Design of a Compostable Menstrual Pad: Fluid acquisition layer and absorbent core

Final Design Report

BIOE 4950

Team 3

Marika Dewar-Norosky

Janel Wyllie-Runner

Noah Duguay

Matthew Pries

Caven McRae

Submitted: April 13th, 2023

Department of Biosystems Engineering

EXECUTIVE SUMMARY

The build-up of non-biodegradable waste is an ever-growing issue in modern society. In one lifetime, a person can produce up to 300 lb of plastic waste by using disposable menstrual products (Labine, 2021). Major manufacturers of menstrual pads make their products out of mostly non-biodegradable materials that end up in landfills. The non-biodegradable components can take up to 800 years to decompose (Pebery et al. 2019).

Aruna Revolution is a company that is working towards creating a compostable menstrual pad to provide a solution to the waste contribution of menstrual products. The intended outcome of this project was to create two layers of a compostable menstrual pad, the fluid acquisition layer and the absorbent core that meets current comfort and performance expectations from users. The project's scope was to research and develop a nonwoven textile for use as the topmost fluid acquisition layer of a menstrual pad and a layer that will serve as the absorbent core, using cattail fibres. The use of cattails is shown to be sustainable, and they are known to be readily available in North America.

An experimental plan was created to develop wet-laid nonwoven prototypes with varying leaf and seed fibre ratios to determine the influence of each type of fibre on how the sample interacts with synthetic menstrual fluid. Additionally, fibre samples were sent to Aruna Revolution, in partnership with Southeast Nonwovens to develop various samples using a hydroentanglement method. The test results showed that a nonwoven material created with a hydroentanglement process [redacted] is suitable for the fluid acquisition layer. Additionally, a nonwoven material created using 100% leaf fibres with a wetlaid nonwoven method is suitable for the absorbent core.

Several test methods were used to verify that the final design met design constraints. Fluid property tests such as the fluid acquisition test and rewet test were completed on the fluid acquisition layer and absorbency tests were completed on the absorbent core. Additional tests were completed such as anti-microbial test, allergen test, durability test and stiffness test to understand how the samples will interact with the user. All test results were promising for the final design and both menstrual pad layers met the design constraints.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Purpose

The build-up of non-biodegradable waste is an ever-growing issue in modern society. Currently, menstrual products are being manufactured of mostly non-biodegradable materials and, as such, they make the overarching waste problem worse. These menstrual products can contain plastics that take up to 800 years to decompose (Pebery et al. 2019). It is estimated that 19 billion menstrual products are used each year in the United States (Hait and Powers 2019). Therefore, a compostable menstrual product capable of competing with current menstrual products in both comfort and performance would be highly beneficial.

1.2 Background

1.2.1 History of menstrual product materials

Prior to the availability of plastics, some options for menstrual products were rags, cotton, wool, rabbit fur and even grass (Rubli 2013). There is evidence that ancient civilizations such as the Egyptians used tampons made with rolled-up cotton or softened papyrus (Ahmed 2022). A plant called sphagnum cymbifolium (blood moss) was used by some groups and because of its high absorption, it could be used as a filling for menstrual pads (Ahmed 2022). In France during the war, nurses began using wood pulp bandages intended for injured soldiers, as pads because of their absorptive qualities (Clark 2020). There was a variety of materials used to absorb menstrual blood and people often had to be creative with the materials that were available around them.

1.2.2 Current menstrual products

There is a wide variety of menstrual pads on the market. The most common options for pads contain plastics and are not biodegradable. There are few options for biodegradable pads that are often made of bamboo or cotton, and even fewer for compostable pads. Current sustainable products that exist to solve the environmental problem of menstrual pads are reusable. These reusable products come with many drawbacks that make them less preferable to disposable options. They must be washed and are initially more expensive. Many people find the concept unpleasant and might not have the same comfort or fit. Most current menstrual products are "comprised of 48% fluff pulp, 36% polyethylene, polypropylene and polyethylene terephthalate, 7% adhesives, 6% super-absorbent and 3% release paper" (Ajmeri and Ajmeri 2010). Synthetic materials are used to conceal menstruation and reduce contact with menstrual blood but have been shown to contain carcinogens and hormonal disruptors (Woytuk and Sondegaard 2022).

1.2.3 Menstrual pad layers and functions

Generally, menstrual pads are composed of 4 functional layers, as shown in Fig. 1.1, the fluid acquisition layer, distribution component, absorbent structure, and liquid impervious membrane (Barman et al. ND). The top layer, the fluid acquisition layer is typically a "perforated film which allows liquid to pass through it quickly into the absorbent structure so that it stays dry" (Barman et al. ND) it is a woven, or nonwoven material typically made of polyester, polyethylene or polypropylene, cotton, or viscose/rayon (UNICEF). The distribution layer is required to distribute the fluid throughout the area of the pad since the liquid only enters the pad at one location. The absorbent structure is generally made from a super-absorbent core that can absorb several times its weight, depending on the material. The absorbent core allows for longer use of the menstrual pad. The bottom layer, the liquid impervious membrane, is required to hold the fluid within the pad to avoid leaking.

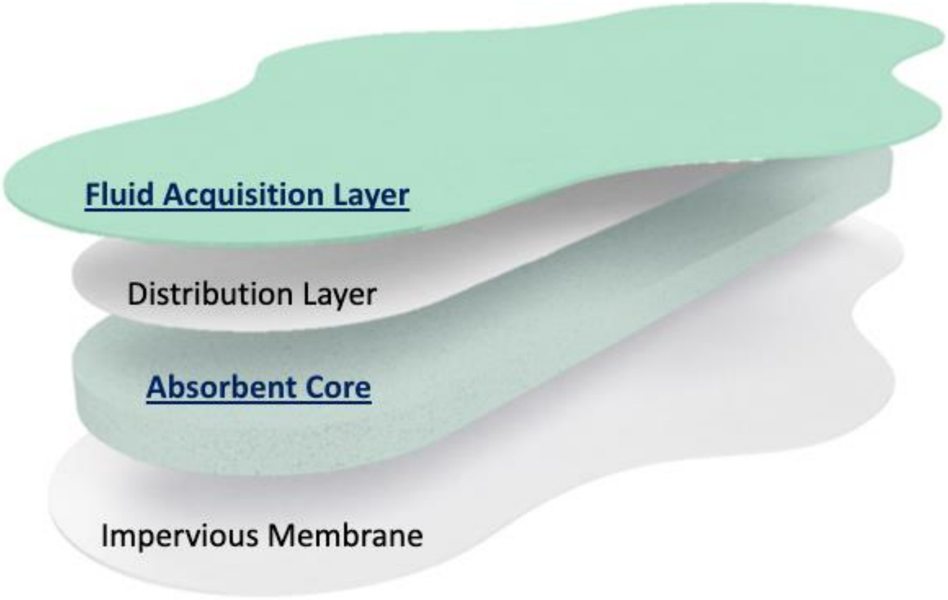

Fig. 1.1 Typical menstrual pad layers

1.2.4 Cattails

Cattails (*Typha* spp.) are flowering wetland perennial plants. Cattails are harvested from wetlands by cutting the stem at the bottom of the plant, near the root. The seed heads are harvested separately by cutting off the top portion of the stem with the seed spike. At the scale of this project, all harvesting is done by hand. They show potential as a sustainable source of natural fibres and are readily available in North America (Khalilur 2021). The emergent parts of cattails are composed of long simple leaves that sheathe a central stem with a flower spike near the top. Drawing on the experience of Dr. Mashiur Rahman, who researches cattail fibres at the University of Manitoba, it is understood that the fibre produced from the stem and leaves is hydrophilic and fibres from the seeds in the flower are hydrophobic. The terms hydrophobic and hydrophilic are generally qualitative terms that are provided by a static water contact angle value range. Hydrophilicity is an affinity for water, and hydrophobicity is the absence of an affinity for water (Law 2014). The contact range for a hydrophobic material is a contact angle greater than 90º, and for a substance to be hydrophilic, the contact angle must be less than 90º (Law 2014).

In research completed by Cao et al. (2016), the cattail seed fibres showed a contact angle of 132.78º when in contact with a water droplet. This contact angle is similar to the contact angle of cotton which is 133.30º (Dong et al. 2015). Cattail seed fibres have a length ranging from 2.25-10.65mm, a fineness of 10-15 um and a pH of 6.7, which is harmless to the human body according to a study completed by Zhang et al. (2018). Additionally, cattail seed fibre pectin mass is found to be 1.013%, which is similar to that of cotton fibre, usually around 1% (Zhang et al 2018).

Cattail leaf fibres have a low density of 1.26 g/cc compared to canola, flax and hemp (Shadhin et al. 2022). The diameter of leaf fibres varies along a single fibre and ranges from 15-40 um (Shadhin et al. 2022). Cattail leaf fibres composition on average is 55-65% cellulose, 8-10% hemicellulose, 8-10% lignin, 5-10% moisture and 4-8% ash content (Rahman et al. 2021).

1.2.5 Nonwoven textiles

The manufacturing of nonwoven textiles involves a wide range of processes, depending on the fibres used and the desired properties of the finished product. In general, the process begins with fibre layup – the formation of a web from the raw fibres – followed by consolidation or bonding to strengthen the nonwoven material and lock the fibres together.

1.2.5.1 Fibre layup for nonwovens

There are three main layup categories for nonwovens: dry-laid, wet-laid, and melt-laid. Melt-laid processes are predominantly utilized with thermoplastic synthetic polymers so they will not be discussed here.

The two main dry-laid web formation processes are carding and air laying. In general, carding is best suited to longer fibres, while in air laying the fibre length is between 1-12 mm (Oji Kinocloth). In the carding process fibres are combed in the carding machine, which separates fibre bundles and orients most of the fibres along a common axis, and the web is formed from one or more layers of carded fibres. This process allows for considerable control over the orientation of the fibres in each layer of the web. Air-laid webs are formed by suspending short fibres in an airstream and depositing them in a layer to form the web. Nonwovens formed in this way often have high porosity, absorbency, and wicking rate (Santos et al.).

The formation of nonwoven wet-laid webs is conceptually like the air-laid process, however; rather than air, the fibres are dispersed in water or another liquid and are deposited on a substrate that allows the drying of the web.

1.2.5.2 Nonwoven web consolidation

For nonwovens that do not contain any thermoplastic fibres, the two main bonding processes for consolidating the web are mechanical and chemical.

Mechanical bonding involves processes that physically entangle the fibres of the web, providing strength through the interlocking of the individual fibres. The two most prevalent processes are needle-punching – using barbed needles to punch through the web and tangle the fibres – and hydro-entanglement, which uses high-pressure jets of water to consolidate the web (EDANA).

Chemical bonding utilizes adhesives to bind the fibres together. There are a wide variety of potential binders for this process, including latex-based adhesives that have been used in conjunction with wet-laid web formation processes (Wilson 2010).

1.3 Project Definition

1.3.1 Problem statement

Considering the business case and environmental benefits identified by Aruna Revolution supporting the development of compostable menstrual pads, there was a need to create two nonwoven textiles using compostable cattail (*Typha* spp.) fibres, one that can serve as the fluid acquisition layer and the other as the absorbent core.

1.3.2 Scope

Through client meetings with Aruna Revolution, it was found that the most beneficial use of resources, skill and time was to research and fabricate a prototype for the nonwoven top layer (fluid acquisition layer) and the absorbent core. The project was dedicated to researching and testing the feasibility of the use of cattails fibres for these layers. The distribution layer and impervious membrane have been left out of scope as well as the method of combining the layers which has already been determined by Aruna Revolution.

Compostability was initially part of the project scope but has been eliminated due to the expected synergistic effect of the different layers when composting as an entire pad. With multiple layers, made from different materials, the possibility for interrelated impacts on compost ability is high. One notable facet of this is the naturally low nitrogen found in cattails increases time required to compost (Biesboer 1984), while a menstrual pad soiled with blood will have a much higher nitrogen concentration and will compost faster. Depending on the composition of other layers it may aid or hinder total compost time.

1.3.3 Problem requirements

To ensure the product was working as intended, standards provided by Aruna Revolution and International Organization for Standardization (ISO) and American Society for Testing and Materials (ASTM) standards were used to test the nonwoven materials created. To test the mass per unit of area, ASTM D3776 (2020) was used. A goal of [redacted] g/m^2 had been provided. To test fluid acquisition time, which is the time required to pull the liquid through the material (Easson 2018), a procedure provided by Aruna Revolution from Nettel Consulting was used. The target time for the material is [redacted]. This same procedure was be used to test material re-wetting, defined as the wetback of liquid from the nonwoven onto a filter paper (Easson 2018), [redacted]. The absorbent core must be approximately [redacted] g/m^2 and absorb [redacted] mL. The entire pad developed must also be compostable in a commercial compost within 28 days. The remaining project requirement is softness, which was tested as stiffness. The remaining tests were durability and safety, safety was tested using a microbial test against a control. The stiffness and durability test were completed against a standard pad as the control.

Table 1. Functions, objectives, constraints

Design Piece	Design Functions	Design objectives	Design Constraints	Standard
Fluid acquisition layer Weight	Design must be of a suitable weight to remain comfortable for users	Mass per unit area [redacted]	Mass per unit area [redacted]	ASTM D3776 (mass per unit area)
Fluid acquisition layer Fluid Transfer	Design needs to quickly transfer fluid from the top layer to the distribution layer	Design must transfer fluids through layer. Liquid should be pulled through the fluid acquisition layer [redacted] initial application without retaining significant fluid within the top layer	Design must transfer fluids through the top layer within 8 s of initial application, without retaining significant fluid within layer. [redacted]	Test Procedure Provided by Aruna Revolution, Developed by [redacted]
Absorbent Core Weight	Design must hold menstrual fluid while maintaining a light weight	Design must be lightweight [redacted]	Design must be lightweight [redacted]	ASTM D3776 (mass per unit area)
Absorbent Core Fluid Transfer	Design must hold menstrual fluid	Design must hold menstrual fluid without fluid leaking into the bottom or top layer	[redacted]	Test procedure provided by Aruna Revolution

Design Piece	Design Functions	Design objectives	Design Constraints	Standard
Material Used	Design must be made exclusively of plant-based materials	Design should use cattail and/or cattail blended with other plant-based products	Design must use plant-based materials	N/A
Product Safety	Design will need to be safe for users	Design must be tested for bacterial growth	Design must be tested for bacterial growth against a control	Testing outlined in Section 3: Design Evaluation
Durability	Design will need to be durable for use	Design should perform similarly to standard pads under a durability test	Design should perform similarly to standard pads under a durability test	Testing outlined in Section 3: Design Evaluation
Stiffness	Design must flexible	Design should perform similarly to a standard pad under a stiffness test	Design should perform similarly to a standard pad under a stiffness test	Testing outlined in Section 3: Design Evaluation
Compostability	Product must be compostable in an industrial compost	Product must be compostable after use and will degrade in less than 28 days	Product must be compostable after use and must fully degrade in 28 days	ISO 11721-1

2. DESIGN SOLUTION

Creating nonwoven textiles from cattails has been researched and shown to be a promising solution for the fluid acquisition layer and absorbent core of a menstrual pad. To produce wicking properties while also keeping the user dry the fluid acquisition layer must be composed partly of hydrophilic materials to provide sufficient capillary action to move the liquid to the distribution layer, and the remaining material must be hydrophobic (Barman et al). The absorbent core must be made with hydrophilic fibres that have a high absorbance capacity.

This section details (1) the proposed fibre extraction processes, (2) the nonwoven manufacturing procedures, and (3) the fibre ratios for the fluid acquisition layer and absorbent core.

2.1 Fibre Extraction

Fibre extraction is required for cattail leaves as the cellulose fibrils in the raw material are bound together in a matrix with a variety of cementing materials such as hemicelluloses, lignins, and waxes (Chakma 2019). Fibres from the seed heads of the plant; however, do not require processing to produce separated fibres, instead needing only to have the seeds removed from them. The fibre extraction process has a 40-60% yield for leaf fibres (Shadhin et al. 2021), and although yield percentages have not been calculated for seed fibres, the only thing removed is the fruit, so yield is expected to be very high. The fibre extraction protocol for both leaf and seed fibres can be found in Appendix C: Project Specific Materials - Standard Operating Procedures (SOPs).

2.1.1 Seed Fibre (SF)

Seed fibres, shown in Fig. 2.1, were provided by Native Plant Solutions, an environmental consulting company with extensive experience processing seeds of wetland plants. Their organization has a use for the fruit of the cattail seeds, but little use for the fibres. In the process they utilize, the seed fibres are separated from the fruit by blending the seeds with several drops of dish detergent – to act as a surfactant – and then letting the fruits settle out while the fibres float to the surface (see Appendix C(2): Seed Fibre Extraction). The fibres extracted in this way from the seeds do not require further processing to break up fibre bundles or remove non-cellulosic matrix components, as in the leaves. However, examination of the provided fibres shows that the removal of fruits is not complete.

An additional seed fibre cleaning process was employed for the samples processed at Southeast Nonwovens. In this instance the seed fibres were passed through a carding machine as part of the web formation process prior to hydroentanglement. The carding action effectively removed the remaining fruits and the samples processed in this way were almost completely free of fruits.

2.1.2 Leaf Fibre (LF)

Fibres were extracted following the standard operating procedure detailed in Appendix C (1): Leaf Fibre Extraction.

Cattail leaves are initially cut to the desired length. To remove the non-cellulose substances, present in the raw material, alkali retting is completed in a bath of 7% potassium hydroxide solution at 85C for 3 hrs. Fig. 2.2 shows the cattail leaves in the retting bath. After retting, the fibres are rinsed multiple times under hot and cold water before being neutralized with a 2% acetic acid solution (Shadhin et al. 2022). The resulting fibres are then dried at room temperature for a minimum of 24 hrs.

Fig. 2.1 Cattail seed fibres provided by Native Plant Solutions

Fig. 2.2 Chopped cattail leaves in retting bath

2.2 Nonwoven Fabrication

Two different nonwoven fabrication methods were used to make samples. In-house fabrication was limited to a simple wet-laid process; however, additional samples were made by Aruna Revolution and a third party – Southeast Nonwovens – using a hydroentanglement process.

2.2.1 Wet-laid nonwovens

The wet-laid samples were manufactured following the standard operating procedure outlined in Appendix C (3): Wet-laid Sample Fabrication. In short, the leaf and seed fibres were mixed in the appropriate ratio, and the mixture dispersed in water. A fine screen was then passed through the mixture to remove the solids, forming a mat on the surface of the screen, which was then dried briefly in an oven and then fully at room temperature.

2.2.2 Hydroentangled nonwovens

Several hydroentangled nonwoven samples were produced by Aruna Revolution working with Southeast Nonwovens. They were supplied with seed fibres, processed as described in section 2.1 Fibre Extraction, which were carded and mixed with processed hemp fibres to create a nonwoven web, which was consolidated using a series of high-pressure water jets and then dried.

2.3 Fibre Ratio Design

The fibre ratio design is summarized in Table 2. These blends have been determined through an iterative process of creating samples with various ratios of leaf fibres and seed fibres and testing them for their fluid properties. After each iteration, the blends and process for creating the wet-laid nonwovens was refined and the results evaluated to determine the most promising blends for achieving the desired properties of each layer. After the iterative process, some fibres were sent to Aruna Revolution for further prototyping using the specialized equipment available to them while working with Southeast Nonwovens.

Table 2. Design summary

Layer	Fibre Ratio	Nonwoven Fabrication Method	Weight (g/m^2)
Fluid Acquisition Layer	[redacted]	Hydroentanglement	[redacted]
Absorbent Core	100% Leaf Fibres	Wet-laid	[redacted]

2.3.1 Fluid acquisition layer design process

The fluid acquisition layer must pull liquid through the top of the pad through to the absorbent core while leaving the user dry. In the prototyping phase of this project, various fibre blends were created to further understand how each type of fibre impacts the fluid acquisition and rewet properties. The fibre blends that were created were 100% Leaf Fibre (LF)/0% Seed Fibre (SF), 80LF/20SF, 70LF/30SF, 60LF/40SF, 50LF/50SF, 40LF/60SF, 20LF/80SF, 0LF/100SF. In the first round of testing, the leaf fibre dominant blends (100LF/0SF, 80LF/20SF) absorbed the fluid too quickly and showed that the liquid was held in the layer, rather than pulling it through to subsequent layer. The seed fibre dominant blends did not allow the fluid to go through the layer and it stayed on the top of the sheet. In the second round of prototyping, different variations of leaf fibre dominant blends were created including 70LF/30SF and 60LF/40SF blends. From the fluid testing, the 70LF/30SF blend had the best results in terms of fluid properties and was chosen to be tested further.

Samples of seed fibres and leaf fibres were sent to Aruna Revolution (working in collaboration with Southeast Nonwovens) to create samples using more specialized equipment. Aruna Revolution was able to fully remove the seeds from the seed fibres (which was not previously possible in the lab) and created a nonwoven material using [redacted]. This nonwoven was created using a hydroentanglement fabrication method. Unfortunately, they were not yet able to work with the cattail leaf fibres and therefore they used hemp as a replacement. Two samples were returned, one was [redacted] and the other [redacted] both samples were soft and flexible. From preliminary fluid property testing, t[redacted] was selected as the final solution for this layer, this textile is shown in Fig. 2.3. Though the in-house samples that were seed fibre dominant did not show similar results, it is hypothesized that the removal of seeds and hydroentanglement method used altered fluid properties to make the material less hydrophobic. Section 3 Design Evaluation outlines the tests completed on the [redacted] and the in-house 70LF/30SF layer to demonstrate design superiority.

Fig. 2.3 [redacted]

2.3.2 Absorbent core design

The absorbent core is one of two middle layers within the pad, the other is the distribution layer. This layer must be hydrophilic and must absorb significant amounts of fluid, up to several times the weight of the layer. From the iterative design process described in section 2.3.1, the leaf fibres were very hydrophilic, absorbing synthetic menstrual fluid immediately upon contact. Whereas the seed fibres are hydrophobic and would not be suitable in this layer. The absorbent core design is made with **100% leaf fibre** (shown in Fig. 2.4). The goal weight per area is [redacted]. With a layer of approximately [redacted], it should absorb [redacted] of fluid.

Fig. 2.4 In-house 100% Leaf Fibre sample

3. DESIGN EVALUATION

A variety of tests, summarized in Table 3, were conducted to evaluate the performance of the nonwoven textiles created during the prototyping phase of the project. Most importantly, tests for acquisition time, rewet, and absorbency provided a quantitative measure of the fluid behaviour of the textiles and could be compared to the functional requirements specified by Aruna Revolution. Additional tests for allergens, anti-microbial properties, durability, and stiffness were performed to better characterize the samples and to allow for a more thorough comparison to existing solutions on the market.

Table 3. Design evaluation summary

Test	Standard Used	Aruna Revolution Test Requirement	Team Objective
Fluid transfer (acquisition time)	Nettel Consulting Solutions	[redacted]	[redacted]
Fluid transfer (rewet)	Nettel Consulting Solutions	[redacted]	[redacted]
Absorbency	Gupta and Chatterjee 2002	[redacted]	[redacted]
Allergen test	Svedman et al.	*NA*	No reaction
Anti-microbial properties	Dr. David Levin	*NA*	Visual zone of inhibition
Final weight	ASTM D3776	[redacted]	[redacted]
Stiffness	ASTM D1388-14	*NA*	Comparable to Standard Pad
Durability	ASTM D4966-22	*N/A*	Comparable to Standard Pad

3.1 Fluid Transfer

The liquid acquisition, strikethrough, and rewet of the prototype nonwoven acquisition layer was tested to verify if the given design constraints were met. These tests were conducted using an FDA, the United States

Food and Drug Administration, synthetic menses formulation. The acquisition was tested by adding the menses formulation to the textile at a specific volume and flow rate. The total volume held by the textile and the amount of fluid transfer, or rewet, was recorded as the results.

Since acquisition testing was only needed for the designed fluid acquisition layer, an absorbent body to hold the fluid was added. For this a commercially available menstrual pad was used in which the manufactured acquisition layer was removed and replaced with the design.

The strikethrough and rewet are calculated using the standards provided by Aruna Revolution [redacted]

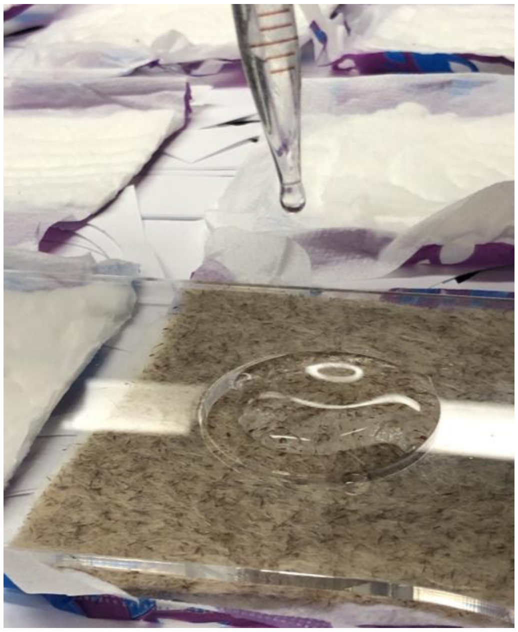

Fig. 3.1 Fluid acquisition test, simulant being applied

3.2 Absorbency

The 100% leaf fibre wet-laid nonwoven proposed for use in the absorbent core was tested to determine its total absorbency. The primary function of the absorbent core is to imbibe fluid as it passes through the fluid acquisition layer and retain it. By testing absorbency, the maximum fluid-holding capacity of the absorbent core material was determined. The testing method for measuring absorbency followed that described by Gupta and Chatterjee (2002): First, a square sample piece was cut from the nonwoven textile that had been conditioned to the lab's ambient temperature and humidity and its mass recorded. Second, the sample was immersed in simulated menstrual fluid for 1 min. Third, the sample was removed from the fluid and placed on a wire rack to drip dry for 10 min. Finally, the sample was weighed again and the difference between initial and final masses was calculated to give the total mass of absorbed fluid.

3.3 Allergen Test

To verify the sample does not create an allergic reaction, common allergens were not be used in textile processing (Svedman et al. 2019). To verify that the nonwoven textile is not an allergen, it was tested to see if it can cause contact dermatitis, which is any localized allergic reaction to the skin. Allergic Contact Dermatitis (ACD) is often formed on skin located in areas of high friction and perspiration and can be induced through textile contact with skin (Mobolaji-Lawal & Nedorost, 2015). Due to the frequency of perspiration and friction in the area around the fluid acquisition layer, there is a potential for naturally occurring allergens from the fibres to leach out of the textile and onto the surrounding skin, causing ACD. Allergic contact dermatitis would mean the product was irritating and even painful for the wearer. To test this, a patch test was conducted. To conduct a patch test, medical tape is applied to a human tester's back and the fabric sample is within as a small patch. This tape is then left on for 48 hours before being removed (Svedman et al 2019). This test was conducted on four of our team members. Positive patch tests are graded as +: Weak reaction, ++: Strong reaction and +++: Extreme reaction. Examples of weak and strong reactions are shown in Fig. 3.2 and Fig. 3.3, respectively.

If any positive reaction was present, further testing would need to be done to determine what component of the textile is causing the reaction. This further testing is more in-depth and would require an ultrasonic bath to extract components from the textile and then patch-testing them as individual reactants (Bruze, 2014).

Fig. 3.2 + Weak Reaction (Coulson 2021).

Fig. 3.3 ++ Strong Reaction (Coulson 2021).

3.4 Fabric Durability

The durability test followed the ASTM D4966-22 Martindale Abrasion Tester Method. Testing was completed using a Martindale M235, which simulates wear by rubbing test fabrics on a standardized wool abrasion fabric with a set pressure of 1.7 kPa, in a Lissajous figure at a constant cyclic rate of 47.5 rpm. The test fabrics are then inspected for damage periodically until destruction. Cycles to destruction are recorded for each test fabric and then compared to the fluid acquisition layer of a standard menstrual pad. There are no testing standards or expected baseline results for this test. The test results were compared to other created textile iterations and a commercially available menstrual pad fluid acquisition layer.

3.5 Fabric Stiffness

A fabric stiffness test was conducted to compare created textile samples to commercially available layers. Testing followed ASTM D1388-14: Standard Test Methods for Stiffness of Fabrics using the cantilever test frame, shown in Fig. 3.4. For the test, 20 mm x 160 mm strips of each layer are cut and slowly slid off the end of the testing frame so one end is cantilevered out. The length of overhang is then measured when the free edge of the specimen droops to an angle of 41.5° below the horizon. The longer the overhang, the stiffer the layer. This test was conducted on a selection of the nonwoven prototype textiles in addition to a commercial acquisition layer.

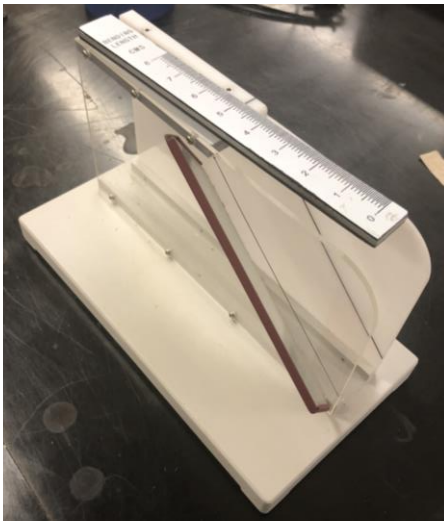

Fig. 3.4 Fabric stiffness tester

3.6 Anti-microbial Testing

Ideally, the final textile would have some antimicrobial properties. This is not a design constraint, but adequate testing should be conducted as this property would prove a beneficial component for consumer use and marketing. It was hypothesized in the literature that cattail extracts possess antimicrobial properties (Ramesh et al 2013).

The anti-microbial test process has been provided by Dr. David Levin from the University of Manitoba. The bacteria used for the experiment was the BL21 strain of *Escherichia coli*. This bacterium was deemed appropriate for testing as it is a gram-negative bacterium that could encounter the product when in application. This strain is also not pathogenic and does not require intense training and biosecurity to handle such as other bacterium that would be useful to test such as *Staphylococcus aureus*.

The procedure for the microbial test was to prepare 9 LB agar plates and spread a bacterial lawn on 6 of them. The 3 plates without the bacterial lawn were used as controls. One control was exposed to a sample of seed fibre, and another was exposed to a sample of leaf fibre. This was to determine if the fibre itself would grow any microbes. One control was the negative control that was not exposed to any bacteria or textile to ensure that the LB agar plates don't culture any microbes from plate and environment. Two samples of seed fibre were placed on three of the plates with the bacterial lawn and two samples of leaf fibre were placed on the other three plates with the bacterial lawn. The plates were then kept at 30° C for

24 hours to allow the bacteria to grow. If the fibres possess antimicrobial properties against the bacterium used the bacteria would fail to grow on and around the sample piece within 24 hours of growth.

3.7 Final Weight

The mass per unit area of the final textile was verified. The ideal value for the fluid acquisition layer is a weight of [redacted] but this goal is flexible. The goal value for the absorbent core is [redacted] This was measured using the standard procedure found in ASTM D3776 (2020), Standard Test Methods for Mass Per Unit Area (Weight) of Fabric. This test is performed with a scale measuring ±0.1% or the true value, and a round cutting die with an area of 2 in^2 or more. The test is conducted at the standard atmosphere of 21 ± 2°C and 65 ± 5% RH. This test was conducted three times and the average resulting data was used to calculate a grams per square meter value.

4. RESULTS

The final proposed design consists of a [redacted] nonwoven material that is [redacted] for the fluid acquisition layer and a 100% leaf fibre nonwoven for the absorbent core. Through testing summarized in Table 4, the chosen design solution was shown to have met each required design criteria.

Table 4. Summary of test results

Test	Aruna Revolution Test Requirement or Standard Pad (SP)	Southeast Nonwoven 50gsm [redacted]	Southeast Nonwoven 85gsm [redacted]	In-House 70%LF/30% SF	100% LF
Fluid transfer (acquisition time)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Fluid transfer (rewet)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Absorbency	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Allergen test	N/A	No reaction	N/A	N/A	No reaction
Anti-microbial properties (SP) (Y/N)	N	N	N/A	N	N
Final Weight	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Stiffness (SP)	19.50 mm	25.25 mm	48.00 mm	48.5 mm	N/A
Durability (SP)	>2000 cycles	>2000 cycles	>2000 cycles	89 cycles	N/A

4.1 In-house Testing for Fluid Acquisition Time and Rewet

The fibre blends that were created were 100% Leaf Fibre (LF)/0% Seed Fibre (SF), 80LF/20SF, 70LF/30SF, 60LF/40SF, 50LF/SF, 40LF/60SF, 20LF/80SF, 0LF/100SF. These samples were cut into smaller 9 cm x 9 cm pieces for testing. The results of the fluid acquisition tests can be seen in Table 5. The in-house seed fibre dominant samples all provided a higher level of softness, but the fibres were too hydrophobic and did not allow the synthetic menses to go through the material. The seed fibre dominant samples also contained a large quantity of seeds still within the fibres. From the samples created in-house, a nonwoven consisting of 70 percent leaf fibre and 30 percent seed fibre yields promising results that meet the design parameters when tested for fluid acquisition and final weight.

Table 5. In-house samples fluid property results

Sample Composition	GSM	Acquisition time (s)	Rewetting Weight (g)
100% LF	[redacted]	[redacted]	[redacted]
100% SF	[redacted]	[redacted]	[redacted]
20 LF: 80 SF	[redacted]	[redacted]	[redacted]
40 LF: 60 SF	[redacted]	[redacted]	[redacted]
60 LF: 40 SF	[redacted]	[redacted]	[redacted]
70 LF: 30 SF (Iteration 2)	[redacted]	[redacted]	[redacted]
70 LF: 30 SF (Iteration 3)*	[redacted]	[redacted]	[redacted]
80 LF: 20 SF	[redacted]	[redacted]	[redacted]
100% LF (Iteration 2)	[redacted]	[redacted]	[redacted]
Commercial Pad	[redacted]	[redacted]	[redacted]
*Note Iteration 3 was performed with a different commercial pad than other testing			

4.2 Southeast Nonwoven Sample Results

Fibre samples were sent to Aruna Revolution to create nonwoven samples with [redacted] The returned samples were [redacted] The results for these samples are shown in Table 6. Compared to the fluid property results in Table 5, these samples are shown to be superior in terms of fluid properties.

Table 6. Southeast Nonwovens sample results

Sample Group	Acquisition Time (s)	Rewetting Weight (g)
50 g/m^2	[redacted]	[redacted]
85 g/m^2	[redacted]	[redacted]

4.3 Absorbency Test Results

The results of the absorbency test – summarized in Table 7 – demonstrate that the 100% leaf fibre wet-laid nonwovens used for the absorbent core prototypes were able to absorb nearly 10x their mass in simulated menstrual fluid. Thus, a textile of this composition with a basis weight of [redacted] would be able to absorb [redacted] of fluid per 1 m^2 of fabric. With the density of the simulated menstrual fluid being [redacted], the area specific absorbency of such a textile would be [redacted] Put in terms of an intensive property of the textile, the absorbency is [redacted]

Table 7. Absorbency test results

Sample	Dry mass (g)	Wet mass (g)	Absorbed Fluid (g)	Absorbency ($g_{fluid}/g_{textile}$)
1	[redacted]	[redacted]	[redacted]	[redacted]
2	[redacted]	[redacted]	[redacted]	[redacted]
3	[redacted]	[redacted]	[redacted]	[redacted]
Average	[redacted]	[redacted]	[redacted]	[redacted]

4.4 Allergen Test Results

Allergen testing was completed as stated in section 3.3. 0 LF : 100 SF and 70 LF : 30 SF patches were adhered to participant's backs or forearms (as shown in Fig. 4.1) for a period of 48 hours. The patches were removed after the time had elapsed and the reactions from both patches were recorded. No contact dermatitis reactions to either patch was noticed on any of the participant's skin, the results can be seen in Table 8 and Table 9.

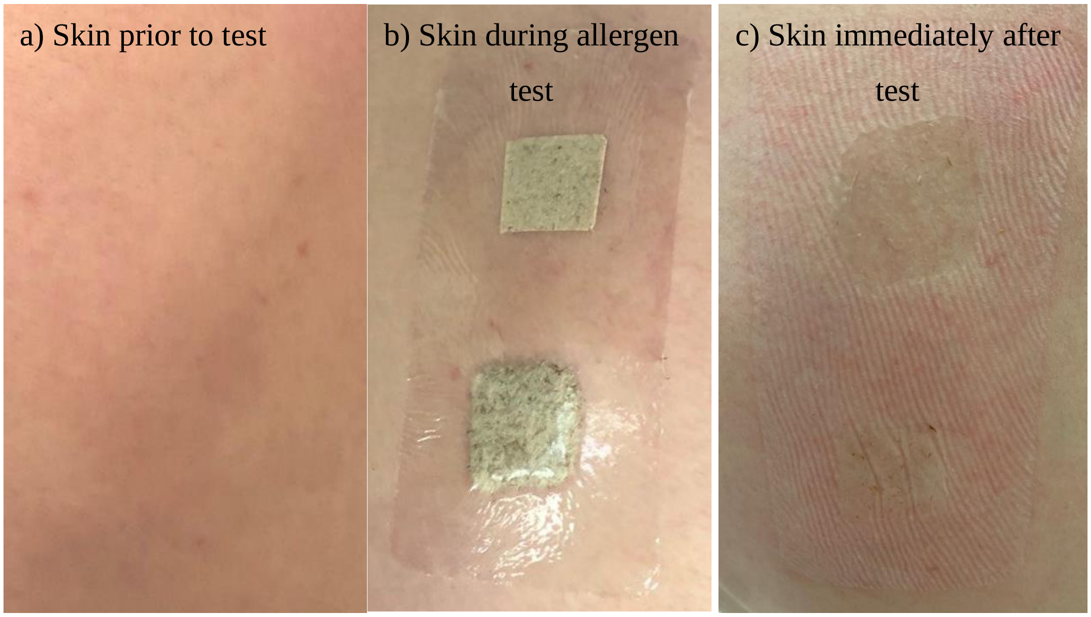

Fig. 4.1 Allergen testing

Table 8. Allergen test results for 100%SF sample

Participant	No Reaction	Mild Reaction (+)	Severe Reaction (++)	Extreme Reaction (+++)
#1	x			
#2	x			
#3	x			
#4	x			

Table 9. Allergen test results for 70 LF: 30 SF sample

Participant	No Reaction	Mild Reaction (+)	Severe Reaction (++)	Extreme Reaction (+++)
#1	x			
#2	x			
#3	x			
#4	x			

4.5 Durability Test Results

Durability testing was carried out using a Martindale m235 abrasion tester. The 4 samples tested included a commercial acquisition layer, the 2 Southeast Nonwoven Layers, and the 70 LF:30 SF nonwoven layer, these results can be seen in Table 10 and Fig. 4.2. Each layer was rubbed against a standardized abrasive textile at a cyclic rate of 47.5 rpm and with a pressure of 1.7 kPa. The number of cycles until destruction was recorded, as that would give a measure of durability when compared to the commercial layer.

Table 10. Acquisition layer durability

Test Sample	Cycles to destruction
Commercial Layer	>2000
Light SE	>2000
Heavy SE	>2000
70 LF: 30 SF	89

Fig. 4.2 (Left to Right: Commercial Layer, Light SE, Heavy SE, 70 LF : 30 SF after testing)

4.6 Stiffness Test Results

Stiffness testing was completed by feeding 20 mm x 160 mm strips of both Southeast layers, the 70 LF : 30 SF layer, and the commercial layer through a fabric stiffness tester. The distance the fabric needed to travel over a free edge for the edge of the textile to droop 41.5 degrees below the horizon was then recorded. Higher slide distances equate to a stiffer or more rigid textile. Results of this test are shown in Table 11.

Table 11. Acquisition layer stiffness

Test Sample	Slide Distance (mm)
Commercial Layer	19.50
Light SE	25.25
Heavy SE	48.00
70 LF: 30 SF	48.50

4.7 Anti-microbial Test Results

The microbial test was completed as stated in section 3.4. The testing found that neither the seed nor leaf fibres possessed any antimicrobial properties against E. Coli bacteria. These results can be seen in Fig. 4.3 for the leaf and seed fibres. The figures clearly show that the leaf and seed fibres do not possess properties that inhibit the growth of E. Coli as there is no area of inhibition.

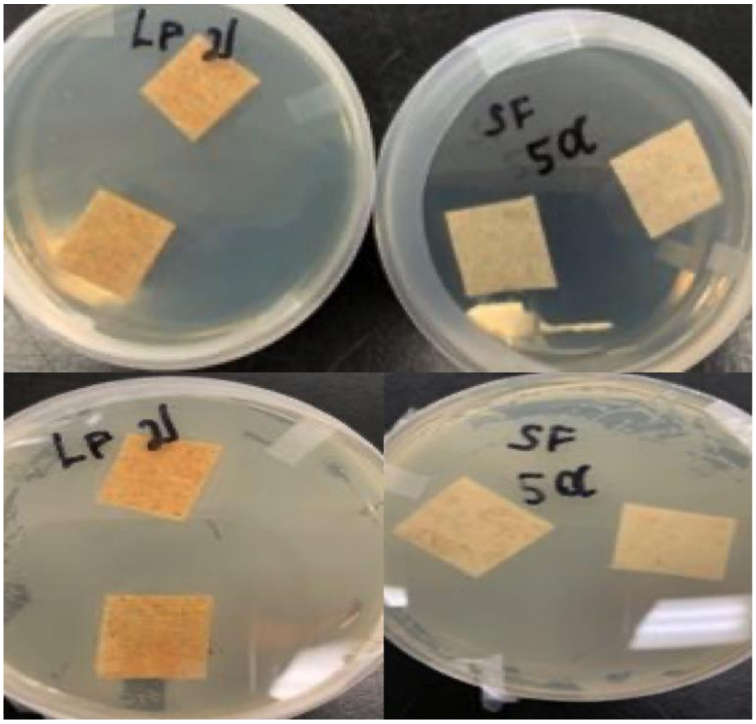

Fig. 4.3 Microbial test before (above) and after 24 hours (below)

The negative control (Fig. 4.4) did not show any microbial growth showing that no contamination was present. The seed fibre control (Fig. 4.5) did not show any microbial growth showing that the sample is sterile and does not pose any microbial risk. The leaf fibre control (Fig. 4.6) did grow some microbes. This is likely due to the sample being handled and contaminated. The use of hydroentanglement may be able to mitigate this risk as the high-water pressure may be able to remove microbes from the surface of the fibre. This may have prevented microbial growth on the seed fibre sample. More testing would be recommended to confirm that the leaf fibre does not promote microbial growth.

Fig. 4.4 Negative control

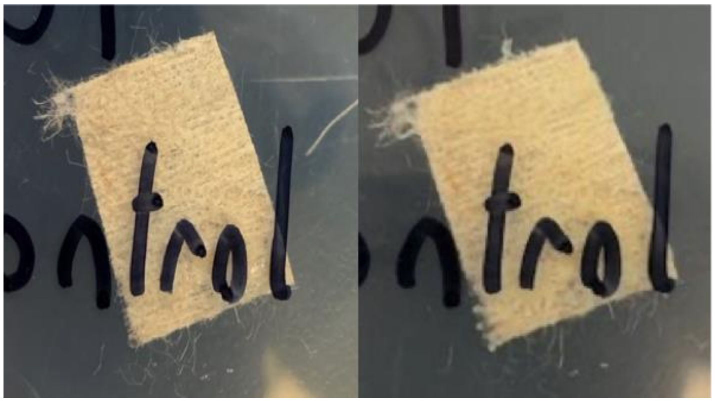

Fig. 4.5 Seed fibre control. Left is initial, right is after 24 hours of growth.

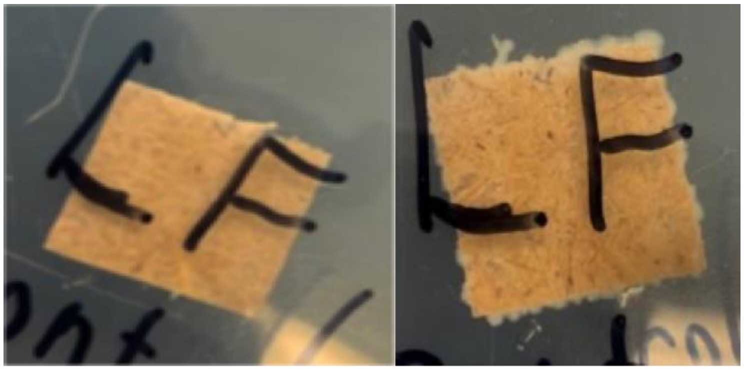

Fig. 4.6 Leaf fibre control. Left is initial, right is after 24 hours of growth.

5. LIMITATIONS OF PROPOSED SOLUTION

1. Manufacturability of the absorbent core may be a limitation. The current wet-laid process is an expensive and water intensive process. When the fibres were sent to Southeast Nonwovens (with Aruna Revolutions) they were not able to use the leaf fibres in a wet-laid or hydroentanglement process to re-create the inhouse samples. More research and testing would be required to fabricate an absorbent core using cattail leaf fibres.
2. Harvesting of cattails was done by hand. Therefore, it was easy to separate the seed head from the cattail stalk. When harvesting at a larger scale it is difficult to separate the leaf portion from the seed head because the seed head will likely disperse the seeds when they are harvested all together. To obtain seed fibres separate from the leaf fibres, a new harvesting method would need to be developed.
3. There are limitations associated with up scaling the fibre extraction process as many of the tasks required to have a successful fibre extraction were done manually. The cattail leaves must be removed from the stalk and then cut down to size. This is a limitation as no mechanical device exists to do this job therefore a human being has to complete the task, making the process expensive to scale up.
4. Until manufacturing processes are streamlined and mechanized the final product may be too expensive to be economically competitive with existing menstrual products as the fabrication processes are currently labour intensive.

6. SUMMARY AND RECOMMENDATIONS

The current production and use of menstrual products creates a significant quantity of non-biodegradable waste. In an ever-growing world, the need to reduce plastic-based waste is important to ensure a healthy and productive space for future generations.

One of the possible solutions to the problem of plastic waste from single-use menstrual products is the use compostable cattail fibres to create nonwoven textiles. This solution is promising because there are ways to replicate the properties – such as capillary action and hydrophilicity or hydrophobicity – of single-use plastic products using plant-based materials, which are compostable and so do not contribute to the buildup of non-biodegradable waste.

In the tests that have been conducted thus far, the hydroentangled [redacted] has been the most effective as an acquisition layer, having test metrics that best align with the acquisition time and rewet weights. The layer most effective as an absorptive core was found to be the [redacted] g/m^2 100% LF layer as it exceeded expectations in absorptive capacity.

Recommendations for further experimentation:

1. The use of carding as a removal of seeds from seed fibres as Aruna Resolutions had success with this method.
2. For future formal verification of compostability, Aruna Revolution could contact their local compost facility, or outsource the testing to a company such as Hohenstein, which specializes in testing biodegradable textiles using the soil burial test outlined in ISO standard 11721-1 (2001). Hohenstein also tests the ecotoxicity of the textile through composting to ensure the final product is safe for standard compost use. While this testing is still important and should be done, it will be significantly more valuable with the finished product rather than independent layers.
3. The design team consists of 5 engineering students who have limited microbiology experience; therefore, a more comprehensive microbial test should be completed. To conduct a comprehensive microbial test it is recommended that a microbiologist complete more extensive testing, as only E. Coli bacteria was used which is a gram-negative bacterium. Testing using Staphylococcus, gram positive bacteria and fungi could prove beneficial.
4. Look into the use of small amounts of other natural fibers in the acquisition layer, as SE Nonwoven had success creating a layer using carded cattail seed fibers along with a small amount [redacted]

REFERENCES

Ahmed, S. 2022. Ruth. https://getruth.ca/blogs/ruth-blog/periods-through-history-a-menstrual-timeline (2022/12/04).

Ajmeri, J.R. and C.J. Ajmeri. 2010. Nonwoven personal hygiene materials and products. In *Applications of Nonwovens in Technical Textiles*, ed. R. Chapman, 85-102. Cambridge, U.K: Woodhead Publishing Limited.

ASTM. 2020. Standard Test Method for Determining the Antimicrobial Activity of Antimicrobial Agents Under Dynamic Contact Conditions. ASTM Standard E2149. (2022/12/06)

ASTM. 2020. Standard Test Methods for Mass Per Unit Area (Weight) of Fabric. ASTM Standard D3776. (2022/12/06).

Barman, A., S.D. Asagekar and P. Katkar. Technical textile.net. An overview on sanitary napkins. https://www.technicaltextile.net/articles/an-overview-on-sanitary-napkins-7850. (08/10/2022).

Biesboer, D. 1984. Nitrogen fixation associated with natural and cultivated stands of Typha latifolia L. (Typhaceae). *American Journal of Botany*, 71(4):505–511.

Bruze, M. 2014. The use of ultrasonic bath extracts in the diagnostics of contact allergy and allergic contact dermatitis. *In Patch Testing Tips* 129-142. Springer, Berlin, Heidelberg.

Cao, S., D. Ting, X. Guangbiao and W. Fumei. 2016. Study on structure and wetting characteristic of cattail fibres as natural materials for oil sorption. *Environmental Technology* 37(24):3193-3199.

Chakma, K. 2019. *Extraction efficiency, quality and characterization of Typha latifolia l. fibres for textile applications*. M.S. thesis, Biosystems Eng., UofM, Winnipeg, MB. https://mspace.lib.umanitoba.ca/xmlui/handle/1993/33616 (2022/10/19).

Chatterjee, P.K. and B.S. Gupta. 2002. Porous structure and liquid flow models. In *Absorbent Technology*, eds. P.K. Chatterjee and B.S. Gupta, 1-55. Amsterdam, NH: Elsevier Science B.V.

Clark, J. 2020. Aisle. https://periodaisle.ca/blogs/all/the-history-of-menstrual-products (2022/12/04)

Coulson, I. 2021. Patch Test Reaction. *In DermNet Consultant Dermatologist.* https://dermnetnz.org/topics/patch-tests (2022/12/06).

Deng, C., W. Liu, Y. Zhang, C. Huang, Y. Zhao and X. Jin. 2018. Environmentally friendly and breathable wet-laid hydroentangled nonwovens for personal hygiene care with excellent water absorbency and flushability. *Royal Society Open Science* 5(4).

Easson, M., J.V. Edwards, N. Mao, C. Carr, D. Marshall, J. Qu, E. Graves, M. Reynolds, A. Villalpando and B. Condon. 2018. Structure/function analysis of nonwoven cotton topsheet fabrics: multi-fibre blending effects on fluid handling and fabric handle mechanics. *Materials*. 11(11): 2077

Gupta, B.S., and P.K. Chatterjee. 2002. Measurement techniques for absorbent materials and products. In *Absorbent Technology*, 390-444. Amsterdam: Elsevier Science B.V.

Hait, A. and S.E. Powers. 2019. The value of reusable feminine hygiene products evaluated by comparative environmental life cycle assessment. *Resources, Conservation and Recycling*. 150(1): 0921-3449.

Hohenstein. 2022. Biodegradation Product. *Textile testing.* Available: https://www.hohenstein.us/en-us/textile-testing/sustainability/biodegradability (2022/10/19).

ISO. 2001. Textiles - Determination of resistance of cellulose-containing textiles to micro-organisms. ISO standard 11721-1. OBP. (2022/12/06).

Khalilur, R.K. 2021. Cattail textile fibre and its research trend. *Kohan Textile Journal.* https://kohantextilejournal.com/cattail-fibre. (08/10/2022).

Labine, J. 2021. City startup produces eco-friendly menstrual products. *Edmonton Journal*. https://uml.idm.oclc.org/login?url=https://www.proquest.com/newspapers/city-startup-produces-eco-friendly-menstrual/docview/2545822062/se-2 (08/10/2022).

Law, K.Y. 2014. Definitions for hydrophilicity, hydrophobicity, and superhydrophobicity: getting the basics right. *The Journal of Physical Chemistry Letters*, Vol 5(4):686-688.

Martínez-Hergueta, F., A. Ridruejo, C. González, and J. LLorca. 2015. Deformation and energy dissipation mechanisms of needle-punched nonwoven fabrics: A multiscale experimental analysis. *International Journal of Solids and Structures* 64–65: 120–131.

Mobolaji-Lawal, M. and S. Nedorost. 2015. The Role of Textiles in Dermatitis: An Update. *Current Allergy and Asthma Reports.* 15:17. https://doi-org.uml.idm.oclc.org/10.1007/s11882-015-0518-0

Nonwovens Manufacturing Process. *EDANA.* https://www.edana.org/nw-related-industry/how-are-nonwovens-made (2022/10/6).

Peberdy, E., A. Jones, D. Green. 2019. A Study into Public Awareness of the Environmental Impact of Menstrual Products and Product Choice. *Sustainability*. 11(2):473.

Rahman, M., N. Cicek and K. Koushik. 2021. The optimum parameters for fibre yield (%) and characterization of typha latifolia L. fibres for textile applications. *Fibres and Polymers* 22(6): 1543-1555.

Ramesh, L., U. Kattegouga, K. Shivsharanappa, J. Hanchinalmath. 2013. Phytochemical screening and in vitro antimicrobial activity of Typha angustifolia Linn leaves extract against pathogenic gram-negative microorganisms. *Journal of Pharmacy Research* 6(2):280-283

Rubli, S. 2013. Femme International. https://femmeinternational.org/the-history-of-the-sanitary-pad/ (2022/12/04)

Santos, A. S., P. J. T. Ferreira and T. Maloney. 2021. Bio-Based Materials for Nonwovens. *Cellulose* 28(14): 8939–8969.

Shadhin, M., D. Mann and M. Rahman. 2022. Probabilistic model for cattail and canola fibres: effect of environmental conditions, structural parameters, fibre length, and estimators. *Textile Research Journal*, 92(13-14): 2513–2528.

Shadhin, M., M. Rahman, R. Jayaraman and D. Mann. 2021. Novel cattail fibre composites: converting waste biomass into reinforcement for composites. *Bioresources and Bioprocessing* 8:101.

Svedman, C., M. Engfeldt and L. Malinauskiene. 2019. Textile Contact Dermatitis: How Fabrics Can Induce Dermatitis. *Current Treatment Options in Allergy* 6(1): 103–111.

Unicef. Technical specifications for reusable menstrual pads. https://www.unicef.org/supply/media/12311/file/technical-specification-reusable-menstrual-pads-2022.pdf (2022/11/26)

Vetayasuporn, S. 2007. Using cattails (typha latifolia) as a substrate for pleurotus ostreatus (Fr.) kummer cultivation. *Journal of Biological Sciences,* 7(1): 218-221.

What Are Nonwoven Fabrics. *Oji Kinocloth.* https://www.kinocloth.co.jp/english/what_is_nonwoven/ (2022/10/6).

Wilson, A. 2010. The formation of dry, wet, spunlaid and other types of nonwovens. In *Applications of Nonwovens in Technical Textiles*, ed. R. Chapman, 3-17. Cambridge, U.K: Woodhead Publishing Limited.

Woytuk, N.C. and M.L.J Sondegaard. 2022. Biomenstrual: more-than-human design of menstrual care products. *Temes de Disseny* 38:116-13.

Zhang, J., Y. Xiaofei, S. Cao and X. Guangbiao. 2018. Morphological characterization and properties of cattail fibres. *Materials and Technology* 52(5):625-631.

APPENDICES

Appendix A: Raw Testing Data

Sample Composition	GSM	Acquisition time (s)	Rewetting Weight (g)
Iteration 1			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
Iteration 2			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
SE Nonwoven Manufactured			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

Sample Composition	GSM	Acquisition time (s)	Rewetting Weight (g)
Iteration 3			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
Iteration 4			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

Appendix B: Bill of Materials

Componant	Qty	Description	Unit Cost ($CAD)	Bulk Unit Cost ($CAD)	Total	Total (Bulk)	Distributor	Distributor P/N	Manufacturer	Manufacturer P/N

[redacted]

Appendix C: Project Specific Materials - Standard Operating Procedures (SOPs)

1. Leaf Fibre Extraction

Version: 1.0 Updated: December 8, 2022

1.1. Introduction

This procedure outlines the standard method used to extract fibres from cattail (Typha *spp.*) leaves. A chemical retting process using potassium hydroxide dissolves lignin and other non-cellulose materials.

1.2. Health and safety

The concentrated potassium hydroxide (KOH) used in this method is highly corrosive and reacts exothermically when mixed with water. Wear goggles and gloves when handling, avoid breathing dust, and avoid contact with skin or mucous membranes. When diluting, always add KOH to water slowly while stirring.

1.3. Equipment

- Chemicals
  - Potassium hydroxide (KOH)
  - Acetic acid (CH_3COOH)
- Heated water bath with non-reactive tank (e.g., stainless steel)
- Fine-mesh sieve
- Electric blender
- Dry cattail leaves
- Scissors or shears

1.4. Method

[1] Fill water bath with a 5% W/V solution of potassium hydroxide (KOH) and heat to 90 °C

[2] Roughly chop the cattail leaves into pieces approximately 5 cm long

[3] Fill blender with chopped cattail pieces and blend for 45 s or until desired fineness is reached

[4] Transfer blended material to the KOH bath – optionally sieving first to remove dust and fines – and stir to distribute

[5] Maintain KOH bath with leaf material at set temperature, stirring occasionally

[6] After 3 h, sieve out extracted fibres from the bath and rinse thoroughly under running water with both hot and cold water while mixing the fibres

[7] Neutralize fibres by submerging in a 2% V/V solution of acetic acid for 30 min

[8] Sieve out and rinse the fibres a final time, then drain and allow to air-dry fully at room temperature

1.5. Notes

If consistent staple fibres of a certain length are desired, the blending step can be omitted. Instead, chop leaves to length and transfer directly to extraction bath.

2. Seed Fibre Extraction

Version: 1.0 Updated: December 8, 2022

2.1. Introduction

This procedure outlines the standard method used to extract fibres from cattail (Typha *spp.*) seed heads (the mature female flower spike). A mechanical separation process is used to separate the fruits from the fibre clusters.

2.2. Health and safety

No special precautions required

2.3. Equipment

- Mature cattail seed heads
- Electric blender
- Dish detergent
- Fine-mesh sieve
- Large vessel (e.g., 5-gallon pail)

2.4. Method

[1] Fill blender container halfway with water and add several drops of dish detergent
[2] Strip the seed heads from the cattail stalks by hand, collecting in the container of the blender
[3] Blend for ~1 min
[4] Pour contents of blender through sieve and rinse out soap
[5] Fill the large container ~2/3 full, then empty contents of sieve into water
[6] Agitate seed head material manually, aiming for uniform dispersion
[7] Allow to rest for 30 min, fruits that have been separated from their fibre bundles will sink
[8] Skim seed fibres from the top of the water, squeeze out as much water as possible, and spread out in thin layer to air dry

2.5. Notes

This method does not remove 100% of seeds. Alternative processes achieving more complete removal are needed.

3. Wet-Laid Sample Fabrication

Version: 1.0 Updated: December 9, 2022

3.1. Introduction

This procedure outlines the standard method used to make wet-laid nonwoven textile samples. Fibres are dispersed in water to form a dilute slurry, and a fine sieve is used to collect a uniform mat of fibres.

3.2. Health and safety

No special precautions required

3.3. Equipment

- Electronic balance
- Processed fibres (less than 2.5 cm long)
- Electric blender
- Flat fine-mesh screen (opening size <1 mm)
- Large vessel (at least big enough to fit screen fully)

3.4. Method

[1] Weigh out desired amount of dry fibres and put in blender container

[2] Add enough water to blender container to cover fibres and pulse until any clumps are broken up and the fibres are individualized

[3] Fill large vessel with water and add contents of blender to make fibre slurry

[4] Agitate slurry manually (avoid creating a vortex) to uniformly distribute fibres

[5] Pass the screen through the slurry – moving straight up from the bottom of the container and keeping the screen flat to ensure the water flow doesn't pile the fibres on one edge of the screen – to collect a uniform nonwoven fibre mat

[6] With fibre mat still on screen, transfer to 80 °C oven and dry for 25 min

[7] Remove screen from oven and quickly invert to separate the nonwoven sample

[8] Allow sample textile to dry fully at room temperature

3.5. Notes

A mixing ratio for fibre to water of approximately 1300:1 (by weight) was used in the tests that informed the development of this SOP; however, a lower ratio could realistically be used depending on the respective sizes of the screen and mixing container.