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ORIGINAL ARTICLE

Fabrication of high efficiency coronavirus filter using activated carbon nanoparticles

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Abstract

In this study design and fabrication of coronavirus filter based on the cellulose and carbon nanomaterials have been investigated. Particulate matter (PM) corona virus has attracted a lot of attention due to its great threat to human health. Nanoparticles are intertwined with fibers and form highly porous air filter paper. The structure of the filter has been characterized using scanning electron microscope (SEM) and Brunauer–Emmett–Teller (BET) analysis. In addition, by optimization with activated carbon (AC) nanoparticles, the prepared AC air filter paper shows a high removal efficiency of more than 95% for PM 100 nm. More importantly, this filter shows less pressure drop and less thickness. This filter has a positive effect on the prevention of this disease during the coronavirus epidemic and show high absorption efficiency air filter for PM more than 100 nm.

Keywords Cellulose · Nanoparticle · Efficiency · Coronavirus

Introduction

High performance air filters divided in two fundamental approaches. The structure-based approaches consist of modifying morphology, hybridizing technology and stacking multiple layer and the interaction-based approaches involve charging, electrostatic precipitator and triboelectric nanogenerator [1]. The coronavirus particles diameter are between 60 and 140 nm [2]. Coronavirus can cause pulmonary complications such as pneumonia and, in more severe cases, acute respiratory distress syndrome [3]. Sepsis is another possible complication of coronavirus that can cause permanent damage to the lungs and other organs. The use of special filters can reduce the risk of this disease more effectively and prevent the penetration of particles with an average diameter of 400 nm. It is estimated that filters can absorb or remove approximately 99% of particles. By knowing the size of viral particles, researchers and physicians can determine the viral characteristics that people are exposed to in different ways. For example, the length of respiratory droplets is between 5 and 10 μm. Therefore, healthy people are more likely to be infected with the coronavirus through respiratory droplets [4]. Respiratory droplets can be transmitted through coughing, sneezing, contact with contaminated surfaces, or even inhalation of airborne particles. For this reason, air must be filtered and respiratory droplets removed from the air [5]. For general ward rooms with natural ventilation, adequate ventilation is considered to be 60 L/s per patient [6]. There are different types of air purifiers in the market, but the best air purifier, in addition to having different filtrations, such as HEPA filter, UV filter and pre-filter and carbon filter has been used to remove odor and taste [7, 8]. The carbon nanotubes (CNTs) were used widely in development of filters fabrication [9–11]. Ref. [12] shows the high efficiency air filter paper for remove toxic and pollutant gases using the multi-walled carbon nanotubes (MWCNTs) and phenol–formaldehyde. They showed the surface area of the fibers was increased by the MWCNTs. In this study, high performance coronavirus air filters based on the AC nanoparticles has been investigated.

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Materials and methods

One of the additives to the filter compositions is single-stranded and double-stranded polyethylene (light and heavy polyethylene), which are in the form of granules. (Fig. 1) shows light and heavy granular polyethylene. In the first step, the polyethylene must be ground into a very fine powder. For this purpose, a granules grinding machine was used.

Calcium carbonate is an exceptional mineral with a molar mass of 100.087 gr/mol and its appearance is white powder. Calcium carbonate ($CaCo_3$) contains more than 4% of the Earth's crust and is found worldwide. Calcium carbonate is one of the most widely used materials known. It is the most important structural composition of cell walls and after the removal of lignin and other types of extractive materials; it is also the most important structural composition of paper. For the filter fabrication the different weight percentages of calcium carbonate (10%), ethylene glycol (4%), cellulose (80%) and polyethylene (6%), were prepared. Using an extender, the material is mixed and after mixing in this machine and extracting the dough, it must be smoothed with a press machine. Nano-inorganic adsorbents are unique materials. Its appearance is black powder. Important application. They are used in the separation of odors, colors, unwanted tastes from water in domestic and industrial operations, solvent recycling, Air purification is especially in restaurants, food and chemical industries. To optimize the filter, first carbon nanoparticles the active ingredient was placed in a stereo (magnetic stirrer) with distilled water and stirred for 60 min. According to (Fig. 2a) the mixing unit is rotated and consists of a fixed and movable disk. The dough solution enters a short distance between these two plates. Due to the rotation of the rotating plate, the stuck fibers are separated from each other, and due to the collision of the disc appendages with the fiber wall, they become fluffy, which connects the fibers to each other. It is of great importance and show the dough machine. in the next step, the dough must be completely pressed, which is done by a machine called a press. After this step, a paper machine was used to have thinner and rounder samples as shown in (Fig. 2b).

Results and discussion

The STOE model of XRD machine has been used to perform X-ray diffraction analysis (Fig. 3). X-ray diffraction spectroscopy was performed to investigate the crystalline properties of calcium carbonate and activated carbon. For structural analysis, X-ray diffraction, Bragg angles 2θ are between 5 and 90 degrees, and the source of Cu copper with a wavelength of $\lambda = 1/54$ angstroms In this model, the diffraction observed at angles 24 and 46 with low intensity is related to the graphite structure of activated carbon. Which refers to

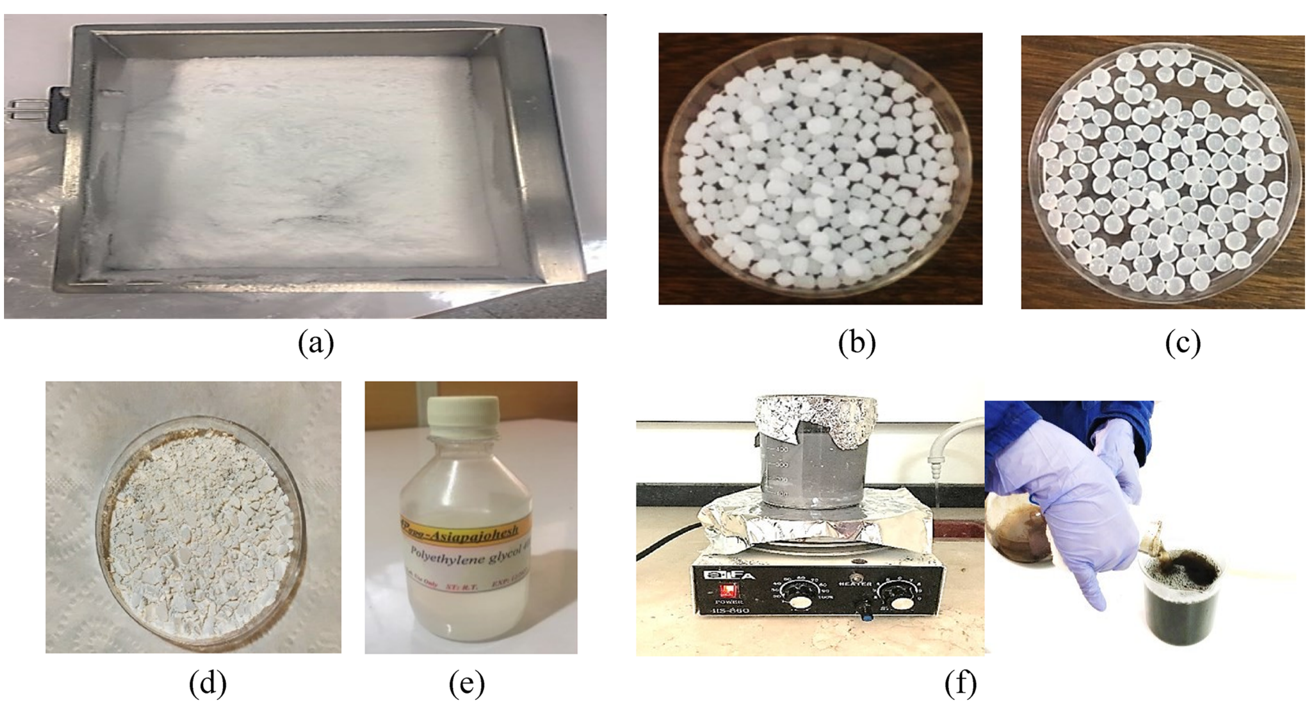

Fig. 1 **a** Polyethylene powder obtained from granule grinding **b** Heavy polyethylene (cylinder) and **c** Light polyethylene (round) **d** calcium carbonate **e** ethylene glycol **f** preparation of nanoparticles

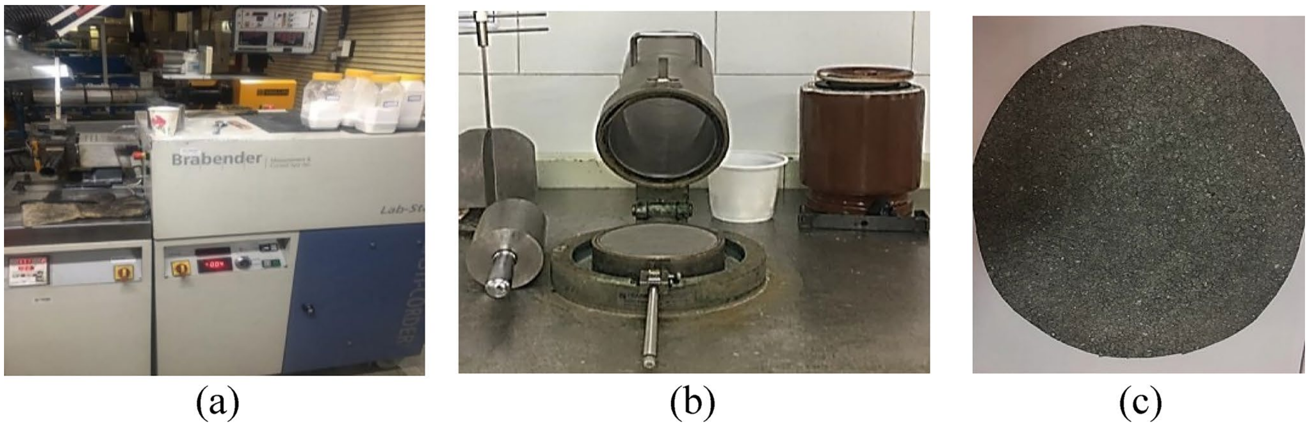

Fig. 2 **a** Dough maker machine **b** Paper making machine (press) **c** AC based filter

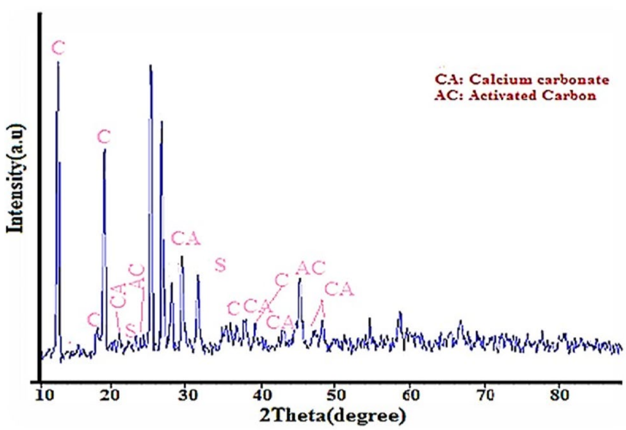

Fig. 3 XRD diffraction peaks from calcium carbonate and activated carbon

the crystal plates (002) and (101) graffiti, respectively. Calcium carbonate with calcite crystalline phase shows diffusions at angles of 23, 29, 36, 39, 43, 47 and 49.Which refers to the crystal plates (012), (104), (110), (013), (202), (018) and (016). Measurement crystallinity in this sample was calculated by the Debye-Scherrer method and the value of 22 nm was obtained. In XRD analysis, the angle and intensity of the peaks contain information from the sample that can be used to determine the atomic structure and phase of the diffuser plates. Materials are available in crystalline and amorphous forms. In the XRD diagram, amorphous spheres have wide peaks. The intensity ratio of these peaks can be used to determine the crystallinity The size of the crystals and the micro-strains are effective factors in the width of the peaks. Obviously, the larger the crystal area and the smaller the lattice defects, the smaller the width of the peaks. As can be seen in (Fig. 3) narrow width of strips Self-determinants of crystallites in the nano range.

Figure 4 shows the FESEM analysis images of optimal filter based on the compositions of calcium carbonate, ethylene glycol, cellulose, polyethylene and activated carbon.

As seen in the pictures improved filter have interconnected pores, pores and channels that represent an effective filter for better gas absorption. Because the more porosity

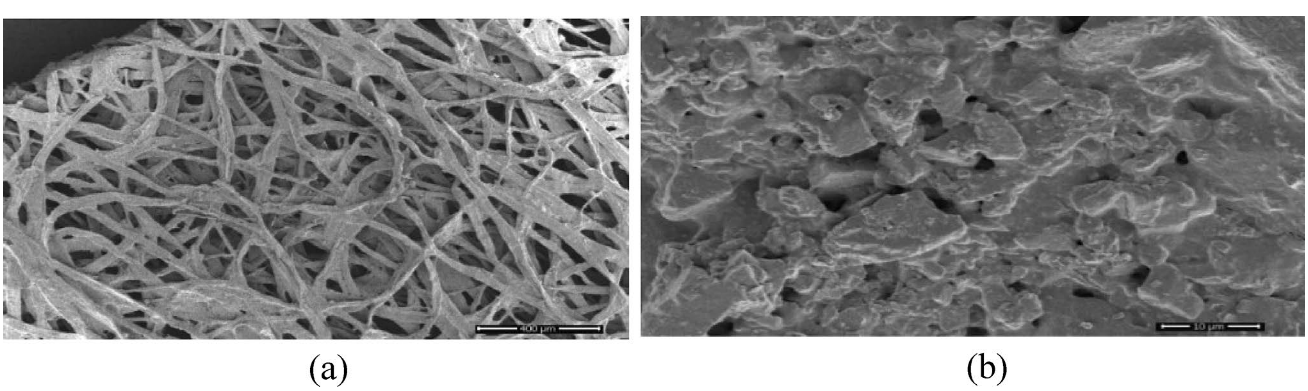

Fig. 4 FESEM images of optimal filter **a** 400 µm scale **b** 10 µm scale

and pores, the more pollutants are absorbed. The BET analysis was used to evaluate the porosity and effective surface measurement characteristics for filter. This analysis determines the pore diameter, surface area, hole volume and hole size distribution of nanoparticles. The effective surface of a substance is extracted from this line graph. In (Fig. 5a) the blue dots represent the absorption and red dots indicate excretion. As can be seen from the (Fig. 5a), the amount of absorption increases with the increase of the inlet gas pressure. Figure 5b shows the BET analysis of gas desorption. A comparison between the absorption and desorption diagrams is shown in (Fig. 5c).

Since the absorption and desorption curves are close to each other and exceed two 0.5 and approximately two points at 0.3, the two curves are stuck together, it means that the diameter of the holes is very small and a few nanometers and in our structure there are both meso and micro. It is necessary to perform an efficiency test and pressure drop to identify suitable filters. Figure 6 shows the efficiency and permeability of filter as function of particles size. The test device of partner company of standard nanoscale technologists was used. This device is able to test efficiency, pressure drop and air permeability. This device is capable of supplying incoming air flow

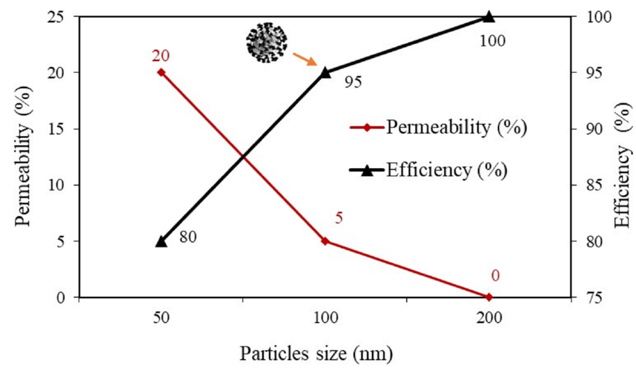

Fig. 6 Comparison between filter efficiency and permeability

from 910 lit/min to 200 lit/min and pressure drop from zero to 1200 Pa. The efficiency can be obtained from [13, 14]:

$$\text{Efficiency (\%)} = \left(\frac{N_1 - N_2}{N_1}\right) \times 100 \tag{1}$$

where N_1 is the number of particles entering the device test and N_2 is the number of particles passing through the filter.

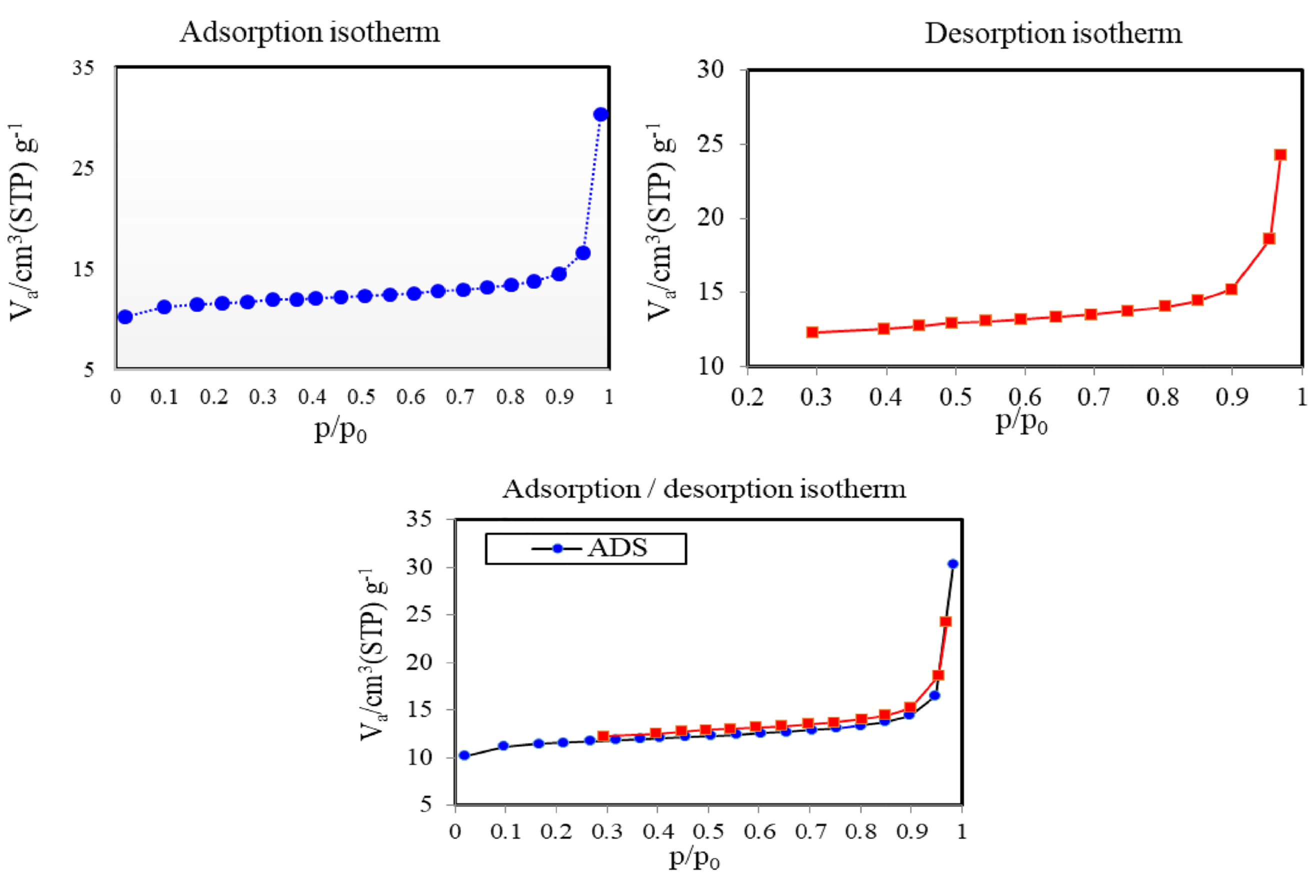

Fig. 5 **a** Filter gas adsorption, **b** Filter gas desorption **c** comparison between adsorption and desorption BET analysis

As can be seen in the Fig. 6, the efficiency of filter for particles with 100 nm size was 95% and by increasing the particle diameter, the permeability was decreased. The permeability can be obtained from [13, 14]:

$$\text{Permeability}\ (\%) = 1 - E(\%) = \left(\frac{N_2}{N_1}\right) \times 100 \quad (2)$$

where $E(\%)$ is the efficiency of the filter, N_1 is the number of particles entering the device test and N_2 is the number of particles passing through the filter. Figure 6 also shows the filter permeability for 100 nm particles was 5%. The goal of pressure drop analysis is to determine the pressure difference of unit under test when air passes through it under predetermined conditions. The pressure drop can be obtained from [13, 14]:

$$\Delta P = -\left(\frac{Ln(1 - E(\%)}{Q_f}\right) \quad (3)$$

where $E(\%)$ is the efficiency of the filter, Q_f is the quality factor of the filter.The pressure drop was 213 Pa for a flow air 30 L/min. The carbon nanomaterials such as activated carbon, graphene and carbon nanotubes were used in filters for different application like indoor air cleaning, environmental pollution, life science and health [15–17]. Mallakpour and et al. [18], reviewed the fabrication of air filters for control the spread of COVID-19 based on the metals, metallic oxide, metal ions, carbon-based nanomaterials, biopolymers and other natural materials. They reported carbon nanomaterials due to construction, chemical stability and antimicrobial behavior have been employed widely in air filters and have an efficiency between 64 and 99.999%. In the Ref. [19], graphene-based air filters for COVID-19 has been investigated. They reported the efficiency of filter for sub-micron particulate filtration (0.3 µm) was 94.3%. The coronavirus filter based on the calcium carbonate/ethylene glycol/cellulose/polyethylene/activated carbon effectively absorbs respiratory fluid droplets that carry many viruses, including coronaviruses, which are produced by coughing, talking and breathing, and are suspended in the air for hours. Compare our results with other report show good agreement in the efficiency of filter performance.

Conclusion

In this study, the coronavirus filter with the structures of calcium carbonate/ethylene glycol/cellulose/polyethylene/activated carbon has been fabricated. The efficiency of the coronavirus filter based on AC for particles size 50, 100 and 200 nm were 80, 95 and 100% respectively. This device test is capable of supplying incoming air flow from 10 lit/min to 200 lit/min and pressure drop from zero to 1200 Pa. The pressure drop was 213 Pa for a flow air 30 L/min. The surface morphology and porous of filter were measured using the SEM and BET test. The results showed the reducing the size of the holes by nanomaterials in the filter to less than 30 nm and increasing the taking smell by the filter (for special applications in mines). Due to the structural changes of the virus and successive mutations, the emergence of resistant strains or highly susceptible strains, the structure and size of the virus and its changes in the design and manufacture of nanomask are very effective in the prevention and treatment of coronavirus. The results of the coronavirus filter efficiency showed the AC nanoparticles have an excellent performance that could be applied for mask fabrication.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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