Abstract

In North America alone, 20 billion pads, tampons, and applicators are disposed of every year, with specifically around 12 billion menstrual pads deposited into landfills (Shreya, 2016). Menstrual pads are composed primarily of plastic and cellulose; materials that are non-biodegradable or take years to degrade, respectively. With Degrade-a-Pad, the waste produced from menstrual products would be completely eliminated. The Degrade-a-Pad is a menstruation product system composed of a chemical-free menstrual pad and a compartment in the toilet tank in which the pad can be disposed of. An enzymatic solution in the compartment degrades the pad within several hours into glucose and lactic acid particles that can be flushed into sewer systems safely. The Degrade-a-Pad will significantly reduce menstrual product waste, provide chemical-free menstrual pads, and act as a starting point for future polylactic acid degradation products.

Present Technology

Women in America menstruate on average for a total of 40 years, and 5 days per month. The menstrual fluid ends up in tampons, pads, and other single-use products composed of plastic material (Borunda, 2019). These products end up in landfills as non-biodegradable waste, polluting the earth. Each year, 200,000 tons of waste as menstrual products and their packaging, composed primarily of plastic, is generated (“Environmental Reasons,” n.d.). The Degrade-a-Pad system allows a menstrual pad to be instantly degraded by an enzymatic solution in an additional compartment of the toilet tank. With the Degrade-a-Pad, the plastic and chemical pollution caused by menstrual products would be eliminated.

Pads are the most widely used menstrual product, followed by tampons. These products are not reusable, and in the United States alone, 12 billion pads are discarded each year (“Environmental Reasons,” n.d.). Pads are rectangles of absorbent material that are attached to the underwear. They are composed of a top sheet, absorbent core, and back sheet, which are commonly made of cotton, absorbent wood cellulose, and polyethylene, respectively. Cotton is made of cellulose and takes about 5 months to biodegrade in a landfill. Polyethylene, a type of plastic, does not biodegrade, leading to significant plastic waste. Tampons are small tubes applied with an applicator or finger that absorb blood from inside the vagina. Tampons are blends of cotton and rayon, with other synthetic fibers (Anzilotti, 2019).

In the past two decades, there has been a demand for transparency regarding the harmful chemicals that major companies include in pads and tampons. These chemicals come in the form of toxic contaminants, fragrances, colorants, dyes, and preservatives that are not disclosed in the product description. Some sanitary napkins emit low levels of carcinogens, stemming serious health concerns for the women using these products (Kounang, 2015).

Because of the plastic waste and undisclosed chemicals in pads and tampons, more environmentally-friendly alternatives are becoming popular. These menstrual products include menstrual cups, which are reusable, funnel-shaped cups that are made of rubber and inserted into the vagina (Dillon, 2017). Period underwear are reusable as well, designed to look like normal underwear but catch menstrual flow with absorbent fabric ("Period Underwear," 2020).

Biodegradable pads and tampons have also emerged on the market. However, they are a significantly higher cost than regular pads and tampons. With many women in underserved communities already struggling for access to menstrual products, biodegradable ones are out of reach. The biggest benefit of these biodegradable pads is their ability to be composted at home. However, for every 16 pads produced by a menstruator per month, the used biodegradable pads take up to 6 months to decompose with the right conditions. The space and resources required for this process is difficult to achieve at landfills, let alone in homes (Jain, 2019). The Degrade-a-Pad system allows for pads to be dissolved more immediately, circumventing current issues with used pad waste and resources to combat it.

History

A perpetual stigma around menstruation makes it difficult to have conversations surrounding the topic, and advances in technology occur slowly (Litman, 2018). The products available to menstruating people have improved throughout the past, but not at the rate that other fields have advanced. Even though modern products are more hygienic than historical methods, the amount of waste they cause is considerable. Most commercial pads and tampons contain plastic in the product, the wrapper, and the applicator, and over the course of a menstruator's life they contribute hundreds of products to landfills (Borunda, 2019).

Several solutions to managing periods were available historically but were dangerous, unhygienic, or uncomfortable. The Ancient Egyptians used papyrus as tampons, and the Ancient Greeks utilized wood wrapped in wool (Simple Health, 2019). In medieval times, the term "on the rag" began because people would bleed into a rag that they kept in their undergarments and washed (KT, 2018). Bacteria could grow on these rags, causing infection (Kotler, 2018).

As companies began to develop more comfortable and hygienic pads and tampons, their products became less environmentally sustainable. Before the current pad and tampon there was the sanitary apron and the menstrual belt (Simple Health, 2019). The sanitary apron was made of rubber and it prevented blood from spilling on clothes and furniture but it was uncomfortable to wear and smelled unpleasant during use. The menstrual belt was a belt that went between your legs and could have absorbent cloth or material pinned to it (Simple Health, 2019).

Around the 1880's the first commercial pad became available. Kotex was the first highly successful disposable pad, and it came out in 1921 (Borunda, 2019). It was made of Cellucotton, a plant based absorbent material. Though better methods of coping with periods have emerged, there are few products that are safe, hygienic, and environmentally ethical all in one.

Future Technology

The Degrade-a-Pad is a menstruation product degradation system composed of a chemical-free menstrual pad and a compartment located in the toilet tank where the pads are disposed. The toilet tank contains an enzymatic solution, made up of a serine protease from the actinobacteria strain *Amycolatopsis* and cellulases secreted from the bacteria *Trichoderma reesei* (*T. reesei*). These enzymes break down the menstrual pad into microscopic particles of glucose and lactic acid that can be flushed into the sewer system safely. Degrade-a-Pad combats the amount of waste deposited in landfills by those using sanitary products during menstruation.

The components of the menstrual pad were chosen because of their ability to break down using enzymes. The pad is made of a base layer of polylactic acid (PLA), a highly absorbent middle layer of wood cellulose, and a top layer of cellulose. The wrapper encompassing each individual pad is made of PLA as well. Pads currently produced by P&G, the largest manufacturer of feminine products, have been found to emit hazardous and carcinogenic chemicals such as styrene, chloroethane, and chloroform (Kounang, 2015). Degrade-a-Pad menstrual pads do not contain the harmful chemicals found in current feminine hygiene products.

PLA is bioplastic, and is both biodegradable and made of natural materials (Piemonte, 2012). PLA can be created from the starch in corn or sugarcane, which is fermented into lactic acid, a monomer of PLA (Gutierrez, 2020). Pads are made of plastics that do not biodegrade, sitting in landfills for years, whereas PLA will degrade naturally in a compost in 60-100 days (Butbunchu & Pathom-Aree, 2019). Even if a Degrade-a-Pad is discarded into the trash rather than dissolved by the enzymatic solution, less damage would be caused than a typical pad.

The PLA in the pad will depolymerize into lactic acid through serine protease enzymes from PLA-degrading actinobacteria of the genus *Amycolatopsis*, also known as PLAase enzymes. Actinobacteria are gram-positive bacteria that are widely used for the decomposition of many organic substances (Puttaswamygowda et al., 2019). *Amycolatopsis* is the most dominant and effective genus found for the degradation of PLA (Butbunchu & Pathom-Aree, 2019). The serine proteases are purified and characterized by the *Amycolatopsis* genus. Serine proteases are enzymes that break peptide bonds of amino acids with the addition of water molecules (Neitzel, 2010). During the process of breaking down the pad, the serine protease will break the bonds and depolymerize PLA into its monomer, lactic acid. The lactic acid will then be able to be safely flushed down the toilet.

The cellulose and wood cellulose in the pad will be broken down into glucose molecules by enzymatic hydrolysis. Enzymatic hydrolysis works to degrade the cellulose by hydrolyzing it into soluble sugars (“Cellulase,” n.d.). Hydrolysis is the process of breaking down the glycosidic bonds holding the glucose units together with a water molecule. The water molecule “must be supplied to render each broken bond inactive” (Wang, n.d.). Water molecules supplied in the compartment of Degrade-a-Pad will aid in the enzymatic hydrolysis used to break down the cellulose.

Cellulose is converted into glucose with cellulase through a two step process of enzymatic hydrolysis. Firstly, cellulose is converted into cellobiose by beta-1,4 glucanase breaking the glycosidic linkage. Then, the “beta-1,4 glycosidic linkage is broken by beta-glucosidase,” turning the cellobiose into glucose (Wang, n.d.). The cellulase enzymes secreted by *T. reesei* will work to degrade the cellulose in the pad. *T. reesei* is one of the most studied species of fungi for the production of cellulase (Wang, n.d.). This protein production host has the high natural capacity to produce cellulase enzymes (Rantasalo et al., 2019).

A separate compartment in the toilet tank will be installed with a lid as well as a second lever on the outside of the toilet. After the Degrade-a-Pad is used and ready to be discarded, its user will place it into the compartment and flush the lever. The lever will activate a trickle of toilet water containing the combination of the cellulase and serine protease enzymes, which will flow slowly for several hours, by which point the pad will be dissolved. At the bottom of the compartment is a pipe topped with a grate leading to the toilet bowl. As the pad breaks down, the particles of glucose and lactic acid will slide through the grate and pipe into the toilet bowl. The next time the toilet is flushed, the dissolved pad particles in the toilet bowl will be flushed into the sewer system. Each month, new enzymes will be added to the water stream to replenish those that have been flushed.

Breakthroughs

Currently, implementing the Degrade-a-Pad is not technologically possible. However, by achieving scientific breakthroughs of speeding up PLA and cellulose degradation periods, making the conditions for PLA degrading enzymes and cellulase enzymes more compatible, and increasing the rate of production of the necessary enzymes, the Degrade-a-Pad will be effectively and easily distributed. One breakthrough necessary for implementation is increasing the effectiveness of the enzymes and reactions that degrade the PLA and cellulose of the pad. Because pads are meant to absorb fluid, they will expand and clog sewage pipes if flushed into standard waste management pipes. Although the Degrade-a-Pad system allows an extra window of time for the pad to degrade in an additional compartment of the toilet tank, the current processes that degrade PLA and cellulose require days, even up to months and years. Considering the limited capacity of the toilet tank, the expansion in size of the pads, and the frequency in which the products are disposed of, current degradation speeds are impractical. Through experimentation and further development, the degradation period should be reduced to within several hours. A possible solution could be the development or discovery of another enzyme to speed up the chemical reactions. Research must be conducted on bacteria and archaea strains to find such an enzyme.

The conditions within the Degrade-a-Pad’s toilet tank compartment must be maintained to activate and continue the reactions. PLAase, or PLA-degrading enzymes from actinobacteria function at an optimal pH range of 9.5-10.5, which is highly basic, and a temperature range of 50-60 °C, which is almost triple room temperature or the temperature of the toilet water

(Butbunchu & Pathom-Aree, 2019). Furthermore, the conditions ideal for PLAase are not identical to the conditions necessary for cellulase to degrade the absorbent cellulose. The cellulase enzymes require the optimal conditions of 80-90 °C, which cannot be maintained without an energy source, and a pH of 1.8, which is highly acidic (Wang et al., 2011). This contrast between the ideal conditions for the two chemical reactions makes it difficult for both to occur simultaneously. The breakthrough that would need to occur would involve reducing the activation energy, in this case temperature, of the cellulase and PLAase enzymatic reactions in order to degrade the pad in room temperature toilet water conditions. This reduction is necessary because heating the toilet tank compartment of the Degrade-a-Pad would be inefficient and costly. This would be accomplished through another enzyme or modification of the current enzymes.

Furthermore, only research will tell which PLAase and cellulase enzymes are optimal for the Degrade-a-Pad technology. Thus, future experimentation must occur to assess the experimental groups of different PLAase and cellulase enzymes on the criteria of achievability of optimal conditions and effectiveness. These factors of assessment include the temperature and pH conditions, speed of reaction, availability of enzyme, and the compatibility of the optimal conditions of the two. An example of an experiment would test the three novel PLA-degrading enzymes called PLAase I, II, and III on how fast each works under room temperature toilet water conditions. Three samples, one of each PLAase enzyme, would be placed into identical toilet water conditions in terms of volume, temperature, and pH. The time it takes for degradation products to form after a reaction with the enzyme occurs would be collected, measured by a SBA- 40C lactate biosensor (Li et al., 2008). This data is quantitative, and the enzyme that degrades PLA the fastest is taken as most effective.

To overcome the obstacle of availability of each enzyme as they are produced by specific strains of bacteria, the cellulase and PLA degrading serine protease enzymes should be manufactured. Although enzymes are not used up in the chemical reaction and can be reused, they must be accessible and widespread in order to distribute the Degrade-a-Pad to all public women's restrooms and restrooms in homes or private facilities.

Design Process

When designing Degrade-a-Pad, we researched different methods of degrading and dissolving cellulose. One of the methods found was using a mixture of sulfuric acid and hydrochloric acid. Although this would effectively dissolve the cellulose component of our pad, after further research we realized that these chemicals are highly corrosive and dangerous. Sulfuric acid is used in fertilizers, explosives, and other acids. Concentrated sulfuric acid can cause explosions when heated or being in contact with other chemicals, and even breathing an extremely small amount can cause harm ("Public Health Statement," 1998). Likewise, hydrochloric acid is used in cleaning, leather tanning, and refining products. It is tremendously harmful when in contact with the eyes, skin, and mucous membranes ("PubChem Compound," n.d.). We decided to veer away from harmful chemicals and research a more efficient and safer way to break down cellulose.

Originally we wanted to implement Degrade-a-Pad with the pads that are currently being manufactured from major and widespread companies. However, we found that many corporations have not explicitly shared all of the materials that are used to create their pads. There is non-transparency between companies and consumers in terms of what is going into their menstrual products (Kounang, 2015). Because of this, we realized that we would not be able to create successful technology that would degrade all components of currently manufactured pads since we do not have a clear understanding of all of the materials. We decided to make our own pad with simply cellulose, wood cellulose, and PLA as well as with no added chemicals so we could degrade it successfully, but also make sure the pad is healthy and safe for users.

Additionally, our initial idea was using a tablet that would be dropped into the toilet bowl. The tablet would have been composed of the combination of cellulase and serine proteases. The enzymes would act to fully degrade and break down the components of the pad in the toilet bowl. The degraded menstrual pad would then have the ability to be safely flushed into the sewage system. After researching the characteristics of enzymes and how they function, we realized that this idea would not be able to fit in the time constraints of putting the tablet in the toilet, waiting for a small period of time for everything to fully break down, and then flushing it safely. Enzymes can take multiple hours or days to properly do their job, and the enzymes would not be able to successfully degrade everything in a couple of minutes as we had envisioned previously. We then modified our technology into something more appropriate and fitting for the time constraints; a compartment installed inside of the toilet tank.

Consequences

If implemented, the Degrade-a-Pad technology will reduce plastic waste in landfills, provide safe, chemical-free pads for menstruators, and act as a starting point for future fast PLA-degrading technology. In just North America alone, every year 20 billion pads, tampons, and applicators are disposed of, with specifically around 12 billion menstrual pads being deposited into landfills. The largest impact of global warming is from the processing of low density polyethylene, a plastic found in pads. Polyethylene processing requires immense amounts of fossil fuel energy, leaving a yearly carbon footprint of 5.3 kg CO_2 equivalents (Shreya, 2016). With Degrade-a-Pad, the waste produced from menstrual products would be drastically decreased and almost eradicated, as the components of the pad would be degraded into microscopic materials that can be safely flushed down into the sewer system, resulting in virtually no waste. This system will immensely help the environment and lessen the negative impacts menstrual products produce.

Pads currently take 500-800 years to fully decompose when disposed of in landfills, as the plastic used is non-biodegradable (Sambyal et al., 2019). The decomposition time span with using Degrade-a-Pad would go from a matter of hundreds of years to a few hours. Placing pads into the compartment and enabling them to degrade with the mixture of enzymes ensures the most efficient and effective method to dispose of products.

Another important effect of the Degrade-a-Pad technology is that the menstrual pad is only composed of cotton, wood cellulose, and PLA. Currently, major companies do not disclose the materials of their menstrual products, including the toxic chemicals that come from the product's fragrances, colorants, dyes, and preservatives. In a study done by the market research group Euroshare, P&G's Always pads emitted dangerous chemicals, including chloroethane, chloroform, and styrene (Kounang, 2015). High levels of exposure to chloroethane can result in lack of muscle coordination and unconsciousness. Exposure to chloroform can cause respiratory injuries, and damage to the liver, heart, brain, kidneys, and bone marrow ("Chloroform," 2013). Styrene is classified as a carcinogen, meaning it is capable of leading to cancer ("Toxic Substances," 2012). These menstrual products with undisclosed chemicals can lead to serious health effects for consumers, all of which are eliminated by the transparency and safe materials of the Degrade-a-Pad.

Furthermore, as with all present menstrual products there is a chance of human error during use. Typical feminine products do not degrade, and absorb fluid to many times their original size. When flushed into standard waste management systems, feminine products clog sewer systems and require extensive effort to remove. With the Degrade-a-Pad, the used menstrual pads will be placed into a compartment of the toilet where it is degraded within hours into microscopic materials that are safe for sewer systems. The ease and convenience of the Degrade-a-Pad disposal systems being implemented into public and private bathrooms will reduce the possibility of menstrual pads being flushed into sewer systems and causing damage.

Because of the similar function and material composition of baby diapers to menstrual pads, the technological advancement of the Degrade-a-Pad system could also be applied to diapers. Disposable diapers are not biodegradable, and are the third largest source of household waste in the United States (“Are Diapers,” n.d.). By creating disposable diapers with the same materials as the Degrade-a-Pad, they can be disposed of and degraded in the same fashion as menstrual pads. This would drastically reduce global plastic waste production even more if combined with the Degrade-a-Pad system.

A difficulty that the implementation of the Degrade-a-Pad could pose is the cost, effort, and energy expended to implement a toilet with a Degrade-a-Pad chamber into every bathroom. However, the amount of labor and cost of installing the Degrade-a-Pad will not exceed that of a typical toilet, as the technology will be implemented over time. The prospect is expensive, but will be a one-time installation, and new toilets are often installed into new and existing buildings. The installation of the Degrade-a-Pad system will not be instantaneous, but the effort will become cost-efficient over time, considering the amount of plastic that will be kept out of landfills and effort needed to remove clogged toilets.

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