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Cellulose nanofibril/PVA/bamboo activated charcoal aerogel sheet with excellent capture for PM2.5 and thermal stability

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Abstract

Particulate matter (PM) in the air, especially PM2.5, often serves as a pathogen carrier is a serious threat to human health. Filtration is one of the most accessible ways to protect individuals from PM pollution. Creating effective air filtration materials from renewable sources remains challenging. This study employs cellulose nanofibril (CNF), poly (vinyl alcohol) (PVA), and bamboo activated charcoal nanoparticles (BAC) to craft a double-filtration system through simple mixing and freeze-drying. The resulting CNF/PVA/BAC aerogel sheet, 3 mm thick, achieves a remarkable 99.69% PM2.5 filtration efficiency. Its network structure provides dual filtration, utilizing CNF, while BAC ensures electrostatic adsorption. The material exhibits exceptional thermal stability, maintaining over 95% efficiency at 200 °C for 1h. Modified with MTMS, the hydrophobic sheet can be water-washed and reused over 5 times, retaining efficiency above 95% and pressure drops below 100pa. This environmentally friendly, high-efficiency aerogel sheet stands as a promising solution amid escalating air pollution.

Forming and working mechanism of aerogel sheet

The CNF/PVA/BAC aerogel sheet was successfully synthesized by blending CNF, PVA, and BAC, followed by freeze-drying (Fig. 1a). This process yielded an intricate three-dimensional network structure through CNF interlacing and ice crystal evaporation.

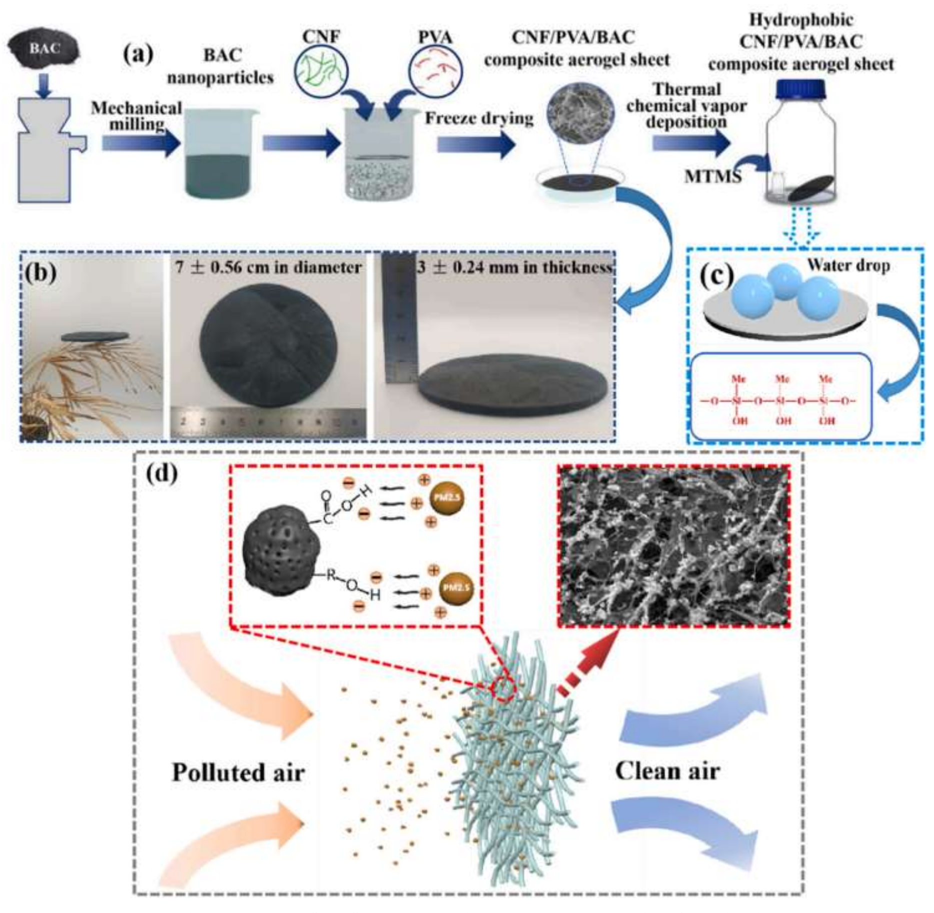

Fig. 1. (a) Illustration for forming, (b) pictures, (c) hydrophobic mechanism and (d) working mechanism of CNF/PVA/BAC aerogel sheet.

In an alkaline milieu, BAC surface -OH and -COOH groups underwent deprotonation, augmenting the negative charge. The aerogel sheet, benefiting from both physical filtration and electrostatic adsorption synergy, exhibited outstanding PM2.5 particle filtration efficacy (Fig. 1d). Hydrophobic modification with MTMS, involving hydrolysis and dehydration condensation, enhanced the recycling capability of the CNF/PVA/BAC aerogel sheet (Fig. 1c).

Results - Filtration capacity

- The CNF/PVA/BAC (2:1:3) one had the best filtration efficiency of 99.69 ± 0.24%.
- The quality factor (Qf) of the CNF/PVA/BAC (2:1:3) was reached 0.152 Pa^{-1}, showing exceptional comprehensive filtration performance.
- Large amounts of fine particles were adsorbed and agglomerated in the interior of the CNF/PVA/BAC aerogel sheet (Fig. 2f-g).

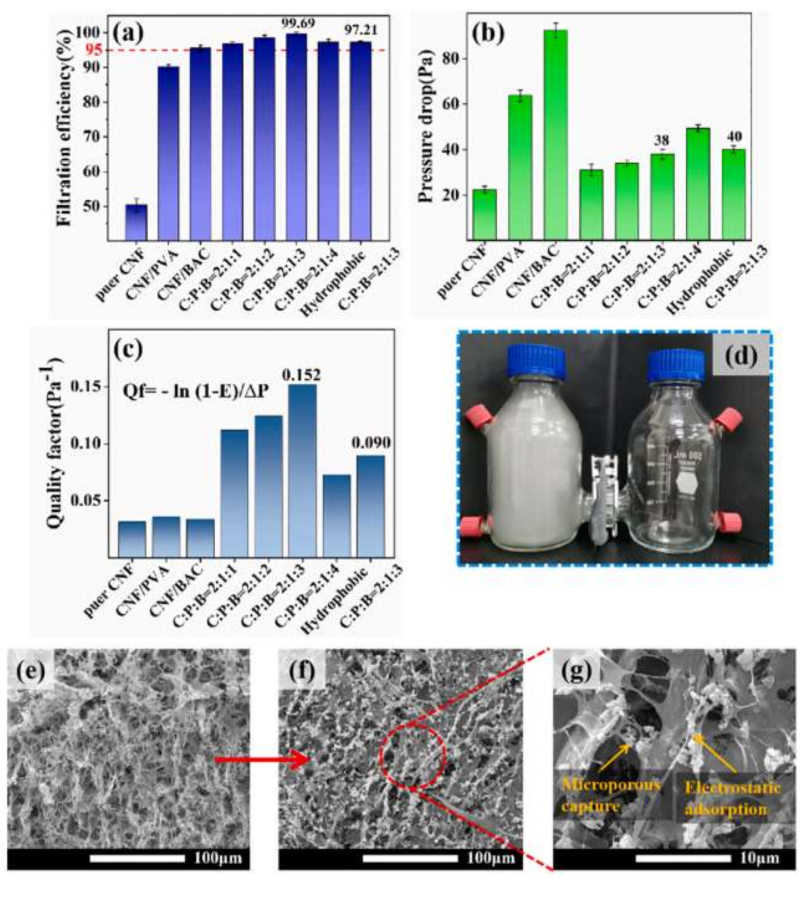

Fig. 2. (a) Filtration efficiency, (b) pressure drop and (c) corresponding quality factor of different aerogel sheets for PM2.5 under gas velocity of 5 cm/s. (d) picture for barrier of sample to PM2.5. SEM images of the CNF/PVA/BAC aerogel sheets interior (e) before and (f, g) after filtration test.

Results - Regeneration

- The aerogel sheet had excellent stability in the high temperature filtration process.
- The hydrophobic CNF/PVA/BAC one still maintained high filtration performance (>95%) after washing for 5 times (Fig. 3b).
- After water washing, most particles on the surface of the sheet were removed and the pores were unblocked (Fig. 3e-g).

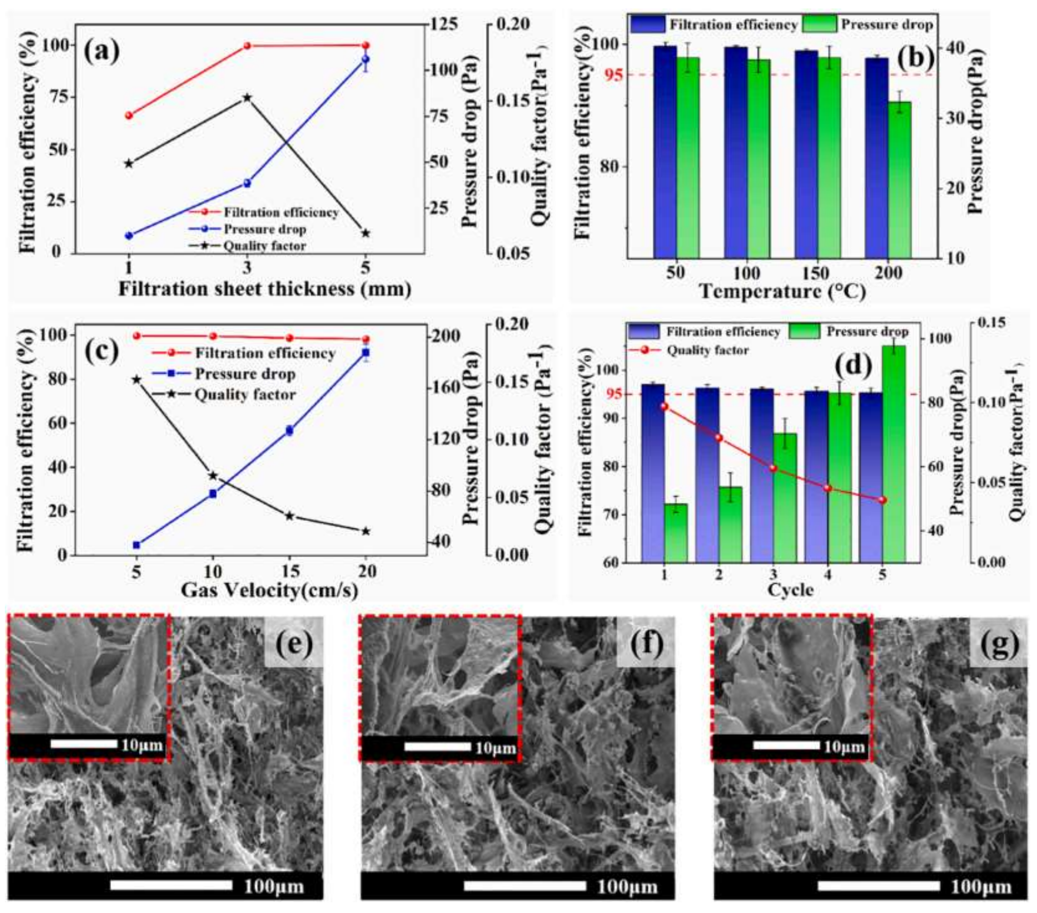

Fig. 3. Filtration performance of CNF/PVA/BAC aerogel sheet under different (a) sheet thickness, (b) temperature treatment for 1h, (c) gas velocities. (d) reusability of hydrophobic CNF/PVA/BAC aerogel sheet. SEM images after water washing (e) 1 time, (f) 3 times, and (g) 5 times.

Conclusions

In this study, the CNF/PVA/BAC aerogel sheet was prepared to creat the synergistic effect of CNF, BAC and PVA for air filtration. When the mass ratio of CNF, PVA and BAC was 2:1:3, the resulting aerogel sheet showed excellent ability to capture PM2.5 and good thermal stability. The addition of BAC increased S_{BET} and enhanced electrostatic incorporation, resulting in a dramatic improvement in the overall filtration performance (the highest capture efficiency of 99.69%). After modification, the filtration efficiency of the hydrophobic CNF/PVA/BAC one still reached 97.21% and showed good reusability. It is worth mentioning that because all the CNF, PVA and BCA are environmentally friendly materials, entire manufacturing process without organic or toxic solvents. The CNF/PVA/BAC aerogel sheet has shown great potential for application in air purification.

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