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DEVELOPMENT OF DISPOSAL FACE MASK NANOFIBERS MEMBRANE THROUGH ELECTROSPINNING TECHNIQUEFOR SMOKE PARTICULATE REMOVAL

NABI BAKHSH MALLAH*[1], ABDUL MAJEED PIRZADA[2], M HASHIM ZUBERI[2], IMRAN ALI[2] AND ABDUL HAMEED MEMON[1]

[1] *Faculty of Engineering, Science and Technology, Hamdard University Karachi.*
[2]*Department of Environmental Science, Sindh Madressatul Islam University, Karachi.*
**Corresponding Author email:* nabi.bakhsh@hamdard.edu.pk

خلاصہ

نینو میٹریلز نے موثر فلٹریشن کے لیے منفرد کردار ادا کیا ہے۔ بڑے سطح کے رقبے سے حجم کے تناسب کی تاثیر کی وجہ سے، نانو فائبرز ہوا سے آلودگی کو آسانی سے جذب کرنے کی صلاحیت رکھتے ہیں۔ چہرے کے ماسک پر سیلولوز ایسیٹیٹ کی بناوٹ کی وجہ سے کچھ نقصان دہ بیکٹیریا اور ہوا کے ذرات ناک اور منہ میں داخل نہیں ہو پاتے۔ تاہم، سیلولوز ایسیٹیٹ نانو فائبرز کی بناوٹ کے بغیر بیکٹیریا اور ہوا کے ذرات اپنے چھیدوں کے بڑے قطر کی وجہ سے چہرے کے ماسک سے آسانی سے گزر سکتے ہیں۔ فیبریکیشن کا فائدہ یہ ہے کہ فلٹریشن کے لیے استعمال ہونے والے چہرے کے ماسک کی درمیانی تہہ کے سوراخ کا سائز کم کر دیا گیا ہے اور فلٹریشن کی کارکردگی میں اضافہ ہوتا ہے۔
اس آرٹیکل میں کمرشل ڈسپوزایبل فیس ماسک کی درمیانی تہہ جس میں فلٹریشن کے مقصد کے لیے بڑے سوراخوں کا قطر استعمال کیا جاتا ہے، اس کی جگہ سیلولوز ایسیٹیٹ نانو فائبرز کی نشوونما سے تبدیل کی گئی ہے جس کی موٹائی 60 µm، 35 µm اور 15 µm ہے، جھلی کی مورفولوجی کی خصوصیت SEM، کیمیائی ساخت کے ذریعے کی گئی تھی۔ FTIR، ٹینسائل ٹیسٹر کے ذریعے مکینیکل سٹرینتھ، ایئر پارگمیبلٹی ٹیسٹر M021S کے ذریعے ہوا کی پارگمیتا اور اسموک ٹیسٹ خود ڈیزائن کردہ سموک ٹیسٹر کے ذریعے کیا گیا۔ یہ پایا گیا کہ 60 µm کی موٹائی والی جھلی میں فلٹریشن کی کارکردگی سب سے زیادہ ہوتی ہے لیکن ہوا کی پارگمیتا متاثر ہوگی لیکن 15-35 µm کے درمیان موٹائی والی نانو فائبرز جھلی کمرشل فیس ماسک سے بہتر ہوا کی پارگمیتا اور فلٹریشن مزاحمت رکھتی ہے۔

Abstract

Nanomaterials have played a unique role for effective filtration. Due to the effectiveness of large surface area to volume ratio, nanofibers have ability to absorb contaminants from air easily. Due to the fabrication of cellulose acetate on face mask some harmful bacteria and air particulates are not able to enter nose and mouth. However, without fabrication of cellulose acetate nanofibers the bacteria and air particulates may easily pass through the face mask due to their larger pores diameter. The advantage of fabrication is that the pore size of middle layer of face mask which is used for filtration has been reduced that increases the filtration efficiency. In this article middle layer of commercial disposable face mask having larger pores diameter used for filtration purpose has been replaced by development of cellulose acetate nanofibers having thickness of 60 µm, 35µm and 15µm.Morphology of membrane was characterized by SEM, chemical structure through FTIR, mechanical strength through tensile tester, air permeability through air permeability tester M021Sand smoke test was performed through self-designed smoke tester. It was found that membrane with thickness of 60 µm have highest filtration efficiency but air permeability was compromised but nanofiber membrane with thickness between 15-35 µm have better air permeability and filtration resistance than commercial face mask.

Key Words: Electrospinning, Nano Technology, Cellulose Acetate, Smoke Particulates.

Introduction

Nanomaterials have played a unique role for effective filtration. Nanotechnology works on the nanoscale scale (from 1 to 100 nm) to develop materials (Gondal, 2023). For few decades, nanotechnology has gained great attention in several fields of research due to its unique properties (Mishra *et al*., 2023).

For few decades, nanotechnology has gained great attention in several fields of research due to its unique properties. Owing to this, researchers have focused increasingly on its promising applications in various fields. Among the various nanostructure formulations, nanoferspossess attractive characteristics such as large surface area, possibility of surface fuctionalization and tunable porosity.

Due to fossil fuel combustion and anthropogenic activities the composition of gases has been changing quickly and air contains some harmful particulates such as carbon monoxide, sulphur dioxide and some other poisonous gaseswhich are the main cause of asthma, lung cancer and heart disease, infections in infants and also chronic diseases in adults. In order to avoid or control such airborne diseases, different types of materials are available in market to be worn on face which includes face masks. From 1900 century for bacterial and virus infection control, use of surgical masks came into practice especially worn by health care providers during surgery. Disposable Face mask consists of 3- ply non-woven flexible spongy pad to cover mouth and nose of wearers with inner and outer layer of non -woven fibers materials while the central layer is designed for filtration purpose. Three layers are bounded together along horizontal and vertical edges. The elastic bounding makes the vertical edges safe. The middle layer is used for filtration purpose that eliminates the number of airborne diseases. The Disposable face masks can also be used in order to stop some harmful particulates entering into our nose and mouth. However, due to the larger diameter of middle layer of disposable face mask, it is not possible to block the harmful particulates, thus affecting filtration efficiency. So the researchers concluded that the diameter of middle layer of face mask which is used for filtration should be small so that it stops tiny harmful particulates easily and increases the filtration efficiency.

For high filtration efficiency and low air resistance, fibrous material is considered as an important material (Pham, *et al*., 2006). Electro spun nanofibers have wide range of application in biomedical such as wound healing, tissue engineering and drug delivery. Fibrous material is efficient for filtration purpose having high filtration efficiency and low air resistance (Tsai, *et al*., 2002).

For developing the effective filter media, cellulose acetate based nano-size fiber is considered as a suitable material (Graham, *et al*., 2002) (Pham, *et al*., 2006). Due to the spongy structures of nanofibers it is fit for filtration purpose (Ramakrishna *et al*., 2006) (Uyar *et al*., 2009). Electrospun nanofibers have an excellent capability for adsorbing pollutants from air and water due to its larger surface area to volume (Thavasi *et al*., 2008). Moreover, due to smaller pore size, lower weight and high permeability of nanofibers media, it also possess a wide range of filtration applications (Barhate, & Ramakrishna, 2007).

In this study, three different cellulose acetate nanofiber membranes has been developed through Electrospinning with different thicknesses range of 60 µm, 35 µm, 15µm was used as a middle layer of disposable face mask. Fabrication of cellulose acetate nanofibers on the middle layer of face mask will reduce its diameter and increase its filtration efficiency of air particulates; larger molecules of air particulates will easily be trapped on the nanofibers membranes without entering to nose and mouth. The filtration efficiency was found to be in range of 60 µm> 35 µm> 15µm respectively.

Materials and Methods

Materials

Cellulose acetate with a molecular weight 30kDa and 39% acetyl content was purchased from Sigma Aldrich (USA).

Electrospinning of Cellulose acetate web with different thicknesses

The Cellulose acetate nanofibers membrane has been developed through electrospinning as reported previous literature (Bakhsh, *et al*., 2021).

The neat cellulose acetate with three different web thicknesses has been prepared through electrospinning. Pure Cellulose Acetate solution with 18%(w/w) was prepared with binary solution of Acetone and DMF(2:1).

Table 1. Optimized parameter for Electrospinning of Cellulose acetate with three different thicknesses.

Membrane Thicknesses (µm)	Voltage (kV) Supplied	Distance between needle Tip to Collector (cm)	Inner diameter of needle(mm)	Horizontal Angle	Electrospinning time (hours)	Drying time (hours)
60	16	11	0.7	11	11	16
35	16	11	0.7	11	3	36
15	16	11	0.7	11	1.5	36

The pure cellulose acetate solution was filled in plastic syringe. A needle of 0.6mm diameter was attached with the syringe for the Electrospinning purpose. In addition to this, a copper wire was inserted in the polymer solution and connected with the positive and negative electrode. 16 kV voltages were applied to the solution of pure cellulose acetate solution and distance of tip was 11- cm with an inclination of $11^{o.}$ In the end, the cellulose acetate nanofibers were collected on the surface of collector due to the opposite charge.

In addition to this, three different layers of cellulose acetate nanofibers with varying thicknesses; 15 micrometers, 35 micrometers and 60 micrometers, respectively, were synthesized during this study. Electrospinning process of 60 micrometers, 35 micrometers and 15 micrometers thick webs continued for 6 hrs, 3 hrs, and 1.30hrs, respectively. After completion of electrospinning process, the cellulose acetate nanofiber webs were dried for 36 hours at room temperature.

Characterization

The surface morphology of cellulose acetate nanofibers webs was characterized by microscopy. The flow of air through the sample was analyzed by the air permeability tester M021S,

A self-designed test: smoke test, was also conducted so as to analyze the smoke particulates as shown in **Fig.1** In smoke test, an elastic rubber pole is attached to the opening ofa plastic bottle filled with water. Filter of cigarette was pressed in the bottle cover gap and the top was screwed with cigarette. Smoke will be produced in the bottle by lighting the cigarette with match. The rubber pole will be opened and the water will be launched out from the gap. Due to continuous water discharge from gap, air will be sucked and smoke will be gathered into the bottle. This procedure will continue until the entire cigarette is consumed and thus, the entire water is shot out from bottle. Next the filter of cigarette will be replaced with nanofiber membrane at the mouth of bottle and secured with elastic band. Strain will be applied to the gap gradually. After applying weight the smoke will move from base to top of the bottle. Weight will be persistently for a few minutes until the entire smoke will be in contact to front layer of nanofiber membrane. The membrane will be expelled from container and it will be noticed that front part of the membrane will be covered with cigarette segments, for example, nicotine, tar and numerous other lethal stuff.

In the test for tobacco smoke, the smoke particles were separated through cellulose acetate nanofiber webs with thickness of 60 micrometre, 35 micrometre, and 15 micrometre. Additionally, the test for tobacco smoke was also conducted on the middle layer of commercial face mask, which is used as a filtering mechanism. The effects of the face cover's centre layer with different-thickness nanofibers have been compared with and without a nanofiber web.

Fig. 1- Cigarette Smoke Testing Material

Results and Discussion

Morphology of with and without nanofibers web treated with cigarette smoke

Cellulose acetate nanofibers membrane prepared with Electrospinning technology possess large surface area, small fiber diameter having ability to filter out smaller particulateand is considered suitable as air filtration material (Balamurugan *et al*., 2011). In this study, cellulose acetate nanofiber web was incorporated as the centre layer of face masks for the purpose of filtration.

The results indicate that the particulates of smoke was separated through cellulose acetate nanofibers layers with thickness of 60 µm (a-b), 35µm (c-d) and 15 µm (e-f) and also separated through commercial face mask having thickness of 15-20 µm (g-h) as shown in Fig 2. It was found that the nanofiber web (a-b) with 60µm thickness had much mor ability to block the higher amount of smoke particulates However Fig. 2 (g-h) shows that the commercial filter is not much more efficient to filter smoke particulates as compared to cellulose acetate membrane

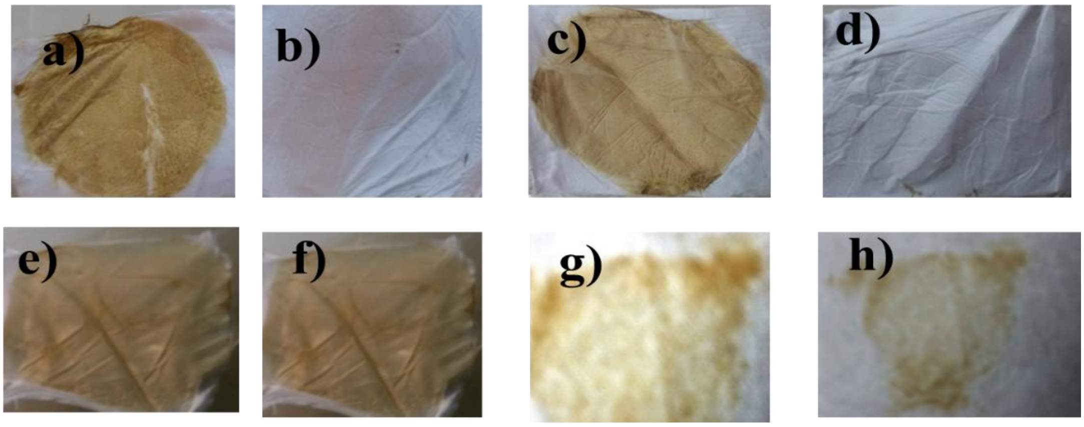

Fig. 2. Back and face layer of cellulose acetate nanofibers (a-f), back and face layer of commercial face mask (g-h)

Scanning Electron Microscope of Cellulose acetate and Commercial Face Mask Layer

Scanning electron microscopy was used to detect the surface morphology of Cellulose acetate nanofibers membrane (Khan *et al*., 2020). The effect of cigarette smoke of all the samples with and without nanofibers web were analyzed through scanning electron microscope as shown in Figure 3 (a-h). The Fig. 3 (a, c, and e) demonstrates the dramatic change that occurred on the back side of the nanofiber web following treatment with cigarette smoke, while Figure 3 (b, d, and f) demonstrates that the front side of the nanofiber web was little bit affected with cigarette smoke**.** Moreover Fig.3 (g-h) represents that sample without nanofiber layers could only block small amount of cigarette smoke and almost all the smoke particles passed through them easily due to the larger diameter and pores of commercial face mask.

A comparative analysis was performed between the samples with and without nanofiber web. It is clearly shown that due to smaller diameter of nanofibers, the smoke particulates are almost stopped while larger pore size and diameter of disposable face mask easily let the smoke particulates pass through it. Therefore, the results clearly indicate the robust performance of samples with nanofiber web.

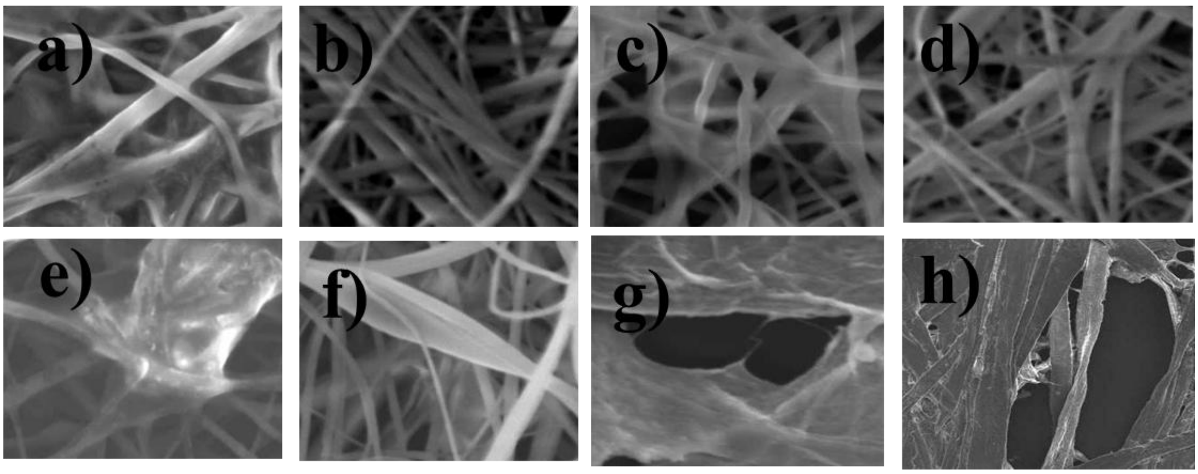

Fig. 3. (a-h)SEM images of back layer and face layer of Mask

Tensile Strength of Cellulose acetate nanofibers

The mechanical properties of Cellulose acetate used for filtration purpose are most importantbecause these materials need some tensile strength as it withholds themselves from air pressure. In **Fig.4** it is shown that the elongation break of CANF is 13.6±1 whereas the tensile is 0.5±1 Mpa.

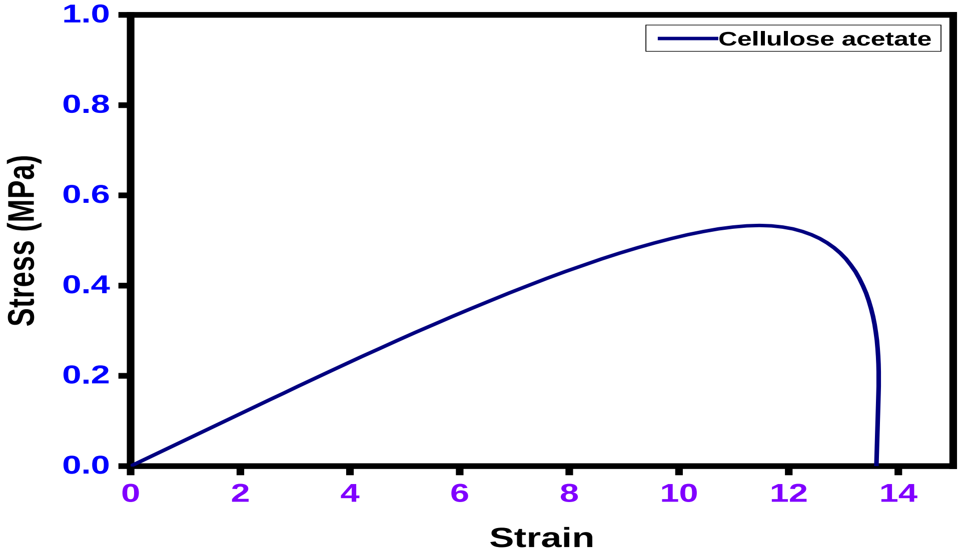

Fig. 4. Tensile strength of Cellulose acetate nanofibers

Air Permeability Testing

The air permeability is used to measure the flow of air through the sample with Air Permeability Tester M021S as shown in Figure **5**. All three samples of nanofibers web having different thicknesses such as 15 micrometers, 35micrometers and 60micrometers were tested for air permeability. Each sample permeates air with different flow rate and 15 micrometers web has greatest air permeability due smaller thicknesses of web as compared to others. Air permeability of face mask without nanofibers lamination is also calculated and it is seen that face mask with and without nanofibers lamination exhibit negligible difference. However, by increasing the nanofibers thickness air permeability will be affected.

Fig.5. Air Permeability Tester

Conclusion

Cellulose acetate nanofiber membrane with varying thickness; 60 µm, 35 µm, 15µm were prepared by Electrospinning technique for replacing the middle layer of face disposable mask to achieve highest smoke filtration efficiency. The cellulose acetate nanofibers webs showed great filtration efficiency as compared to the commercial disposable face mask. However, by increasing the thickness of CA nanofibers membrane web, highest filtration efficiency was achieved but air resistance was affected, so the thickness between 15-35µm was suitable for filtration as well as air permeability as compared to commercial face mask.

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