Enhancement of filtration efficacy for particulate matters using β -glucan coated commercial masks

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Abstract Ambient air pollution, in particular, particulate matter (PM) pollution imposes serious health concerns such as hospitalization and premature deaths, worldwide. While commercial breathing masks are in use for protection against this hazardous issue, yet their efficiency in filtering PM was not up to the par, besides several other discomforts such as poor breathability due to reduced air flow, sweat production etc. In this study, commercial face mask coated with β -glucan, a high molecular weight polymer is tested for its efficacy in filtering PM. Quantification of PM before and after filtration and microscopic observation (using scanning electron microscopy (SEM)) of the fabric used in filtering the dust pollutants (generated from wood chips and cigarette) showed that β -glucan coated fabric were significantly efficient in capturing PM (size of 10 and 2.5 μm in diameter) than that of the untreated control fabric, wherein the former had filtration efficacy with fold increase of 11.6 and 2.6 towards capturing PM_{2.5} and PM₁₀ respectively than the latter. Thus, β -glucan coated fabric was found to be effective in filtering PM.

Keywords β -glucan · Face mask · Particulate matter

Introduction

World Health Organization (WHO) reckons air pollution as the deadly cause of global death (totaling 11.6% to other cases) with 6.5 million losses of life due to indoor and outdoor air pollutions. For people to be deemed as living in ambient environment, WHO sets a guideline in which PM_{2.5} (fine particulate matters whose aerodynamic diameter is less than 2.5 μm) and PM₁₀ (coarse particulate matters whose aerodynamic diameter is less than 10 μm) should be around 10 and 20 $\mu\text{g}/\text{m}^3$ annual mean, respectively. However, it was confirmed that 92% of the world's population lives in places where the set level is off-limit, with people more prone to develop acute respiratory infections, stroke, heart diseases, lung cancer etc. While PM₁₀ is said to have shorter life time in air between few minutes to hours with relatively shorter travelling distance, PM_{2.5} has relatively longer exposure from several days to weeks thereby imposing regional and global threats (<https://www.who.int/airpollution/en/>).

Face masks are widely used to filter air-borne pollutants, a serious concern rising due to the poor air quality. Commercially available masks such as ITO PM_{2.5}, N95 and R95 face limitations such as poor interception of fine particles, high respiratory resistance, high discomfort, substandard water vapor etc. [1] Thus, proper care has to be given in addressing the design of face masks such as efficient particulate capture; air permeability; absorbing biological contaminants etc. The thickness of the mask layers also plays an important role in governing the resistance imparted to air flow and PM removal efficiency.

Functionalization of face mask aids in improving their quality in terms of efficacy in filtering out PM, thereby highlighting their use in biomedical sector [2]. Polymers with polar functional groups exhibits strong affinity to PM with enhanced air permeability [3-4]. Variety of polymers including polyvinyl alcohol, polyethylene oxide, polyethylene glycol, polyvinyl pyrrolidone, polycaprolactone, alginate, cellulose, starch, chitosan etc. have been extensively studied for the purpose of air filtration [5]. In this work, commercial face mask is functionalized using β -glucan, a high

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molecular weight polymer with polar functional groups. The high molecular weight and high viscous nature of the polymer are expected to trap the PM passing through the mask.

Materials and Methods

Materials

β -glucan (isolated from *Schizophyllum commune* having average molecular weight of about 1.8×10^6 Da) used in this study was provided by Quegen Biotech Co. Ltd. (Gyeonggi-do, Republic of Korea). The filtering capacity (targeting PM2.5 and PM10) of the fabric masks was analyzed using portable particle counter (HT-9600, Hongtai Instrument Co., Ltd., Hongkong, China).

Filter fabric preparation

β -glucan coated fabric mask was prepared using dip coating technique wherein commercially available fabric mask was dipped in β -glucan solution for 30 min. The dipped fabric was subjected to blow drying for 15 min followed by drying in ambient atmosphere for 48 h.

Filtration test

Wood chips and cigarette was used as the test pollutant. The experimental set up is given in Scheme 1. Polluted air from burning the pollutant source was collected and injected into the experimental set up and made to pass through the chamber holding the fabric mask (uncoated and β -glucan coated) membrane. To the other end of the polluted air inlet, an exhaust was placed in order to pump out the air through the membrane. Quantitative measurement of PM was carried out using portable particulate counter unit, wherein its monitor displays quantitative

counts of dust particles associated with PM10 and PM2.5 when placed in the path of pollutant outlet as shown in Scheme 1. Particulate removal efficiency is represented in terms of particles escaping the filter, wherein higher the particles escaped, lower the removal efficiency.

Morphology observation

Field Emission Scanning Electron Microscope (MIRA 3 model, TESCAN in Bio-Health Materials Core-Facility) was employed to observe the adsorbed particulate matters onto the surface of the fabric mask. Uncoated and β -glucan coated fabric mask from before and after the passage of polluted air was subjected to Platinum sputter coating followed by scanning electron microscopy (SEM) analysis.

Statistical analysis

All data were given as mean $\pm$ Standard error from a minimum of three independent experiments. Statistical significance was calculated using t-test and considered to be significance when $p < 0.05$.

Results and Discussion

Particulate matters generated from different activities such as biomass burning, coal combustion, soil dust, inorganic aerosol, industrial pollution, waste incineration etc. differ in their department based on their chemical composition, morphologies, physical properties etc. [6]. Such engendered PM have complex compositions comprising soft organic (volatile organic compounds and elemental carbon) and rigid inorganic (oxides of carbon, nitrogen, sulfur etc.) matters [7-8]. Short term (WHO Air Quality standard of 25 and 50 $\mu\text{g}/\text{m}^3$ 24 h mean for fine PM2.5 and coarse PM10,

Scheme 1 Experimental set up designed to analyze the PM filtration efficacy by β -glucan coated commercial face mask

Fig. 1 Visual observation of β -glucan coated and uncoated commercial mask before and after testing against cigarette-generated smoke pollutants

respectively) as well as long term (WHO Air Quality standard of 10 and 20 $\mu\text{g}/\text{m}^3$ annual mean for fine PM_{2.5} and coarse PM₁₀, respectively) prolonged exposure to inhalable PM has life-threatening health effects associated with respiratory, cardiovascular and cerebrovascular systems such as asthma, heart attack, lung cancer, stroke etc. [9-10] In general, two basic types of air filters are used-porous membrane and thick fibrous air filter for the effective removal of the widespread airborne particulate matters [11-12]. While the former system relies on size exclusion-based filtration, the latter system works through thick fibrous barrier and adhesion of particulate matter onto the filters. Fibrous air filtration

has several filtration mechanisms through which it filtrate air-borne pollutants as follows: Straining (when the gap between adjacent media membranes is smaller than the incoming particulate), Inertial impaction (unable to abruptly change its course of movement, the coarse particulates tends to hit the filter membrane and gets trapped), Interception (smaller particulates surfaces the filter membrane and comes to rest on it), Diffusion (Brownian movement of particle allows them to get bumped on the fibrous filter membrane thereby capturing them), Electrostatic attraction (charged particulates got attracted to oppositely charged particulate collects thereby purifying the air) etc. [13].

Herein the current study, β -glucan polymer is used in the process of air pollutant filtration. The β -glucan coated fabric mask is effective in capturing pollutants from cigarette. As seen in Fig. 1, the pollutants from the cigarette smoke got adsorbed onto the β -glucan coated face mask. We could visually see a lot of particulates adhered onto the β -glucan coated fabric mask than the uncoated mask as the white fabric turned more yellowish brown in color in the former. SEM images (Fig. 2) also show that there is lot of particulate matters (of size ranging even less than 2.5 μm) attached onto the β -glucan coated fabric mask than the uncoated fabric when subjected to cigarette smoke. Further, β -glucan coated using dip coating method was found to be even as the fiber diameter was almost same across the fabric. Next, the investigation on filtering PM_{2.5} and PM₁₀ (calculated in terms of particles escaped (lower the particles escaped, higher the filtration efficacy)) produced from wood chips (Fig. 3A) and cigarette (Fig. 3B) showed that, compared to uncoated fabric mask, β -glucan coated fabric mask was worthwhile in capturing particulate matter under 10 and 2.5 μm . It was quantitatively observed that β -glucan

Fig. 2 Scanning electron microscope (SEM) analysis on the β -glucan coated and uncoated commercial mask before and after testing against cigarette-generated smoke pollutants. Scale bar: 50im and Magnification: 1000×

Fig. 3 Quantification of Particulate Matter (PM) removal using portable particulate monitor by β -glucan coated and uncoated commercial mask before and after testing against air pollutant sources of (A): wood chips and (B): cigarette. All data were given as mean $\pm$ standard error from a minimum of three independent experiments. $p < 0.05$ is considered to be statistically significant

coated fabric had filtration efficacy (in collecting pollutants from cigarette smoke) with fold increase of 11.6 and 2.6 towards capturing PM_{2.5} and PM₁₀ respectively than the uncoated control fabric. Thus, β -glucan coated fabric was found to be effective in filtering PM.

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Conflict of interest The authors declare no conflict of interest

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