minute, and 5 minutes of UV lights. For this round of testing, a small fan was attached to the bottom of the chamber to aid in

the circulation of the H_2O_2 vapor. Each of the tests from round two showed a reduction of over 10,000%, meaning that the strips were effectively sterilized. The results from these tests are shown below in Table 5.4.

Table 5.4: Test Results from Round 2

Run	Components	Time	Concentration	Results
4	H_2O_2 UV lights	30 seconds 60 seconds	3 mg/L 4 light bulbs	>10,000%
5	H_2O_2 UV lights	5 minutes 1 minute	3 mg/L 4 light bulbs	>10,000%
6	H_2O_2 UV lights	5 minutes 5 minutes	3 mg/L 4 light bulbs	>10,000%

The final set of spores were tested on Thursday April 17, 2014. The first three tests ran a 30 second H_2O_2 soak, followed by 1 minute of UV lights. These tests were run with the specific test items, the hemostat, laboratory notebook, and plastic tackle box, to insure that none of the items were damaged during the process. None of the items were damaged during the sanitization cycle. A fourth test was also ran at 30 seconds of H_2O_2 soaking, followed by 40 seconds of UV light. This test was to check how much bioburden reduction could be achieved by H_2O_2 alone. The 40 seconds of UV lights was necessary to decompose the H_2O_2 vapor to safe levels, and was the shortest amount of time to achieve safe levels. Results for the final set of tests will be available on Wednesday April 23, 2014.

5.3 Results

Results from the testing showed that the bioburden levels were decreased significantly, meeting the main requirement of the project. This is especially true for the second set of spores. The results from round two actually showed that there were 0 spores left on each of the test strips. The time constraints were also met. The original cycle time was limited to 15 minutes. Run 4, seen in Table 5.2, completely inactivated all of the *Bacillus atrophaeus* spores in only 90 seconds.

6.0 Cost Analysis

This project was given a budget of $3,000 that was to go towards the entirety of the project. The budget mainly concerns the bill of materials but it is also important to know the manufacturing and manpower costs.

6.1 Bill of Materials

Table 6.1 shows the cost for the bill of materials. The materials listed includes everything purchased throughout the course of the project. The total amounts to about $1,961.

Table 6.1: Bill of Materials

Sub-System	Components	Cost
Chamber		
	Frame	$536.94
	Al Panels	$180.00
	Door	$267.02
	Misc. and finishing hardware	$146.86
UV Lighting		
	Lights	$195.36
	Ballasts	$33.98
	Light holders/wiring	$49.22
Fogger		
	Fog machine	$70.00
	Tubing/wiring/mounting HW	$41.23
	Testing materials	$64.33
Control system		
	Arduino (+kit)	$208.00
	Relays	$13.58
	Buttons/wiring	$85.94
	AC to DC transformer	$35.98
	Lock	$32.66
Total		$1,961.10

6.2 Manufacturing Costs

In Table 6.2, the estimated cost for manufacturing is calculated. The manufacturing that was foreseen was be used is fabrication and welding. During the fabrication of the chamber, no welding was needed so the time spent was zero hours. The rate is estimated based off of how much professionals make. The total cost of manufacturing came out to $300.

Table 6.2: Manufacturing Costs

Task	Time (hr)	Rate ($/hr)	Cost ($)
Fabrication	10	30	300
Welding	0	20	0
Total			**300**

6.3 Cost of Manpower

To determine the overall cost of manpower, the estimated hours per person and pay per person needed to be calculated. In Table 6.3 below, the estimated hours per person is shown throughout the duration of the project. The tasks include research, design, analysis, prototype, and testing. The total amount of hours per person is 65 hours.

Table 6.3: Estimated time

Tasks	Estimated time per person (hr)
Research	10
Design	10
Anlaysis	5
Prototype	20
Testing	20
Total	**65**

A flat pay rate of $30 is charged for each engineer. Benefits and overhead costs were also added. The team is not for profit, therefore there is no additional percent charged. With these charges, the billable rate for each engineer is $58.5 per hour. These calculations can be seen in Table 6.4

Table 6.4: Estimated pay for group

Person	Base pay ($/hr)	Benefits (%)	Actual Pay ($/hr)	Overhead (%)	Billable Rate ($/hr)
Beauchamp, Robertson	30	30	39	50	58.5
Blackburn, Jacob	30	30	39	50	58.5
Kieffer, Lauren	30	30	39	50	58.5
Nation, Elliot	30	30	39	50	58.5
Soto, Angel	30	30	39	50	58.5
Zha, Dangxian	30	30	39	50	58.5
				Total	**351**

Using the hours and pay for the group and the total cost for the group is shown in Table 6.5 below. The cost for the group is calculated to be $22,895. To calculate the total cost of manpower, the travel expenses between campus and W.L. Gore & Associates are included. The travel expenses come out to be $80. The personnel and travel costs make up the total cost of manpower which is $22,895.

Table 6.5: Cost of manpower

1.0 Personnel	# of Person	Estimated time per person (hr)	Rate ($/hr)	Total Cost ($)
	6	65	58.5	22815
2.0 Travel	**# of Local meeting**	**Distance (miles)**	**Cost per mile ($/mi)**	**Total cost of Meetings ($)**
Gore	4	8	0.5	16
Campus	64	2	0.5	64

6.4 Total Cost of Production

Knowing the bill of materials, manufacturing costs, and the cost of work hours provides what is needed to find the overall cost. The overall cost is calculated to be $25,068, which is found in Table 6.6. Since the budget of the project was $3,000 and the bill of materials is $1,961, the final product was well within the budget.

Table 6.6: Cost of project

Type of Production	Cost ($)
Bill of Materials	1,961
Manufacturing	300
Man Power	22,895
Total	25,156

7.0 Conclusion

A portable sanitization chamber was designed and built to reduce the bioburden levels on three different objects; a metal hemostat, a plastic tackle box and a laboratory notebook. The design utilizes a two process system of vaporized hydrogen peroxide and UVC lights controlled by an Arduino MEGA.

Through the testing and results, all of the requirements were met under the given constraints. The use of the UV lights to decompose the hydrogen peroxide makes the process quicker and safer for the user. An emergency stop switch and a safety lock were also implemented in the design for safety. The size of the chamber is fully scalable and can be modified for smaller or larger applications allowing for more portability or larger items. The final testing showed that the *Bacillus atrophaeus* spores on the testing samples were completely inactivated within the 10 minute constraint. Further optimization testing would result in a shorter cycle time. However, the cycle chosen for this sterilization process used 30 seconds of hydrogen peroxide vapor, followed by 40 seconds of UV light. The final cost of the chamber was approximately $1,900, keeping the project under the $3,000 budget.

Some modifications that can be made to the design include a sensor to measure the humidity in the chamber. When used multiple times in a short time period, the humidity inside the chamber increases if it is not aired out. The humidity sensor would be a necessity in high humidity climates. A fan attached to the chamber would also help with this. Another modification would include more options for the user. There would be an interactive interface that allows the user to choose how long the process needs to run, depending on the amount of materials that are in the chamber at a time. This would also allow the user to only run the UV lights if desired. Since the system is scalable, it would have been better to make the chamber to a smaller size, include less lights, and change some of the metal materials to plastic so the system is more lightweight.

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Appendix A: Project Scope

Title: Portable Sanitization Chamber for Medical Manufacturing Use

Information on Project Sponsor:
At W. L. Gore & Associates, our products are designed to be the highest quality in their class and revolutionary in their effect. We resolutely live up to our product promises, and our associates address technical challenges with innovative, reliable solutions.

Our fluoropolymer products provide innovative solutions throughout industry, in next-generation electronics, for medical products, and with high-performance fabrics. We've repeatedly been named among the "100 Best Companies to Work For," in the U.S. by FORTUNE magazine, and our culture is a model for contemporary organizations seeking growth by unleashing creativity

and fostering teamwork.

While we may be best known for our GORE-TEX® fabrics, all our products are distinguished in their markets. Our technologies and fluoropolymer expertise are unsurpassed.

We create next-generation cable assemblies and components for the electronics industry, set the standard for outerwear comfort and protection, solve difficult industrial problems with innovative materials and technology, and Gore medical products work in harmony with the body's own tissues to restore normal body function.

Scope of Work:
The scope of this project is to design and build a portable sanitization chamber for use in the medical industry. The chamber should sanitize various materials with complex geometry by reducing the bioburden to less than routine final bioburden levels. A portable sanitization chamber could be used as an in line solution to reduce contamination during manufacturing, for sanitizing materials for entry into cleanrooms, or for entry into sterile hospital settings.

Portable Sanitization Chamber Requirements (provide appropriate justification for meeting requirements):

- SAFETY
    - No harmful materials
    - Users are not at risk of exposure to sanitizing source
    - Applicable OSHA safety standards met
- Cleanliness standard
    - Samples will be tested for bioburden levels before and after chamber use
- Ease of use
    - Short cycle time
    - Cycle ends automatically when complete
    - Easily transported by one person
- Materials to be sanitized (must not be adversely impacted by sanitization process)
    - Tackle Box
    - Cleanroom Approved Notebook
    - Hemostats

Desired Engineering Majors: Biomedical, Mechanical, and Electrical

Budget:
$3,000[1] to cover the cost of:
· Documentation (reports, presentation boards, etc.)
· Materials for testing and prototyping
· Construction of a working model

Deliverables: Detailed report, all engineering analysis, cost estimate to duplicate, drawing package, software files (if applicable), bill of materials, all receipts for purchases/expenses, and functional sanitization chamber.

Competition between Arizona Universities: This project is being sponsored by Gore at ASU and

NAU. Gore will provide all team members a trip to Flagstaff Facility during the second semester for presentation to Gore team, at which time a winning design will be selected.

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[1] Other resources may be provided as needed/justified.

Appendix B: Constraints, goals, and actual results

Customer Requirements	Design Specifications	Reasoning and justification	Quantity or Pass/Fail	Actual
CLEANLINESS STANDARD reduce the bioburden levels	Process effectively inactivates *Bacillus atropheaus* spores	Medical studies measure contaminant levels in log units	1 log unit reduction	6 log reduction
SAFETY No harmful materials Users are not at risk of exposure to sanitizing source Applicable OSHA safety standards met	Physical components do not cause user harm	OSHA employee safety guidelines	pass/Fail	pass
	Chemical concentration	Allowable substance exposure from OSHA standard	H_2O_2: 1 ppm (8 hour exposure) 75 ppm short term	10-50 ppm short term
	Electrically grounded	User electrical guidelines from OSHA standards	pass/fail	pass
EASE OF USE Short cycle time Cycle ends automatically when complete Easily transported by one person	Duration of process	Compared to common autoclave	15 minutes	1.5 minutes
	Control System	automatically executes process	pass/fail	pass
	weight	Human lifting average	75 lbs	~50 lbs
	width	Fits through doorways and on counters	3 feet	2 feet
SANITIZE VARIOUS MATERIALS e.g. Tackle Box Cleanroom Notebook Hemostats	Temperature	Avoid melting of common polymers	120°c	<100 °C
	Does not saturate material	Prevents pourous materials from absorbing substances	pass/fail	pass
BUDGET	Cost to generate design prototype	Client specified	$3,000	<$2100