Paper ID #35819

Poly(-caprolactone) Nanofiber filter for better thermal comfort in Facemasks

Utomwen David Irabor, Prairie View A&M University

Utomwen D. Irabor is a Senior student and Research Assistant at the Chemical Engineering Department at Prairie View A&M University.

Dr. Nabila Shamim, Prairie View A&M University

Poly(ε-caprolactone) Nanofiber Filter for better Thermal Comfort in Facemasks

Utomwen D. Irabor
Chemical Engineering Department,
Prairie View A&M University

Nabila Shamim, Ph.D.
Chemical Engineering Department
Prairie View A&M University

Abstract

The indisputable and widespread Coronavirus disease (COVID-19) has caused tremendous social life changes. COVID-19 has expeditiously taken the lives of innocent individuals. Combined with social distancing and quintessential hygiene habits, one of the key protective strategies to reduce the coronavirus spread and return to the norm is to wear facemasks. The purpose of this study is to experimentally characterize a commercial K95 and disposable nonsurgical masks (NSM) with electrospuned nanofiber membrane used as a filtration unit in a facial mask. The goal is to enhance the user's thermal comfort as heat generated from prolonged use causes fatigue, skin rash, and discomfort to an individual. The masks were modified using polycaprolactone nanofiber mesh to provide better thermal comfort and protection against coronavirus and compare the results with the commercially used KN95 and disposable masks. The IR transmittance rate of the filtration layers was investigated using the Attenuated Total Reflection (ATR). The higher IR transmittance shows an excellent cooling effect of body temperature for PCL nanofibers (85%) compared to nonsurgical (25%) and K95 (35%) masks. The mechanical strengths of the commercial and modified filtration layer show PCL membrane have adequate strength to withstand maximum inhale and exhale respiratory pressure. Therefore, face masks with better thermal management will be helpful for prolonged use and enhanced comfort. The future goal of this work is to study composite layer-based finite element simulation with transport properties and modify the mask with a nanofiber-based face mask.
Keywords: Electrospuned Nanofibers, Coronavirus, Facemask.

Introduction

As humans evolved around the world, infectious diseases have been a constant companion throughout history. Even in the modern era, outbreaks are nearly endless. Though the viral infectious outbreaks cannot be stopped, preventive measures can be taken to fight future variants. According to the Centers for Disease Control and Prevention, "people, including children older than two, should wear a mask in indoor public places if they are not fully vaccinated, or fully vaccinated and in an area with the substantial transmission or with weakened immune systems" [1]. Wearing a face mask can significantly reduce the spread and help us return to the norm. Commercial facemasks are usually made of many layers of fibers and capture particulate matter by a combination of physical barrier and adherence. To achieve high removal efficiency masks, need to be thick, leading to a large pressure drop across the mask. Thus, breathing through masks becomes uncomfortable [2,3]. It is reported that facial temperature augmentation can trigger a panic disorder caused by elevated CO_2 levels near the mouth with hot flashes and sweating [4,5]. For this reason, many people misuse face masks without covering their noses. Recent reports show that increased temperature near the mouth can cause bacterial infection leading to serious oral health issues [6]. Breathing helps us regulate our temperature when it is hot. Thus, wearing a mask traps heat near the face can feel stifling. The problem worsens when it gets hot and humid. The humidity common in Texas prevents sweat from evaporating and cooling people off. Picking a comfortable mask is a battle. Wearers would also want to put on a cover that prevents skin rash and heat exhaustion. Nanofibers with a large surface-to-volume ratio have shown great potential for filtration application and biological and chemical contamination. Therefore, it is challenging to design a filtration layer that efficiently removes airborne pollutants with low airflow resistance. In this project, we used Polycaprolactone (PCL) nanofiber, which is biocompatible, and FDA approved [7], to modify the filtration layer and examine the thermal comfort of a selected mask, analyze the chemical and physical properties of facemasks, investigate the contact angles for nonsurgical face mask and the polycaprolactone membrane. These tests listed would help select the ideal mask under hot conditions that would serve the wearer best.

Materials and Methods

Facemasks generally are built with several layers of protection. In today's commercial masks, two common materials are melt-blown material and non-woven polypropylene. The K95 mask has three filtration layers, and the nonsurgical mask has one. The PCL nanofibers were fabricated at the University of Central Oklahoma and shipped to PVAMU for characterization. The nanofibers were fabricated using methods described by Morshed et al. [8].
Characterization: The SEM images shown in figure 1 for the commercial protective layers are taken from literature [9] and the PCL nanofibers were taken using JEOL JSM-6010LA Scanning Electron Microscope (SEM). The infrared transmittance was measured by using Attenuated Total Reflection (ATR). CAM-Plus Optical Tensiometer was used to examine the contact angle between the surface of a selected mask's surface. The mechanical strengths of the layers were studied by using Shimadzu EZ-SX tensile testing machine. Finally, a Vernier Caliper was used to measure the thickness of the protective layers. The ambient temperature and humidity were also recorded during the experiments.

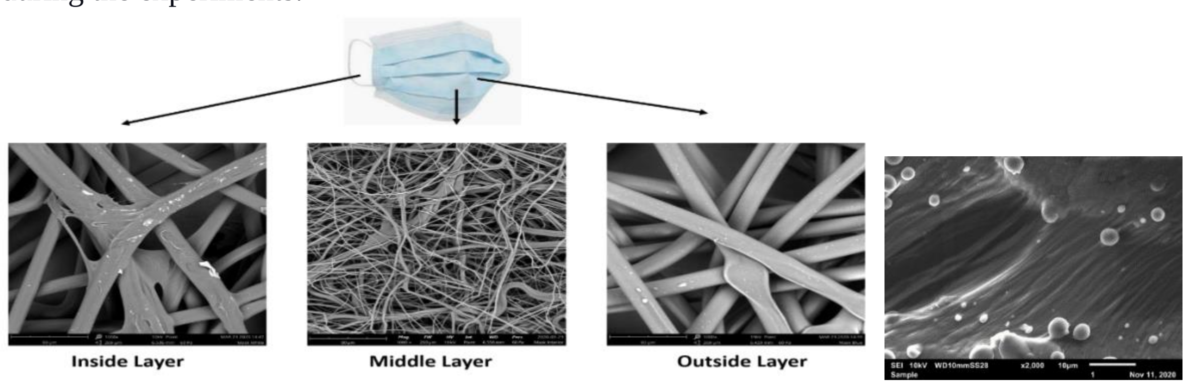

Figure 1. SEM Images of filtration layer of non-surgical mask and PCL nanofibers

Experimental Results

Attenuated Total Refraction (ATR) Test

The ATR tests were carried out for protective filtration layers of K95, nonsurgical (NSM), and PCL nanofiber at a temperature range of 25 °C - 35 °C because the mean breath temperature is approximately 34.5 °C. Attenuated Total Reflection (ATR) is a sampling technique used in conjunction with infrared spectroscopy, which enables samples to be examined directly in the solid-state without further preparation. The Fourier Transform converts the detector output to an interpretable spectrum and generates spectra with patterns that provide structural insights. The spectrums are shown in figure 2. It shows that the layers' chemical composition and percentage of transmittance did not change throughout the temperature range of 25 °C to 35 °C. Similarly, no changes were observed for the PCL electrospun membrane as a function of temperature. This indicates that PCL is safe to use as a face mask, and the chemical composition of the face masks does not change as humans exhale. The nonsurgical and K95 masks show four peaks outside the fingerprint region. These peaks are C-H, O-H, and carboxylic acids group. An important focus of this study is how much IR radiation is passed through or absorbed by the mask. The transmitted signal at the detector is the spectrum representing a molecular 'fingerprint.' The results show the IR transmittance rate for the PCL nanofibers are higher, about 85%, compared to NSM and K95 masks, which are 25 % and 35%, respectively which reflects an excellent cooling effect of exhaled body temperature by PCL nanofibers.

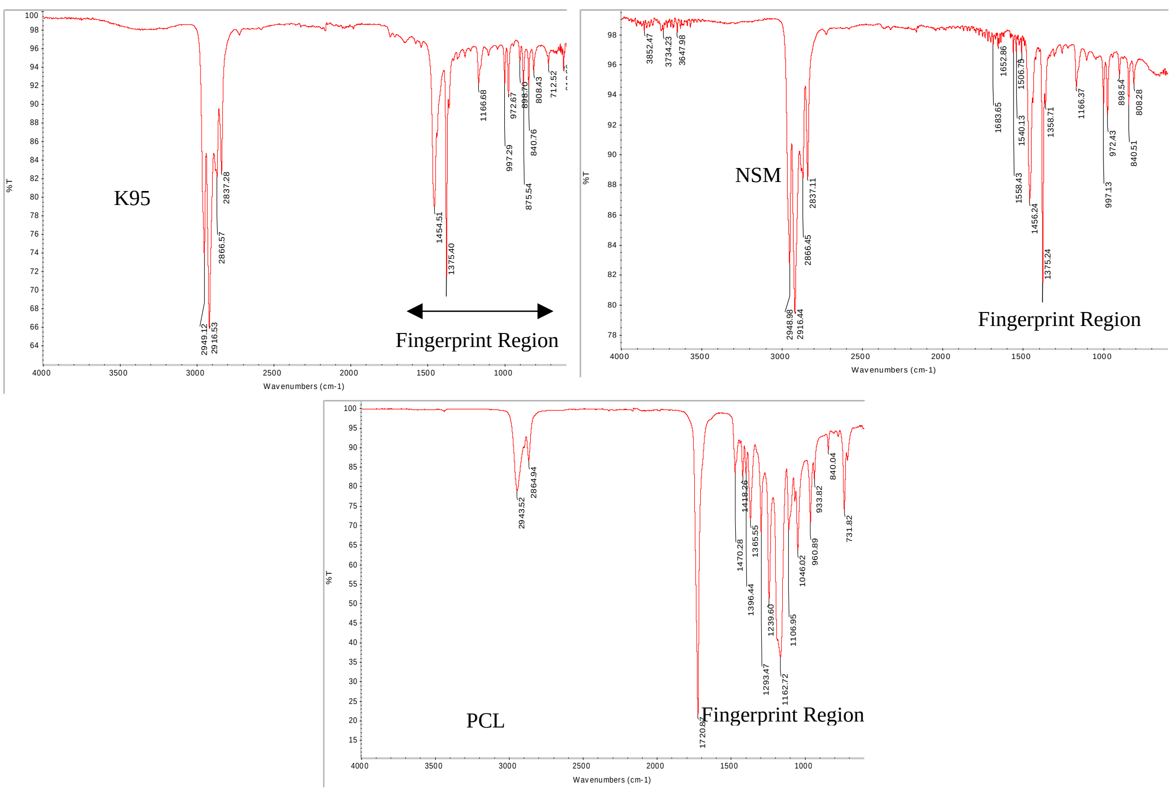

Figure 2. ATR results for Non-surgical Mask (NSM), K95 and Polycaprolactone (PCL) filtration layer

Mechanical Tensile Testing:

The strength of the protective layers for commercial face masks and PCL nanofiber was measured using the Shimadzu Compact Tabletop Testing Machine EZTest (EZ-X Series) with a maximum 500 N load capacity and a crosshead speed range of 0.001 to 1000 mm/min. The tests were carried out at a 4 mm/min stretch rate.

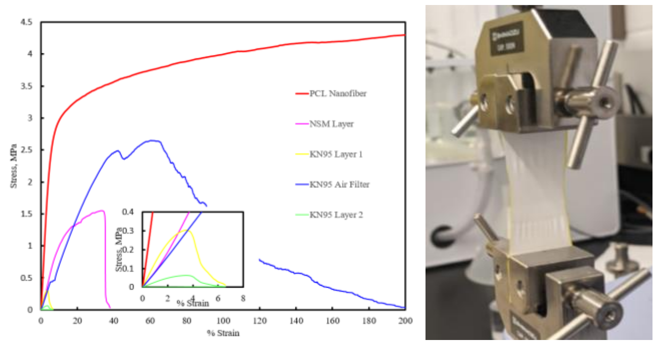

Figure 3. Stress-Strain diagram for a) PCL, NSM and KN95 filtration layers and b) tensile testing of PCL nanofiber

The gauge length of the samples was 1 inch. The maximum tensile strength of the layers was calculated from the stress-strain diagram shown in Figure 3. The strain was calculated by dividing displacement over the original length, and stress was calculated by dividing stress over the area. The figure shows a significant amount of stretching for the PCL nanofibers; however, breakage of fibers occurred for NSM and KN95 protective filter layers. The engineering stress-strain curve indicates that the PCL membrane's strength is higher than the protective layers in the other masks. According to The Breathing Process from the Anatomy and Physiology II textbook, during inspiration and expiration the intrapleural pressure fluctuates. The fluctuation is approximately 4 mm Hg or $5.3 \times 10^{-4}\ MPa$ throughout the breathing cycle [10]. From the stress-strain diagram in figure 3, all layers of the facemasks, especially the PCL membrane can withstand the respiratory pressure of the average user.

Contact Angle Test

A CAM-Plus optical Tensiometer is a 6x standard magnification is used to measure the contact angle of protective layers of commercial masks and PCL nanofiber. The membranes were heated to 25 °C, 30 °C, and 35 °C, and the resulting angle was the same after heating to different temperatures. The contact angle for the polycaprolactone membrane is 64° angle, while the nonsurgical mask, the droplet, gives a 104° angle. According to literature, the inner protective layer should be hydrophobic, readily absorbing expelled fluids and reducing humidity for the wearer. Therefore, the viruses entrapped in the fluid can dry faster and absorb the layer, thus decreasing spreading. However, the nonsurgical mask's hydrophobic behavior can cause humidity buildup by the wearer inside the mask. This humidity can be the breathing ground for bacteria, resulting in rash, discomfort, and fatigue. According to Melayil and Mitra [11] research on wetting, adhesion, and droplet Impact on face masks, it is reported that a superhydrophobic coating may not be the best choice for a regular cover as it can give rise to several smaller droplets that can linger in the air for longer times and can contribute to the transmission of potential viral loads. When added as a filtration layer to the mask, the electro spun material is wettable and will not cause potential harm.

Summary and Conclusion

In this study, the filtration layers of two commercial masks were compared with an electrospuned PCL nanofiber to provide better thermal comfort and flexibility. The chemical structures of all layers were investigated using an Infrared spectrometer. The result shows that PCL can transmit heat and give better thermal comfort. The tensile testing results show that the electrospuned fibers have adequate strength and stretching properties as a protective layer in facemasks. The contact angle showed that the NSM layer is hydrophobic, and the Polycaprolactone electro spun membrane allows adequate wetting. It reduces humidity in the mask and reduces transmission of coronavirus.

References

1. “Your Guide to Masks.” *Centers for Disease Control and Prevention*, Centers for Disease Control and Prevention, 25 Oct. 2021, https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/about-face-coverings.html.
2. General Respiratory Protection Guidance for Employers and workers, Occupational Safety and Health Administration, 2011.
3. Ankun Yang, Lili Cai, Rufan Zhang, Jiangyan Wang, Po-Chun Hsu, Hongxia Wang, Guagmin Zhou, Jinwei Xu and Yi Cui, “Thermal Management in Nanofiber Based Face Mask, NanoLetters, 2017, 17,3506-3510.
4. Respiratory Protective Equipment at Work, Health and Safety Executive, 2013.
5. Antonio Scarano, Francesco Inchingolo and Felice Lorusso, Facial Skin Temperature and Discofort When Wearing Protective Face Masks: Thermal Infrared Imaging Evaluation and Hands Moving the Mask, Int. J of Environmental Research and Public Health, 2020, 17, 4624-4632.
6. Célia-Regina-Maio Pinzan-Vercelino,corresponding, Karina-Maria-Salvatore Freitas, Valquiria-Mendes-Pereira Girão,3 Daniella-de Oliveira da Silva, Renan-Morais Peloso, and Arnaldo Pinzan, Does the use of face masks during the COVID-19 pandemic impact on oral hygiene habits, oral conditions, reasons to seek dental care and esthetic concerns?, Journal section: Community and Preventive Dentistry Publication Types: Research, 2021;13(4),369-75.
7. Khandaker, Morshed, et al. “Effect of Collagen-Polycaprolactone Nanofibers Matrix Coating on the In Vitro Cytocompatibility and In Vivo Bone Responses of Titanium.” Journal of Medical and Biological Engineering, U.S. National Library of Medicine, Apr. 2018. www.ncbi.nlm.nih.gov/pmc/articles/PMC5977393/ .
8. Morshed Khandaker, Helga Progri, Dhakshyane Tamil Arasu, Sadegh Nikfarjam and Nabila Shamim, Use of Polycaprolactone Electrospun Nanofiber Mesh in a Face Mask, Materials 2021, 14, 4272. https://doi.org/10.3390/ma14154272
9. Verma, Devendra. “Effectiveness of Masks: Fast Answers with Automated SEM Analysis.” Nanoscience Instruments, Nanoscience Instruments, 10 Apr. 2020, https://www.nanoscience.com/applications/materials-science/effectiveness-of-masks-fast-answers-with-automated-sem-analysis/.
10. “Anatomy and Physiology II.” *The Process of Breathing | Anatomy and Physiology II*, Lumen Learning, https://courses.lumenlearning.com/suny-ap2/chapter/the-process-of-breathing-no-content/.
11. Melayil, Kiran Raj, and Sushanta K Mitra. *Wetting, Adhesion, and Droplet Impact on Face Masks*, 12 Feb. 2021, pp. 2825–2829. www.ncbi.nlm.nih.gov/pmc/articles/PMC7901139/#cor1.

NABILA SHAMIM, Ph.D.
Dr. Shamim is an Assistant Professor in the college of Engineering at Prairie View A&M University. She has research interests in polymer, thin films, and nanomaterials.
UTOMWEN DAVID IRABOR
David is a senior student in the chemical engineering department at Prairie View A&M University. David has research interests in the use of polymers and epoxy materials to withstand impact in space suits during extravehicular activities.
Special thanks to Dr. Morshed Khandaker**,** Department of Engineering and Physics, University of Central Oklahoma, Edmond, OK 73034, USA, for providing the PCL nanofibers. Thanks to the Faculty Research and Innovation Success and Excellence (Faculty-RISE) program at Prairie View A&M University for funding the project.