Final Report

Spring 2024

BMEN 3200.001

May 3, 2024

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Table Of Contents

List of Figures

List of Tables

Executive Summary (AM)

This research proposal focuses on enhancing the healing process of burn wounds by optimizing the electrospinning process to produce Polyethylene Oxide (PEO) nanofiber scaffolds, which are crucial for skin regeneration. The primary objective is to identify and maintain humidity conditions, between 40% to 70% which is the optimal percent necessary for creating high-quality nanofibers with the desired characteristics—uniform diameter, mechanical integrity, and biocompatibility.

The methodology involves the preparation of PEO polymer solutions and setting up a controlled electrospinning environment where humidity levels are precisely regulated using advanced sensors and a combination of humidifiers and dehumidifiers. The fibers produced will be collected and subjected to thorough analytical testing to evaluate their structure and functional properties, ensuring they meet the necessary criteria for effective wound healing.

There are various factors that can cause changes in the nanofiber production, namely the distance between the spinneret and the collection plate, the temperature in the area, and the humidity. All these parameters must be within an optimal range to create effective fibers for human applications. The parameter that we have chosen to control is the relative humidity which is a measure of the amount of moisture in the air compared to the maximum amount of moisture the air can hold at a given temperature. It is important to control the percentage of humidity in the air because high humidity can lead to thinner, weaker fibers with increased pore size, which might be beneficial for certain biomedical applications like tissue scaffolding, whereas low humidity generally results in thicker, more uniform fibers with better mechanical strength. It is important to consider the application that the fibers will be implemented for when controlling such factors.

Our final design consists of an enclosed acrylic box in which the collection plate is placed in. There is an interface on the outside that allows the users to set a desired humidity level. The dehumidifying mechanism consists of a desiccant chamber filled with silica gel packets known to absorb moisture in the air. There are two fans connected to the chamber, one for circulating the dry air from the chamber into the enclosed box and one for moving the air from the enclosed box into the desiccant chamber. The humidifying component is achieved through a grove water atomizer that atomizes water molecules and turn them into a mist that sprays therefore increasing the moisture in the environment.

The stakes of this research are high, as the technology could set new standards in burn care and recovery. With the support of the University of Texas at Dallas. Dr. Schmidtke, Dr. Rivera, and collaboration with healthcare professionals, this project seeks to bring scientific innovation directly to clinical application, ensuring that burn patients benefit from the latest developments in biomedical engineering. The project will also seek FDA approval post-trial to move from controlled research setting to widespread clinical use.

Background (AK, AM, MG)

Introduction

The skin is the largest organ in the body and is the first line of defense. Damage to the skin can lead to many issues, both internal and external. People such as burn survivors often form serious raised scars known as keloids that take years to fade if they ever do. The entire healing process is time-consuming, especially with serious injuries. After the two-year mark, most scars stop healing and are permanently left as they are. The aesthetic impacts on scars are well known, as intense scarring can lead to a harmed body image and low self-esteem. The consequences of incomplete healing are more than cosmetic since scarred skin is weaker than normal skin as seen in **Fig 1**[1]. Scarred tissue has a lower tensile strength which makes it susceptible to re-opening with excessive exertion. Additionally, the slow healing process allows more time for an infection to set in if the wound is not able to properly block out bacteria. In recent years, new technology has allowed for grafts and scaffolds to be generated in a method known as electrospinning.

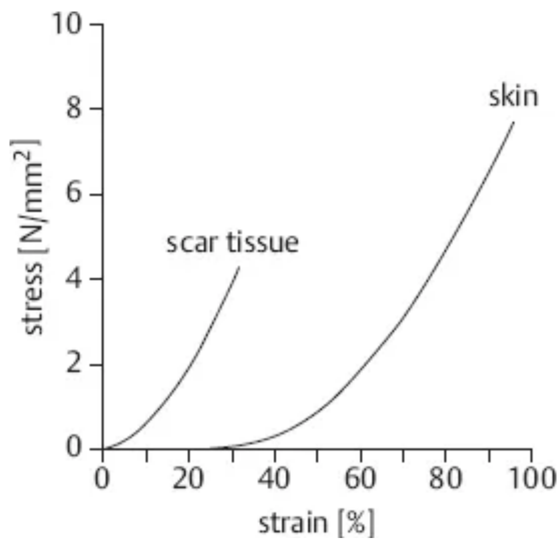


Fig. 1 [1]

Mechanical properties of scarred vs normal skin

Polyethylene Oxide Applications in Electrospinning

Electrospinning using polyethylene oxide (PEO) offers various benefits in drug delivery and wound care. The nanofibers are created to act as a wound dressing as they can mimic the extracellular matrix of the skin and therefore provide a scaffold that will allow for cell attachment, growth, and proliferation overall [2]. Also, incorporating drugs into the fibers will allow for enhanced delivery to the site of the burns and this can aid in pain management and therefore prevent infections from forming. As the product of electrospinning is fibers, they are a breathable material that forms an effective barrier between the wound and external environments and will maintain proper moisture to create an optimal healing environment. There are various properties that electrospun fibers possess that make them a great wound dressing alternative. This includes the fact that fibers can be spun to mimic the diameter (60 to 120 nm) of the extracellular matrix of the dermis, allowing it to properly integrate into the body [3].

We will be using PEO because it is a very biocompatible material with a low toxicity rate. PEO's biocompatibility and low toxicity make it well-suited for direct contact with living tissues, ensuring minimal adverse reactions. It also has low ash content and thermoplasticity which means that it can be easily melted and reshaped easily according to its desired conditions. Lower ash content indicates that the polymer is purer in nature as the presence of other inorganic substances can hinder the performance and quality. PEO is also hydrophilic in nature which means that it can absorb and retain moisture in the fibers extremely well [5]. This polymer is also known for its ability to suppress protein adhesion, and this is very often leveraged in biomedical applications. In tissue engineering and wound dressing applications, suppressing protein adhesion to the surface of the dressing reduces the risk of infection as it acts as a barrier that protects the wound site. This in turn promotes the exchange of oxygen and maintains moisture that is crucial for tissue repair. However, uncontrolled protein adhesion can lead to the formation of biofilms or unwanted cell adhesion, which may hinder the performance of the material or device [6]. By using PEO in these applications, the material can resist protein adhesion and minimize the risk of inflammatory responses or other complications.

PEO is not the only polymer used for such applications but other polymers such as polysaccharide electrospun nanofibers were also shown to be a good alternative as they are commonly used in wound dressing material already [4]. This process combines the properties of polysaccharides and electrospun fibers and is extremely biocompatible as it promotes cell growth, respiration, and regeneration.

Electrospinning

Electrospinning is a technique used to create nanofibers from a polymer solution. Electrospinning works by setting up a needle, also called the spinneret, at around a 20 cm distance from the collection plate [**Fig 2, Fig 3]**.

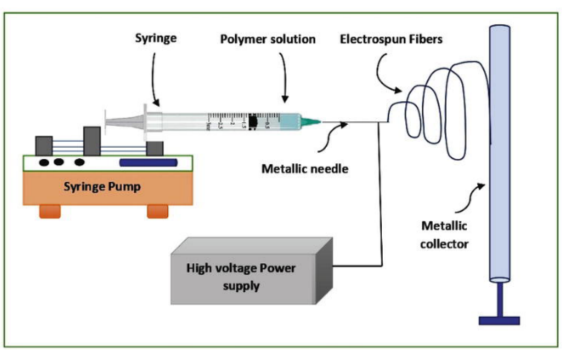


Fig. 2 [7]
Electrospinning configuration with flat plate

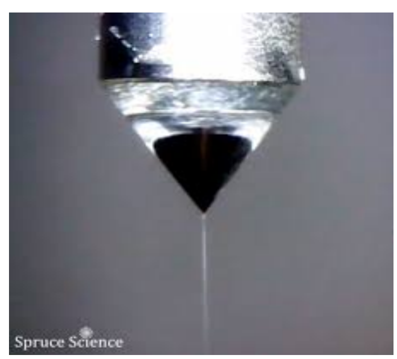


Fig. 3 [8]
Taylor cone

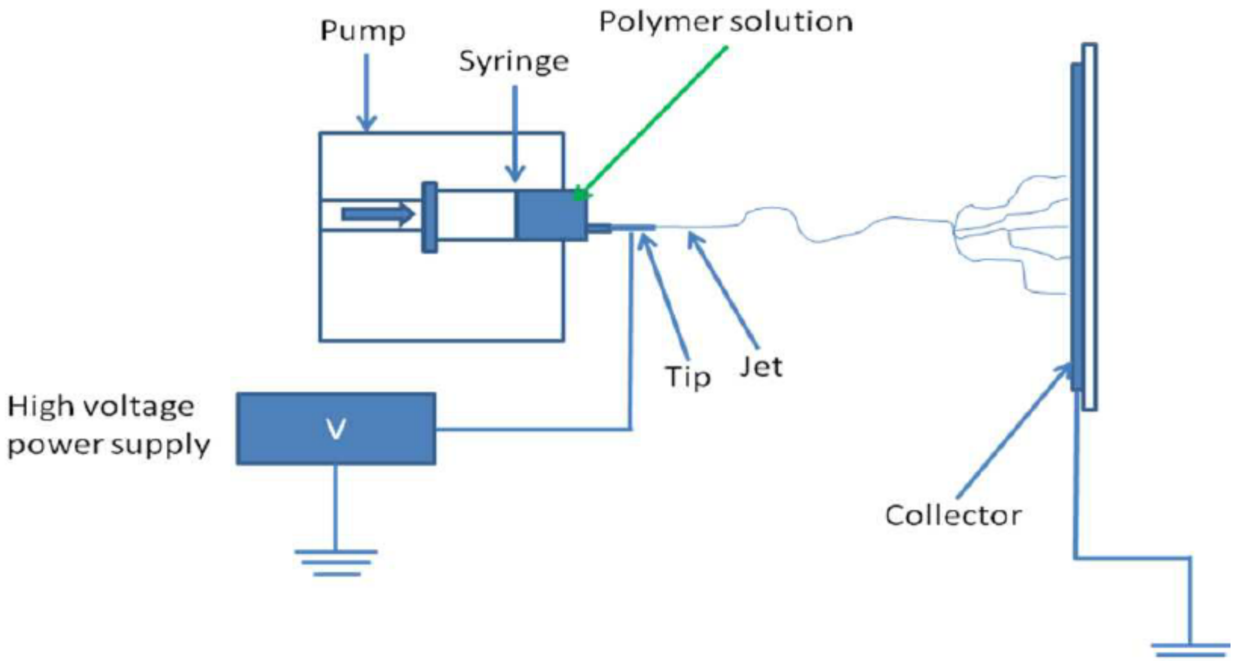


Fig. 4 [9]

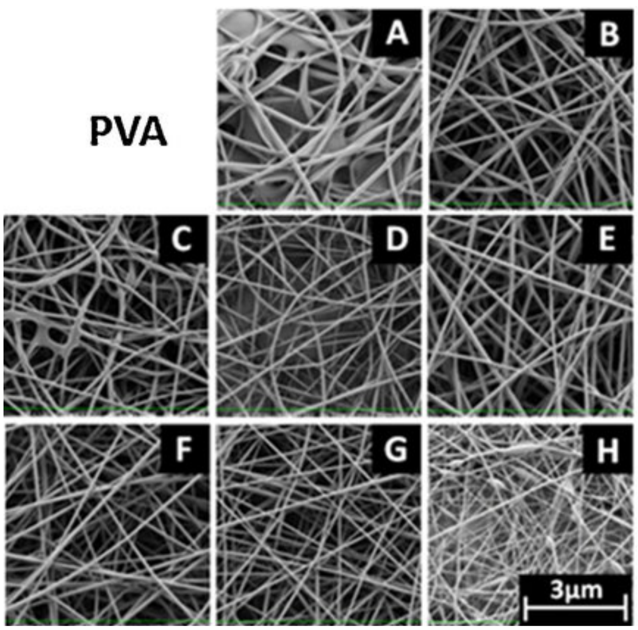
Electrospinning parts diagram

The needle will release a small droplet of a solution that is made up of a solvent and a polymer as seen in **Fig 4**. A high voltage is then added to the droplet of solution via the spinneret, causing the formation of a Taylor cone. A Taylor cone, as seen in Fig 3, is the shape required to obtain optimal fibers. The required properties of the optimal fibers depend on the application of the fiber generated. For application in skin scaffolding, it is necessary for these fibers to be biocompatible, have optimal mechanical properties, low degradation rate, and be functional in the human body. Non optimal fibers refer to beading, which is the formation of polymer droplets on the collection plate instead of a continuous strung fiber. Beading can occur due to numerous factors, and damage the mechanical properties of the fibers, so it is important to properly control the components of the system to prevent these from forming. Once the Taylor cone is formed, the charged liquid is then expelled out from the needle as an ultrafine jet. As the liquid travels through the air to the collector plate, the solvent evaporates leaving only the nanofibers of the polymer. The fibers can then be collected from the collector plate and used in applications such as biomedical engineering, textiles, and filtration systems, or any other instance where a light, breathable, mesh is required.

Electrospinning Challenges

Electrospinning is not a foolproof process, many minute factors can play a part in the quality of the fibers. This includes concentration of fluids, voltage, temperature, flow rate, distance of syringe from collector plate, and humidity. For this project, the main concern is humidity. If all other factors remain constant and humidity is increased, the electrospinning process becomes more difficult as evaporation does not happen as quickly. When water-based solvents are used, high humidity can cause thinner fibers to form which are often weak, with thicker fibers formed under low humidity as seen in [**Fig 5, Fig 6**]. The downside of forming thin fibers is that they lack mechanical strength and have improper structure which is harmful for applications in skin tissue scaffolding. However, increasing the humidity can also cause an increased amount of surface pores.

For biomedical applications, increased surface pores are a positive since it allows for better cell adhesion, resulting in the graft being more successful. Additionally, controlling the amount of surface pores allows the fibers to be customized for filtration, tissue engineering, and drug delivery [10]. Too high of an evaporation rate, however, can result in an irregular formation of fibers such as beading or inconsistent fiber diameters [10]. These results are consistent for all electrospinning using water-based solvents. According to a study involving the electrospinning of PEO, with a temperature of 23°C, a voltage of 25kV, and 20 cm distance, the relative humidity should be 48% to 50% to eliminate the occurrences of droplets [11]. This is the optimal humidity for use in creating skin scaffolds as it allows enough pore formation while maintaining the required mechanical properties. Overall humidity plays a crucial role when creating skin fibers, especially considering pore formation and its mechanical properties. Poor humidity can result in faulty fibers being formed which is detrimental to skin grafts as they don’t have a moist environment which is necessary for skin grafts to have proper healing properties. It can also lead to the development of infections as it would be conducive to bacterial growth. The final reason that fibers generated under improper humidity is that it can lead to crust formation over the site of the graft, and this interferes with the fibers ability to integrate with the surrounding tissue.



	Relative humidity [%]	Average fiber diameter [nm]	RSD [%]
A	4 ± 1	667 ± 83	12
B	10 ± 1	550 ± 72	13
C	20 ± 1	445 ± 63	14
D	30 ± 1	349 ± 54	15
E	40 ± 1	258 ± 54	21
F	50 ± 1	174 ± 40	23
G	60 ± 1	161 ± 42	26
H	70 ± 1	74 ± 99*	134*

Fig. 5 [12]

Relative humidity in relation to fiber diameter

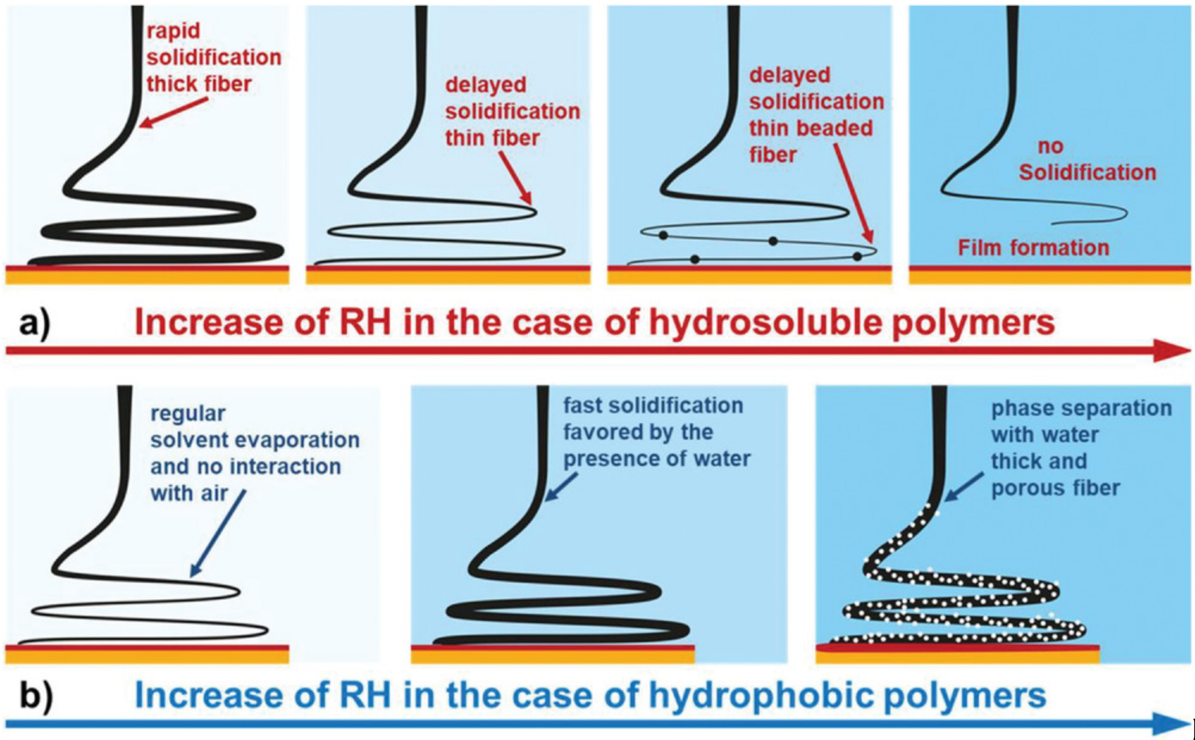


Fig.

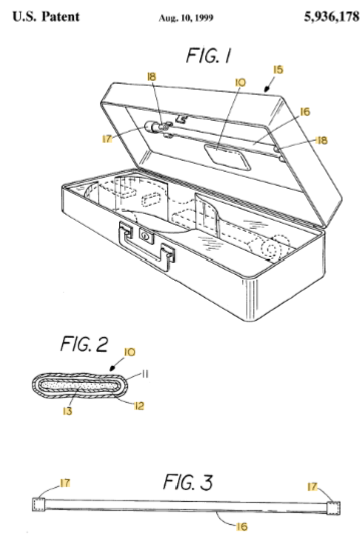
Fig. 6 [9]

Effect of RH on fiber diameter in cases of a) hydrophilic polymers and b) hydrophobic polymers

Patents

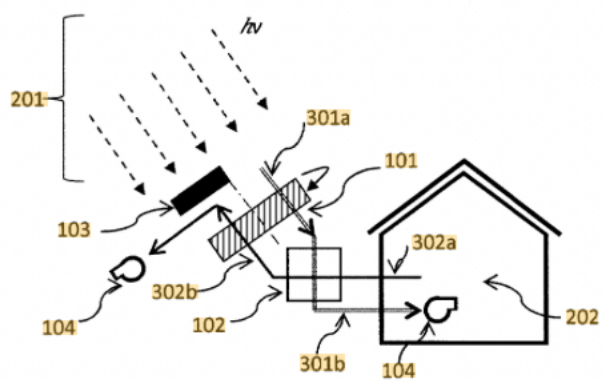
There are a few patents that exist for humidity control systems:

US5936178A [**Fig 7**]- A humidity control device for use in maintaining a desired humidity, the device including a protective case, a water vapor permeable pouch and a thickened saturated solution, the solution having a suitable humidity control point. This device is beneficial because it includes a protective casing and uses thickened salt as a means to control humidity. The humidifying devices and dehumidifying devices take up a substantial amount of space and simply will not fit within a violin case. Further improvements can be done in minimizing the area[13].



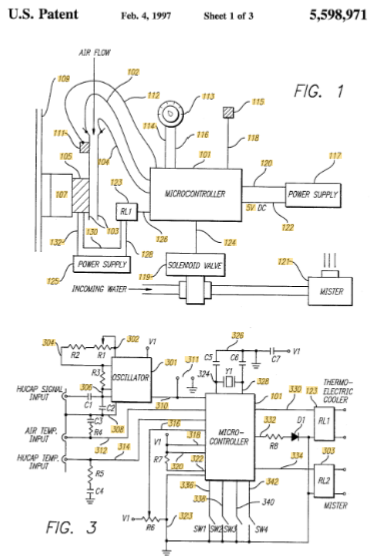
Patent *US5936178A*, Fig. 7 [13]

CN106061582B [**Fig 8**] - The purpose of the present invention is to provide humidity control devices for being avoided that the problem of forming hydrophobic film on the outside and being not easily taken out internal hydrone. This design consists of a moisture absorption and desorption material and a photothermal conversion material as essential components in a desiccant sheet. The device uses sunlight as one of the means to dehumidify, so the device works better on sunny days rather than cloudy days [14].



Patent *CN106061582B,* Fig. 8 [14]

US5598971A - The present invention provides a capacitive humidity transducer-based humidity control system. The invention comprises a humidity sensor, a temperature source for the heated cabinet air, a temperature source at the sensor, and a regulated water mist discharged into the cabinet air circulation system. An electronic system combines the input from the sensor, the temperature inputs, and the humidity percentage setting to regulate the timing and duration of the water mist discharge, thereby allowing to adjust percentage of humidity in heated holding cabinets. The device uses a simple feedback system technology to accomplish the solution. When cabinet humidity falls below a predetermined threshold value and a corresponding change in capacitance of the capacitive sensor is detected, the humidity control system turns on a water mister to spray water into cabinet air flow until a desired relative humidity level is reached in the heated cabinet. [15].



Patent US5598971A Figure 9 [15]

Similar Products

A similar product that performs the function of humidifying and dehumidifying an enclosed space is a terrarium. The terrarium utilizes feedback control to set the humidity inside the enclosed space. This is important for those who keep exotic pets such as lizards and amphibians which need a set amount of relative humidity to thrive. These terrariums work by spraying mist to increase the relative humidity. To reduce the humidity in the terrarium, ventilation is used to push out the humid air [16]. These terrariums are often especially effective at maintaining high humidity levels consistently, however, since terrariums use ventilation to reduce the humidity, if the outside relative humidity is higher than the desired value inside, it is not able to lower the internal humidity value.

Stakeholders

This project examines the range of humidity levels at which electrospinning results in nanofibers that can be treated for burn wounds. Patients with second and third-degree burns are the primary stakeholders on whom this project is focused on. With nanofibers created within specific humidity conditions, optimal fibers can be created. This means that primary stakeholders can receive consistent results with fibers of the proper mechanical and functional properties. This will benefit the users as it can accelerate healing, reduce scarring, and overall improve the functionality. Tightly controlling the relative humidity can prevent the formation of defects within the fibers such as beading, bundling, or bonding of the fibers and the polymer. Moreover, by incorporating a tissue-regenerating medium into the nanofibers, the potential for successful wound healing is further enhanced. The nanofibers through electrospinning will include tissue regenerating medium which can promote the growth of skin on the affected area. To create these nanofibers, the polymer solution—in this case, polyethylene oxide—is poured into the syringe. These materials like the polymer solution, regenerative medium, and sterilized equipment can be bought from manufacturers who act as secondary stakeholders. The University of Texas at Dallas, Dr. Schmidtke, Dr. Rivera, played a crucial role in funding this project and assisting the engineering team. The engineering team uses these biomaterials to achieve the desired results after obtaining the nanofibers through electrospinning and taking on a stakeholder position. Healthcare professionals use a spraying technique to properly establish the fibers on the skin and act as secondary stakeholders. Additionally, once the project undergoes completion, the FDA must approve before the procedure is applied to patients.

Problem Statement (MG, AK)

Patients with second and third-degree burns can use nanofiber scaffolds as a means to regenerate skin. When preparing these nanofibers, humidity is a parameter that must be precisely controlled to effectively generate them. Humidity affects the average diameter of the electrospun fibers, the solvent evaporation rates, pore formation, and can also influence the charge dissipation of the apparatus. The goal of this project is to control humidity levels that impact the electrospinning process with a relative humidity of 40% to 70% to achieve the desired nano-fiber characteristics for skin regeneration.

Requirements (YN and AlexM)

Table 1: This table below lists the requirements for the overall design. Higher numbers indicate higher priority.

Requirement ID	Requirement Name	Description	Justification	Priority (1 Low 3 High)
1	Humidity Control	The device should be able to reach any chosen relative humidity level within a range of 40 – 70% around the electrospinning tip and collector plate for this specific application.	A relative humidity of 45% produces PEO fibers with a diameter of 144nm [11]. 144nm fibers are good for wound dressing and healing purposes. However, values above 50% induces beading and poor-quality fibers [11].	3
2	Distance	The distance of the collector plate should be 15 cm from the spinneret.	Typically, the distance used in PEO electrospinning is between 10-20 cm [11]. Distances below 10 cm result in excessive bead formation [11]. Distances above 20 cm result in thicker fibers, which are not desirable for this application at the chosen humidity levels since we are trying to stay closer to 120 nm fiber diameter.	3
3	Safety	The device should not have any exposed sharp edges or exposed screws,	These safety requirements will prevent the user from experiencing harm while setting up and operating the device.	3
4	Manufacturability	The device should be relatively simple to manufacture using the skillset of a college engineering student and the tools they have available to them at the university. Using these tools they should complete the manufacturing within 3 weeks.	This allows for easy buildability to be able to test and iterate multiple design versions in a shorter time frame to minimize wasted time and resources.	3

5	Collector Plate Dimensions	The collector plate must be at least 6 inches long and 6 inches wide.	This ensures that the fibers that are generated do not fall to the sides of the collector plate, this also provides ample room for fluctuations in the eventual fiber distribution. The collector plate should be large enough to collect all the electrospun fibers and these dimensions are the minimums from our experimental testing.	3
6	Warning mechanisms	The device should adequately warn the user about the high voltage areas as well as any moving parts to prevent injury	This helps prevent unnecessary injury when using the device.	3
7	Remote Interlock	The device should have a remote interlock mechanism installed.	The remote interlock is a safety system for high-voltage sources in devices. It ensures that the device only powers on when button is pushed	3
8	ASTM Standard	The polymer scaffolding from our device should follow Designation: F215019, the standard guide for the characterization of and testing of biomaterial scaffolds.	Our device is intended to create scaffolding for biomaterials. ASTM standards should be followed for characterization and best communication with the scientific world.	2
9	Easy setup	The device will be provided with a manual and should not require knowledge beyond the scope of a junior engineer.	This makes sure that the setup is not overly complex and doesn't require high level professionals to set up and operate.	2
10	Easy Setup Time	The device should not take more than 20 minutes to set up with the existing apparatus.	We want our device to be more of a help than a burden to use. Having a shorter setup time will make it more convenient for electrospinning teams to control the desired parameter.	2
11	Ambient Humidity Resistance	The device must be able to accurately hold the humidity within ± 2.5% of the confirmed value within a relatively isolated system.	This ensures accurate results in terms of humidity every time we go to make PEO fibers.	2

12	Cost	The device should be under $130.	This is on the higher end for a terrarium-like device, which is what our device will be most similar to.	1
13	Non-obstructive	The device should be accessible for users and not impede the electrospinning process.	This ensures that the device maximizes the quality of the fibers produced.	1
14	Humidity Monitoring Instruments	The device should be able to monitor the internal humidity of the box with a sensor and display the said value to the user.	This ensures that we are producing fibers at either high, low, or medium humidity while communicating the interior conditions to the user of the apparatus.	1
15	Collector Plate Replacement	It must be a simple process to remove and replace collector plates within the device.	After multiple uses, the foil can become saturated with nanofibers. It should be easy to replace with a clean foil.	1
16	Humidity Adjustment Speed	Considering a starting range of humidity between 40% and 70%, be able to bring the interior humidity to the desired range (45-50%) within 15 minutes of operation.	This ensures a relatively quick adjustment to the interior humidity levels, so that if the values do fall beyond the desired range, they can quickly be brough back to within range without spending too much time at subpar humidity levels.	3
17	Electrical Safety	There should be no exposed wiring/risk of electrocution without adequate labeling.	Making sure that all electrical components are covered ensure the safety of the user as well as protection of the wires from becoming damaged or dislodged	2
18	Weight	The device should weigh less than 10 pounds	This allows the device to be easily portable since a lower weight makes it easier for the device to be transported	3

Conceptual Design

Design one:

The design [**Fig 7**] involves using a humidifier at the bottom of the acrylic box, and a dehumidifier on the opposite side. The acrylic box is transparent with all possible leakage spots covered in order to maintain a closed system. The humidifier has a coin-like component which sits on top of a small cup of water with a tissue floating on top. The humidifier sprays water from the top of the coin in order to increase the humidity inside of the box. The dehumidifier is a larger component which uses desiccants in the form of silica gel in order to reduce the overall humidity in the box when turned on. The humidity sensor is placed near the top to ensure that the proximity to the humidifier or dehumidifier does not disrupt the readings. The humidifier acts as a method to increase humidity, and the dehumidifier to decrease humidity.

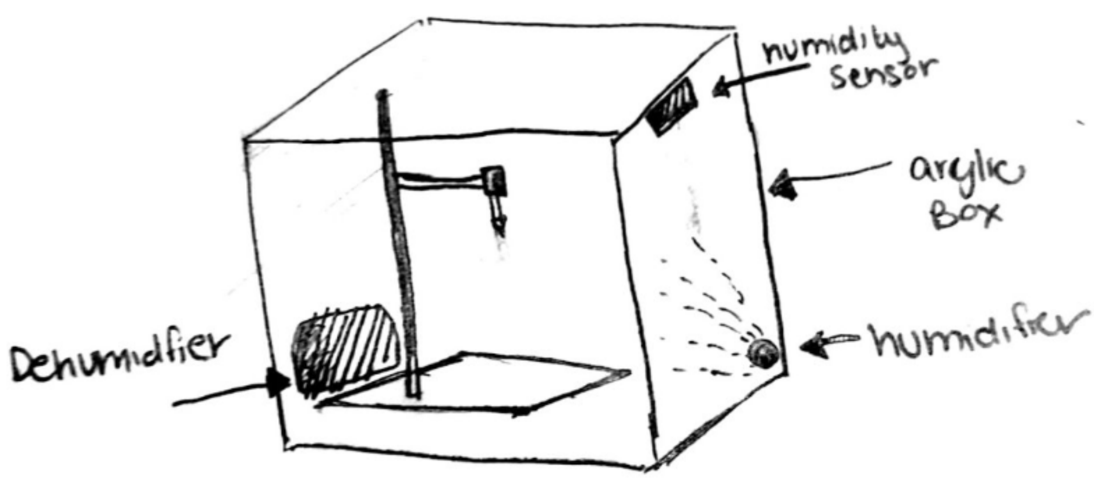


Fig. 10, Design one

Design Two:

The design **[Fig 8]** includes a humidifier placed near the bottom of the box to increase humidity, and a humidity sensor near the top to ensure that there is no disruption in the readings. Across from the humidifier is a metal collection plate. Outside of the box is a cooling fan, which through a hole in the acrylic, a metal rod connects the cooling fan to the metal plate **[Fig 9]**. This causes the metal plate to cool from the air of the cooler, so that water inside of the box condenses and collects. This will reduce the humidity inside of the box by removing the water present in the air.

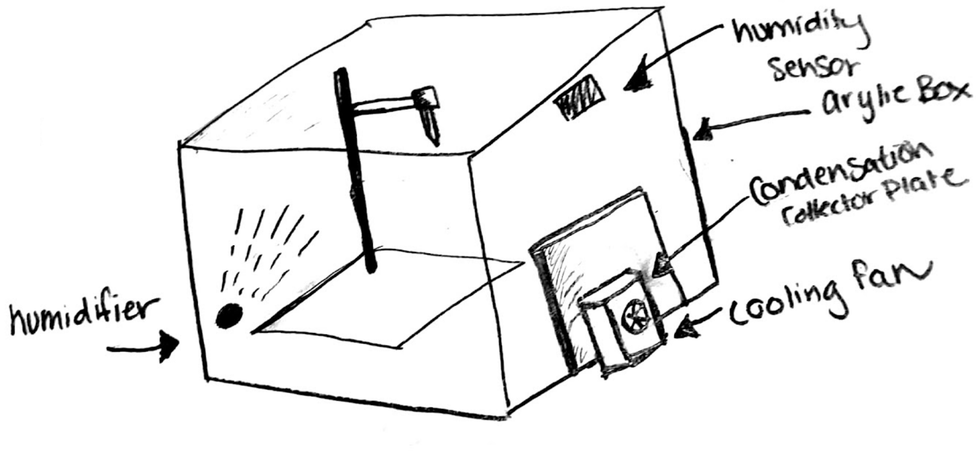


Fig. 11, Design two

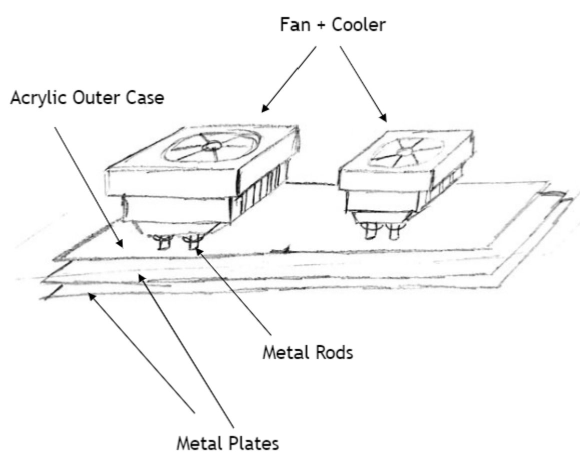


Fig. 12, Fan, and condenser plate

Design Three:

This design **[Fig 10]** includes a clear acrylic box with a humidity sensor near the top to prevent the reading from being affected by the humidifying or dehumidifying parts. There is an air intake tube that is placed in the acrylic box **[Fig 11]**. The tube takes in air from the outside and uses a fan to blow the air in the box. The tube is filled with desiccants to dry out the outside air before it enters. The fan will only turn on when the humidity is too high and will keep running until it reaches the desired humidity value.

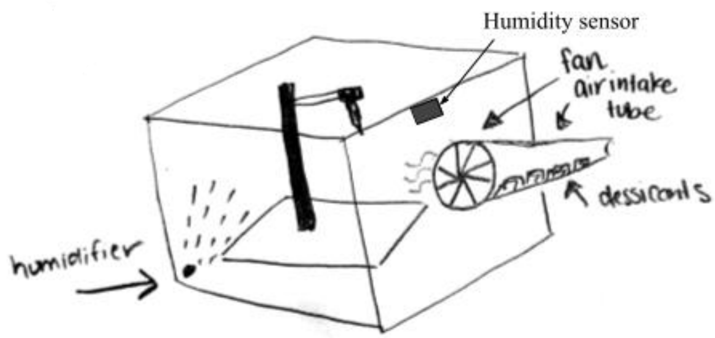


Fig. 13, Design three

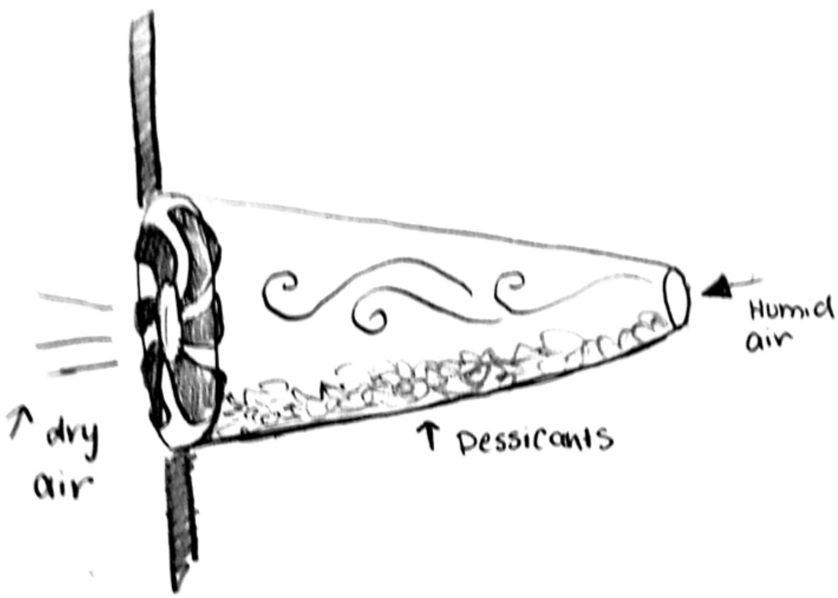


Fig.14, Desiccant Fan

Concept Down-Selection

Criteria

The following are the criteria for the down selection for conceptual designs. The criteria fulfill 14 of the 16 requirements we have listed in the previous design updates.

1. Consistent Humidity Levels → Be able to regulate and stabilize humidity at the desired level (between 45 to 50% relative humidity)

Requirements Fulfilled: 1, 2, 11, for control over humidity both increasing and decreasing within the device. Consistent distance from tip to collector plate with each round of electrospinning is also particularly important because when the distance is altered the needed relative humidity level changes and throws off our baseline control metrics. Resisting large humidity changes by having sensitive, calibrated equipment is important as we need accurate measurements within the device and the ability for fine control over humidity levels.

2. Feasibility → Should be within the means of the BMEN 3200 class involving cost, manufacturability, and team skillset.

   Requirements Fulfilled: 4 & 12 as it keeps the costs lower since we do not have a large amount of funding as a multinational company would and since we are just college students with access to a makerspace and not professional manufacturing techniques.

3. Easy to setup → The set-up process should be simple and easy to follow when looking at the provided instructions.

   Requirements Fulfilled: 9 & 10, reducing the knowledge barrier needed to setup the solution as well as making it less time-consuming when fully assembled is imperative to making this solution easy to use and implement in existing electrospinning setups.

4. Non-obstructive → The device should not obstruct the process of electrospinning. This ensures seamless fitting on to existing setups with little or no modification required to fit this solution

   Requirements Fulfilled: 13, being able to essentially 'plug and play' a solution on to existing setups makes it attractive to improve the humidity-controlling aspect of an existing electrospinning setup can be.

5. Responsiveness → The device should be quick to respond to fluctuations without falling to far out of the desired humidity range, exacting proper control, and consistent humidity levels

   Requirements Fulfilled: 14 and 16, being able to monitor humidity levels accurately is key in quickly being able to respond to changes when the humidity level falls out of the range of 45-50%. If the humidity were to fall out of the desired range, then quickly bringing the level back to appropriate levels is key in maintaining a stable humidity level.

6. Safety → The device should be safe and without possible exposed wires.

   Requirements Fulfilled: 3, 6 & 7 keeping the user as safe as possible and giving them ample warning mechanisms and fail-safes to prevent injury during use.

7. Aesthetic → The device should look aesthetically pleasing, and not take up too much space

8. Reusability → The system should be reusable, and not be damaged after one use. Parts that need to be changed after each use should not have an overly complicated process to replace or a high environmental impact

   Requirements Fulfilled: 15, This ensures that the collector plate is easily replaceable between runs to ensure effective collection of fibers and create a fresh base for new fibers to collect.

9. Feedback → do not want only one control or a passive method, we want to have a method to both actively increase and decrease the humidity level within the chamber.

Down Selection Weighted Matrix

The following is a weighted matrix depicting the scores for each design corresponding to the requirements:

Table two: Weighted matrix displaying the scores of each design. The weight category ranges from two-five with five being of highest importance and 2 being the least. The scores for each category vary from one to ten with one being the lowest and ten being the highest, indicating success.

Requirements	Weight	Design 1	Design 2	Design 3
Consistent Humidity Levels	5	10	7	7
Feasibility	4	4	8	8
Easy to Setup	2	6	3	6
Non-obstructive	3	6	4	6
Responsiveness	5	8	7	8
Safety	3	10	8	10
Aesthetic	2	2	7	3
Reusability	3	10	10	6
Feedback	4	8	8	8
Total Weighted Score	31	232	220	223

Table 2

Final Design Description

The design is mainly constructed of lightweight acrylic and duct tape weighing about 6.5 pounds fulfilling requirements 3 & 18 for safety and weight. The electrospinning setup is enclosed by a clear acrylic box (10 inches by 10 inches by 6inches) ensuring a collector plate size of at least 6x6 and a tip to collector distance of 5.9 inches (15cm) fulfilling requirements 2 & 5. The main chamber is connected to a desiccant chamber and an electrical chamber. The electrical chamber houses the circuit and any exposed wires fulfilling requirement 17 for electrical safety. The desiccant chamber consists of two ends, with air flowing in from one side and out from the other, as seen in **Fig.13.** The interior of the extra desiccant chamber will contain two fans oriented in a manner that one fan serves as an intake and the other fan serving as an exhaust fan. The interior of the chamber itself will be filled with silica gel packets which should dehumidify the air being brought into the chamber. The interior humidity of the main chamber is measured by the SHT humidity sensor and displayed to an OLED display fulfilling requirement 14 for humidity monitoring. Both fans will turn on if the current interior humidity level rises above the confirmed humidity level. The intake fan on the near side opening of **Fig. 13,** will draw in the humid air from the main chamber. As the air is drawn into the desiccant chamber, it is dehumidified by the silica gel packets. The dehumidified air is directed towards the exhaust fan at the far end of the chamber and sent back into the acrylic box decreasing the humidity of the air in the main chamber. However, if the interior humidity falls below the last confirmed value, the humidifier module will be activated. The humidifier is immersed in a small container that has cotton tissue and water present. The module uses high-frequency vibrations to vaporize water, this causes the air to increase in humidity. When the humidity reaches the desired level, the desiccant chamber fan and the humidifier module are both turned off and the interior humidity begins to stabilize. This process runs continuously to maintain the desired humidity level. This control and quick response time over our humidity levels fulfills requirements 1, 11, & 16. The design also features several doors in both the main chamber and the desiccant chambers to ensure quick collector plate and silica gel replacement fulfilling requirements 10 & 15.

We chose this final design as it scored the highest in our weighted matrix. We believed that using a closed chamber design to isolate the air from the outside was the quickest way to influence the humidity of the chamber. Design 2 would need to run for some time for the metal fins to get cold enough to collect any water for dehumidification and the collected water proves a risk for any exposed electrical components. Design 3 does not have air isolation from the outside environment and is thus more heavily impacted by the ambient humidity conditions, air with high humidity would not dehumidify as much and make it much harder to decrease the internal humidity. As a result, our final design (a modification of design 1 from the PDR) was believed to be the most responsive to humidity changes, and best able to change the humidity levels within the main chamber in a timely manner. The quick response times would also help in preserving a consistent humidity level much better than the other two designs.

Our Final Design differed from our PDR prototype in several different ways. The first being the change from using a dehumidifier module to using silica gel packets in the desiccant chamber. In our research we discovered that the dehumidifier module utilizes the same desiccant technology to dehumidify the air and by using silica gel to fill the chamber we would be able to pack more desiccants into the same space compared to if we used the dehumidifier. The second modification being the change from a U-shaped tube to a unified chamber. The reason for this modification is that the rubber tubing we were given during the design process couldn't bend at such a sharp angle and kept kinking. Also, by creating a unified rectangular chamber as seen in **Fig. 13,** we also made more space for the silica gel packets, allowing us to use even more desiccants than initially planned for. The third modification is adding a separate electronics chamber above the main chamber. This electronics box allowed us to fulfill requirement 17 which stated that there shouldn't be any exposed wiring on the outside of the box to prevent shock to the user.

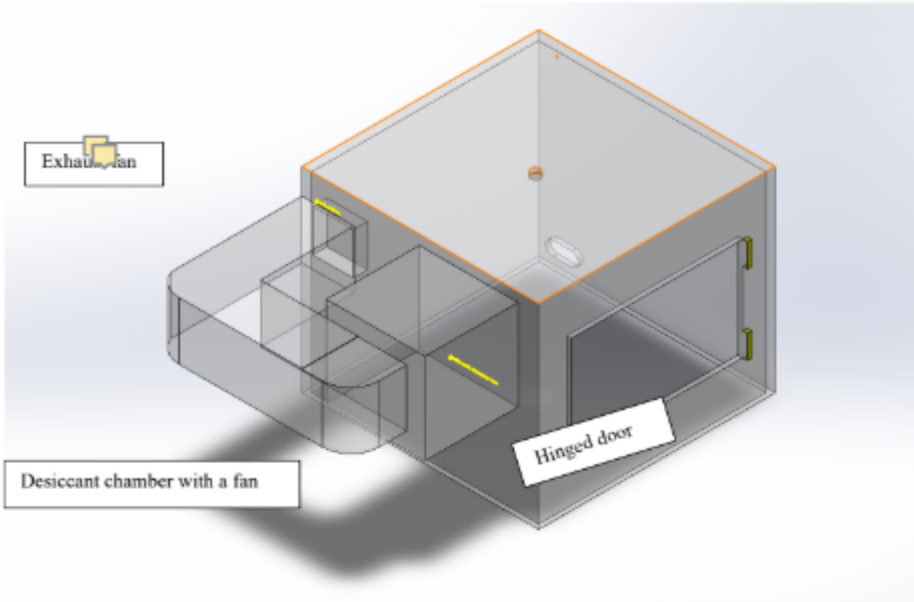


Fig. 15 Chosen Prototype CAD Rendering

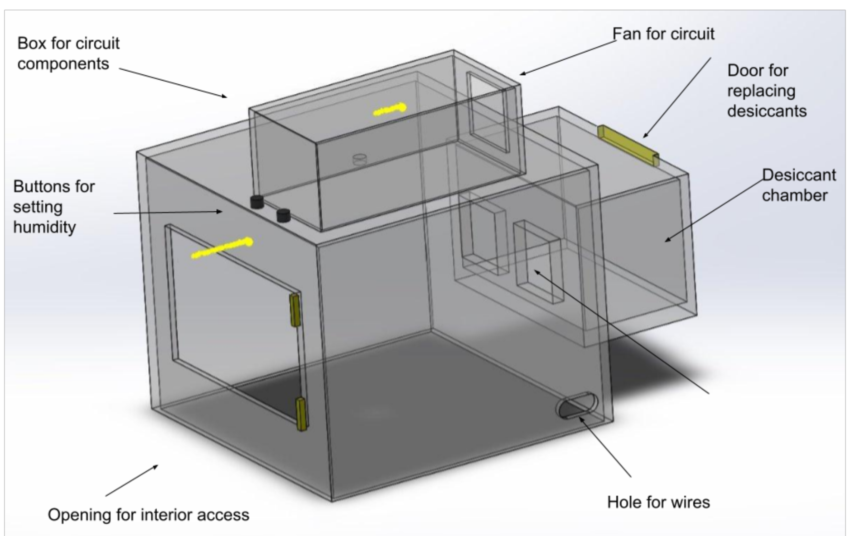


Fig. 16 Final Design CAD Rendering

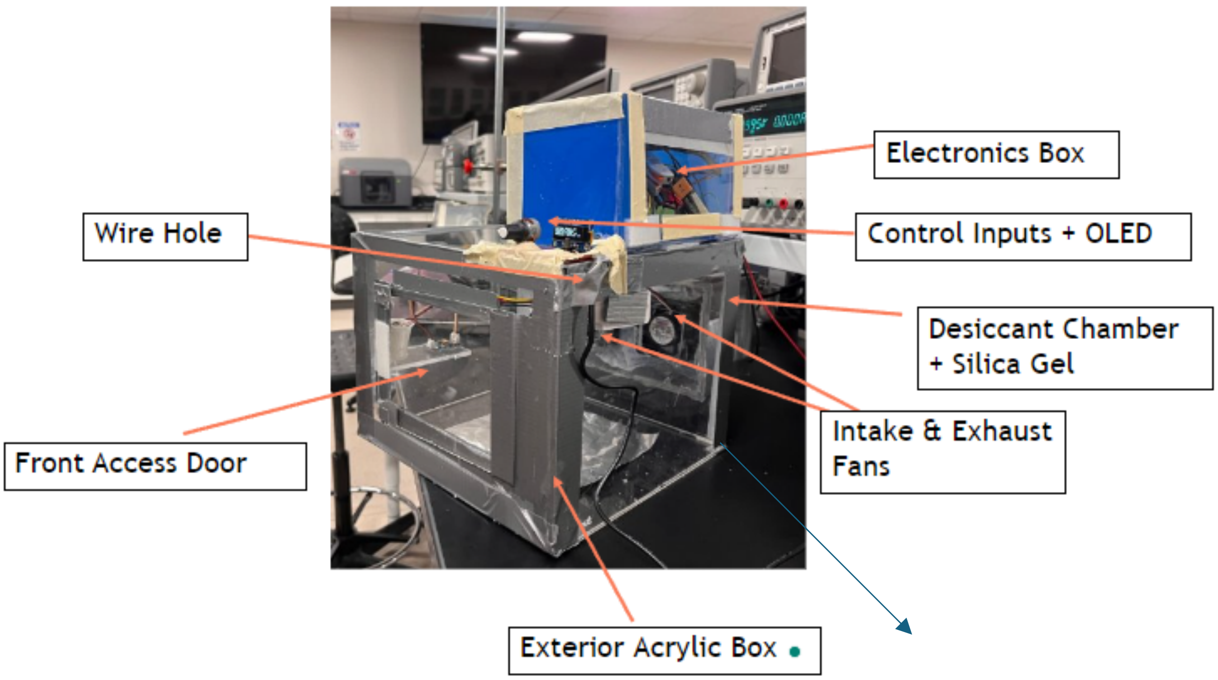


Fig. 17 Image of Final Design

The final design is a combination of conceptual designs 1 and 3. This is because design one had a simple and effective design when relating to the positioning of the humidifier and dehumidifier as well as the sensor yet was lacking space inside since the dehumidifier was bulky. Meanwhile design three had an external chamber loaded with desiccants and fans to reduce the humidity. This left more open space inside the box and allowed for faster dehumidification. In conceptual design 1, as we have mentioned, there will be a humidifier and a dehumidifier present in the box controlling humidity. In our final design, we are designing our own dehumidifier by using the idea of a desiccant chamber. This design is feasible and easy to set up. Because of the hinged door we have in our final design, the process of replacing the water in the humidifying container becomes easier. The desiccant chamber cubic box also has a door which will help in easier replacement of the silica gel. The box does not obstruct the electrospinning process because the dehumidifying chamber is placed outside of the box. The components inside the box are not affected because of the water in which is placed, and the wires as well are properly placed through the hole created on the side of the box in Fig.12. There will also be a warning label present on the box which ensures the user to safely uses the device. So, the safety requirement is fulfilled. The box is clear and compact which will aid the user to carefully work. The design is aesthetically pleasing. The feedback loop used in this design will make the dehumidifying chamber turn on only when the humidity is higher than 50%. This fulfils our last requirement.

The final design's manual fabrication will be done by Yash Nasrin. The code and the CAD rendering will be done by Anusha, Ashritha and Mohana. The circuit buildup is done by Alex.

Pseudocode

This pseudocode **[Fig 13]** represents a humidity control system. It reads the desired humidity value entered by the user, and humidity data from a sensor constantly. It then displays the current and desired humidity consistently on an OLED screen. If relative humidity drops below the desired value, it activates a humidifier and displays that the humidifier is on until it reaches the desired value. If humidity exceeds the desired value, it activates the fans of the desiccant chamber and displays that fans are on until the humidity returns to the desired range. Once the relative humidity is within the desired range, the humidifier and the fans turn off.

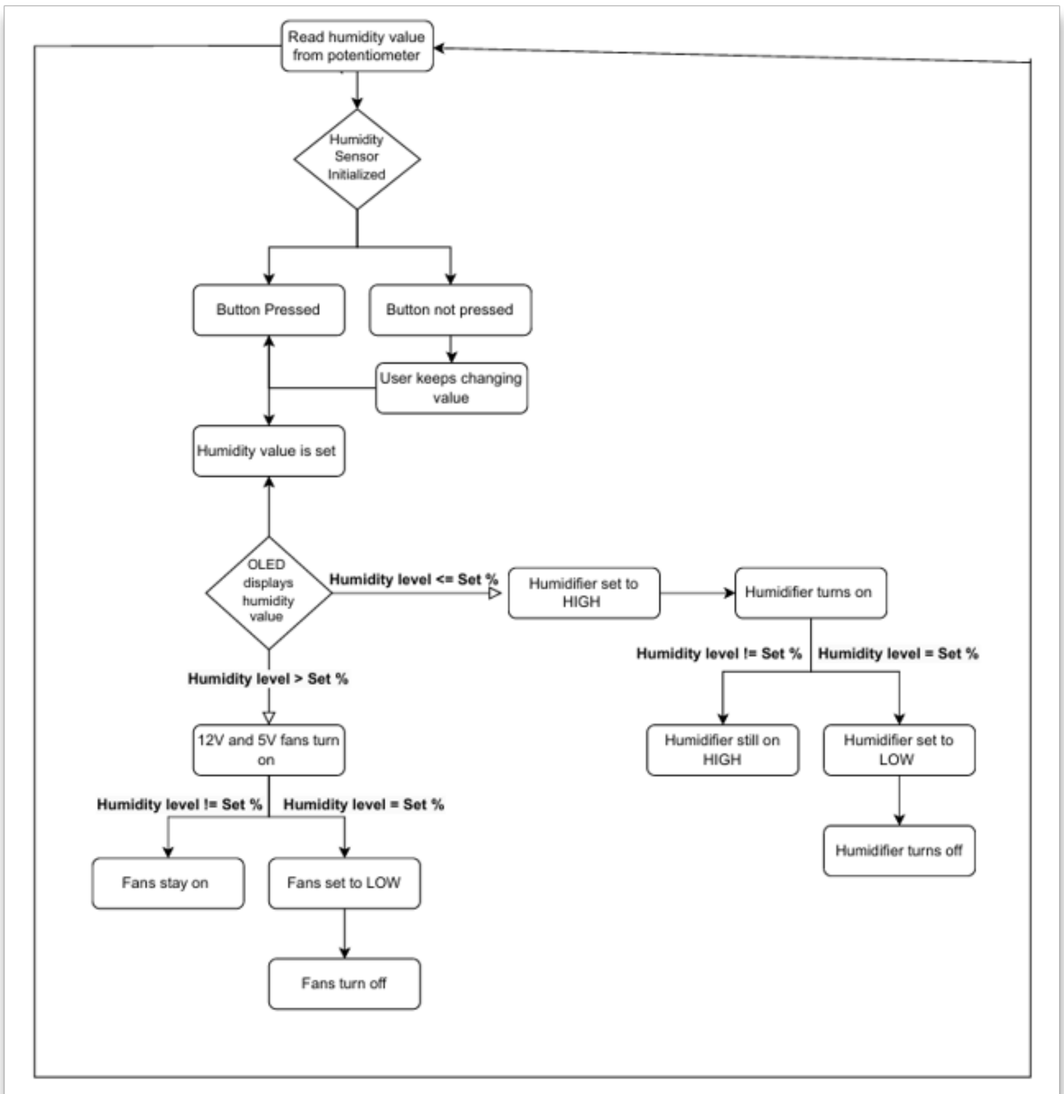


Fig. 18, Pseudocode

Functional diagram

This functional diagram **[Fig 14]** is intended to represent the basic functionality of our constructed humidity model. It only considers the humidity adjustment model and does not represent the inputs and outputs of the electrospinning apparatus itself. As seen in the black box model in the top left, the design is intended to take in water, silica gel packets, electrical energy, and human energy to properly function. Human energy combined with the water and silica gel packets is important for getting the mechanisms for increasing and decreasing humidity ready. Once setup, human energy is converted to an activation signal and required to begin the electrospinning process (syringe pump). Electrical energy is used to boot up the Arduino and the humidity sensor for reading and control. Throughout the process, the humidity sensor is continuously measuring the relative humidity levels within the apparatus and those measurements are sent to the Arduino to determine if corrective action is to be taken or not. If the measured humidity falls above or below the desired range, the Arduino sends an activation signal to the dehumidifying chamber or the humidifier to decrease or increase the humidity respectively. Once the range falls back in line, both the dehumidifier and the humidifier are signaled to turn off. Throughout this entire process, the system is displaying the interior humidity to communicate the current situation within the apparatus to the user.

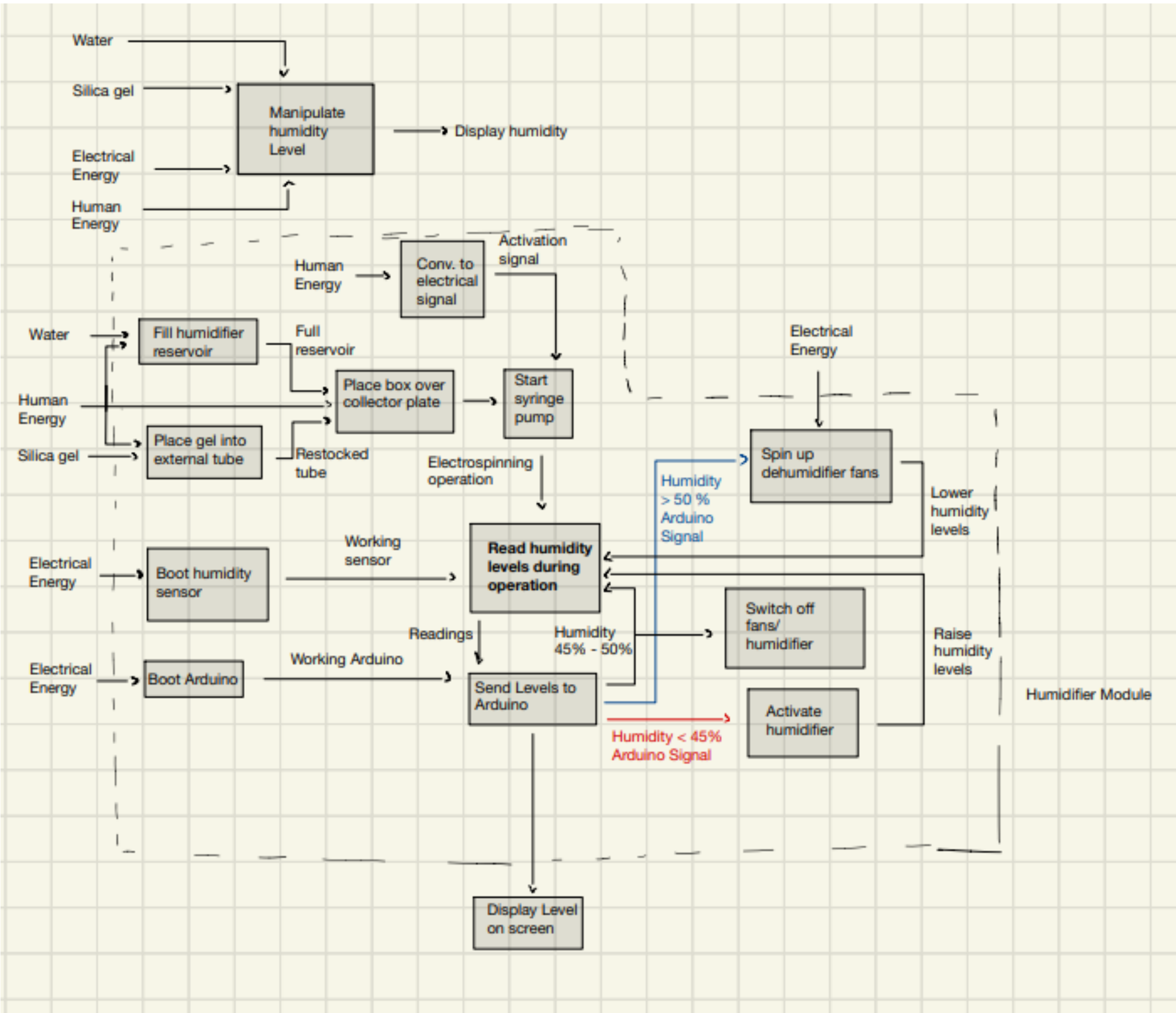


Fig. 19, Functional Diagram

Circuit Diagram

The circuit diagram below **[Fig 15]** displays the circuit connections and wiring. The atomizer is connected to digital pin 2 on the Arduino Uno and the 3.3 volt power supply from the Arduino. Two fans are connected in parallel through a mosfet and are connected to digital pin 3 on the Arduino. They require a 5 volt power source. The humidity sensor is wired to Analog ins four and five, as is the OLED display.

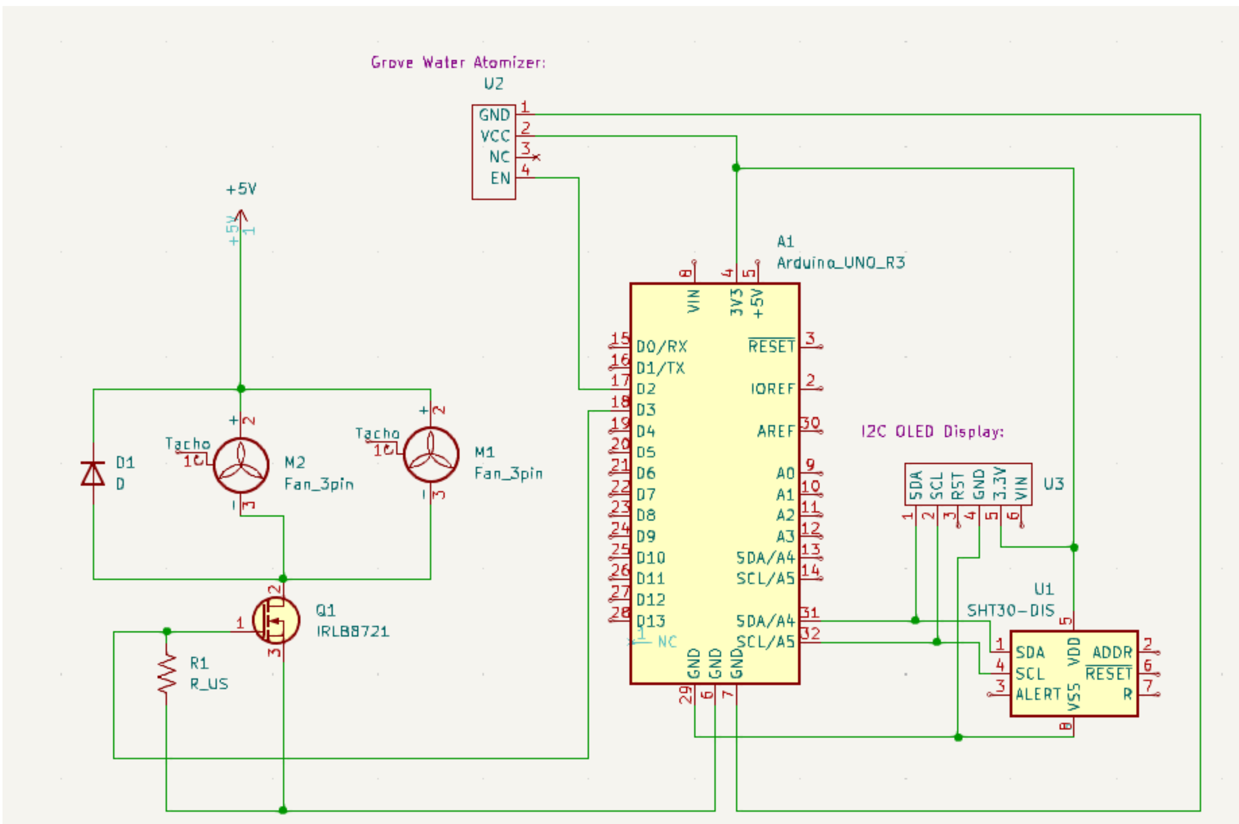


Figure 20, Circuit Diagram

Design Validation

The following table displays the verification methods associated with a select few requirements:

Table 3: To validate the design of the project, various verification tests will be performed for select requirements listed in Table 2.

Requirement #	Requirement	Final specification	Accepted outcome	Verification Method	Test Result	Pass/ Fail	Notes
1	Humidity range	The device should be able to control the relative humidity around the electrospinning machine to a specific level between 40% and 70%	The humidity should be maintained at a specified level between the range of 40% and 70 %	The humidity display should be within the range of 40-70 % with a 5 % error at the high and low end.	The desired humidity was reached within the error constraints	Pass	70% humidity reached from 65% in 4 minutes. 55% reached from 65% in 25 minutes
2	Distance	The distance of the collector plate should be 15 cm from the spinneret.	The distance from the spinneret to the collector plate is 15 cm	A tape measure used to find the distance between the spinneret and the collector plate should read 15 cm	A distance of 15 cm fit in the collector plate	Pass	
3	Safety	The device should not have any exposed sharp edges or exposed screws,	The device should be safe to touch using bare hands when unplugged	Visual inspection of possible sharp edges or corners.	There were no visible sharp edges	Pass	
17	Electrical Safety	There should be no exposed wiring/risk of electrocution without adequate labeling.	The device should be safe to touch, without exposed wires	Visual inspection ensuring no visible wires on the outside of the device when	There were no visible wires outside of the box	Pass	
18	Weight	The device should weigh less than 10 pounds	The device should be under 10 pounds	When the entire device is weighed the scale reads a weight under ten pounds	The weight was 6.46 pounds	Pass	
5	Collector Plate Dimensions	The collector plate must be at least 6	The collector plate must measure to at	The collector plate used for electrospinning	The collector plate of the	Pass	

		nches long and 6 nches wide.	least 6 in by 6 in	should measure to have a size of 6 in by 6 in, and fit within the acrylic box	desired size fit in the box		
9	Ease of Use	The device will be provided with a manual and should not require knowledge beyond the scope of a junior engineer when .	The device should be able to be set up by a junior engineer, without needing to ask questions	Have another student set up the box while a team member gives them instructions. Make sure that they can set up the box without needing help within 25 minutes.	The student was able to set up the device in 54 seconds	Pass	
10	Quick Set Up	The device should not take more than 20 minutes to set up with the existing apparatus	The time that it takes to set up the complete apparatus should be under 20 minutes	Have a team member set up the electrospinning apparatus and the device in under twenty minutes	The team member was able to set up the device in 1 minute 5 seconds	Pass	
11	Feedback	he device must be ble to accurately old the humidity vithin ± 1% of the lesired relative umidity within a elatively isolated ystem.	The humidity should stay within a range of 1% relative humidity of a value defined by the user in the functional range	Bring the box to the desired humidity level and make sure the relative humidity does not fluctuate between more than 1 percent of that value over the course of 5 minutes	The humidity did not fluctuate outside of the range within five minute	Pass	
15	Fiber Collection	t must be a simple rocess to remove nd replace collector lates within the levice.	The collector plate should be easy to remove, without damaging the fibers with the device in place	Have a team member remove an aluminum foil sheet the size of the collector plate and ensure that the sheet can be removed without being folded or distorted within 3 minutes	The collector plate was removed in well under the required time for 10 trails	Pass	

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