Gloria H. Tie

11

*Proposed Manufacture of Antibacterial and Hydrophobic Textile*

Advanced Materials

Commercialization Plan

**Part 1: Elevator Pitch**

With the antibacterial and hydrophobic textile, uniforms for the medical and military fields will no longer need to be washed and replaced frequently. This textile, electrospun from a chlorine halamine and polytetrafluoroethylene mixture, has replenishable properties when washed in a chlorine bleach and is both antibacterial and hydrophobic for any type of environment.

**Part 2. Executive Summary**

From preventing potential nosocomial infections in hospitals to helping soldiers maintain better hygiene during training or deployment and reduce laundering costs, the use of a liquid resistant, antimicrobial fabric is needed. The chlorine halamine solution that provides the antibacterial aspect of the fabric binds and destroys bacteria. The polytetrafluoroethylene (PTFE) solution added to the fabric is highly hydrophobic due to the $CF_2$ molecular structure. Solutions of the two would be simultaneously sprayed through a dual nozzle in an electrospinner where the nanofibers would be collected on a collection plate. The fabric is intended for reusage and will require less laundering than regular clothing due to its antibacterial and hydrophobic properties. In addition, the chlorine ions are replenished with a chlorine bleach wash so the effectiveness of the antibacterial uniform is not diminished. The uniforms would be sold at a range from $30-$50 and is projected to have $2,000,000,000 in revenue (ChartBin, 2010). With this hydrophobic and antibacterial textile, the applications are multifaceted and boundless.

**Part 3. Problem Summary and Proposed Solution**

The need for an antibacterial and hydrophobic textile is evident in medical and military professions. According to a study done in 2002, "NI (nosocomial infection) accounted for 1.7 million infections in 2002, which resulted in 99,000 deaths in the United States" (Henderson, 2010). Medical staff and students who had their lab coats swabbed showed that "64.7% of the isolated organisms were *Staphylococcus aureus* and coats that were contaminated with potentially pathogenic organisms could function as fomites for the transmission of pathogenic organisms" (Anand, Banu, Nagi, 2012). Additionally, during active duty overseas, many soldiers wear the same clothes for several days, "Sometimes in training sessions, we may go four or more days without changing our uniforms. Even then, when we do change our uniforms it's usually from one dirty uniform to another dirty uniform. We don't really have that much time to change or wash them" says one soldier (personal communication, October 8, 2015).

The solution is a hydrophobic and antibacterial textile that replaces the old uniform materials of the medical staff and military members. The textile would consist of spun nanofibers of polytetrafluoroethylene (PTFE) and chlorine halamine through the use of an electrospinner. The resulting product would be able to reduce bacteria growth previously found on medical and military uniforms, as well as prolong the life of the uniforms with fewer washes.

**Part 4. Summary of STEM Concepts & Principles Underlying the Overall Plan**

The proposed textile uses two polymers, chlorine halamine and polytetrafluoroethylene (PTFE), in combination with the electrospinning process to be created. Only in the last few years, researchers and developers have utilized the two compounds for textile uses (Sun, 2014). The N-halamines are one proposed solution for an antibacterial textile coating. N-halamines are created from an imide, amide, or amine that is attached to a halogen such as chlorine, bromine and iodine (Sun, 2014), which would then be released on contact with bacteria. The intermolecular forces between the fluorine and carbon atoms in the PTFE is being applied to create the hydrophobic textile. The second main principle used is electrospinning, a process in which a polymer solution is turned into nanofibers. A liquid polymer is pushed out through a syringe where a high voltage power supply charges the polymer solution at the tip, causing the solution to jet out. The end result is the fibrous membranes are then caught on the collection plate. Because of the two separate polymers, a solution for combining the two in the pumps so that it delivers a mixture of PTFE and chlorine halamine nanofibers to create a hydrophobic and antimicrobial textile. The combination of the electrospun chlorine halamine and PTFE is the novel approach for a new textile.

**Part 5. Commercialization Assessment of the Overall Plan**

Problem

The American Journal of Infection Control found that "on average, lab coats were washed every 12.4 days, scrubs every 1.7 days, and four medical providers indicated washing their white coats every 90 days or more" (ScrubMed, 2014). The bacteria accumulated on the uniforms could easily come in contact with other people and objects, thus spreading the bacteria (Sanon, Watkins, 2012). Since hospitals are found everywhere, finding a way to minimize the spread of bacteria from dirty uniforms is important to the health of patients and other community members. In addition, findings showed that "Soldiers cannot avoid getting their uniforms dirty while carrying out their missions, especially on the battlefield. Laundering clothes is time-consuming, adds to the logistics burden on the force, and is not always available to forward-deployed soldiers, who may come into contact with mud, dirt, water, and an assortment of contaminants such as petroleum, oils, and chemicals" (Foran, 2013). The billions spent on regular military uniforms and the lives lost from nosocomial infections presents a large issue in today's society.

Proposed Solution

The textile will use cotton with chlorine halamine to create its antibacterial properties, and polytetrafluoroethylene (PTFE) to be used for the hydrophobic aspect. Electrospinning, the process used to create this textile, is a process in which a polymer solution is turned into nanofibers. First, the liquid polymer is pushed out through a syringe. A high voltage power supply creates an electrical field that charges the polymer solution at the tip of the syringe causing the solution to jet out. The fibrous membranes are then caught on the collection plate (Gao, Truong, Zhu, Kyratzis 2014). Because I have two separate polymers, I will mix the solutions in the pumps so that it delivers a mixture of PTFE and chlorine halamine nanofibers onto the cotton fabric to create a hydrophobic and antimicrobial blend textile. With previously tested chlorine halamine coatings, it was found that the chlorine halamine was still effective in destroying bacteria even after 50 washes and under 24 hours of UV radiation (Li, Liu, McFarland, Ren, Acevedo, Huang, 2016), so durability would not be an issue for the uniforms. In addition, to combat any skin irritation caused by the chlorine halamine, the uniforms would be washed in a halogen-containing liquid so that the reducing agent would readily react with excess chlorine and subsequently be rinsed away (Liu, Ren, Liang, 2015).

Target customers and intended users

The two biggest targeted consumers for this textile would be the hospital and healthcare facilities as well as the army. There are about 8,747,790 physicians in the world (ChartBin, 2010) that could be potential intended users, not to mention other medical staff in a hospital. For the military, any soldier currently training or in active duty would most likely benefit from this water resistant, bacteria killing textile. Accounting for the active, guard, and reserve soldiers total, there are about 1,105,301 total soldiers in the U.S army (Army Demographics, 2012). In total, the number of intended users would be over 9,853,091 people. The U.S government just recently issued new uniforms to all soldiers, and the total cost per uniform was around $102 (Jahner, 2015). That means around a total of $112,784,914 was spent on military uniforms. In addition, medical scrubs and lab coats are on average $20 (AllHeart, 2015), so around $174,955,800 would be spent on medical uniforms. Because uniforms are essential to the medical and military fields, it is not surprising that there is a high potential dollar value for this market.

Competitors

The two big companies that produce antibacterial textiles are Trevira and Microban. Both Microban and Trevira offer textiles using silver particles to kill bacteria. When a microbe comes in contact with the silver treated textile, the Ag ions rupture its cell wall, attaches to the DNA, and inhibits the reproduction of more bacteria. However, the problem with a silver particle coating is that it loses Ag particles every time it kills bacteria. This solution is not very effective for the mass production of military and medical uniforms since there is no cost effective way to replenish the silver particles, so the solution is not as long-lasting.

Customer value proposition and competitive advantage

For the proposed solution, the chlorine halamine coating would be replenishable with chlorine bleach so the treated textile would be able to continue to kill bacterium. The electrospun nanofibers consisting of PTFE and chlorine halamine create a textile that can be hydrophobic and antibacterial, which is one of the biggest competitive advantages of this product. The added liquid resistant feature that would benefit soldiers in otherwise dirty environments is something else not provided by Microban and Trevira. In research done with chlorine halamine treated textiles, 99% of E-coli and S. aureus bacteria were killed within two minutes (Sun, 2014). Furthermore, the chlorine halamine was also able to kill *Salmonella,* and *resistant Staphylococcus*, common bacteria also found in hospital settings. In the long term, the investment in hydrophobic and antibacterial clothing would reduce laundering costs of uniforms, in particular, medical uniforms, which on average costs up to around $30 per uniform (UniFirst, 2015). Not only that, but with antibacterial uniforms, incidents of nosocomial infections that cost the country $9.8 billion dollars each year to treat (Waknine, 2013) would be reduced. Additionally, less military uniforms would be purchased per person because of the hydrophobic properties of the textile that would allow soldiers would be able to wear the uniforms for a longer duration. The antibacterial, hydrophobic textile is the solution to reducing uniform laundering, money spent on multiple uniforms, and nosocomial infections and would be a forerunner in the market for textile and textile markets.

Principal revenue streams expected

The medical and military uniforms would be sold at a price range starting from \$30-\$50 depending on the uniform type. For the military uniforms, the cost of the entire uniform, including pants, shirts, and jacket would be sold for around \$50 if the clothing was mass manufactured. If only 5% of the total intended users were to purchase these uniforms, the estimated revenue generated would be around \$2,000,000,000 (ChartBin, 2010) with definite growth potential.

Principal startup and operating costs expected to be incurred

The main costs for start up would stem from the electrospinning machine, the PTFE, and chlorine halamine solutions. Operating costs would include the electricity usage from the electrospinner, which would be \$6.88/kilowatt hour, according to the Energy Information Administration. The general electrospinner and parts would cost around total of \$1760 (Invenso, 2015). The PTFE would cost around \$165 for 100 grams (Sigma-Aldrich, 2016), the cost of creating a chlorine halamine solution would be \$360 (Sigma-Aldrich, 2016), and the cost of cotton fabric would be around \$0.30/meter (Hancock Fabrics, 2016). In total, the start-up costs would be \$2000.

**Part 6. Science and Technology Proof of Concept**

The purpose of the proposed solution was to create a uniform both hydrophobic and antibacterial that didn't require as much cleaning than regular fabrics. The use of N-halamines is one proposed solution for an antibacterial fabric coating. N-halamines are created from an imide, amide, or amine that is attached to a halogen such as chlorine, bromine and iodine (Sun, 2006). The halamines are stabilized when bonded to a halogen as seen in Figure 1.

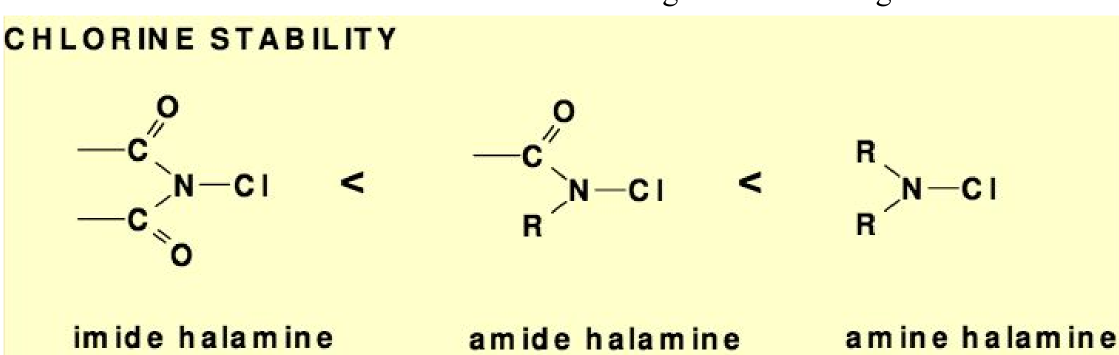


**Figure 1**: N-Halamine stabilized with chlorine
From: Sun (2014)

Tests show that the chlorine halamine treated textiles were able to kill bacteria that came in contact with it (Malik, Nogja, Goyal, 2015). Essentially, because chlorine halamine as an +1 oxidation state, when it comes in contact with bacteria, the chlorine is transferred to the bacteria cell and destroys its enzyme processes, which effectively kills bacteria (Dong, Dong, Morigen, 2015). Since the chlorine is released, a bleach chlorine solution would occasionally be used to wash the fabric in order to replenish the chlorine ions (Figure 2).


**Figure 2**: Chlorination of N-halamine
From: Sun (2014)

A solution for a hydrophobic coating would be the polymer, Polytetrafluoroethylene (PTFE). These tetrafluoroethene molecules are constructed from $CF_2$ compounds. Because both elements have high electronegativities, it is hard for other atoms to break the carbon-fluorine bonds and form another chemical reaction (Clark, 2015).

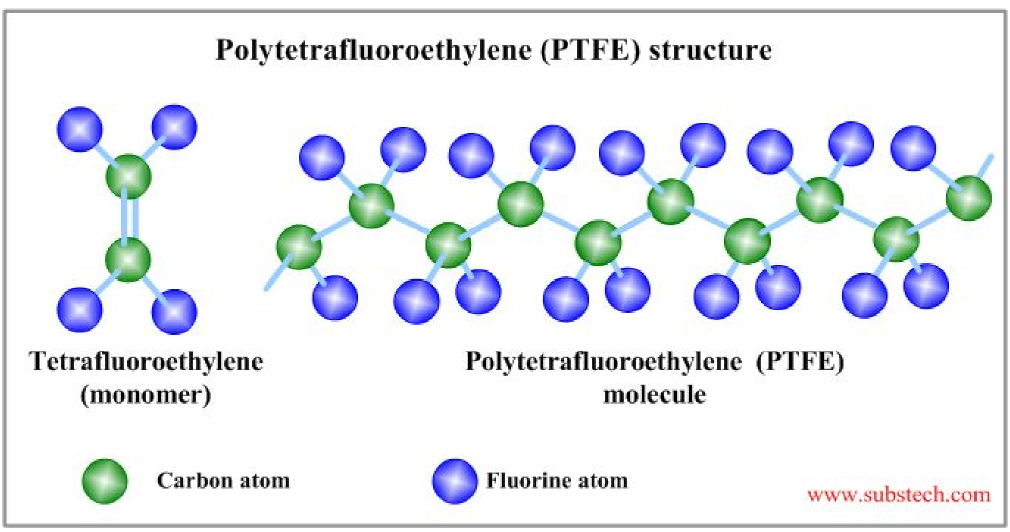


**Figure 3**: Polytetrafluoroethylene (PTFE) model
From: Sentry Air (2013)

With these two compounds, the plan to create an hydrophobic, antibacterial uniform is feasible. To achieve this, PTFE and chlorine halamine will be electrospun to create a fiber to be used to make the clothing. Electrospinning is a process in which a polymer solution is turned into nanofibers. First, the liquid polymer is pushed out through a syringe. Fibrous membranes are created when a high voltage power supply creates an electrical field that charges the polymer solution at the tip of the syringe(Gao, Truong, Zhu, Kyratzis 2014). Because I have two separate polymers, I will mix the solutions in the pumps so that it delivers a mixture of PTFE and chlorine halamine nanofibers to create a hydrophobic and antimicrobial fabric (Figure 4).

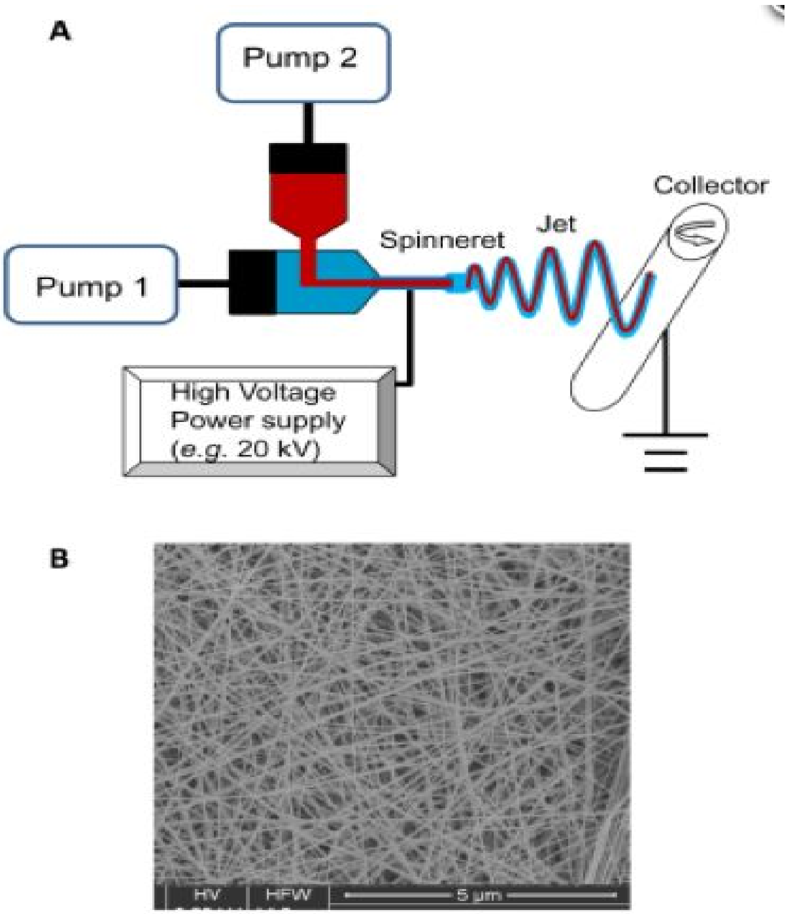


**Figure 4**: Electrospinning process
From: Gao, Truong, Zhu, Kyratzis (2014)

Researchers have previously been able to create a chlorine halamine fabric coating and have tested it against various forms of bacteria. Cotton textiles that were treated with amide or imde halamines were able to completely inactivate a virus during a five minute incubation. Even after twenty machine washes, the treated fabrics were still able to inactivate the virus (Sun, 2014). In addition, scientists have also been able to create and test a hydrophobic fabric that has been electrospun. In the results, the electrospun PTFE was able to repel water at a contact angle of 125° and a rolling angle of 25° **(**Rane, Altecor, Bell, Lozano, 2009).

**Part 7. Acknowledgements**

First and foremost, I would like to thank my wonderful mentor, Mr. Gerdes, for helping me through this research paper. He has been of invaluable help for me, and I would like thank him for taking time to be my mentor.

Secondly, I would like to credit my AP Chemistry teacher, Mrs. Sfiligoj for reading and editing this paper and giving me suggestions.

Lastly, I would also like to acknowledge my sister, Shan, and my parents, Feng Tie and Ying Huang for helping me with the inception of this idea.

**Part 8. References**


Allheart. (n.d.). Nursing Uniforms [Advertisement]. Retrieved January 29, 2016, from Allheart website: http://www.allheart.com/

*Army Demographics*. (2012). Retrieved October 8, 2015, from https://web.archive.org/web/20150503072500/http://www.armyg1.army.mil/hr/docs/demographics/FY12_ARMY_PROFILE.pdf

Banu, A., Anand, M., & Nagi, N. (2012). White Coats as a Vehicle for Bacterial Dissemination. *National Center for Biotechnology Information Search database Search term*, *6*(8). Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3471503/

Clark, J. (2015, February). Intermolecular bonding and the physical properties of PTFE. Retrieved January 29, 2016, from Chemguide Co. website: http://www.chemguide.co.uk/qandc/ptfe.html

Cotton Fabric [Advertisement]. (2016). Retrieved March 15, 2016, from Hancock Fabrics website: http://hancockfabrics.com/cotton-quilting-fabric

Dong, Q., Dong, A., & Morigen. (n.d.). Evaluation of Novel Antibacterial N-Halamine Nanoparticles Prodrugs towards Susceptibility of Escherichia coli Induced by DksA Protein [PDF]. *MDPI*. Retrieved from http://www.mdpi.com/1420-3049/20/4/7292/pdf

ChartsBin. (2010). Global Distribution of Physicians per 10,000 population. Retrieved November 18, 2015, from ChartsBin website: http://chartsbin.com/view/gcu

Foran, A. (2013, February 25). Self-cleaning clothing: wear without wear. Retrieved October 7, 2015, from Army.Mil website: http://www.army.mil/article/95276/

Gao, Y., Truong, Y. B., Zhu, Y., & Kyratzis, I. L. (2014). Electrospun antibacterial nanofibers: Production, activity, and in vivo applications. *Journal of Applied Polymer Science*, *131*(18). Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/app.40797/full

Henderson, J. (2010). The Endangered White Coat. *Oxford Journals*. Retrieved from http://cid.oxfordjournals.org/content/50/7/1073.full

Inovenso. (2013). Electrospinning Parts. Retrieved February 18, 2016, from Inovenso website: http://inovenso.com/store/#!/c/0/inview=product45179177&offset=0&sort=normal

Jahner, K. (2015, June 2). Army's new camouflage uniforms hit stores July 1. Retrieved January 29, 2016, from USA Today website: http://www.usatoday.com/story/news/nation/2015/06/01/army-combat-uniforms-camouflage/28314895/

Liu, Y., Ren, X., & Liang, J. (2015). Antibacterial Modification of Cellulosic Materials [PDF]. *BioResources*. Retrieved from https://www.ncsu.edu/bioresources/BioRes_10/BioRes_10_1_1964_Liu_Ren_Liang_Antibacterial_Mod_Cellulosic_Mater_Review_6557.pdf

Liu, Y., Li, J., Li, L., McFarland, S., Acevedo, O., & Huang, T. S. (2016). Characterization and Mechanism for the Protection of Photolytic Decomposition of N-Halamine Siloxane Coatings by Titanium Dioxide. *NCBI*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/26824841

Malik, T., Nogja, S., & Goyal, P. (n.d.). Self cleaning textile. Retrieved September 11, 2015, from Technical Textiles website: http://www.technicaltextile.net/articles/clothing-textiles/detail.aspx?articleid=389

Rane, Y., Altecor, A., Bell, N. S., & Lozano, K. (n.d.). Preparation of Superhydrophobic Teflon® AF 1600 Sub-Micron Fibers and Yarns Using the Forcespinning tm Technique [PDF]. *Jeff J. Journal*. Retrieved from http://www.jeffjournal.org/papers/Volume8/V8I4%2811%29%20K.%20Lozano.pdf

Sanon, M.-A., & Watkins, S. (n.d.). Nurses' uniforms: How many bacteria do they carry after one shift? *PubMed Central*, 311-315. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4180417/

ScrubMed. (n.d.). Medical Uniforms [Advertisement]. Retrieved January 29, 2016, from ScrubMed website: https://www.scrubmed.com/

Sigma-Aldrich. (2016). Polytetrafluoroethylene. Retrieved from Sigma-Aldrich website: http://www.sigmaaldrich.com/catalog/search?term=Poly%28tetrafluoroethylene%29&interface=Product%20Name&N=0+&mode=mode%20matchpartialmax&lang=en&region=US&focus=productN=0%20220003048%20219853286%20219853269

Sun, G. (n.d.). *HALAMINE CHEMISTRY AND ITS APPLICATIONS IN MEDICAL TEXTILES*. Retrieved from http://iom.nationalacademies.org/~/media/4AB41AD931C54AE499A51D373C243573.ashx

Sun, X., Cao, Z., Porteous, N., & Sun, Y. (n.d.). N-halamine-based rechargeable antimicrobial and biofilm-controlling polyurethane. *NCBI*. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3289718/

UniFirst. (n.d.). Medical Uniform Cleaning [Advertisement]. Retrieved January 29, 2016, from UniFirst website: http://www.unifirst.com/

Waknine, Y. (2013, September 13). Hospital Infections Cost Billions, Study Shows. Retrieved December 11, 2015, from Medscape website: http://www.medscape.com/viewarticle/810372