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Development of Activated Charcoal-Treated Polyester Cotton Blend Fabric for improving Pollutant Removal Efficiency

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ABSTRACT

Air pollution has become a critical global issue, particularly in urban environments, due to the increasing prevalence of industrial activities and vehicular emissions. Conventional air filtration systems, although effective against particulate matter (PM), struggle to capture gaseous pollutants such as total volatile organic compounds (TVOCs) and CO_2, necessitating advanced filtration materials. Activated charcoal, with its high surface area and porous structure, is an effective adsorbent for both particulate and gaseous pollutants, making it a valuable component for air filtration technologies. In this study, the prime challenge was to optimize different parameters to enhance filtration efficiency without affecting the fabric's usability. Thereby, this study explored the enhancement of polyester-cotton (PC) blend fabric filtration efficiency by applying activated charcoal. Optimization of parameters, viz. activated charcoal concentration (1-5%), acrylic binder concentration (0-20%), and exhaustion time (5-40 minutes), resulted in a balance between filtration performance and fabric usability. The optimal conditions were found to be 3.5% activated charcoal, 10% acrylic binder, and 25 minutes of exhaustion time, yielding improvements in water contact angle (>135°), air permeability (10.75 $ft^3/min/ft^2$), and wetting time (3600s). The treated fabric exhibited significant improvements, achieving 17.75% enhancement in PM2.5 filtration, 21.19% in PM10, 12% in CO_2 reduction, and an impressive 24.77% in TVOC removal. Additionally, the treated fabric demonstrated a 95% and 93% reduction in the growth of Staphylococcus aureus and Klebsiella pneumoniae, respectively. Overall, the study has resulted in the development of activated charcoal-treated PC fabric that offers a practical solution to the health risks posed by indoor air pollution while also offering antimicrobial properties, making it suitable for diverse applications in air purification and healthcare.

Keywords: *Activated charcoal, air filtration, indoor air quality, pad-dry-cure, volatile organic compounds, cotton, nanoparticle, PM2.5, PM10, air permeability*

INTRODUCTION

Air pollution has emerged as a significant environmental and health concern worldwide, with particulate matter (PM), volatile organic compounds (VOCs), and carbon dioxide (CO_2) among the leading pollutants. These airborne contaminants pose severe threats to respiratory health, particularly in urban environments, where their concentrations are markedly higher due to industrial activities and vehicle emissions [1,2]. As a result, the demand for effective air filtration materials, especially those capable of mitigating both particulate and gaseous pollutants, has surged. Traditional air filtration systems, while effective against particulate matter, often fail to capture harmful gaseous pollutants, necessitating the development of advanced filtration materials[3].

Indoor air pollution can occur in households or workspaces due to various sources such as tobacco smoke, emissions from solid fuels used for cooking, burning incense sticks, candles, and even from air conditioning and cooling systems.

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The presence of these pollutants in enclosed spaces leads to constant exposure, which can be harmful to the occupants over time. This has earned indoor air pollution the reputation of being a "friendly killer" due to the subtle and continuous nature of the exposure, often leading to severe health implications without immediate awareness [2,3]. The impact of indoor air pollution is significant, as it can lead to respiratory diseases, cardiovascular issues, and long-term conditions such as asthma or lung cancer [4]. Poor ventilation exacerbates the problem, trapping harmful particles and gases inside homes and offices. Vulnerable groups such as children, the elderly, and people with pre-existing health conditions are particularly at risk.

Activated charcoal plays a crucial role in air filtration due to its high surface area and porous structure, which allows it to effectively adsorb harmful pollutants[5,6], including particulate matter (PM), volatile organic compounds (VOCs), and gaseous pollutants like CO_2. Its ability to trap both particulate matter and gaseous pollutants makes it a promising candidate for textile-based filtration systems [3,4]. When coated onto textile fabrics, activated charcoal enhances the filtration capacity of the fabric without significantly compromising breathability. Furthermore, fabrics treated with activated charcoal demonstrate improved hydrophobicity, air permeability, and water contact angle, making them suitable for use in high-performance filtration

environments [7]. The combination of activated charcoal with textiles allows for versatile applications, such as in masks, air filters, and protective clothing, providing both comfort and enhanced air quality protection [8,9].
The ability of activated charcoal to adsorb a wide range of contaminants, coupled with its integration into textiles, offers a sustainable solution for improving indoor air quality, particularly in densely populated or polluted environments [2]. The continuous development of activated charcoal-based textile coatings highlights its potential for advancing air filtration technologies while maintaining fabric usability and durability.
Textile materials such as polyester-cotton (PC) blends are widely used due to their durability, breathability, and comfort. Increasing the cotton content in the fabric enhances breathability and comfort, whereas increasing the polyester content improves strength and durability [10]. The functionalization of these fabrics with activated charcoal particles has the potential to combine the benefits of textile comfort with enhanced filtration efficiency. However, achieving optimal performance requires careful optimization of parameters such as the concentration of activated charcoal, binder concentration, and exhaustion time during the application process.
This study aims to investigate the process optimization for applying activated charcoal to PC blend fabrics using the pad-dry-cure method. The goal is to maximize the fabric's filtration efficiency against particulate matter (PM2.5, PM10), volatile organic compounds (VOCs), and CO_2, while maintaining essential textile properties such as breathability and durability. The study also evaluates the impact of activated charcoal concentration, acrylic binder concentration, and exhaustion time on the fabric's performance, ultimately determining the optimal conditions for achieving the desired balance between filtration efficiency and fabric usability.
By developing an effective activated charcoal-treated fabric, this research addresses the growing need for versatile filtration materials capable of mitigating a wide range of airborne pollutants, offering potential applications in environmental protection and healthcare.

METHODOLOGY

Raw materials

The commercially available polyester-cotton (PC) blend fabrics (grammage: 91 g/m2, warp count 63.8 Tex, weft count: 65 Tex, ends per inch: 69, picks per inch: 59, thickness: 0.32 mm, cover factor: 13.70) were used in the study. Activated charcoal granules were procured from the market. Using a ball mill (M/s. RetschPvt. Ltd., Model MM 400), the particles were ground to a size of approximately 639 nanometers, analyzed using the nanoparticle size analyzer (M/s Cor-douan Technologies®, France, scattering angle: 170°) based on the optical fiber dynamic light scattering and autocorrelation principles.

Application of activated charcoal particle on PCblend fabric

To eliminate added impurities, the fabric underwent a pre-washing and relaxation process using 2 gpl of non-ionic detergent at a material-to-liquor (M:L) ratio of 1:20. The treatment was carried out at 70°C for 20 minutes, followed by drying at room temperature [11]. Activated charcoal micro particle was applied on PCblend fabric in two stages. Firstly, activated charcoal solution was prepared, and secondly prepared solution was applied on the fabric using the pad-dry-cure method.

Optimization of the concentration of activated charcoal particles on PC blend fabric

Optimizing the concentration of activated charcoal particles on PC blend fabric involves determining the ideal amount of charcoal to achieve the desired properties while maintaining the fabric's usability and performance. Hence, for optimization, the difference level of activated charcoal particle, acrylic binder concentration, and exhaustion time were considered, keeping the M:L ratio as 1:10 constant. This study explored the impact of different concentrations of activated charcoal particles (ranging from 1.0 to 5.0% in 0.5% increments), acrylic binder levels (ranging from 0 to 20.0% in 2.5% increments), and exhaustion times (ranging from 5 to 40 minutes in 5-minute increments). To prevent charcoal particle agglomeration, the prepared solution underwent ultrasonication. It was transferred to a container and placed in an ultrasonic vibrator for 20 minutes, ensuring a uniform and well-dispersed distribution of the charcoal microparticles without clumping.
The pad-dry-cure method was employed to apply the charcoal microparticle solution to the fabric [12]. Initially, the fabric was soaked in the solution for a designated exhaustion period to allow for optimal absorption. Following this, it was passed through a padding mangle to eliminate any excess solution. The treated fabric was then dried at 90°C for 10 minutes and subsequently cured at 150°C for 2 minutes using a stenter machine. This process effectively facilitated the incorporation of charcoal microparticles into the PC-blended fabric.

Testing the performance of the activated charcoal-treated fabric

Carbon weight yield

Carbon weight yield is calculated as the ratio of the weight of the activated carbon-treated fabric to the initial weight of the cotton fabric, both on a dry basis, and is expressed as a percentage using the following equation [7].

$$Carbon\ weigh\ yield\ (\%) = \frac{Weight\ of\ activated\ carbon\ treated\ fabric}{Initial\ weight\ of\ the\ fabric} \times 100$$

Wetting time

The wetting property of the fabric was determined using the method reported by [11]. The fabric sample was placed on a horizontal platform, ensuring that its surfaces did not come into direct contact with the platform and that it remained under normal tension. A syringe filled with distilled water was mounted horizontally on an appropriate stand, positioned 40 mm above the fabric. The syringe was carefully pressed to release a single drop of distilled water onto the fabric's surface. Upon contact, the water drop was immediately absorbed by the fabric, gradually spreading as the fabric became wet. The time interval from the moment the water drop touched the fabric until it completely diffused and spread across the surface was accurately measured using a stopwatch [13]. This measured duration was recorded as the wetting time of the fabric. The average of the readings obtained from ten strips per fabric sample was calculated and noted.

Air permeability

The air permeability of the fabrics was evaluated using a KES-F8-AP1 air permeability tester (KATO TECH CO., LTD., Japan). This method measures the rate at which air flows perpendicularly through a specified fabric area under a defined pressure differential across its surfaces. The air permeability results were expressed as air resistance (R) in kPa·s/m, where higher values indicate lower air permeability and lower values signify better air flow through the fabric. For an effective filtration fabric, a balance between high filtration efficiency and sufficient air permeability is essential [14, 15].

$$Air\ permeability\ (ft^3/\min/ft^2) = \frac{12.455 \times 0.002119}{R \times 0.001076}$$

Water contact angle
To assess the wettability and hydrophobicity of the treated fabric, the water contact angle was measured using a goniometer (Rame-Hart Instrument Co., USA) (Fig. 1). The fabric sample was placed on the designated stage, and a water droplet of approximately 7 µl was dispensed onto the surface using a syringe. An illumination lamp and camera were activated to capture an image of the droplet within 10 s of deposition. The contact angle was determined by analyzing the droplet's shape using drop shape analysis software integrated with the goniometer. The software recorded both the droplet images and the corresponding contact angle values. A total of 10 measurements were taken at different locations on each fabric sample to ensure accuracy.

Filtration efficiency
The optimized fabric was tested for its ability to filter hazardous substances, including particulate matter (PM), volatile organic compounds (VOCs), and CO_2, using a custom-designed filtration assessment instrument developed at ICAR-CIRCOT, Mumbai.
This innovative device features two chambers for analyzing incoming and filtered air (Fig. 2a), each equipped with four advanced sensors: Honeywell HPMA115C0-003 for PM, piD Tech eVxRed for VOCs, Amphenol Telaire 6613 for CO_2, and Bosch sensors for temperature and humidity (Fig. 2b). A 7-inch TFT touchscreen enables seamless operation, with data stored on a USB drive (Fig. 2c).
During testing, a 10×10 cm fabric sample was secured between Teflon and silicon mounts. As air passed through, real-time measurements and graphical representations of filtration efficiency were displayed (Fig. 2c). The instrument provided results every 100 microseconds, with continuous testing capabilities from 20 minutes to 6 hours, ensuring precise and reliable performance assessment.

$$Filtration\ efficiency\ (\%) = \frac{C1 - C2}{C1} \times 100$$

Where,
C1= Concentration of pollutant at input chamber
C2 Concentration of pollutant at output chamber

Scanning Electron Microscope (SEM)
A Scanning Electron Microscope (SEM) analysis was conducted using a Philips XL30 SEM (Netherlands) at an accelerating voltage of 10 kV in high vacuum mode. The treated fabric sample was examined. The samples were precisely cut to 2 × 2 cm and coated with a gold-palladium mixture to enhance their conductivity for SEM imaging. This preparation enabled detailed visualization and analysis of the fabric structure and surface morphology at the microscale, with images captured at various magnifications.

Anti-bacterial property
The control and treated fabric were evaluated for their quantitative antibacterial activity against *Staphylococcus aureus*- a gram-positive strain and *Klebsiella pneumoniae* gram gram-negative strain using the AATCC Test Method 100-2019 [16].
In this test, the working standard was prepared with a final bacterial population of 1.4 ± 0.1 × 10^5 CFU/mL for *Staphylococcus aureus* and 2.6 ± 0.2 × 10^5 CFU/*Klebsiella pneumoniae*. The control and treated fabric samples were cut into square swatches of 3.8 × 3.8 ± 0.1 cm and inoculated with standardized bacterial suspensions in triplicate. All the samples were incubated at 37 ± 2°C for 24h. After incubation, bacteria were eluted from these swatches by vigorous shaking in 100 mL of neutralizing solution for 1 min. The number of bacteria in the eluted solution was counted, and the count was used to calculate the antibacterial efficacy of control and treated fabric samples according to the equation. Percentage reduction (%R) was reported as the average of three replications for each sample.

$$Reduction\ (\%) = \frac{T1 - T2}{T2} \times 100$$

Where,
T1 refers to Bacterial colonies (CFU/mL) at the initial stage
T2 refers to Bacterial colonies (CFU/mL) after 24 h incubation

Statistical Analysis
The physical properties of the fabric treated with activated charcoal were presented as the mean ± standard deviation (SD). Each experiment was carried out in triplicate to ensure reliability. Data analysis was conducted using SPSS software (version 16.0). A one-way Analysis of Variance (ANOVA) was performed, followed by the least significant difference (LSD) test, with statistical significance set at $p < 0.05$.

RESULTS AND DISCUSSION

Optimization of acrylic binder concentration for activated charcoal coating on PC blend fabric
Acrylic binders play a critical role in ensuring the effectiveness, durability, and uniformity of activated charcoal treatments on fabric, while also preserving the fabric's original properties and ensuring ease of application [17]. For the application of the activated charcoal particle solution, various concentrations of acrylic binder were tested, ranging from 0 to 20%, while maintaining a constant 1% activated charcoal concentration, 25 minutes of exhaustion time, and a 1:10 ML ratio (Fig. 3a). It was observed that the carbon add on percentage increased from 2.85 to 3.85% as the acrylic binder concentration rose to 10% (Table 1). However, beyond this concentration, the carbon addition decreased from 3.85 to 2.82%. Briquettes have been prepared from charcoal using tapioca starch binder varying from 5-20%. The study reported that the highest yield of briquette was observed at 14% binder concentration before declining beyond this point. This pattern may be due to insufficient binder at lower concentrations to coat all the activated charcoal particles. As binder concentration increases and more particles are effectively coated, the yield improves. However, once all particles are coated, additional binder does not increase the weight further, resulting in a decrease in overall yield [1].
In the Table. 1, the data revealed that as the concentration of acrylic binder increased from 0 to 10%, the contact angle value increased significantly from 62.45° to 91.15°. This suggests that with the addition of acrylic binder, the fabric's hydrophobic properties improved, which is often desirable for applications where water resistance is important [18]. However, when the concentration of acrylic binder exceeded 10%, the contact angle values began to decrease. This decline suggests that the benefits of increased binder concentration start to plateau and even reverse.

Instead of improving water repellency, this excess binder could create a surface that is less effective at maintaining a high contact angle, possibly due to changes in surface texture or interactions with the activated charcoal particles [19]. Additionally, an overly high concentration of binder might lead to a less porous surface or an uneven distribution of the binder and charcoal particles, which can negatively impact the fabric's water-repellent properties.

As the concentration of acrylic binder increases from 0% to 10%, there is a notable decrease in air permeability from 44.68 to 32.73 $ft^3/min/ft^2$ (Table 1). The decrease might be due to enhanced material density and reduced voids. On a similar line, [20] reported that as the binder concentration increases, the film that forms becomes thicker, which significantly reduces the air permeability of the printed fabric. The binder greatly restricted the flow in the out-of-plane direction, reducing permeability by 98%. Beyond this optimal range (above 10% acrylic binder), additional binder appears to increase the air permeability, potentially due to changes in the binder's interaction with the material or due to the formation of less cohesive structures [21].

As the amount of acrylic binder increased from 0 to 10%, the wetting time lengthened from 4.80 to 18.13 s. This could be due to the increased viscosity and cohesive effects of the binder, which make the material more resistant to quick saturation. However, when the binder concentration was increased further, the wetting time showed a reverse trend. This reversal might be due to changes in the binder's effectiveness, the formation of a different material structure, or other complex interactions between the binder and the liquid. Based on the observations obtained, a 10% concentration of acrylic binder was identified as optimal. Therefore, this concentration has been selected for further investigation.

Optimization of exhaustion time for activated charcoal coating on PC blend fabric

The exhaustion time in the pad-dry-cure method is crucial because it directly affects the efficiency and effectiveness of the chemical treatment applied to the fabric [13]. For applying the activated charcoal particle solution, different exhaustion times ranging from 5 to 40 minutes were tested, while keeping the activated charcoal concentration at 1%, the acrylic binder at 10%, and the ratio at 1:10 ML constant (Fig. 3b). The results showed that the percentage of carbon add on, contact angle and wetting time was increased from 1.82 to 3.85%, 72.18 to 91.21°, 5.01 to 18.13 s, respectively as the exhaustion time extended from 5 to 25 minutes (Table 2). This increase indicates that longer exhaustion times allow more activated charcoal particles to adhere to the fabric, making the fabric more hydrophobic, which likely affects the fabric's ability to quickly absorb water [19], whereas air permeability decreased from 43.79 to 32.75 $ft^3/min/ft^2$. This decrease is likely due to the additional charcoal particles filling the fabric's pores, reducing its breathability. However, no significant change in the carbon add-on percentage, contact angle, air permeability, and wetting time was observed for exhaustion times exceeding 25 minutes. This suggested that the fabric reached its maximum capacity for absorbing the charcoal, and additional time did not enhance the uptake further.

Overall, these results demonstrate that there is an optimal exhaustion time for the pad-dry-cure method when using activated charcoal. However, once this optimal period is reached, extending the exhaustion time further does not provide additional benefits and can lead to unnecessary increases in processing time and cost without enhancing the fabric's properties. Therefore, from the above findings, 25 minutes of exhaustion time was optimized for further experimentation.

Optimization of activated charcoal particle concentration for coating on PC blend fabric

In the study of applying activated charcoal particle solutions, various concentrations of charcoal, ranging from 1 to 5%, were tested while keeping the exhaustion time at 25 minutes, the acrylic binder at 10%, and the ratio at 1:10 ML constant (Fig. 3c). The results revealed that increasing the charcoal concentration up to 3.5% significantly enhanced the carbon add-on percentage, which rose from 3.85 to 12.36%. This increase reflects a higher amount of charcoal adhering to the fabric. Concurrently, the contact angle, which indicates the fabric's water-repelling properties, improved from 91.95° to 135.74°, showing increased hydrophobicity [18]. The wetting time, or the time needed for the fabric to become saturated with water, extended dramatically from 18.30 to 3600 s (1 h), signifying that the fabric's resistance to water penetration increased with higher charcoal concentrations. Additionally, air permeability decreased from 32.36 to 10.75 $ft^3/min/ft^2$, suggesting that the fabric became less breathable as more charcoal was applied, likely due to the pores being filled with charcoal particles. However, when the charcoal concentration exceeded 3.5%, agglomeration occurred, where charcoal particles began to clump together. This clumping led to a reduction in carbon add-on percentage, less effective water repellency, and a decrease in wetting time. Additionally, air permeability increased, indicating that the fabric's breathability improved due to the uneven distribution of agglomerated charcoal particles disrupting the fabric's structure.

Thus, while increasing charcoal concentration initially improved the fabric's properties, excessive concentrations led to adverse effects due to particle agglomeration. Therefore, 3.5% of activated charcoal concentration was optimized.

It was determined that the optimal conditions for applying activated charcoal to PC blend fabric were a 10% concentration of acrylic binder, 25 minutes of exhaustion time, 3.5% activated charcoal concentration, and a 1:10 ML ratio. These parameters were chosen because they effectively balance the application of charcoal with the maintenance of the fabric's key properties. Beyond these conditions, no further improvements in carbon add-on percentage, contact angle, air permeability, or wetting time were observed. This suggests that these settings have maximized the performance and functionality of the fabric, achieving a state of equilibrium where additional adjustments no longer yield significant benefits.

Filtration efficiency of fabric

The filtration efficiency of activated charcoal-treated PC blend fabric was conducted at optimized conditions such as 10% concentration of acrylic binder, 25 minutes of exhaustion time, 3.5% activated charcoal concentration, and a 1:10 ML ratio. The PM2.5, PM10, and CO_2 and TVOC filtration efficiency of the fabric was evaluated by passing air at one end of the chamber and collecting it at the other end of the chamber. The fabric sample was mounted between the inlet and outlet of the air passage, and the sensor measured the pollutant level present in both chambers.

From Fig.4a-d, the study revealed that polyester-cotton (PC) blend fabric treated with 3.5% activated charcoal exhibits significantly enhanced filtration efficiency compared to untreated fabric, effectively capturing pollutants such as PM2.5, PM10, CO_2, and TVOCs. Specifically, the treated fabric showed improvements of 17.75% for PM2.5, 21.19% for PM10, 12% for CO_2, and an impressive 24.77% for TVOCs. These enhancements are attributed to the high surface area and adsorptive properties of activated charcoal, which not only increase the fabric's ability to trap harmful particles and gases but also suggest its potential for applications in air purification and protective clothing. The filtration efficiency of 100% polyester fabric (1.06 mm thickness) and PC blend fabric (21% cotton and 79% polyester with 0.86 mm thickness) against 0.3 µm size particles was 9 and 12%, respectively as reported by [9].

PC blend fabric (30% cotton and 70% polyester) with a thickness of 0.304 mm and a gram weight of 136.17 g/m^2 exhibited a filtration efficiency of 28.15% for 0.3 µm particles and 67.85% for 2.5 µm particles, along with an air permeability of 391 mm/s. Their findings suggest that composite fabrics can enhance filtration efficiency more effectively than multiple layers of the same fabric [22].

SEM analysis of fabric

The optimized PC blend fabric sample was analyzed using Scanning Electron Microscopy (SEM) to evaluate its microstructure and filtration performance. Measurements indicate that the fabric effectively captures particles smaller than 1 µm, with notable particle sizes ranging from approximately 548 to 940 nm (Fig. 5). The filtration mechanism is influenced by both physical and chemical properties of the fabric. Larger particles, typically above 1 µm, tend to be more effectively trapped due to mechanical interception and inertial impaction. Smaller particles, on the other hand, are captured through diffusion and electrostatic interactions.

Anti-bacterial activity of fabric

The antibacterial activity of untreated and activated charcoal-treated PC blend fabric was evaluated using a standard procedure to determine the percentage reduction in bacterial population. As shown in Table 4, the control sample exhibited no antibacterial activity against *Staphylococcus aureus* and *Klebsiella pneumoniae*, which aligns with the known susceptibility of cellulosic materials to bacterial attack and decay [16]. In contrast, the charcoal-treated fabric demonstrated significant antibacterial properties, with a 95% reduction in *Staphylococcus aureus* and a 93% reduction in *Klebsiella pneumoniae*. This indicates that activated charcoal effectively inhibits bacterial growth, likely due to its high surface area, adsorption properties, and ability to disrupt bacterial membranes. The strong antibacterial performance of the treated fabric suggests its potential applications in healthcare textiles, protective clothing, and antimicrobial filters, where bacterial resistance is crucial.

CONCLUSION

The study successfully optimized the process parameters for developing activated charcoal-treated PC blend fabric, focusing on acrylic binder concentration, exhaustion time, and activated charcoal concentration. Statistical analysis ($p < 0.05$) validated the results, showing significant enhancements in carbon add-on, hydrophobicity, air permeability, and wetting resistance. The optimized treatment conditions-10% acrylic binder, 3.5% charcoal concentration, 25-minute exhaustion time, and a 1:10 material-to-liquid ratio—greatly improved the fabric's performance, making it highly effective for air filtration and protective applications. The treated fabric outperformed the untreated fabric in filtration efficiency, effectively capturing PM2.5, PM10, CO_2, and TVOCs. Additionally, antibacterial testing demonstrated a remarkable 95% reduction in *Staphylococcus aureus* and 93% in *Klebsiella pneumoniae*, emphasizing its strong antimicrobial properties.

FUTURE SCOPE OF THE STUDY

The findings of this study position activated charcoal-treated fabric as a cutting-edge solution for environmental and healthcare applications, offering great potential for air purification, protective clothing, and pollutant filtration. The future research should focus on durability, washing fastness, and large-scale production feasibility to facilitate commercial adoption.

CONFLICT OF INTEREST

There is no conflict of interest among the authors.

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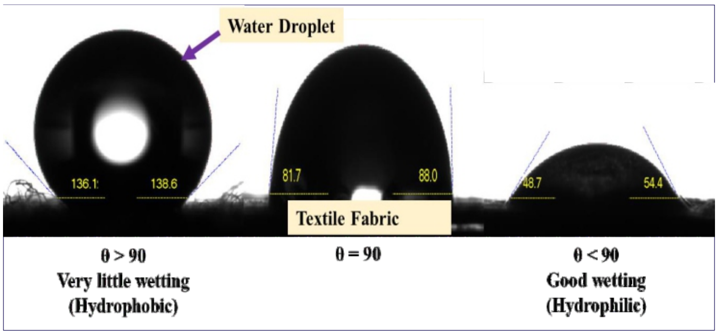


Fig. 1. Contact angle shows the wetting nature of a fabric

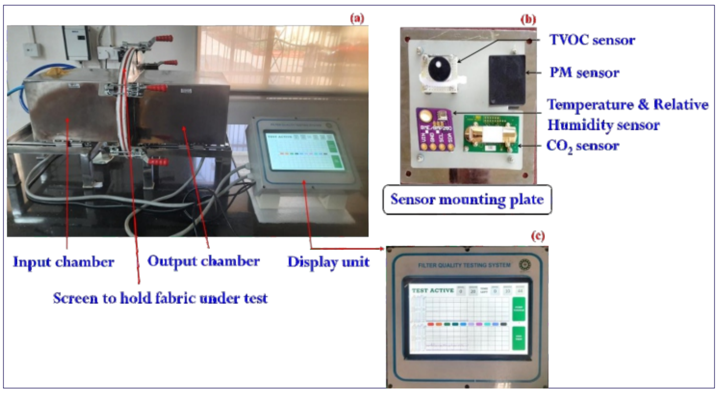
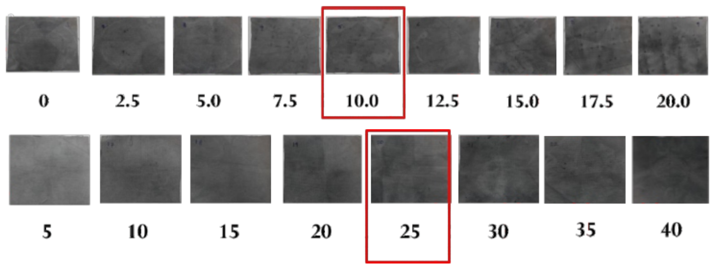


Fig. 2. Equipment for air filtration evaluation of the fabrics



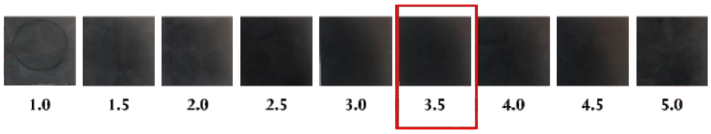
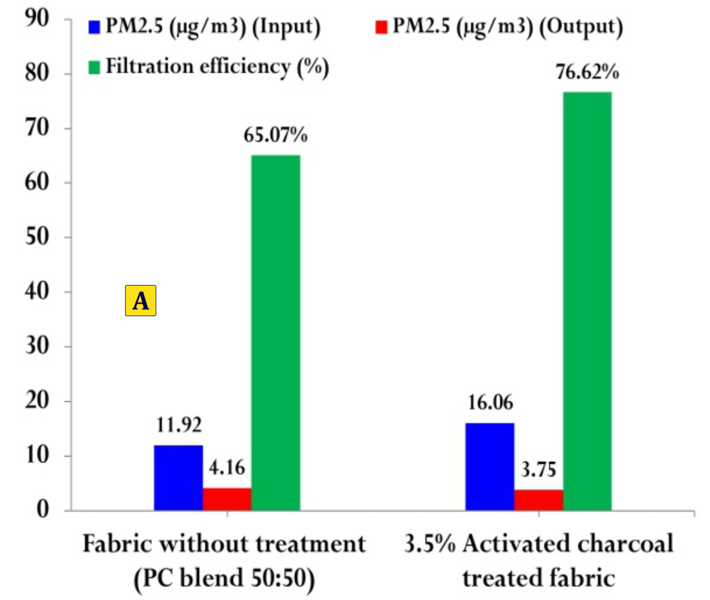
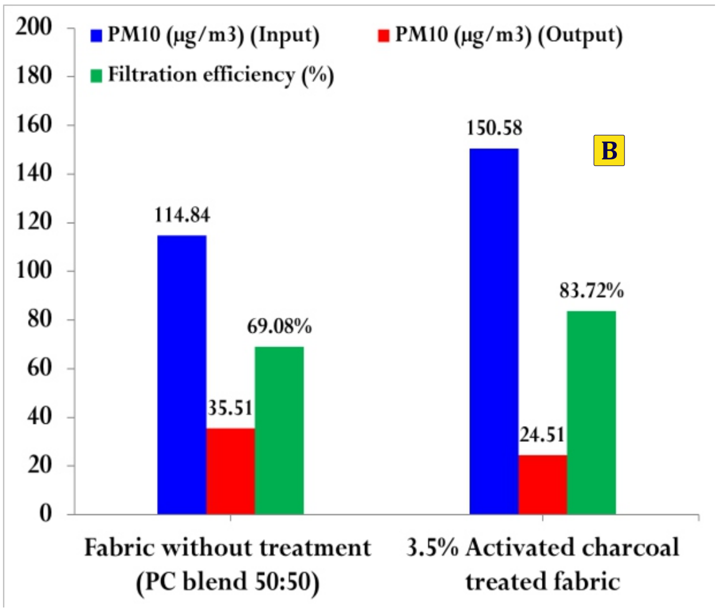
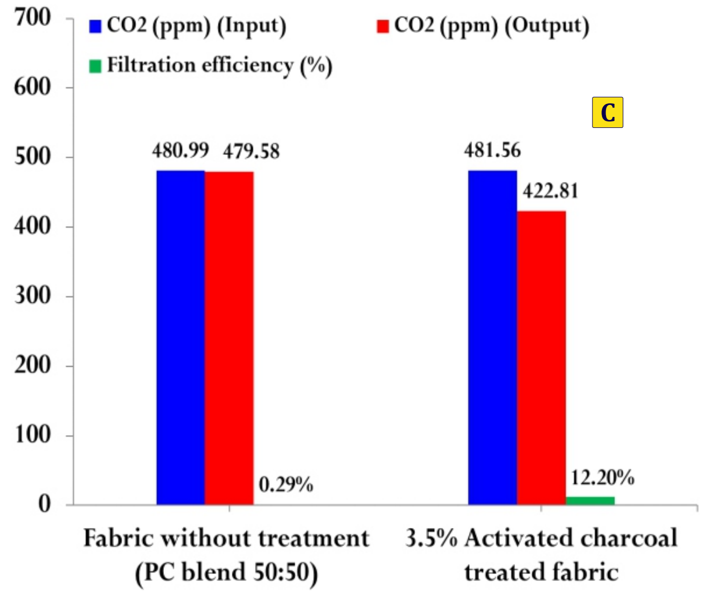


Fig. 3. Activated charcoal coated fabric at different (a) acrylic binder concentration (%) (b) exhaustion time (minutes) (c) activated charcoal particle concentration (%)







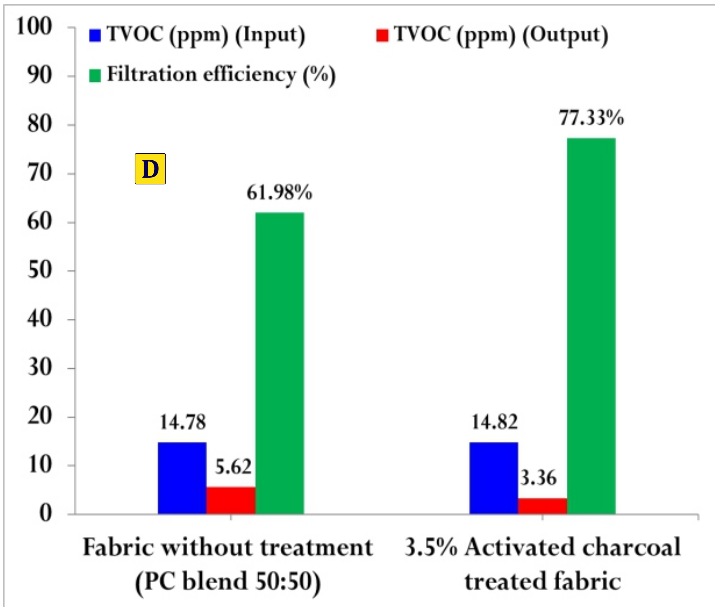


Fig. 4. Filtration efficiency of (a) PM2.5 (μg/m^3) (b) PM10 (μg/m^3) (c) CO_2 (ppm) (d) TVOC (ppm) at inlet and outlet chamber

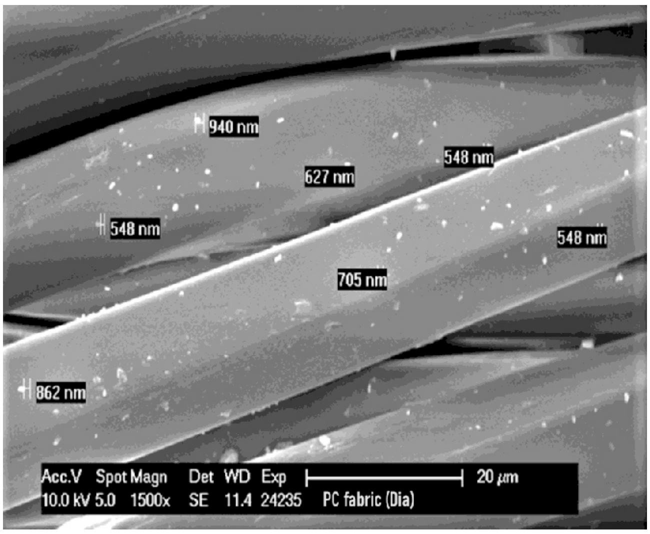


Fig. 5. Scanning Electron Microscopy (SEM) of activated charcoal treated PC blend fabric after filtration testing of fabric

Table 1. Effect of acrylic binder concentration on properties activated charcoal coated fabric

M:L ratio	Activated charcoal (%)	Exhaustion time (min)	Acrylic binder (%)	Carbon add on (%)	Contact angle (°)	Air permeability ($ft^3/min/ft^2$)	Wetting time (s)
1:10	1	25	0.0	2.85±0.63^{ab}	62.51±0.50^{a}	44.68±1.22^{e}	4.80±0.23^{a}
1:10	1	25	2.5	3.15±0.52^{abc}	76.60±0.43^{d}	40.42±1.31^{cd}	10.22±0.10^{c}
1:10	1	25	5.0	3.50±0.21^{abc}	87.26±0.85^{f}	38.67±1.69^{c}	13.17±0.29^{d}
1:10	1	25	7.5	3.63±0.31^{bc}	90.80±0.92^{gh}	36.07±0.90^{b}	14.53±0.45^{e}
1:10	1	25	10.0	3.85±0.28^{c}	91.36±0.56^{gh}	32.73±0.58^{a}	18.13±0.25^{f}
1:10	1	25	12.5	3.81±0.34^{c}	89.60±0.64^{g}	33.60±0.86^{a}	17.70±0.37^{f}
1:10	1	25	15.0	3.77±0.30^{c}	85.60±0.39^{e}	36.16±0.74^{b}	14.40±0.23^{e}
1:10	1	25	17.5	2.74±0.27^{a}	65.47±0.46^{b}	41.66±0.42^{d}	5.00±0.37^{ab}
1:10	1	25	20.0	2.82±0.16^{ab}	68.11±0.70^{c}	42.06±0.12^{d}	5.50±0.29^{b}
ANOVA							
p value (<0.05)				0.023^{S}	0.000^{S}	0.000^{S}	0.000^{S}

Values are mean ± SD of three replications; mean in the same column followed by same superscript letter are not differed significantly at P ≤ 0.05; ^{S}Significant

Table 2. Effect of exhaustion time on properties activated charcoal coated fabric

M:L ratio	Activated charcoal (%)	Exhaustion time (min)	Acrylic binder (%)	Carbon add on (%)	Contact angle (°)	Air permeability ($ft^3/min/ft^2$)	Wetting time (s)
1:10	1	5	10.0	1.82±0.08^{a}	72.18±1.43^{a}	43.79±0.68^{d}	5.01±0.16^{a}
1:10	1	10	10.0	2.00±0.17^{a}	76.09±0.85^{b}	38.63±0.56^{c}	8.70±0.27^{b}
1:10	1	15	10.0	3.13±0.11^{b}	88.61±0.64^{c}	35.23±0.72^{b}	10.70±0.48^{c}
1:10	1	20	10.0	3.22±0.16^{b}	89.47±0.90^{c}	34.55±0.59^{b}	15.25±0.28^{d}
1:10	1	25	10.0	3.85±0.22^{c}	91.21±0.50^{d}	32.75±0.33^{a}	18.13±0.34^{e}
1:10	1	30	10.0	3.86±0.11^{c}	91.40±0.60^{d}	32.04±0.75^{a}	18.30±0.44^{e}
1:10	1	35	10.0	3.84±0.23^{c}	92.10±0.51^{d}	32.97±0.38^{a}	18.67±0.31^{e}
1:10	1	40	10.0	4.03±0.32^{c}	91.82±0.73^{d}	32.31±0.82^{a}	18.23±0.33^{e}
ANOVA							
p value (<0.05)				0.000^{S}	0.000^{S}	0.000^{S}	0.000^{S}

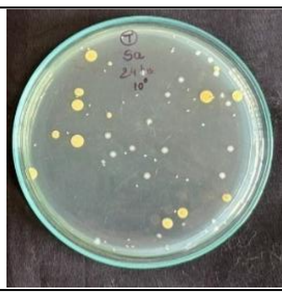
Values are mean ± SD of three replications; mean in the same column followed by same superscript letter are not differed significantly at P ≤ 0.05; ^{S}Significant

Table 3. Effect of activated charcoal particle concentration on properties activated charcoal coated fabric

M:L ratio	Activated charcoal (%)	Exhaustion time (min)	Acrylic binder (%)	Carbon add on (%)	Contact angle (°)	Air permeability ($ft^3/min/ft^2$)	Wetting time (s)
1:10	1	25	10.0	3.85±0.22^{a}	91.95±0.60^{a}	32.36±0.54^{g}	18.30±0.52^{a}
1:10	1.5	25	10.0	3.97±0.34^{a}	115.96±0.21^{b}	28.64±0.81^{f}	1320±1.33^{b}
1:10	2.0	25	10.0	5.34±0.23^{b}	128.72±1.04^{c}	27.89±0.71^{f}	2100±2.60^{c}
1:10	2.5	25	10.0	6.86±0.44^{c}	132.54±0.86^{d}	20.91±0.69^{e}	2400±2.28^{d}
1:10	3.0	25	10.0	8.83±0.60^{d}	133.27±0.20^{de}	16.31±0.26^{c}	3120±1.08^{f}
1:10	3.5	25	10.0	12.36±0.41^{g}	135.74±0.52^{g}	10.75±0.58^{a}	3600±1.63^{i}
1:10	4.0	25	10.0	10.36±0.20^{f}	135.04±0.26^{fg}	12.11±0.44^{b}	3360±1.63^{h}
1:10	4.5	25	10.0	9.60±0.38^{e}	134.34±0.48^{ef}	17.57±0.42^{d}	3240±0.82^{g}
1:10	5.0	25	10.0	6.65±0.71^{c}	129.76±0.69^{c}	20.09±0.78^{e}	2520±1.27^{e}
ANOVA							
p value (<0.05)				0.000^{S}	0.000^{S}	0.000^{S}	0.000^{S}

Values are mean ± SD of three replications; mean in the same column followed by same superscript letter are not differed significantly at P ≤ 0.05; ^{S}Significant

Table 4. Effect of charcoal treatment on bacterial reduction of cotton fabric sample

	Staphylococcus aureus		***Klebsiella pneumoniae***	
Sample	Control	Treated fabric	Control	Treated fabric
0h	1.5×10^5	1.3×10^5	2.7×10^5	2.4×10^5
24h	1.8×10^5	8.9×10^3	3.8×10^5	2.4×10^4
Viability reduction (%)		95.05		93.68
				

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