Design of a Device to Fabricate Menstrual Pads in Refugee Camps

Submitted to:

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International Federation of Red Cross and Red Crescent
Geneva, Switzerland

Prepared by:

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Mechanical Engineering Design Projects Program
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Thank you also to Mr. William Carter and Ms. Alexandra Machado, our contacts from the International Federation of Red Cross and Red Crescent, for taking time to advise and educate us on the needs of the communities they support.

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EXECUTIVE SUMMARY

The International Federation of the Red Cross and Red Crescent (IFRC) must overcome the challenge of supplying disposable menstrual pads with the necessary customizability to Syrian refugee communities in Lebanon. To resolve the disparity between limited supply and essential need, the IFRC sought a device to locally fabricate and customize the size, fluid retention, and quality of low-cost menstrual pads. This report outlines the design alternatives, details the architecture of the low-cost menstrual pad, discusses the functional prototype design and features, and recommends future actions towards scaled implementation.

The menstrual pad must contain three layers: a wicking skin-facing layer, an absorbent central layer, and an impermeable garment-facing layer. An off-the-shelf rotary cutter and a Sizzix Big Shot Plus roller press and cutting-die assembly cut the raw fabrics into the correct dimensions. Then, the layers are stacked in a custom-built thermoplastic heat sealer that fuses the outer layers together. Finally, an adhesive backing is manually added, and an off-the-shelf ultraviolet (UV) sanitation chamber disinfects the pad before it is ready for use.

Pad size is varied by the size of the cutting-die and the heating elements in the heat sealer, fluid retention is varied with the absorbent layer thickness, and quality is varied by the fabrics selected for the pad and the amount of adhesive backing used.

The next design team to refine this project towards scaled implementation should consider three primary improvements. The most critical refinement is the manufacturability of the heat sealer's heating element, as the pad fabrication process is limited by the efficiency of the heat sealing. We recommend outsourcing the manufacturing to a silicone heating manufacturer like Michaels Enterprises, Inc. Another improvement is the addition of safety features to the heat sealer, including a timing circuit that can be used to indicate press duration to the user, to ensure reliable pad production. Finally, they should incorporate renewable power generation and storage to supply the device's energy demands in areas with limited access to electricity.

1 INTRODUCTION

1.1 Overview of Report

This report details the research, design, and prototype of a multi-step device that fabricates menstrual pads in refugee camps. After reviewing the logistic challenges and cultural issues of menstrual hygiene in refugee camps, the report transitions to the engineering behind the solution. This includes requirements and constraints set by the team and sponsors, patent searches for similar devices, and other concept generation techniques. After this step, the team created low-resolution prototypes to evaluate and select fabrics and concept solutions. The following sections explain the chosen solution: justifications for the fabric choices for the pad, an overall process description to show how each stage of the fabrication process works, and the details of key features in each step of the final design. The team also included three economic analyses: cost per pad, overall device cost, and a production output study for a possible production benchmark. The report concludes with an evaluation of the device and recommendations for future work.

1.2 Sponsor Background

The International Federation of Red Cross and Red Crescent (IFRC), founded in 1919, is the "world's largest humanitarian organization" and focuses on "disaster response, disaster preparedness, and health and community care" (International Federation, n.d.). The organization has been involved in a variety of emergency responses: natural disasters, outbreaks, and displacements, including the Syrian refugee crisis which affects an estimated 13.5 million people (Syria crisis, n.d.). Lebanon hosts 1.1 million of these refugees, the target end users of our device. Roughly 30% of the population are women of reproductive age, but in 2017, only 12,000 of those women received any kind of menstrual hygiene management aid in the form of disposable sanitary pads and laundry soap (Lebanese Red Cross, 2017). The IFRC was searching for a low-cost solution to utilize locally, rather than relying on unreliable distribution of materials. They plan to first test this solution in Lebanon in summer 2019, but it must be dynamic enough to assist a variety of communities at a later stage.

1.3 Faculty Advisor Background

The design team consulted with two faculty advisors, Dr. Janet Ellzey and Dr. Katherine Polston. Dr. Ellzey is a professor in the Mechanical Engineering Department and a cofounder of the Humanitarian Engineering Certificate. She has worked with the IFRC on multiple design projects in the past. Dr. Polston is a professor in the Division of Textiles and Apparel with valuable insight on textile selection for menstrual pads.

1.4 Team Background

The design team consisted of four Mechanical Engineering seniors from The University of Texas at Austin. Team members are Andréa de Wied, Siddharth Kurwa (team leader), Pratik Patel, and Claire Puccini. The team has a diverse background with industry experiences spanning energy production, mechatronics, product development, structural analysis, technical writing, and marketing.

1.5 Problem Context

There are several issues that necessitate the creation of a low-cost pad making device. The IFRC must tackle the logistic challenges of storing and distributing menstrual hygiene materials while considering the cultural sensitivities towards these products.

1.5.1 Logistics Challenges

The IFRC "has a significant amount of pre-positioned stock" of only one type of each hygiene product that is "sufficient to meet the needs of 300,000 people" (Our stock, n.d.). For example, a reusable women's hygiene set includes two pairs of underwear, four pads, and one bag. The only variety is with the underwear sizing and the option of a maxi or super maxi pad which may not be appropriate for all body types (Our stock, n.d.). For comparison, a single store in the United States can carry up to four different types of menstrual pad brands with at least three sizing options per brand (CVS, n.d.). The IFRC does not provide the same variety as commercial U.S. manufacturers; they respond to dynamic global crises and cannot predict the type and variety of pads needed to serve a particular region (J. Ellzey, personal communication, September 7, 2018). Stocking additional pad sizes to cater to every woman is logistically complicated and expensive for a resource-strapped non-profit organization.

1.5.2 Menstrual Hygiene Management in Lebanese Refugee Camps

Due to cultural taboos surrounding menstruation in Syrian communities, commercial pads can be expensive and scarce. Studies have shown that Syrian women prefer commercial pads because they are more comfortable and reliable, but they may not always have the funds to access them. This issue compounds when women are displaced in a crisis, and they must rely on Non-Food Items (NFIs) from the IFRC's relief efforts. Distribution of these materials is erratic at best, so women will use materials like tissues, newspaper, and old clothing or blankets and save their disposable pads for emergencies. Either source for menstrual hygiene is unreliable, and women opt to stay home while menstruating instead of going to work or school and risking a leakage considered shameful in their culture (Schmitt et al., 2017).

The Lebanese Red Cross conducted a study in 2017 in which they distributed Women's Emergency Kits containing disposable sanitary pads and other hygiene necessities. After three months, the study's results revealed the pads were too small for adult women and the nylon fabric caused some allergic reactions. However, all participants agreed the kits were a necessity for daily life, even if they were no longer in a state of emergency, due to the difficulty of obtaining commercial products.

Another study tested menstrual pads of varying thickness and measured physical and emotional stresses of Muslim women as they exercised or rested. The women previously preferred very thick maxi-type pads for maximum leak protection, but after using the ultra slim pads common in Western cultures, their preferences changed. Women reported the pads were flexible, light-weight, and did not chafe. Decreasing their discomfort also reduced their physiological and psychological distress, enabling women to perform their daily activities without worry or pain and to the same level as if they were not menstruating (Mohamed et al., 2014).

Both studies demonstrate the need for a variety of pad sizes. Different women desire varying sizes depending on the size of their bodies and the heaviness of their bleeding. According to the IFRC, their previous exposure to menstrual products may lead to the desire to change the material of the pad itself, to be closer to what they are familiar with. Local access to customizable disposable pads within refugee camps removes reliance on NFIs and expensive products from local stores.

Additionally, the manufacturing process requires women to be involved in the production of their own pads, empowering them to take charge of their hygiene and reduce fear and shame surrounding the topic of menstruation. As evidenced with similar devices used in rural India, women are given jobs and educated about menstrual hygiene and do not have to choose between buying food for their families or menstrual products (Venema, 2014). In the long term, this may help relieve the need for the IFRC's fabrication device.

1.6 Problem Statement

To address the IFRC's logistic challenges of meeting varying individual needs and cultural sensitivities towards menstrual pads, the design team created a prototype device to fabricate customizable disposable pads in refugee camps using bulk materials.

1.7 Deliverables

The implementation of this project involves several steps from fabric procurement to production. Accordingly, the team has provided details for the architecture of the pad, a list of bulk fabric suppliers and fabric alternatives, a functional prototype of the manufacturing process, operational instructions, and documentation to refine and use the prototype in the next phase of the project.

1.8 Constraints and Performance Metrics

The pad fabrication device needed to satisfy five user needs that the design team derived from the project background and IFRC's requirements: customizable output, disinfection, operational ease, cost efficiency, and transportability. Within each of the user needs, a breakdown of performance metrics and constraints are compiled in Table 1.

The IFRC specifically requested a customizable output to fulfill the varying needs of the end user. Under advice from Dr. Ellzey, the design team concluded there should be at least three customizable features - size, fluid absorption, and overall quality - to fit the comfort and economic needs of an individual. By changing the length and thickness of the pad, the device can meet the varying size requirements for many individuals. On average, a woman bleeds 1.5 fluid ounces per cycle with significant variance to each individual woman, prompting the need for fluid absorption customizability (Cole, Billewicz & Thompson, 1972). Fabric choice controls the overall quality: the amount of adhesive backing, additional layers of the skin-facing fabric, or additional absorbent sheets increase cost but also add comfort and security. Alternatively, less expensive fabrics decrease quality but also decrease the cost of the pad which some communities may prioritize over comfort.

Table 1: Constraints and performance metrics derived from user needs.

User Need	**Specification**	**Measure**	**Constraint**
Customizable output	Customizable pad design	≥ 3 features	X
	Fluid retention	≥ 1.5 fl. oz	
Disinfection	Use certified sanitation method	≥ 60 seconds under UV light	X
Operational Ease	Maximum manual force required	50 lbs	X
	Number of subassemblies	≤ 4	X
	Operational training time	≤ 120 minutes	
Cost efficient	Percentage of local materials or materials that can be procured in bulk	100%	X
	Price of prototype	≤ $2,000	X
	Production rate	≥ 100 pads per day	
Transportable	Maximum component weight	≤ 25 lbs	X
	Footprint	≤ 132 ft^2	X

Menstrual pads are health products with direct contact to a sensitive area of the human body, and the design team needed to minimize risk with a disinfecting step during manufacturing. According to a study by the American Journal of Infection Control (2015), 60 seconds under a UV light is sufficient to achieve acceptable disinfection.

The team derived labor metrics for operational ease from specifications of a similar existing pad fabrication device, discussed in further detail in Section 2.1. The intended operators of this device are female refugees with 120 minutes of training, like the preexisting device's requirement, so the device needs to be simple to operate. Per an OSHA ergonomics recommendation, the device cannot require more than 50 lbs of pushing force (Materials, n.d.). Though fabricating a pad is a multi-step process, the prototype can require no more than four subassemblies to maintain simplicity. The IFRC is a non-profit organization, making cost a critical factor. In agreement with Dr. Ellzey, the prototype development costs less than $2,000 and must be capable of fabricating at least 100 pads per day for initial device testing in the summer of 2019.

Refugee camps are not typically located in developed countries and lack the necessary infrastructure to transport and house large machinery typical of commercial manufacturers. Due to this limitation, the team aimed to develop individual components no heavier than 25 lbs and have a maximum system footprint of 132 ft^2.

2 ALTERNATIVE DESIGNS

2.1 Existing Solutions

The team conducted a preliminary patent search to identify existing solutions. Arunachalam Muruganantham created a pad fabrication device with similar functionality to what the design team set to achieve. His patent disclosed a multi-stage machine that defibers and compresses wood cellulose or cotton fibers into rectangles that are subsequently stacked between two one-way permeable thermoplastic sheets. The machine fuses these sheets' edges with a heat sealer, and operators manually add adhesive backing and packaging (Muruganantham, 2009). This patent explained the process of fabricating low-cost menstrual pads from which we derived the function model shown in Figure 1.

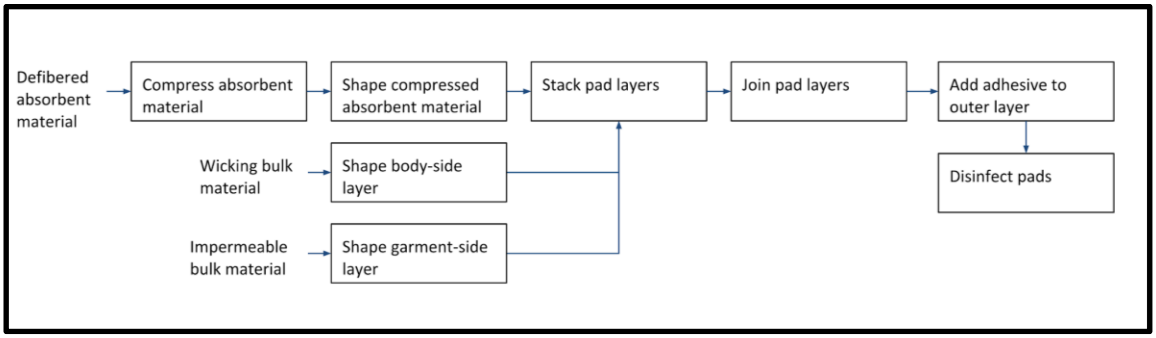

Figure 1. Initial device function model.

Muruganantham's design gave insight to the scope of the project, but it did not offer any customizable features, the main requirement from the IFRC. Therefore, we performed a more in-depth patent search that revealed important design decisions regarding the fabric choices and joining process.

2.1.1 Method of Making Menstrual Napkins

A patent awarded to John Jones Sr. helped the team gain a better understanding of the fabrics to make a menstrual pad. His invention detailed the fabric weights and dimensions for each layer, the ability to use multiple absorbent layers of wood cellulose tissue paper to keep the pad thin but reliable, and a method of sealing with adhesive bonding (Jones, 1975). The estimated fabric weights provided an initial metric when choosing fabric from bulk suppliers. The idea of using tissue-like paper instead of defibered cellulose would combine the compression and shaping steps from our function model into one cutting step. However, the method of injecting hot melt glue to join the pad layers mentioned in the patent seemed dangerous and inefficient to do manually.

2.1.2 Impulse Heat Sealer

As an alternative to adhesives, the team then investigated the heat sealing process by studying a patent for an industrial impulse heat sealer. This patent proved impulse heating was a means of minimizing burn risks and reducing total energy consumption by resistively heating a nichrome wire to cut and seal thermoplastic fabrics simultaneously (Wright, 1982). The patent prompted the idea of nichrome wire as the heating element for thermoplastic sealing and develop an impulse circuit to rapidly heat the wires.

2.2 Concept Generation

After conducting background research, the design team began conceptualizing different versions of the prototype. With the multi-step process from our function model in Section 2.1, we used a mindmap to brainstorm possible solutions for each function, shown in Figure 2. After creating the mindmap, the team used a 4-3-5 exercise to incorporate the solutions from the mindmap into a cohesive process.

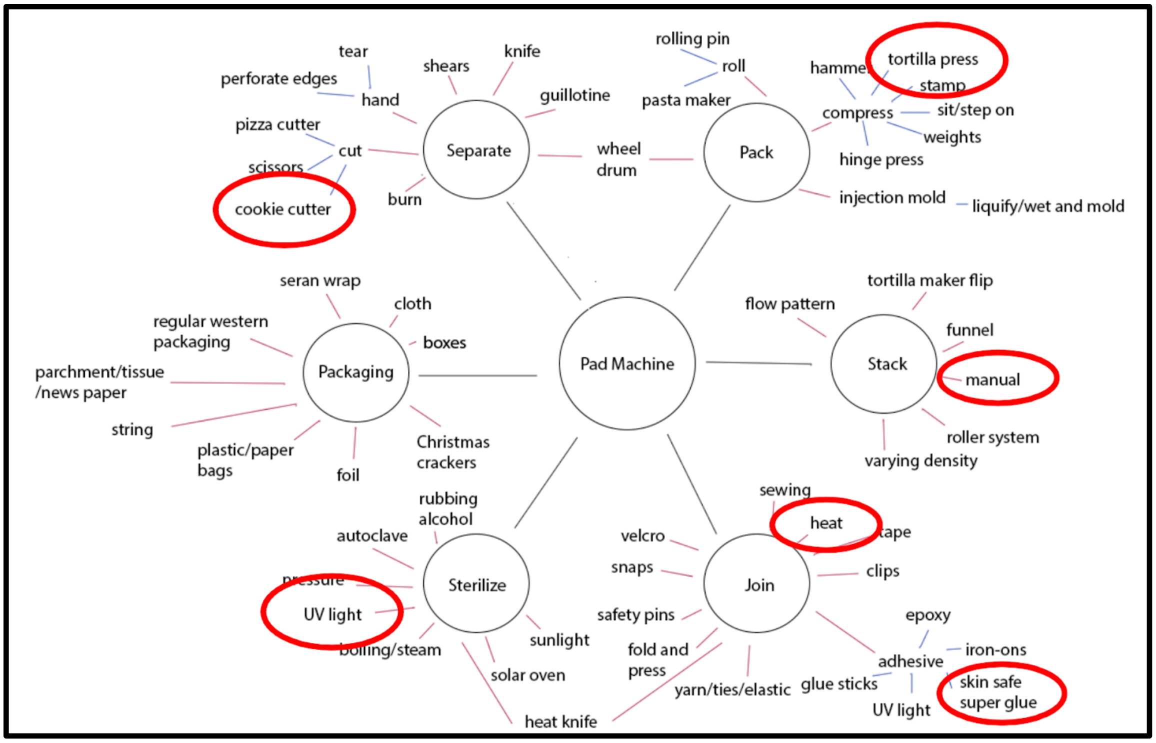

Figure 2. Mindmapping.

Recurring ideas presented in the 4-3-5 are circled in Figure 2: a press or cutting combination to create the pad shape, heat sealing or adhesion with glue or tape to join the layers, UV light for sanitation, and manual transitions to help employ local labor.

2.3 Fabric Testing

Fabric selection was a major component of this project, so the design team performed several rounds of low-resolution prototyping to test the feasibility of various fabrics. In commercial pads, there are three main layers of fabric: the skin-facing layer, the center absorbent layer, and the garment-facing layer. The skin-facing layer is wicking and soft, the absorbent layer must hold shape while retaining a large amount of liquid, and the garment-facing layer must not allow any liquid to leak through (Always, n.d.). The team acquired fabrics from several vendors including Jo-Ann Fabric and Craft Store, Quanzhou Xingyuan Supply Chain Co., and Changshu Jinda Nonwoven Products Company. The design team was primarily interested in testing the Chinese bulk suppliers' fabrics since their products are scalable to the IFRC's intended operation. Fabrics from Jo-Ann Fabric and Craft Stores, a local retail supplier, were only for initial evaluation while waiting for overseas shipping of the Chinese materials. We considered the following criteria: abrasion, permeability and impermeability, uniform fluid retention, sealability, cut resistance, sourceability, and cost. The testing results are summarized in Tables 2-4 with dark green as excellent, light green as good, yellow as okay, and red as poor.

Table 2. Skin-facing fabric test results.

	Abrasion	Permeability	Sealability	Cut Resistance	Sourceability	Cost	Final Selection
Pellon Interfacing							
100% PP 30 gsm							
100% PP 50 gsm							
100% PP 60 gsm							
100% PP 75 gsm							
100% PE 80 gsm							
Perforated Hot Air Hydrophilic Nonwoven							X

Table 3. Absorbent layer fabric test results.

	Uniform Fluid Retention	Cut Resistance	Sourceability	Cost	Final Selection
Fluff Paper + SAP Absorbent Paper with 40% SAP					X
50% SAP Tissue + SAP Absorbent Paper					
Quick Craft Polyester					
Super Absorbent Fiber - 52 mm					
Super Absorbent Fiber - 6 mm					

Table 4. Garment-facing fabric test results.

	Impermeability	Sealability	Cut Resistance	Sourceability	Cost	Final Selection
PE Film 100%						
PE Film 70%						X
BRND Upholstery Underlining						
Pellon 360 EZ Stitch						

2.3.1 Abrasion

The manufacturer's intended purpose for the fabric and the team's qualitative observations led to the ratings for abrasion. For example, the Pellon interfacing layer provided excellent permeability, but according to our faculty advisor, the fabric is meant to sit in between layers and provide structure. Since the fabric was never intended to interact with skin, comfort was not a product requirement, which supports the team's observations, giving the Pellon interfacing fabric an "okay" rating.

2.3.2 Permeability and Impermeability

We tested the permeability of each fabric by applying 0.25 fluid ounces of water to the surface of each fabric resting on a dry paper towel. The liquid rested for a minute, and we applied pressure to simulate day-to-day activities. After resting for another minute, we removed the fabric to see if any water passed through to the paper towel. The spot size determined the ratings for each fabric. Results can be seen in Figure 3. The bottom row shows polypropylene (PP) fabrics of different weights from Changshu Jinda Nonwoven Products Company. The top left-hand group shows the fabrics from Jo-Ann Fabric and Craft Stores. The fabrics, in order from left to right, are: Pellon Interfacing, Pellon EZ Stitch, and upholstery lining. The top right-hand group shows fabrics from Quanzhou Xingyuan Supply. The fabrics, in order from left to right, are: perforated nonwoven, 70% polyethylene (PE) Film, and 100% PE Film.

Figure 3. Fabric permeability testing.

2.3.3 Uniform Fluid Retention

We tested fluid diffusion by pouring 1.5 fluid ounces of water onto an eight inch by 2.25 inch absorbent layer strip. The Fluff Pulp + SAP Absorbent Paper with 40% SAP (fluff pulp) evenly distributed the liquid across the entire area. The Tissue Paper + SAP Absorbent Paper with 50% SAP (tissue paper) did not evenly distribute the fluid. A majority of the fluid remained concentrated at the pouring location. The tissue paper began to bulge and lose SAP granules from the side of the absorbent layer. Results of the testing can be seen in Figure 4.

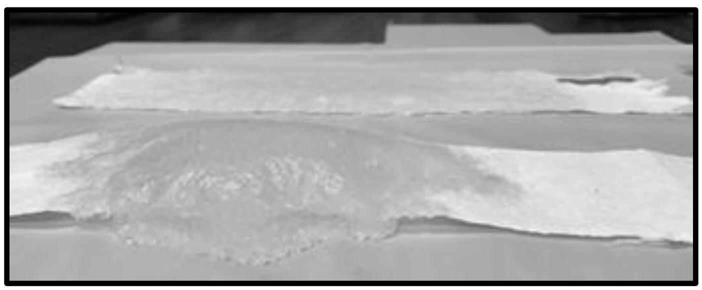

Figure 4. Absorbency testing results for 1.5 fluid ounces of liquid. The strip in the bottom of the image is fluff pulp and the strip in the top of the image is tissue paper.

In addition, we also tested the maximum fluid retention to meet our pad specification of 1.5 fluid ounces. From the testing, we found that an eight by 2.25 inch layer of the fluff pulp could retain 2.4 fluid ounces before fluid began to drip out of the fluff pulp. This was consistent with a commercial *Always Ultra Thin Long Super Pad* which retained 2.4 fluid ounces as well in our testing. Two layers of the fluff pulp were able to retain 5 fluid ounces, demonstrating customizability of fluid retention.

2.3.4 Sealability

Once we identified potential fabrics for the skin-facing and garment-facing layer, we tested the sealability of each fabric. Based on our patent research, heat sealing was a viable way of sealing fabrics, and we expected all the fabrics to respond favorably to adhesives. Using an iron, we tried to adhere various combinations of skin-facing and garment-facing layers. Through these tests, the design team discovered both outer layers could not be thermoplastic because they would both melt when exposed to heat and would not join. If the skin-facing layer retained its structure, it was acceptable, and the opposite was true for any garment-facing layer. Fabrics that adhered to a variety of other fabrics were rated higher than fabrics that failed to provide a good seal with others.

2.3.5 Cut Resistance

The preliminary cut resistance of each fabric was tested using a paper cutter. The results of this test allowed the team to determine what types of commercialized cutting equipment would be sufficient to cut through the fabrics and predict which fabrics were easiest to cut. Since the loose fibers had to be pulled apart instead of cut, they received a "Poor" rating. Once we chose a cutting solution, the fabrics were retested.

2.3.6 Sourceability and Cost

Sourceability indicated if the fabrics could be ordered in bulk. All the Chinese suppliers provide fabric to commercial-sized factories and could supply fabrics in the order of thousands of kilograms. Meanwhile Jo-Ann Fabrics is a crafting supplier and cannot provide materials in bulk. We also rated the unit cost, usually per kilogram or kilometer for the Chinese suppliers, for each fabric.

2.4 Fabric Sealing

From the team's patent search and concept generation, we tested three methods of joining the skin-facing layer and garment-facing layer: adhesives, heat sealing with exposed heated nichrome wire, and heat sealing with a flat heated surface. Within the adhesives, we tested 3M Scotch-Weld super glue and Liquid Stitch, a common fabric glue. The 3M Scotch-Weld super glue was ineffective, passing through the fabric entirely, and the Liquid Stitch required 30 minutes to cure with constant pressure along the seam, demonstrating that the adhesives were inefficient options.

To evaluate the heat sealing method, the team created two low-resolution heat sealers and pressed them against the fabrics for approximately 15 seconds. We prototyped the exposed nichrome wire alternative using a formed copper wire held to the surface of a clothing iron with Kapton tape as shown in Figure 5. The flat surface heat sealer is the edge of an iron.

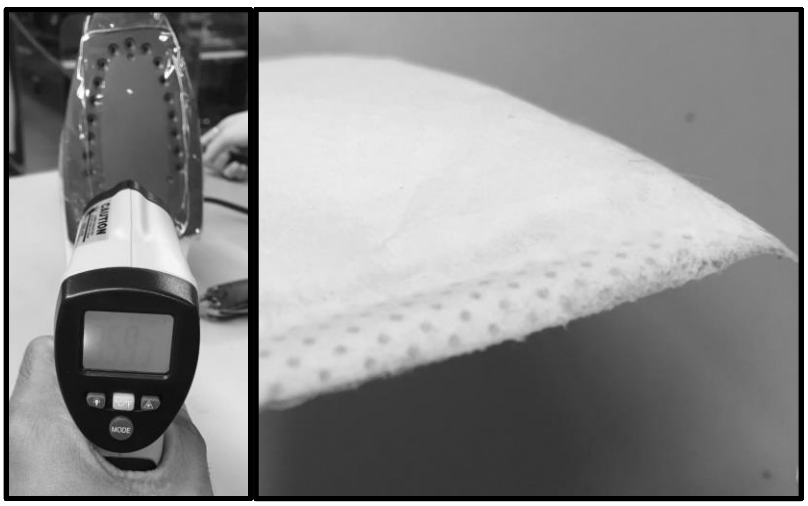

Figure 5. Low-resolution heat sealing. The left image is a low-resolution heated wire sealer and the right image is the resulting edge of a flat heat sealer.

The exposed wire created an uneven seal that was easy to tear. On the other hand, the iron edge created a thick and smooth seal.

Lastly, the team needed to determine the optimal seal width. We tested a 0.5 inch, 0.25 inch, 0.125 inch, and 0.0625 inch seal to determine ease of fabrication. Based on our measurements, the seal thickness for an *Always Ultra Thin Long Super Pad* is 0.125 inch, but we chose a 0.25 inch width seal with 0.125 inches of tolerance since our process would not be as refined as a commercial-scale process.

2.5 Nichrome Wire Insulation Alternatives

A heating element with a flat surface produced the best seal during the fabric testing, so the nichrome wire needed to be encased in a thermally conductive medium to provide a greater surface area. We initially chose Resbond 940 LE (ceramic) due to its compatible temperature range with the nichrome wire and at the recommendation of our faculty advisor (J. Ellzey, personal communication, October 17, 2018). The ceramic proved to be brittle, evidenced by the cracking during the heating element prototyping, as seen in Figure 6. The cracking continued to be an issue as ceramic pieces kept breaking off while operating the heat sealer, posing a safety issue if these shards were to be embedded in the fabrics. A layer of protective Kapton tape encased the ceramic to prevent the ceramic from directly touching the fabrics.

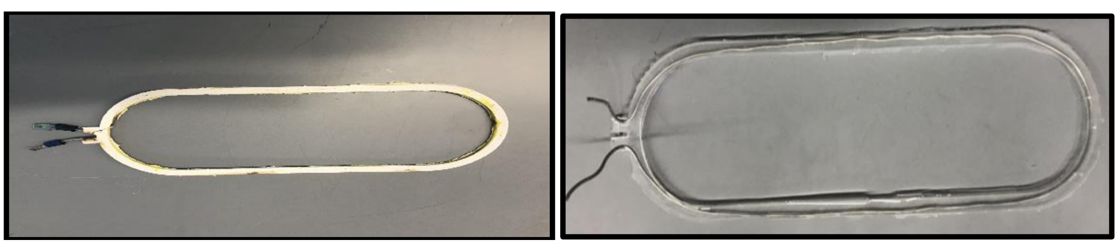

Figure 6. Heating element prototyping. Left image is nichrome wire encased in ceramic with evidence of cracking. Right image is nichrome wire encased in silicone potting.

The design team found an alternative to the ceramic by using Mold Star 20T Silicone (silicone potting) that had a compatible temperature range, minimized the effects of prototyping defects, and improved the flexibility and durability of the heating element. The elasticity of the silicone potting allowed it to withstand the pressure due to the handling load. The silicone potting was also resistant to fracture compared to the brittle ceramic, and the Kapton tape was no longer necessary to protect the fabrics.

2.6 Concept Selection

After evaluating alternatives through prototyping, a Pugh chart helped the team select leading concepts for each station in the pad making process. Four concepts derived from the brainstorming activities were compared using the criteria from the engineering specifications, as well as functional feasibility and manufacturing complexity, shown in Appendix C. The results of concept selection are summarized in Table 5.

Table 5. Concept selection and justification.

Process Step	**Concept**	**Justification**
Cutting	Roller-die	Different dies make shape or size customizable, allow for curved edges
Sanitation	UV chamber	Fast and commonly accepted method of sanitation and no need to dry or expose the pads afterwards
Joining	Heat sealer	Based on testing, thermoplastics seal more reliably and quickly with heat rather than adhesives
Adhesive backing	Alvin double sided tape	Flexible, lightweight, low-cost, and available in bulk
Stacking	Manual	Employs refugees and reduces complexity

The roller-die is a solution commonly used in industry to rapidly cut shapes out of fabrics. For the project's purposes, this would enable customizability by varying the cutting-dies for different sizes, something that would be more difficult to do with other options considered. UV exposure provided an efficient method to disinfect the pads in a rapid manner per recommendation from the project sponsor (W. Carter, personal communication, October 16, 2018). The low-resolution prototype with the iron validated heat sealing as a joining method and proved which adhesive backing was viable. Lastly, using manual labor to stack the fabric layers inside the heat sealer is efficient and does not add unnecessary complexity to the process.

3 PROJECT SOLUTION

3.1 Pad Architecture

Based on the results from Section 2.3, the primary fabric choices are the perforated hot air hydrophilic nonwoven for the skin-facing layer, the Fluff Pulp + SAP Absorbent Paper with 40% SAP for the absorbent layer, and 70% PE Film (not embossed) for the garment-facing layer. At the recommendation of our faculty advisor, a second layer of perforated hot air hydrophilic nonwoven will be included in the pad to minimize the potential of the user's skin interacting with the SAP (K. Polston, personal communication, October 24, 2018).

However, it may not always be possible to procure the primary fabric choices, so alternatives with similar qualities have been provided in Table 6 based on fabric testing, supplier recommendations, and Dr. Polston's evaluation. These alternatives can customize the quality of the pad. Per Tables 2-4, each of the alternatives has some disadvantages in the user experience compared to the primary selection, but they are still viable to be used in the low-cost pad.

Table 6. Alternative fabrics for each layer with primary fabrics shaded.

Layer	Fabric name	Supplier	Weight	Cost	Minimum Order	Validation
Skin-facing layer	Perforated hot air hydrophilic nonwoven	Quanzhou Xingyuan Supply Chain Co. (Quanzhou)	25 gsm	$4.95/kg	1000 kg	Testing
	Embossed hot air hydrophilic nonwoven	Quanzhou	25 gsm	$4.6/kg	1000 kg	Supplier/ Advisor
	Spunbound polypropylene trampoline fabric	Qingdao L&A Orient Nonwoven Manufacture Co.	30 gsm	$2.92/kg	1000 kg	Testing/ Advisor
Absorbent layer	Fluff pulp + SAP absorbent paper 40%	Quanzhou	120 gsm	$2.30/kg	1000 kg	Testing
	Tissue + SAP absorbent	Quanzhou	90 gsm	$2.50/kg	1000 kg	Testing
	Airlaid paper with SAP	Quanzhou	120 gsm	$2.50/kg	300 kg	Advisor
Garment-facing layer	70% PE film (not embossed)	Quanzhou	25 gsm	$1.95/kg	1000 kg	Testing
	100% PE film	Quanzhou	15 gsm	$2.25/kg	1000 kg	Testing
	Embossed 85% PE film	Quanzhou	25 gsm	$2.00/kg	1000 kg	Supplier/ Advisor
	85% PE film	Quanzhou	25 gsm	$2.30/km	1000 km	Supplier/ Advisor

3.2 Fabrication Process

With the final fabrics and leading concepts from Section 2.6 chosen, the team re-evaluated the function model. Figure 7 illustrates the evolved pad fabrication process. The first step is to remove the fabric from bulk rolls using a rotary cutter. Then, the fabric is passed through the roller-die to cut out the correct size. An operator will manually stack the layers inside the heat sealer, pressing the lid down for ten seconds with at least ten pounds-force to ensure an even seal. Then, the operator manually removes the pad, adds the double-sided tape, and places the pad inside the UV chamber for sanitation.

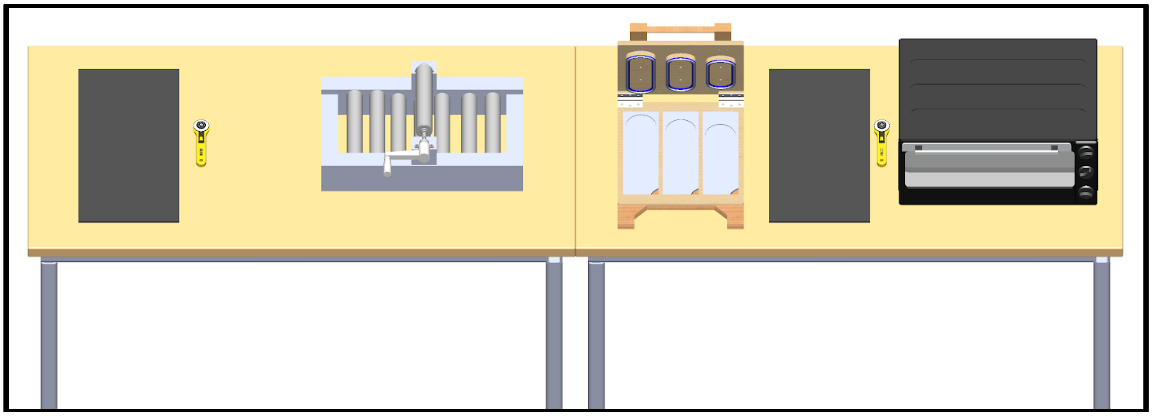

Figure 7. Updated pad fabrication process.

3.3 Roller-Die

A roller-die is commonly used in crafting and fabric industries to create shapes and patterns; for this project, it will cut out the shape of the skin- and garment-facing fabric layers. The design team selected an off-the-shelf Sizzix Big Shot Plus, shown in Figure 8, because it is intended for small business use consistent with our function and is strong enough to cut thin sheet metal (Sizzix, n.d.).

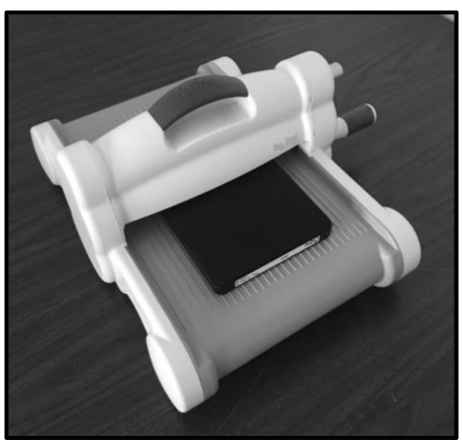

Figure 8. Sizzix Big Shot Plus.

Once the bulk fabric is separated from the roll, the operator stacks it on top of the die, a foam plate with an embedded blade in the shape of the pad. Two acrylic plates then sandwich these items, and the entire stack of materials passes through the roller-press. This off-the-shelf roller-die was an elegant solution for this project since it is manual, which employs the use of local labor as the IFRC requested, and the roller manufacturer creates custom dies. Further, our faculty advisor advocated for this solution over custom-engineered alternatives as it reduced the development complexity of this fabrication step (J. Ellzey, personal communication, October 5, 2018).

Sizzix has a two-week lead time to manufacture custom die shapes after final approval. To create the dies, the team examined commercially manufactured pads of different sizes for starting dimensions, optimized the measurements with SAP expansion testing, and sent sketches with these dimensions to Sizzix. Figure 9 shows the two dies the team created. Each pad is 3.5” wide, and the lengths are 9”, 10.5”, and 12” to replicate the size variance in commercial products. The dies are 8” wide, so two pads will fit on one die, which reduces manufacturing costs and fabric waste. Now that the team has established this relationship, it will be very easy for the IFRC to add more shapes and sizes later. Furthermore, since the dies are compact, a large number can go to a refugee site as a first response, and then the IFRC can exchange them between sites depending on the community’s preferences.

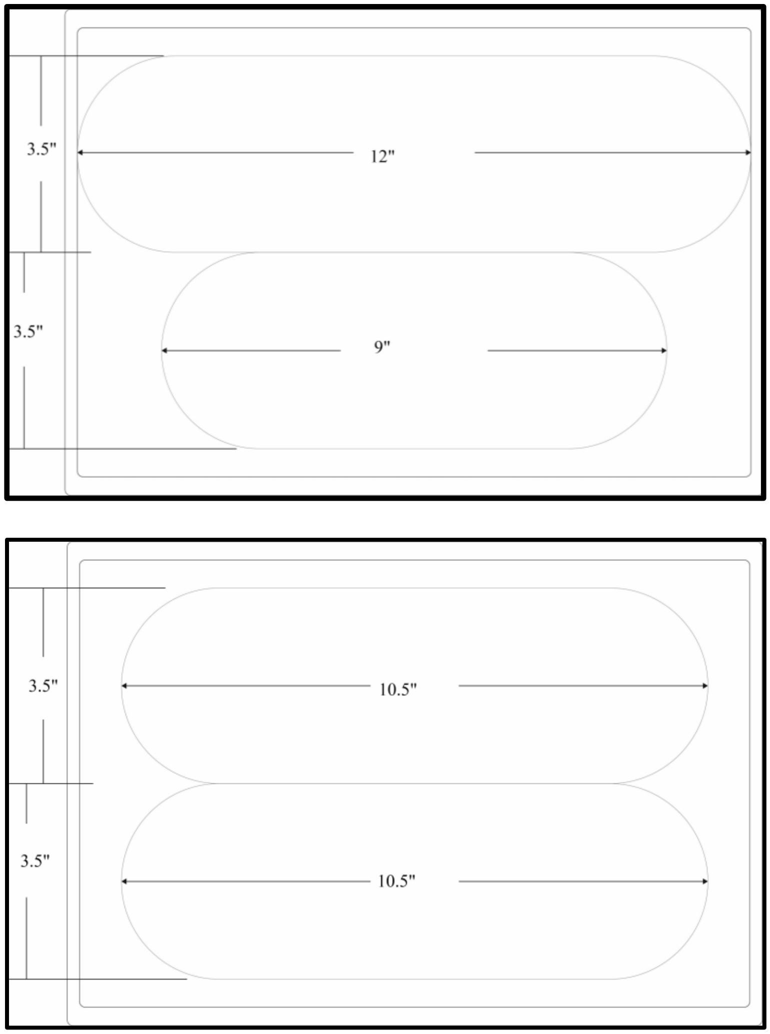

Figure 9. Die layouts.

To reduce cost and manufacturing complexity, the absorbent layer can remain a rectangle instead of the pill shape. According to our faculty advisor, Dr. Polston, commercially manufactured products are often made this way, and the IFRC can custom order the SAP paper to match the width of the die to minimize material waste. The absorbent layer must be slightly smaller than the outer layers to allow the fabrics to seal properly and allow room for the SAP to expand, as found in the team's low-resolution prototyping.

3.4 Heat Sealer

The team designed a custom solution for the heat sealer as we could not find an off-the-shelf thermoplastic heat sealer with customizable heating elements and curved edges. Figure 10 shows the model of the prototyped solution.

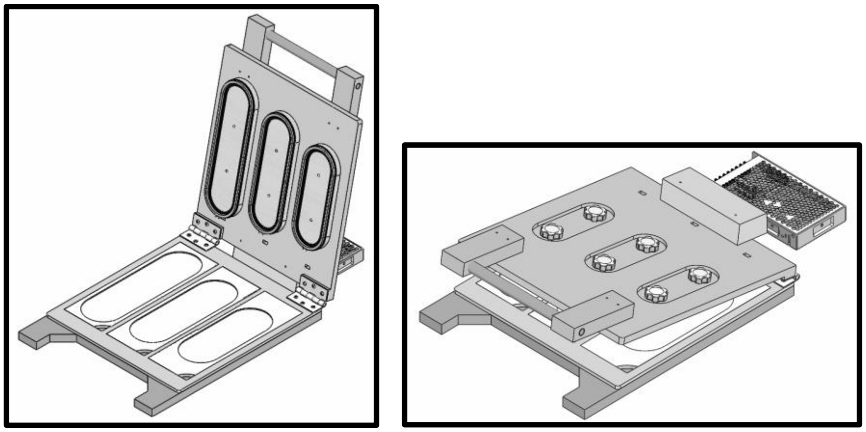

Figure 10. Heat sealer design.

3.4.1 Operation

The function of the heat sealer is to seal the edges of the outer pad materials using a steady state heating element. While the device is open, the operator places materials in the appropriate mold size in the following order: one garment-facing layer, one or two absorbent sheets depending on the desired absorbency, and then two skin-facing layers. A Pellon layer covers the pad materials to protect them from excessive heating and from sticking to the heating element. Then, the operator closes the lid for five seconds to allow the heat to join the materials. After five seconds, the operator opens the lid, rotate the mold with the pad materials 180° for complete seal coverage, close the lid for five more seconds, open the lid again, and remove the pad from the mold.

The device incorporates interchangeable mold trays and dies based on the user's desired pad size. Each cavity in the base plate of the heat sealer contains a removable mold with different sized cutouts per the different pad sizes, and a cutout that allows the user to easily lift and remove the mold when needed. The different sized dies match with corresponding molds. The dies are the most complex portion of the design and went through several iterations, so we discuss them in more detail in Section 3.4.4.

3.4.2 Usability

The user's interaction with the heat sealer called for special attention with the handle and the lid hardstop. For ease of use, the handle is eight inches wide which allows for at least one hand to fit comfortably with clearance. The hardstop is angled to allow the heat sealer to remain open at a 100° angle with respect to the heat sealer's base. This angle prevents the top plate from accidentally closing on the user if the heat sealer is bumped or moved.

Per our specifications, the heat sealer must withstand a 50 lbf load on its handle during operation without being unsafe for the user or causing excessive deformation that interferes with the heat sealer's functionality. The design team performed three analyses: tipping, top plate deflection, and a fastener check.

From the preliminary heat sealer design, we predicted the heat sealer would tip after applying the specified 50 lbf load due to the handle extending three inches past the base. In the tipping calculation, the heat sealer was modeled right before rotation occurs. The entire normal reaction the table supplies passed through the edge of the heat sealer's base, as seen in Figure 11. From the free-body diagram, the tipping moment was computed to be 4.31 lbf-ft, and the location where the normal reaction would create zero rotation due to the handling load and the heat sealer's weight is 1.04 inches to the left of the heat sealer's base. Therefore, the base needed to minimally be extended 1.04 inches to prevent rotation while operating. For an added measure of safety, we extended the base by three inches. Further explanation of the analysis can be found in Appendix B.

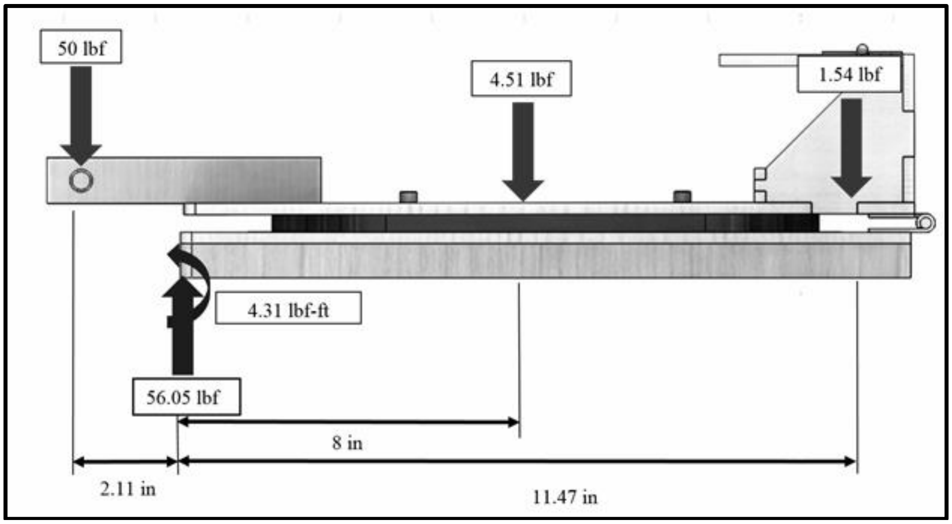

Figure 11. Free body diagram for tipping calculations.

The second analysis performed was to assess the deflection of the top plate. There is 1.39 inches of clearance between the handle and the base plate. The handling load cannot cause the top plate to deflect to interfere with the base plate as that would limit the device's ability to create a proper seal. We modeled the top plate as a cantilever beam with the hinged end fixed, as seen in Figure 12. To approximate a worst-case scenario and cover the range of possible deflections, we neglected the stiffening of the dies and the handle's moment of inertia. The wood is birch, and the "Paper Green" specification was chosen for conservatism because it had the lowest modulus of elasticity (Green, 1999).

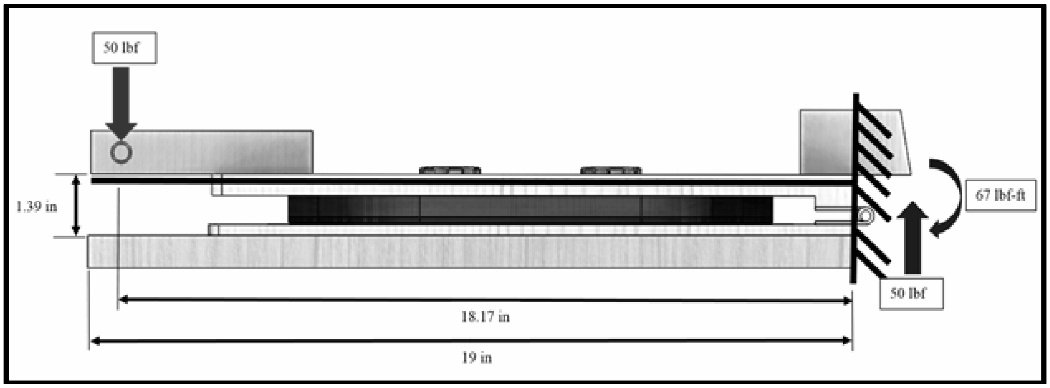

Figure 12. Free body diagram for top plate deflection of new heat sealer design.

If the top plate had a quarter inch thickness, it would deflect 4.66 inches with the handling load, clashing with the base plate. If the top plate's thickness increased to 0.5 inch, it would only deflect 0.58 inch. The 0.5 inch thick top plate was sufficient to prevent interference between the plates with the specified handling load. Further explanation of the analysis can be found in Appendix B.

Lastly, we analyzed the fasteners to ensure they could transfer the load from the handle to the top plate without failing. There are two fasteners on each handle support to secure the handle to the top plate. The handle was modeled as a cantilever beam because the fasteners prevent rotation and translation, as seen in Figure 13. To create the worst case scenario, this calculation placed the entire 50 lbf handling load on one arm to be reacted by a pair of fasteners. This is conservative since we anticipate the handling load be applied in the center of the handle and will be more evenly distributed between the two arms. The assumed failure mode is tension because the load due to shear is significantly less (Fastenal, 2009).

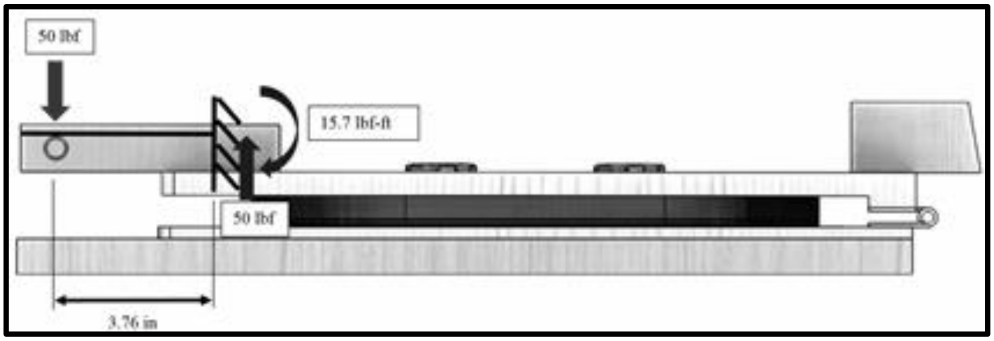

Figure 13. Free body diagram for fastener calculations.

There is a reaction of 50 lbf at the fastener location, and since there are two fasteners, each fastener must withstand 25 lbf in tension. A #8 zinc-plated steel screw with penetration depth of 0.625 inches in particle board has been tested to have an allowable tension of 265 lbf (Gates, 2009). Birch wood has a higher rupture modulus than particle board and the screw has a 1.25 inch penetration depth in the heat sealer (Youngquist, 1999). Therefore, the #8 screws used in the heat sealer will be sufficient by comparison to the tested case since they are inserted further into stronger material and will see a lower tensile load.

3.4.3 Steady-State Design

When developing the heat sealer, the team chose between an impulse-based sealer and a steady-state heat sealer. To make this selection, we analyzed the peak power consumption of the different sealing methods. We first determined the necessary voltage for impulse sealing to heat the nichrome wire to thermoplastic melting temperature within two seconds. The resistive heating analysis was based on an energy balance over finite time steps shown by equation (1) in which E_{in} represents the energy entering the nichrome wire from the power supply, which is directly proportional to the voltage, E_{rad}

represents losses to radiation, E_{conv} represents losses to convection, E_{stored} represents the stored energy within the wire, and δt represents the finite time step.

$$E_{in} = E_{conv}(\delta t) + E_{rad}(\delta t) + E_{stored}(\delta t) \quad (1)$$

This analysis resulted in the heating curve in Figure 14 for a 12 V power supply that shows the wire exceeds the thermoplastic temperature requirements of 277°F within 2 seconds of heating. Further detail on this analysis can be reviewed in Appendix B.

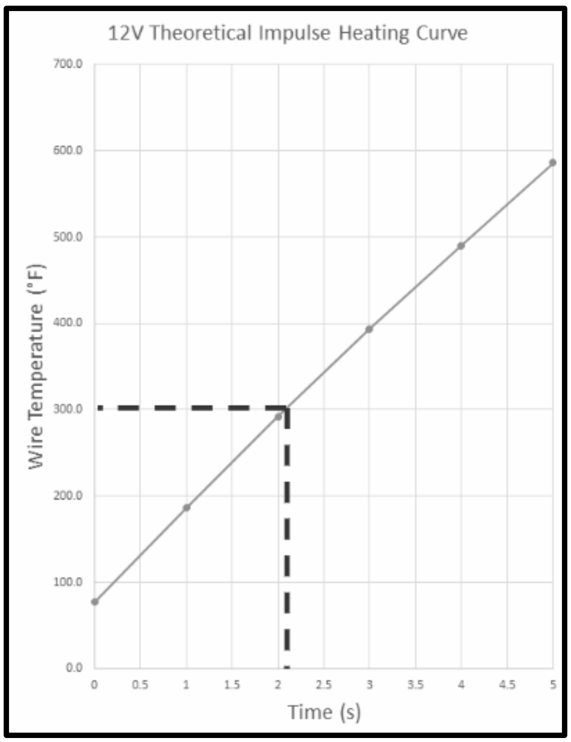

Figure 14. Resistive heating of nichrome wire with 12 V power supply.

The steady-state heat sealer required a 5 V power supply to achieve 300°F at steady-state based on empirical heating data provided by a nichrome wire supplier (Jacobs, n.d.).

With the required voltages determined for impulse and steady-state heat sealers and a known 0.61 Ω resistance through 16 American Wire Gauge (AWG) solid-core nichrome wire, equation (2) was used to compute the power load on each power supply with a 1.25 factor of safety. In the equation, P represents power, V is the power supply voltage, and R is the resistance of each wire.

$$P = \frac{1.25V^2}{R} \tag{2}$$

From the expected power consumption per heating element, we surveyed power supplies on DigiKey, an electronics supplier, and compared their cost as shown in Appendix D. Based on the research, a 5 V power supply was 82% cheaper than a 12 V power supply for three heating elements and would be far more cost effective if the device is scaled to include more elements in the future. Further, our advisor and sponsor recommended we pursue the steady-state heat sealing route after discussing this challenge (J. Ellzey, personal communication, October 24, 2018). Therefore, we purchased a 5 V 200 W power supply that accepts a 115 or 230 VAC input, making it compatible with voltage standards in the United States and Lebanon.

3.4.4 Die Design

The dies come in multiple sizes with corresponding heating elements that will seal the edges of the pad, and several other components for insulation and ease of use. We discuss the justification for the heating element design along with each component in detail in the following sections.

3.4.4.1 Heating Element Design

The heating element seals the outer edges of the pad. To develop this component, we shaped 16 AWG solid-core nichrome wire around a plastic 3D-printed mold as shown in Figure 15, then covered it with silicone potting with a cure time of 30 minutes.

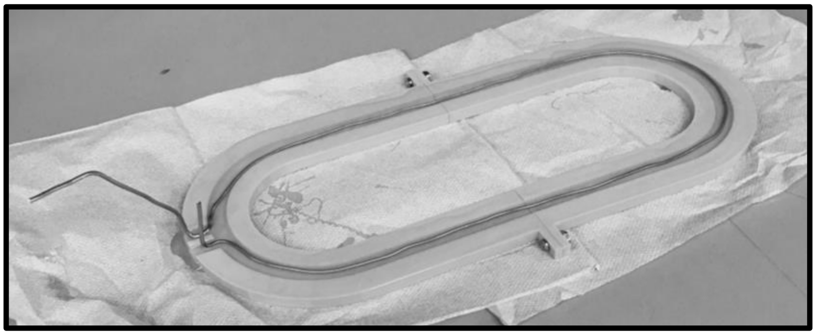

Figure 15. Mold for nichrome wire shaping and silicone setting.

The silicone potting encases the nichrome wire to enable the 0.25” seal width determined through testing in Section 2.4.

We found that the heating element surface must heat up to at least 300°F to exceed the 277°F melting temperature of the thermoplastic pad film (Wang, 2013). However, after trying to seal a pad, we observed sections that were not sealed. This indicated that the surface temperature of the heating element may not be uniform and was confirmed through experimentation shown on Figure 16 in which the unsealed areas of the pad matched the section of the heating element that were below 277°F.

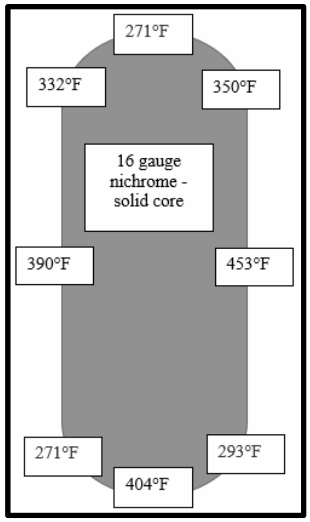

Figure 16. Temperature distribution around 16 AWG heating element.

We hypothesized that this was due to depth variation of the nichrome wire within the silicone potting. Based on analysis of unidirectional conductive heat transfer from the wire to the potting surface, we confirmed this hypothesis. Figure 17 shows that the temperature varies from 450°F to 250°F as the wire moves from the surface to 0.12 inches below.

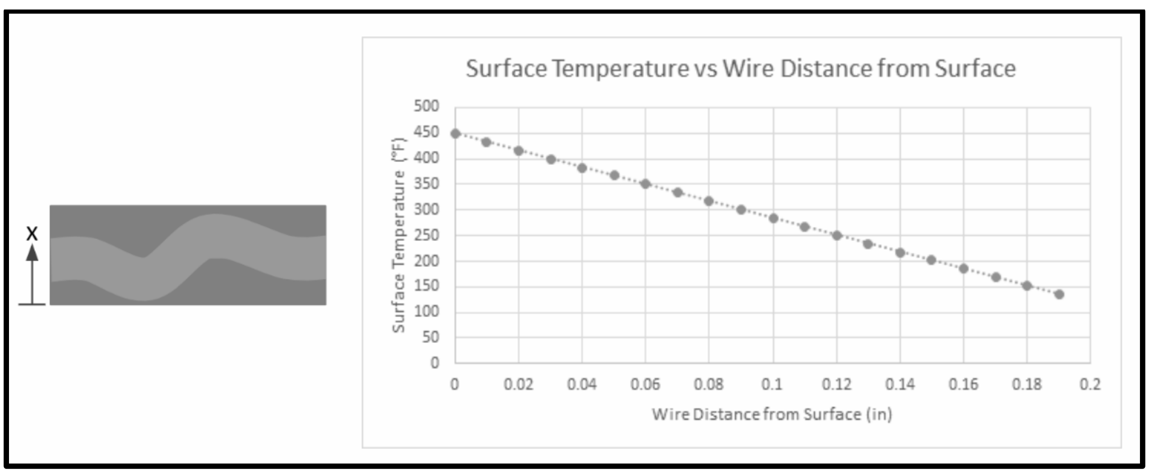

Figure 17. Silicone potting surface temperature as a function of wire distance.

After confirming variance in wire depth caused the heat sealing issue, we iteratively improved the design to use five to seven strands of loose 22 AWG nichrome wire that created the same effective resistance as the 16 AWG solid-core nichrome wire, 0.61Ω. By using 22 AWG wire, we improved the formability of the element by reducing the wire diameter and, therefore, the stiffness.

With the improved formability of loose 22 AWG nichrome wires, we prototyped heating elements that exceeded the target 300°F temperature thresholds, as shown in Figure 18.

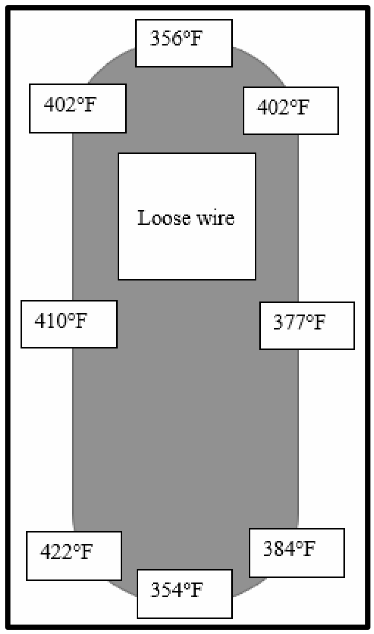

Figure 18. Temperature distribution around loose 22 AWG wire heating element.

While we developed a prototype solution for this problem, the manufacturing process of these heating elements requires improvement for scalability and reliability. For this reason, we have submitted a Request for Quote (RFQ) with Michaels Enterprise, a custom silicone heater manufacturer, per our specifications of the heating element that will be further discussed in Section 5.2.

3.4.4.2 Assembly

The heating element design is incorporated into the die assembly. Each die consists of four layers and are all equivalent in design except for varying size. The outermost component of the die is a threaded insert with a ¼"-20 thread to fit the thumb screws. The threaded inserts press fit into the wood per the supplier's instruction, using a match drilling technique for precision. A 0.5 inch thick piece of birch wood makes up the body of the die, an ideal material for its insulating properties and ease of construction. Next, a High-Temperature Silicone Sheet with a thickness of 0.125 inches insulates the nichrome wire heating element from the wooden die. It is cut to the width of the heating element to allow for varying pad thicknesses when the lid is closed. Hardman Fast Cure epoxy attaches the silicone sheet to the wood.

Lastly, the heating element consists of five to seven strands of 22 AWG nichrome wire. The wires are crimped at the ends where they connect to the power supply but are left loose within the silicone potting. The heating element is adhered to the high temperature silicone sheet using Sil-Poxy, a silicone-to-silicone adhesive.

The team conducted a thermal analysis of the die assembly to determine the validity of the materials and their thicknesses. The analysis assumed the device was at steady state, and heat generation from the heating element was constant and distributed on the entire area of the silicone sheet. For a conservative analysis, all of the heat generated from the heating element went through the die assembly. This assumption allowed the team to neglect any convection and radiation effects on the heating element side of the die. Equations (3)-(5) describe the temperature calculations between each layer in Figure 19. Appendix B provides more detail on this analysis.

$$P = \frac{Q_{gen}}{t} = VI \tag{3}$$

$$Q_{gen} = Q_{conduction,silicone} = \frac{-kA(T_2 - T_1)}{L} \tag{4}$$

$$Q_{conduction,wood} = Q_{convection}; \frac{-kA(T_3 - T_2)}{L} = hA(T_3 - T_\infty) \tag{5}$$

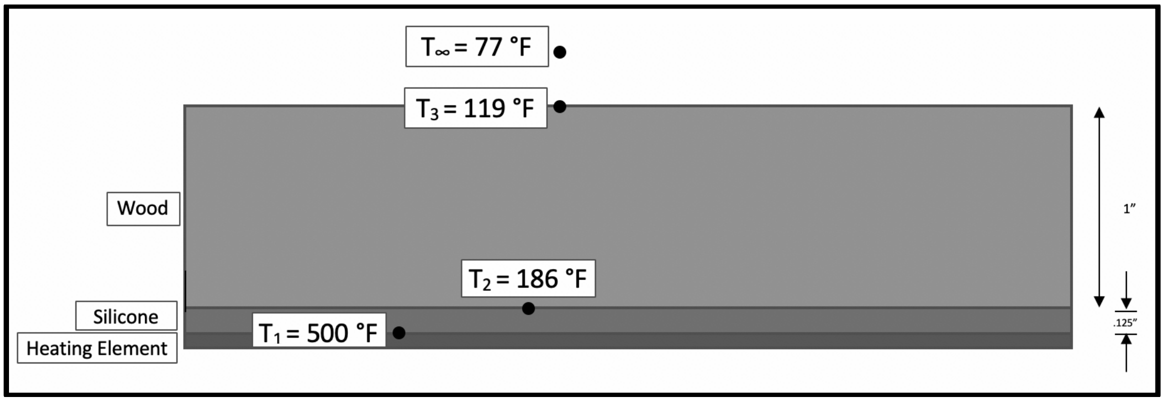

Figure 19. Thermal calculation results.

From the results of the analysis shown in Figure 19, the temperature on top of the lid at steady state will not exceed 119 °F. This is a safe temperature for the user to handle during the pad manufacturing process (ASTM, 1999), so the team made no changes to the die design. We later verified these calculations during a steady state heating experiment. Measuring the top of the lid with a thermocouple confirmed the wood only reached 96°F after the machine was on for 15 minutes.

3.5 UV Chamber

The operator manually applies an adhesive backing before the final step: sanitation in a UV chamber. The product shown in Figure 20 contains a removable shelf and reflective walls to sanitize eight pads at once. The UV bulb sanitizes the fabric within 60 seconds.

Figure 20. Ultraviolet Sterilizer Cabinet (Salon Sundry, n.d.).

UV chambers like this often clean and sterilize salon or medical tools. The bulb emits light at a wavelength of 254 nm, which kills 99% of microorganisms, and operates for 8,000-10,000 hours with only 11 watts of power consumption. The entire chamber weighs less than 15 pounds, takes up less than one square-foot of space, and only costs $84.99 (Salon Sundry, n.d.). This makes it a cost effective, validated solution the IFRC can easily purchase.

4 ECONOMIC ANALYSIS

4.1 Cost Per Pad Calculations

From the team's investigation, commercial pads cost $0.12-0.14 each. Our pads must be manufacturable at a similar or lower cost to be a valid alternative to commercial pads. Table 7 summarizes the cost calculations using the primary fabric selections at 50%

and 100% efficiency. Even with 50% fabric waste, the manufacturing cost is still within 20% of that goal, and most of that cost comes from the adhesive backing. We do not foresee a 50% waste of tape occurring, since it only requires one straight cut to use. We also anticipate the unit price will decrease once it is purchased in bulk.

Table 7. Cost per pad based on bulk material and shipping prices.

Description	Size	Minimum Order Quantity	Application	Unit Price	Cost/Pad 100% Efficient	Cost/Pad 50% Efficient
White 70% PE film	25 gsm	1000 kg	Garment-facing layer	$1.95/kg	$0.0013	$0.0026
Perforated hot air hydrophilic nonwoven	25 gsm	1000 kg	Skin-facing layer (x2)	$4.95/kg	$0.008	$0.016
40% SAP absorbent paper	120 gsm	1000 kg	Absorbent core	$2.50/kg	$0.0079	$0.0158
Alvin double-sided tape	1" by 36 yds	36 yds	Adhesive backing	$14.89/roll	$0.07	$0.14
				Material Cost Total	**$0.09**	**$0.17**

These are also conservative estimates, based on using only the largest pad dimensions, where the outer layers are 3.5”x12” and the absorbent layer is 2.25”x10”. The total cost accounts for two layers of the perforated hot air hydrophilic nonwoven determined from testing, the $1/kg shipping cost for a shipping container of 3500 kg of fabric, and six inches of tape as the adhesive backing. We can also adjust the amount of adhesive, which could further reduce the cost per pad and meet our quality factor of customizability.

4.2 Prototype Cost Estimation

Over the course of the semester, the design team spent $945.52 to prototype, test, and iterate our device. Excluding the development costs of test materials, the price to build the low-cost pad fabrication prototype is $768.38. The cost includes the roller press with two custom cutting dies, a custom-prototyped heat sealer, a UV chamber, and peripheral tools for raw material preparation. These estimations do not account for the costs of the workspace and workbench. A detailed Bill of Materials (BOM) can be reviewed in Appendix E.

4.3 Production Output

This device needed to make at least 100 pads per day, so the team timed the duration of each step and added 10 seconds to each step to make a more conservative estimate. The results of this procedure are displayed in Table 8.

Table 8. Production rate of each step.

Process Step	Pads/Step	Time/Step (s)	Production Rate (pads/s)
Prepare material	4	40	0.1
Cut material with roller-die	4	60	0.07
Stack layers in heat sealer	3	45	0.02
Sealing	3	20	0.15
Apply adhesive backing	1	10	0.10
Sanitization	10	60	0.17

We have custom-ordered the skin- and garment-facing fabrics to be twice the cutting-die width, so the fabrics can be folded in half and cut at the same time. The operator should include two folded sheets of the skin-facing fabric, since we need two layers of this per pad. This results in four sets of outer layers, but the present heat sealer can only seal three pads at a time. As the limiting production rate is the stacking step, at 0.02 pads per second, this production rate was extrapolated over the course of an eight-hour day to estimate that approximately 570 pads could be produced per day.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Evaluation of Solution

The design team's solution meets all engineering specifications in Table 1. Our functional prototype demonstrates the ability to customize size with different cutting dies and corresponding heating elements, fluid retention with quantity of absorbent layers, and quality with alternative fabric options. From low-resolution testing, a single sheet of the chosen SAP paper can retain 2.4 fluid ounces of water, which the user can adjust by adding another sheet to provide up to 5 fluid ounces of absorption. The three overarching subassemblies are: the roller-die, the custom-built heat sealer, and the UV chamber. The chosen UV chamber fulfills the sanitation requirement. Further, based on our interaction with the device, it takes 10 lbf to operate the device, and we estimate 60 minutes of training time, well within the requirements. We will be conducting training with the HERS team, who will be implementing the device in Lebanon in summer 2019, on December 10, 2018 for a more accurate training metric.

Through the production output study, assuming a linear relationship we can project the machine will make 570 pads per day using 100% bulk-sourceable materials. The UV chamber is the heaviest component, weighing 13.7 pounds, and the entire process with all stations fits in a 132 square-foot area, making it easily transportable and viable to set up in areas with limited space.

5.2 Recommended Improvements

We successfully fulfilled the requirements of this semester's work and provided the deliverables necessary to continue the improvement of the fabrication process towards implementation. This section outlines the features that the team recommends focusing on improving.

The heating element is the most critical subcomponent of the heat sealer; without it the fabrics will not seal, so the next design team should focus on improving this component first. In its current state, the heating element is difficult to manufacture due to the loose wires, and using the silicone potting is time consuming. For scalability, it would be simpler and more reliable to outsource this process to a company that manufactures custom silicone heaters such as Michaels Enterprises Inc. If this solution is not cost effective, the team should create a pegboard-like tool to help shape the nichrome wire before placing it in the 3D-printed mold with silicone potting.

Safety features could be incorporated in the heat sealer. Adding a timing circuit to indicate when the seal is complete may improve the manufacturing process, and reduce the risk of burning the fabrics. We created a circuit with this function when we were considering an impulse based heat sealer and have included the diagram in Appendix F.

The team identified a concept solution of a paper towel holder to organize and dispense the bulk fabric rolls with the guidance of our faculty advisor (K. Polston, personal communication, November 19, 2018). Structural analysis and design needs to be conducted to develop this subsystem.

Finally, to incorporate this product globally where there may be limited access to electricity, it is necessary to add a renewable power source. The prototyped heat sealer and UV chamber consume a combined 1.2 kilowatt-hours over a full day, which a solar panel or similar device can reasonably produce (Zientara, 2018).

5.3 Next Steps Toward Lebanon

In January 2019, the HERS team, under the supervision of Dr. Ellzey, will begin performing surveys with local Syrian refugees to get their feedback on pad features including shape, size, and material preference. These suggestions should be incorporated into the pad design in order to appropriately meet user needs. The current fabrication prototype is highly modular, so these changes should only involve changing the heating elements and working with Sizzix for new die designs. The design team also recommends that the HERS team performs studies with the Syrian refugee communities on the ease of operation of the pad fabrication devices. These studies will provide insight into critical safety feature needs and production optimizations that the spring 2019 design team should make.

Once the functional prototype has gone through another round of optimizations and improvements, the HERS team will test the device in Lebanon with a small Syrian refugee community to validate the prototype before implementation at scale. For this trip to Lebanon, the design team advises the HERS team to take spare heat sealer dies with them. This includes the complete heating element, silicone sheet and wood assembly with threaded inserts. In the event a heating element malfunctions, the team can easily replace the entire die without interrupting production. With these improvements, the design team's solution will effectively produce customizable pads for Syrian refugees, and the IFRC can use the data collected in this report to scale the prototype for global communities.

REFERENCES

Always (n.d.). What Ingredients are in Always Pads? Retrieved from https://always.com/en-us/about-us/what-ingredients-are-in-always-pads

ASTM. (1999). Standard Guide for Heated System Surface Conditions That Produce Contact Burn Injuries. *Annual Book of ASTM Standards*. Designation: C 1055 – 99

Brooks, D., Selvy, A. (2013). Basics of Ceramic Heaters. *Machine Design.*

Cole, S. K., Billewicz, W. Z., & Thomson, A. M. (1972). Sources Of Variation In Menstrual Blood Loss. *Obstetrical & Gynecological Survey, 27*(6), 448-449. doi:10.1097/00006254-197206000-00017

CVS pharmacy. (n.d.). Retrieved September 17, 2018, from https://www.cvs.com/shop/personal-care/feminine-care/pads?page=3

Fastenal Engineering Design Support. (2009). *Mechanical Properties of Steel Fasteners in Service.* Bolted Joint Design. 3-4.

Gates, J. C. (2009). Test Evaluation Report. *Screw Withdrawal Strength in 9Wood's Assemblies,*1-28. Retrieved November 24, 2018, from https://www.9wood.com/files/rd_reports/screw_withdrawl.pdf.

Green, David W.; Winandy, Jerrold E.; Kretschmann, David E. 1999. Mechanical properties of wood. Wood handbook : wood as an engineering material. Madison, WI : USDA Forest Service, Forest Products Laboratory, 1999. General technical report FPL ; GTR-113: Pages 4.1-4.45

International Federation of Red Cross and Red Crescent Societies. (n.d.). International Federation. Retrieved September 17, 2018, from https://media.ifrc.org/ifrc/

International Federation of Red Cross and Red Crescent Societies. (n.d.). Our stock. Retrieved September 17, 2018, from http://www.ifrc.org/en/what-we-do/logistics/procurement/who-we-are/our-stock/

International Federation of Red Cross and Red Crescent Societies. (n.d.). Syria crisis. Retrieved September 17, 2018, from http://www.ifrc.org/syria-crisis

Incropera, F. P., Dewitt, D. P., Bergman, T. L., & Lavine, A. S. (n.d.). Appendix A: Thermophysical Properties of Matter. In *Fundamentals of Heat and Mass Transfer*(6th ed., pp. 929-953).

Jacobs Online. (n.d.). Nichrome Wire Resistance Wire. Retrieved on October 31, 2018 from https://www.jacobs-online.biz/nichrome/NichromeCalc.html

Jones, J. (1975). Method of Making Menstrual Napkins. U.S. Patent No. 3,878,283. Washington, DC: U.S. Patent and Trademark Office.

Lebanese Red Cross Disaster Management Unit. (2017). *WEK Monitoring and Evaluation Report.* Unpublished manuscript.

Materials Database. (n.d.). Retrieved from https://thermtest.com/materials-database-popup/

Materials Handling: Pushing, Pulling, and Carrying. (n.d.). Retrieved from https://www.osha.gov/SLTC/etools/electricalcontractors/materials/pushing.html

Messina, G., Burgassi, S., Messina, D., Montagnani, V., & Cevenini, G. (2015). A new UV-LED device for automatic disinfection of stethoscope membranes. *American Journal of Infection Control,43*(10). doi:10.1016/j.ajic.2015.06.019

Mohamed et al. (2014). The effect of wearing sanitary napkins of different thicknesses on physiological and psychological responses in Muslim females. *Journal of Physiological Anthropology, 33(28)*

Muruganantham, A. (2009). India Patent No. 1827/CHE/2008. Coimbatore, Tamil Nadu: National Innovation Foundation - India.

Professional Tabletop Ultraviolet UV Sterilizer Cabinet 609728828431 (Salon Sundry).

Schmitt et al. (2017). Understanding the menstrual hygiene management challenges facing displaced girls and women: findings from qualitative assessments in Myanmar and Lebanon. *Conflict and Health, 11(19).*

Sizzix (n.d.). Retrieved October 29, 2018 from https://www.sizzix.com/big-shot-plus.

TEMCo Industrial. (2017). Nichrome Wire. Retrieved October 10, 2018, from https://temcoindustrial.com/product-guides/wire-cable-and-accessories/resistance-and-non-resistance-wire/nichrome-wire

Venema, Vibeke. (2014, March 4). *The Indian sanitary pad revolution.* Retrieved from https://www.bbc.com/news/magazine-26260978

Wang et al. (2013). Melting behavior of typical thermoplastic materials--an experimental and chemical kinetics study. *Journal of Hazardous Materials, 15(262).*

Whitelaw, J. H. (2011, February 2). CONVECTIVE HEAT TRANSFER. Retrieved from http://www.thermopedia.com/content/660/

Whiteside, J. D., PE (Producer). (2018, March 30). *Calculating Wire Temperature is Not Complicated (nichrome example)*[Video file]. Retrieved October 10, 2018, from https://www.youtube.com/watch?v=QNS0LrlRHbs

Wright, D. R. (1982). U.S. Patent No. 4359361. Washington, DC: U.S. Patent and Trademark Office.

Youngquist, John A. 1999. Wood-based composites and panel products. Wood handbook: wood as an engineering material. Madison, WI : USDA Appendix

Zientara, B. (2018, August 07). How much electricity does a solar panel produce? Retrieved from https://www.solarpowerrocks.com/solar-basics/how-much-electricity-does-a-solar-panel-produce/

APPENDIX A: GANTT CHART

Task	Subtask	Status	Owner	9/10	9/12	9/17	9/19	9/24	9/26	10/1	10/3	10/8	10/10	10/15	10/17	10/22	10/24	10/29	10/31	11/5	11/7	11/12	11/14	11/19	11/21	11/26	11/28	12/3	12/5
Hard Deadlines	Oral problem statement	Complete	All	09/10																									
	Gantt chart	In Progress	All			9/17																							
	Project proposal due to TA	Complete	All				9/19																						
	Final project proposal	Complete	All				9/21																						
	Oral project proposal	Complete	All						9/26																				
	Agreement on proposal from sponsor	Complete	All								10/5																		
	Notebook/Gantt check	Complete	All									10/8																	
	Oral design review	Complete	All											10/15															
	Oral design revision	Complete	All													10/22													
	Notebook	Complete	All															10/29											
	Synopsis form	Complete	Andrea & Sid																		11/7								
	Written design review	Complete	Andrea																	11/5									
	Send design reviews to sponsors	Complete	Sid																			11/12							
	Outline of final report due	Complete	Andrea & Sid																				11/14						
	Final oral presentation	Complete	All																								11/28		
	Webshot	Complete	Andrea																									12/5	
	Final written report	Complete	All																									12/4	
Task Clarification	Meeting with IFRC	Complete	All																										
	Research cultural needs	Complete	Andrea																										
	Customer Needs	Complete	Andrea																										
	Determine bulk materials for absorbent layer	Complete	Claire																										
	Determine bulk materials for skin facing layer	Complete	Pratik																										
	Determine bulk materials for garment facing layer	Complete	Andrea																										
	Determine feasible joining methods for layers	Complete	Sid																										
	Determine adhesive for wings	Complete	Sid																										
	Determine what to sterilize and to what extent	Complete	Pratik																										
	Specification sheet	Complete	Pratik & Sid																										
Concept Generation	Mindmapping	Complete	All																										
	4-3-5	Complete	All																										
	Black box model	Complete	Claire																										
	Function modeling	Complete	Sid																										
	Design by analogy	Complete	Pratik																										
	Patent search	Complete	Andrea																										
	Pugh Chart for concept selection	Complete	All																										
Prototyping	Select textile/adhesives to order/purchase	Complete	All																										
	Review selections with project advisors	Complete	All																										
	Order textiles/adhesives	Complete	Claire																										
	Low-resolution testing of pad-making viability	Complete	Pratik & Claire																										
	Engineering calculations/analysis	Complete	All																										
	3D modeling	Complete	Andrea, Sid, Pratik																										
	Select parts/make BOM	Complete	Andrea & Claire																										
	Test nichrome wire heating	Complete	Sid																										
	Prototype electronics	Complete	Sid																										
	Review design with faculty advisors	Complete	All																										
	Review design with IFRC	Complete	All																										
	Order parts	Complete	Andrea & Pratik																										
Refinement	Build mechanical assembly	Complete	Pratik																										
	Build electrical assembly	Complete	Sid																										
	Custom die coordination and ordering	Complete	Andrea																										
	Test to verify the design is meeting specifications	Complete	All																										
	Analyze results and iterate through improvements	Complete	All																										
	HERS team training	Complete	Andrea & Claire																										
	Fluid/process testing	Complete	Andrea & Claire																										

Figure A.1. Gantt chart.

APPENDIX B: CALCULATIONS

B.1 Tipping Calculations

Objective:

- Determine the optimal base length that prevents tipping when handling load is applied.

Assumption:

- The original heat sealer is modeled right before rotation occurs, where the normal reaction from the table is passing through the edge of the heat sealer's base.

Constraints:

- The 50 lbf handling load cannot cause the heat sealer to rotate during operation.

Original Heat Sealer:

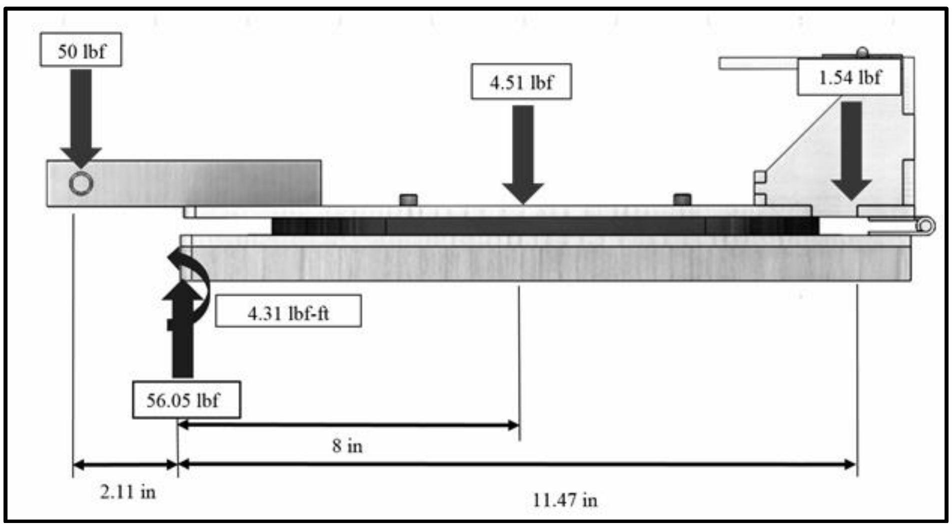

Figure B.1.1. Free body diagram for tipping calculations with old heat sealer design.

Moment at edge of heat sealer:

$$M_{edge} = (50\ lbf)\left(\frac{2.11\ in}{12\ in}\right) - (4.51\ lbf)\left(\frac{8\ in}{12\ in}\right) - (1.54\ lbf)\left(\frac{11.47\ in}{12\ in}\right)$$

$$M_{edge} = 4.31\ lbf - ft$$

Updated Heat Sealer Design:

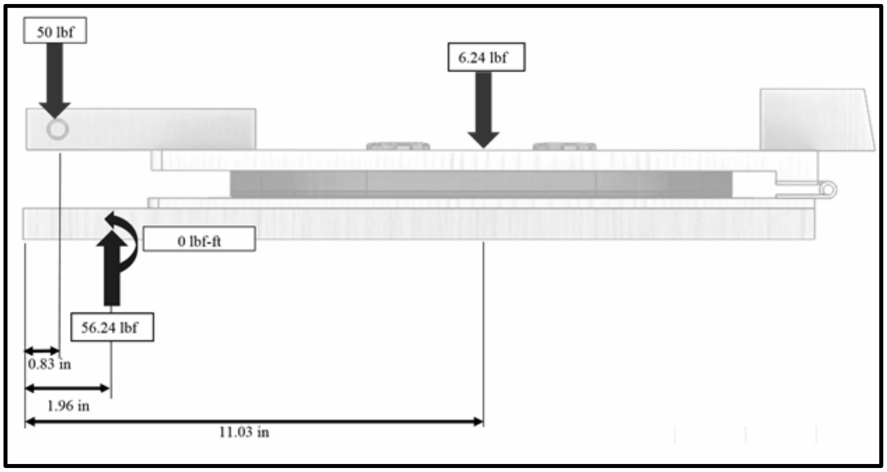

Figure B.1.2. Free body diagram for tipping calculations with new heat sealer design.

Location of 0 rotation:

$$M_x = (50\ lbf)\left(x - \frac{0.83\ in}{12\ in}\right) - (6.24\ lbf)\left(\frac{11.03\ in}{12\ in} - x\right)$$

$x = 1.96\ in$

<u>Conclusions:</u>

- The heat sealer's base must extend at least 1.04 inches from the front edge to prevent rotation.
- The new heat sealer's base extends 3 inches from the front edge of the base and is good by comparison.

B.2 Top Plate Deflection Calculations

<u>Objective:</u>

- Determine the top plate thickness to prevent interference with base plate when handling load is applied.

<u>Assumptions:</u>

- Top plate modeled as cantilever beam with hinged end acting as fixed end because it prevents translation and rotation when lid is closed.
- For worst case scenario, beneficial stiffening effects of die were ignored.
- For worst case scenario, beneficial effects of change in moment of inertia from top plate to handle are ignored.
- For worst case scenario, birch wood assumed to be "Paper Green," which has the lowest modulus of elasticity.

<u>Constraint:</u>

- The top plate must not deflect more than 1.39 inches.

Table B.2.1. Properties of heat sealer (Green, 1999).

Single Layer Lid	**Values**	**Double Layer Lid**	**Values**
Thickness (in.)	0.25	Thickness (in.)	0.5
a (in.)	18.17	a (in.)	18.17
Length (in.)	19	Length (in.)	19
Width (in.)	15	Width (in.)	15
I_z (in^4)	0.0195	I_z (in^4)	0.1563
Wood	Birch Paper Green	Wood	Birch Paper Green
E (MPa)	8100	E (MPa)	8100
E (lbf/in^2)	1174805.37	E (lbf/in^2)	1174805.37
F (lbf)	50	F (lbf)	50
δ_{max} (in.)	4.66	δ_{max} (in.)	0.58
Clearance b/w Lid and Base (in.)	1.39	Clearance b/w Lid and Base (in.)	1.39
Interference?	Yes	Interference?	No

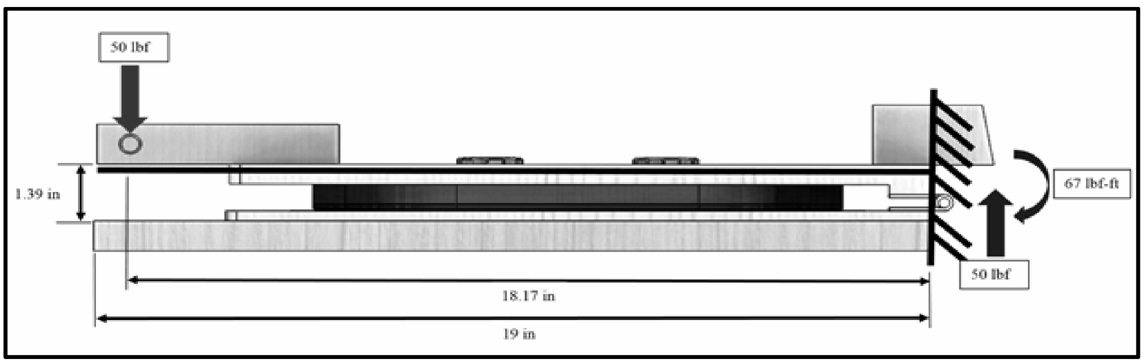

Figure B.2.1. Free body diagram of top plate bending calculations.

Top Plate Moment of Inertia:

Single Layer

$$I_x = \frac{1}{12} bh^3 = \frac{1}{12}(15\ in)(0.25\ in)^3 = 0.0195\ in^4$$

Double Layer

$$I_x = \frac{1}{12} bh^3 = \frac{1}{12}(15\ in)(0.5\ in)^3 = 0.1563\ in^4$$

Top Plate Deflection:

Single Layer

$$\delta_{max} = \frac{Pa^2}{6EI_z}(3l - a)$$

$$\delta_{max} = \frac{(50\ lbf)(18.17\ in)^2}{6\left(1174805\ \frac{lbf}{in^2}\right)(0.0195\ in^4)}(3(19\ in) - 18.17\ in)$$

$$\delta_{max} = 4.66\ in$$

Double Layer

$$\delta_{max} = \frac{Pa^2}{6EI_z}(3l - a)$$

$$\delta_{max} = \frac{(50\ lbf)(18.17\ in)^2}{6\left(1174805\ \frac{lbf}{in^2}\right)(0.1563\ in^4)}(3(19\ in) - 18.17\ in) =$$

$$\delta_{max} = 0.58\ in$$

<u>Conclusion:</u>

- A 0.5 inch thick top plate will deflect 0.58 inches and will not interfere with the base plate.

B.3 Fastener Calculations

<u>Objective:</u>

- Determine an acceptable fastener to react out the applied handling force.

<u>Assumptions:</u>

- Handle is modeled as a cantilever beam with fastened end acting as fixed end because fasteners prevent translation and rotation.
- For worst case scenario, 50 lbf handling force applied to only one handle arm.
- Fasteners will support the load equally.
- Failure mode is fastener pull-out due to tension because shear loads are so low (Fastenal, 2009).

<u>Constraints:</u>

- Two fasteners must react out the 50 lbf handling load in both tension and shear without failure of the fastener’s or handle’s functionality.

Figure B.3.1. Free body diagram for fastener calculations.

Fixed End Reactions:
Axial

$$F_y = 0 = -P + R_{fastener} = -50\ lbf - R_{fastener}$$
$$R_{fastener} = 50\ lbf$$

Moment

$$M_{fixed\ end} = 0 = P(x_{handle}) - M_{fasteners}$$
$$M_{fixed\ end} = 0 = (50\ lbf)\left(\frac{3.76\ in}{12\ in}\right) - M_{fasteners}$$
$$M_{fasteners} = 15.67\ lbf - ft$$

Single Shear Load on Fastener:

$$M_{single\ fastener} = \frac{(15.67\ lbf - ft)\ (12)}{2} = 94.02\ lbf$$
$$\sigma = \frac{Mc}{I} = \frac{(94.02\ lbf - in)(0.25\ in)}{0.167\ in^4} = 140.75\ psi$$
$$P_{single\ shear} = \frac{\sigma \pi d^2}{4} = \frac{(140.75\ psi)\pi(\frac{5}{32}\ in)^2}{4} = 2.70\ lbf$$

<u>Conclusions:</u>

- Tension is the critical loading case on the fasteners.
- 2 #8 zinc plated self-piercing point sheet metal screws provide enough margin to react out the 50 lbf handling load in tension (Gates, 2009).

B.4 Nichrome Wire

<u>Objective:</u>

- Determine the necessary voltage to heat a 16 AWG nichrome wire to 300°F within 2-4 seconds.

<u>Assumptions:</u>

- Heat loss due to convection and radiation.
- Heat loss due to conduction by the silicone sheet and wood is ignored.
- Values for convection constant and emissivity constant are interpolated from a graph to apply to bounded temperature regions.
- Nichrome 80 wire is used.

- Effects of temperature on the heat capacity of the nichrome wire is ignored.

<u>Constraint:</u>

- Solid core 16 AWG nichrome wire.

Energy Loss:

$$E_{in} = E_{conv}(\delta_t) + E_{rad}(\delta_t) + E_{stored}(\delta_t)$$

Expanded Energy Form:

$$I^2R(\delta_t) = hA(T_{n-1} - T_0)(\delta_t) + \varepsilon\sigma A\left({T_{n-1}}^4 - {T_{amb}}^4\right)(\delta_t) + mC_p(T_{n-1} - T_0)(\delta_t)$$

Table B.4.1. Energy input constants for heating curve calculations (TEMCo Industrial, 2017).

E_{in}	
I (A)	19.06
R (Ω)	0.63
dt (s)	1
V (V)	12
R/ft (Ω/ft)	0.2519

Table B.4.2. Energy loss constants for heating curve calculations (TEMCo Industrial, 2017).

E_{store}		**E_{conv}**		**E_{rad}**	
m (kg)	0.00839	h (W/m^2K^4)	Refer to Table B.4.2	ε	Refer to Table B.4.2
C_p (J/kgC)	461	A (m^2)	0.00309	σ (W/m^2K)	5.67E-08
T_0 (°C)	25	T_0 (°C)	25	A	0.00309
ρ (kg/m^3)	8415	dt (s)	1	T_0 (K)	298.15
L (m)	0.762			dt (s)	1
Ø (m)	0.001291				
AWG	16				

Table B.4.3. Temperature-dependent variables for calculating heating curve (Whiteside, 2018).

16 AWG Nichrome Wire			
T (°C)	h (W/m^2K)	T (°C)	ε
<37	18.75	0<T<200	0.65
37<T<120.5	25	200<T<400	0.775
120.5<T<204	37.5		
204<T<1093	25		

Conclusion:

- Model is extremely sensitive to the resistance. Experimental tests need to be conducted to validate model.
- In theory, a 12 volt power supply can raise the temperature of nichrome wire from room temperature to 300°F in 2 seconds.

B.5 Thermal Analysis

Objective:

- Determine if the temperature of the top surface of the device is safe to touch during operation.

Assumptions:

- Steady state heating.
- Uniform conduction profile.
- Neglect losses due to convection and radiation.
- Assume a 10 A draw from the power supply at 5 V for steady state heat sealer.

Constraints:

- The top level of the wood exposed to the air shall not exceed 122°F or 50°C if contact is made for 100 seconds, according to ASTM C1055 (threshold B, reversible epidermal injury, figure 1 from ASTM C1055).
- User should be able to place hand on wood for a brief amount of time (5-20 seconds) to manufacture pad.

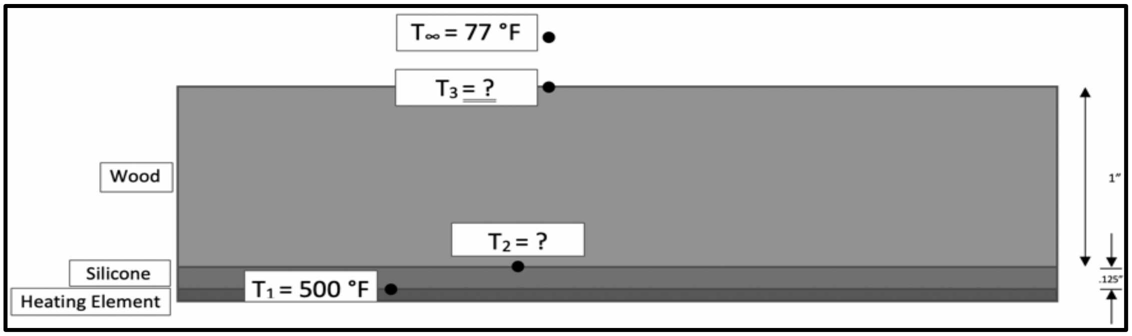

Figure B.5.1. Known conditions for thermal analysis.

Geometry of small die design:

Table B.5.1. Dimensions for the small die and silicone cutout.

Small Wooden Die Dimensions		**Silicone Cutout Dimensions**	
Parameter	Value	Parameter	Value
Width (in)	3.5	Width (in)	2.5
Length (in)	9	Length (in)	8
Radius (in)	1.75	Radius (in)	1.25

Area of Small Wooden Die

$$A_{Small\ Wooden\ Die} = (L - 2R)(W) + \pi R^2$$

$$A_{Small\ Wooden\ Die} = (9\ in - 2 * 1.75\ in)(3.5\ in) + \pi(1.75\ in)^2$$

$$A_{Small\ Wooden\ Die} = 28.87\ in^2$$

Area of Silicone Cutout

$$A_{Silicone\ Cutout} = (L - 2R)(W) + \pi R^2$$

$$A_{Silicone\ Cutout} = (8\ in - 2 * 1.25\ in)(2.5\ in) + \pi(1.25\ in)^2$$

$$A_{Silicone\ Cutout} = 18.66\ in^2$$

Effective Area:

$$A_{effective} = 28.87\ in^2 - 18.66\ in^2 = 10.21\ in^2 = 0.00659\ m^2$$

Power generation of one nichrome wire heating element:

$$P = \frac{Q_{gen}}{t} = VI = (5\,V)(10\,A) = 50\,W$$

Temperature Profile:

Table B.5.2. Values for calculating T_2 and T_3.

Values for calculating T_2		**Values for calculating T_3**	
Parameter	Value	Parameter	Value
k (W/mK) (low k silicone rubber)*	0.138	k (W/mK) (hardwood, birch is a hardwood)**	0.16
Effective Area (m^2)	0.00659	h (W/m^2K) (low speed forced convection)***	10
T_1(°C)	260	Wooden Die Area (m^2)	0.018626
L (Thickness of of silicone) (m)	0.003175		

*(Materials Database, n.d.).
**(Whitelaw, 2011)
***(Incropera, Dewitt, Bergman, & Lavine, n.d.).

Find T_2

$$Q_{gen} = Q_{conduction,\ silicone} = \frac{-kA(T_2 - T_1)}{L}$$

$$\frac{-(0.138\ \frac{W}{mk})(0.006589\ m^2)(T_2 - 260°C)}{0.003175\ m} = 50\ W$$

$$T_2 = 85.41°C$$

Find T_3:

$$Q_{conduction,\ wood} = Q_{convection}$$

$$\frac{-kA(T_3 - T_2)}{L} = hA(T_3 - T_\infty)$$

$$\frac{-(0.16\frac{W}{mk})(0.018626\ m^2)(T_3 - 85.4°C)}{0.0256\ m} = (10\frac{W}{m^2k})(0.018626\ m^2)(T_3 - 25°)$$

$$T_3 = 48.23℃$$

Conclusions:

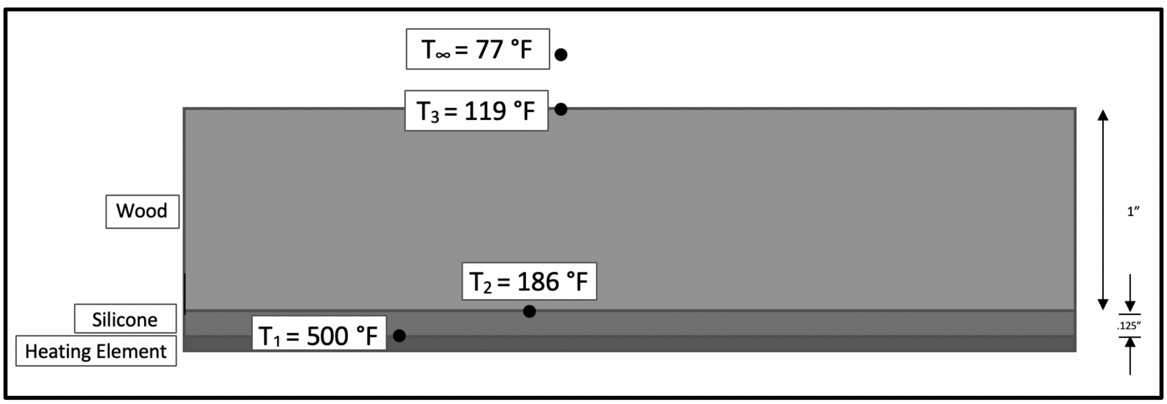

Figure B.5.2. Results of thermal analysis.

- Even when assuming all heat is going through the die and everything is at steady state, the highest temperature the top level of the lid exposed to the ambient air is expected to reach 119 °F.
- This temperature is within our requirements.
- The device is safe enough to touch for 100 seconds without permanent damage. Before that happens, the user will be able to tell if it is too hot for them to handle.

APPENDIX C: CONCEPT SELECTION

Table C.1. Pugh chart, concept 1 datum.

	Roller-die/Heat Sealer (datum)	**Panini Style/Glue**	**Heated wire/plate**	**Paper cutter/heat sealer**
Criteria:	C1	C2	C3	C4
Customizable output	0	0	0	-1
Number of subassemblies	0	0	1	0
Price	0	-1	0	1
Maximum component weight	0	-1	-1	0
Volume	0	-1	1	-1
Project difficulty; can the design team do it?	0	1	-1	1
Functional feasibility; quality of product output?	0	-1	1	-1
Maximum force needed	0	-1	-1	-1
Total	0	-4	0	-2

Table C.2. Pugh chart, concept 2 datum.

	Roller-die/Heat Sealer	**Panini Style/Glue (datum)**	**Heated wire/plate**	**Paper cutter/heat sealer**
Criteria:	C1	C2	C3	C4
Customizable output	0	0	0	-1
Number of subassemblies	0	0	1	0
Price	1	0	0	1
Maximum component weight	1	0	0	-1
Volume	1	0	0	-1
Project difficulty; can the design team do it?	-1	0	-1	-1
Functional feasibility; quality of product output?	1	0	1	0
Maximum force needed	1	0	0	0
Total	4	0	1	-3

Table C.3. Pugh chart, concept 3 datum.

	Roller-die/Heat Sealer	**Panini Style/Glue**	**Heated wire/plate (datum)**	**Paper cutter/heat sealer**
Criteria:	C1	C2	C3	C4
Customizable output	0	0	0	-1
Number of subassemblies	-1	-1	0	-1
Price	0	0	0	1
Maximum component weight	1	0	0	-1
Volume	-1	0	0	-1
Project difficulty; can the design team do it?	1	1	0	1
Functional feasibility; quality of product output?	-1	-1	0	-1
Maximum force needed	1	0	0	1
Total	0	-1	0	-2

APPENDIX D: POWER SUPPLY SURVEY

Constraints:

- Factor of safety (FOS) is 1.25.
- 12 V supplies 20 A per heating element.
- 5 V supplies 9 A per heating element.

$$P = \frac{(FOS)V^2}{R}$$

Table D.1. Power supply reqiurements vs heating element count for impulse and steady-state.

	12V			5V		
Number of Elements	Peak Amperage (A)	Peak Power (W)	Cost	Peak Amperage (A)	Peak Power (W)	Cost
1	25	300	$ 71.72	11.25	56.25	$ 18.91
2	50	600	$ 81.75	22.5	112.5	$ 30.47
3	75	900	$ 171.39	33.75	168.75	$ 30.47
4	100	1200	$ 265.33	45	225	$ 39.62
5	125	1500	$ 265.33	56.25	281.25	$ 39.62
6	150	1800	$ 403.91	67.5	337.5	$ 54.38

APPENDIX E: BILL OF MATERIALS

Table E.1. Bill of materials.

STEP	ITEM	MANUFACTURER	SOURCE	NOTES	COMPONENT	UNIT QTY	UNIT COST	TOTAL COST
MATERIAL PREP	Rotary cutter	Fiskars	Amazon	-	-	2	$6.00	$12.00
	Cutting pad	Fiskars	Amazon	-	-	2	$11.43	$22.86
ROLLER-DIE	Roller press	Sizzix	Sizzix	-	-	1	$124.97	$124.97
	Small/large cutting die	Sizzix	Sizzix	Custom order; 2 week lead time	-	1	$125.00	$125.00
	Medium cutting die	Sizzix	Sizzix	Custom order; 2 week lead time	-	1	$175.00	$175.00
HEAT SEALER	Nichrome wire	Master Wire Supply	Amazon	22AWG-100' Nichrome 80	HeatSealer-HeatingElement	1	$9.99	$9.99
	Wood dowel	-	Home Depot	3/4"OD-48"	HeatSealer-Handle-Dowel	1	$2.98	$2.98
	Silicone rubber sheet	-	McMaster-Carr	12"x12"-1/8" (50A)	HeatSealer-InsulationLayer	1	$17.95	$17.95
	1/4" birch plywood	-	Home Depot	2'x4'-1/4"	HeatSealer-Base-Tray, HeatSealer-Die, HeatSealer-TopPlate	3	$13.46	$40.38
	3/4" birch plywood	-	Home Depot	2'x4'-3/4"	HeatSealer-Base-BottomPlate	1	$26.99	$26.99

	1/8" birch plywood	Woodworkers Source	Maker Studio	20"x30"-1/8"	HeatSealer-RemovableMold	1	$3.72	$3.72
	Sil-poxy	Smooth-On	Amazon	Silicone adhesive	HeatSealer-RemovableDie	1	$24.95	$24.95
	Silicone potting	Smooth-On	Amazon		HeatSealer-Potting	1	$33.27	$33.27
	Epoxy	Hardman Double Bubble	Amazon	Wood-to-silicone adhesive	-	5	$1.71	$8.55
	Thumb screw	-	McMaster-Carr	0.25”-20, 0.5” length	-	6	$1.79	$10.75
	Threaded insert	-	McMaster-Carr	0.25”-20 internal threads, 0.375” length	-	6	$1.42	$8.50
	Wood screw	-	McMaster-Carr	#8-1.25" zinc-plated (100 qty pack)	-	4	$0.94	$3.76
	Hinge	-	McMaster-Carr	Includes mounting fasteners	-	2	$3.61	$7.21
	Kapton tape	Rincons Heat Press	Amazon	1/2"-100'	-	1	$4.98	$4.98
	Power supply	Mean-Well	Digi-Key	5V/200W output	-	1	$30.47	$30.47
	Power cord	-	McMaster-Carr	6.5' length	-	1	$5.77	$5.77
	Black electrical wire	-	McMaster-Carr	18AWG-25'	-	1	$5.03	$5.03
	White electrical wire	-	McMaster-Carr	18AWG-25'	-	1	$5.03	$5.03

	Rocker switch	FBApayipa	Amazon	15 qty pack	-	3	$0.43	$1.30
	Spade connector	TE Connectivity	Digi-Key	16-22AWG	-	9	$0.36	$3.24
	Bullet connector	AIRIC	Amazon	50 qty pack	-	6	$0.16	$0.96
	Butt connector	Molex	Digi-Key	10-12AWG	-	6	$0.44	$2.64
UV CHAMBER	UV Chamber	Salon Sundry	Amazon	Includes 10,000-hour bulb	-	1	$84.99	$84.99
							TOTAL COSTS	**$768.38**

APPENDIX F: TIMING CIRCUIT DESIGN

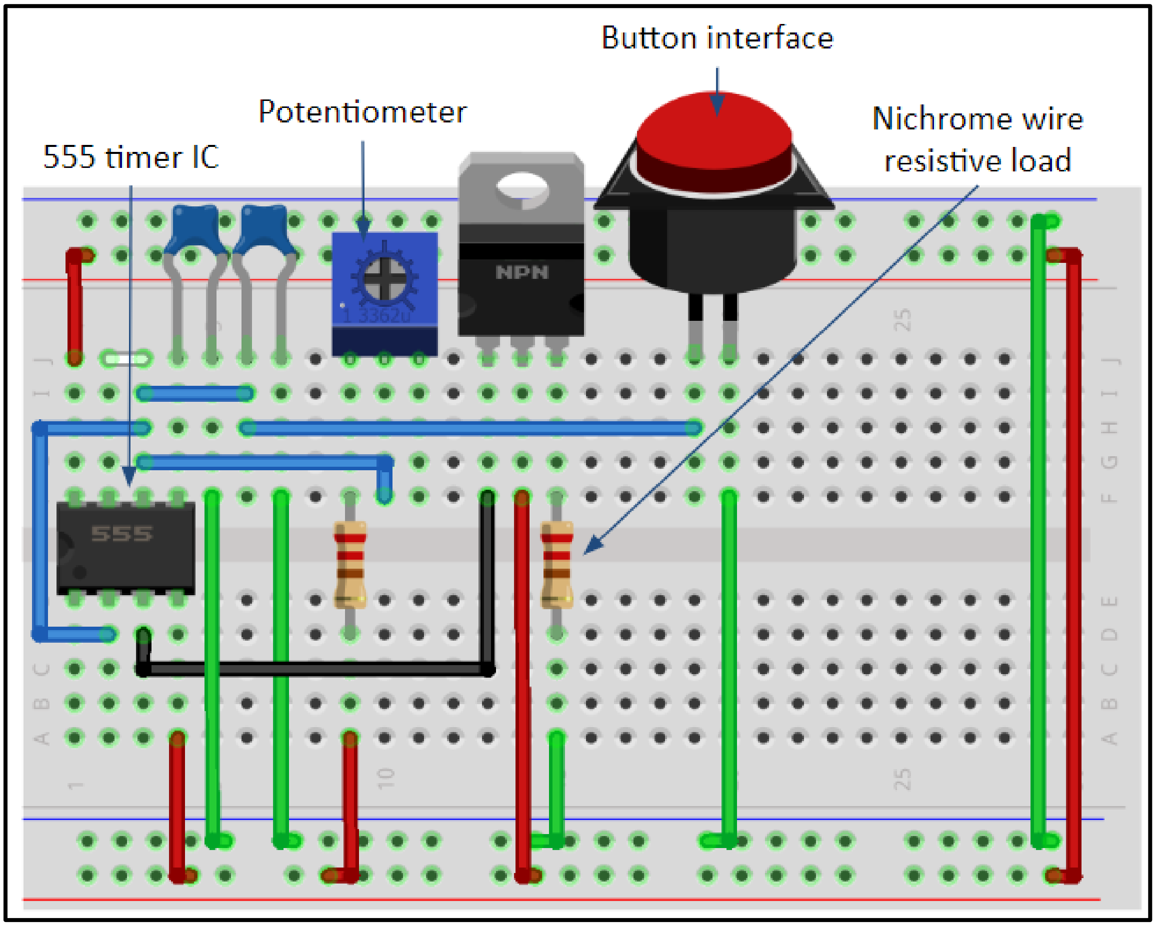

Figure F.1. Timing circuit for future recommendations.