Review Article

# Cationic Nanocellulose as Promising Candidate for Filtration Material of COVID-19: A Perspective

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**Abstract**
The threat of the novel coronavirus (COVID-19) pandemic is worrying as millions of people suffered from this outbreak. The COVID-19 can be airborne spreaded by attaching to human nasal or saliva secretion of an infected person or suspended fine particulates in the air. Therefore, in order to minimize the risks associated with this pandemic, an efficient, robust and affordable air-borne virus removal filters are highly demanded for prevention of spreading viruses in hospitals, transportation hubs, schools, and/or other venues with high human turn-over. Respirators such as N95, N99 and N100 as well as surgical masks have been widely used. To date, there is no filter standards or special filter technologies tailored for effectively adsorbing the airborne viruses. Studies had shown the electrostatic fibers were capable to entrap the negatively charged viruses including COVID-19. Researchers believed that the positive surface charge of filtration material is an important key to efficiently adsorb the negatively charged viruses. Nanocellulose has emerged as a new class of biobased material with promising potential application in the filtration of viruses. Nanocellulose is uniform in diameter and has excellent nanofibrillar morphology. To the best of our knowledge, further studies are necessary to determine the efficiency of cationic nanocellulose as filtration material of COVID-19.

**Keywords**: COVID-19, Nanocellulose, Filtration material

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## 1 Introduction

On December 31, 2019, the World Health Organization (WHO) was notified of a cluster of pneumonia cases associated with individuals who visited a wholesale seafood and wildlife market in Wuhan City, Hubei Province, in the People's Republic of China [1]. The etiologic agent was identified as a novel *betacoronavirus*, subsequently named SARS CoV-2, and then known as COVID-19 that rapidly spread throughout the world [2]. Later on, the WHO had declared the COVID-19 outbreak as a pandemic on March 12, 2020 [3]. The COVID-19 keeps circulating and the number of contaminated people is still rising.

In the midst of the novel COVID-19 pandemic, there has been much uncertainties. Scientists are remaining uncertain about its precise origin, structure, composition, rapid test, suitable vaccines, effective protective barrier. They are also questioned whether or not the disposable surgical masks are really effective. Surgical face masks are now a legal requirement in many public spaces around the world. However, a surgical mask does not protect against "airborne" infectious agents so it will not prevent the wearer from being potentially contaminated by a virus including COVID-19. It could only be possible to reduce the risk of transmission of the virus [4]. Besides, surgical masks were causing litter problems on land and at sea. This is because, the polypropylene which is one of the main materials used in surgical mask is known to be non-biodegradable and non-renewable. Figure 1 shows the example of used surgical masks that were not properly disposed.

Therefore, scientists are urgently need to find the best solution of this issue. Nanocellulose can be a great candidate of filtration material of COVID-19 contaminated in air and water. This material is well known for its versatile and excellence properties of high specific surface area, biodegradable, renewable, allow surface functionalization, high mechanical strength.

Nanocellulose can be employed in several fields in our life, such as composite materials, filters, packaging, biomedical products, military, energy, and cosmetics [5]–[16]. Interestingly, nanocellulose has been proved as one of most effective material that can filter several microbes especially viruses and bacteria [6]. The filtration of virus using nanocellulose is usually done by size-exclusion method. According to

**Figure 1**: The used surgical masks that were not properly disposed.

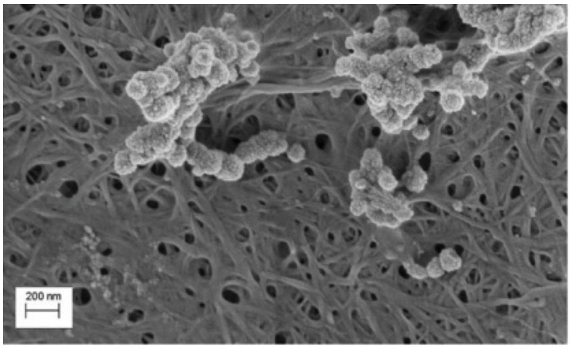


**Figure 2**: SEM images of SIV particles filtration on nanocellulose membrane. Reproduced with permission from [17].

Metreveli *et al.* [17], the nanocellulose filter managed to entrap the Swine Influenza Virus (SIV) particle as shown in Figure 2. This SIV has a typical particle size of 80–120 nm which is similar to the COVID-19 (70–90 nm) [18].

Moreover, to increase the effectiveness of nanocellulose as virus filter, functionalization on its surface is necessary. This method needed to undergo surface functionalization on nanocellulose to make it cationic charged. The corona virus and several other viruses are known to have the negatively charged surface [3]. Figure 3 shows the coronavirus structure with proteins embedded in bilayer negatively charged lipid head groups. The electrostatic attraction between the negatively charged of virus and the positively charged nanocellulose will effectively entrap the virus. Therefore, this manuscript provides knowledge and direction for the scientists to stimulate future research in this area.

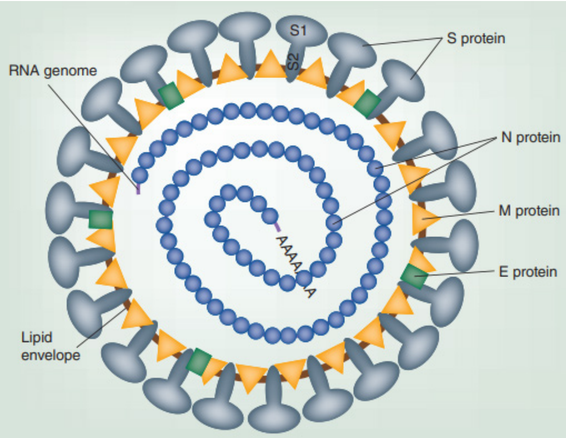


**Figure 3**: Schematic representation of a coronavirus particle. Reproduced with permission from [19].

## 2 Properties of Nanocellulose as Virus Filtration Material

As mentioned above, there are many interesting characteristics of nanocellulose including an extremely high specific area, able to surface functionalization, good adsorption capability, high porosity with excellent pore interconnectivity, low weight, biodegradable and renewable [20]–[27]. Table 1 summarizes the importance of these special characteristics of nanocellulose which related to its application as a filtration material.

**Table 1**: Several properties of nanocellulose related to adsorbent properties

| Property | Advantages | Reference |
|---|---|---|
| Nanoporous | - Give good virus filtration by size-exclusion method. Usually, the pores size of nanocellulose are below than 100 nm.<br>- The term "aerogel" is commonly used interchangeably to describe nanocellulose-based porous materials.<br>- It can be prepared by sublimating a liquid component through lyophilization (freeze-drying) or by critical point drying to remove the solvent to become a high porous, lightweight and networked material. | [17], [28] |
| Surface functionalization | - Functionalization of nanocellulose with several compounds to make it cationic charged. This causes an increase in binding affinity toward COVID-19.<br>- Functionalization can be done through oxidation, esterification, etherification, silylation, addition, and grafting. | [29] |
| High specific surface area | - It provides a large surface area for functionalization. Therefore, it can increase the interaction efficiency.<br>- Nanocellulose aerogel is usually has with high porosity and large specific surface areas. | [30] |
| Renewable | - The source of nanocellulose can be easily obtained from plant biological waste. It can eliminate the use of polypropylene which is obtained from petroleum.<br>- Oil palm biomass, wood, bamboo, sago hampas, wheat straw, and sugar palm fiber are the example of plant-based biomass which are usually use to produce nanocellulose. | [21], [31]–[33] |
| Biodegradability | - This is important aspect to save the environment. It is biodegradable in the landfill.<br>- Thus, the current environment issue on used surgical masks can be reduced. | [34] |
| High mechanical properties | - High strength filter mask and respirator can be produced.<br>- Composites of nanocellulose based filters have been proven to have an excellent mechanical performance.<br>- This can be done by a layer deposition method to prepare a series of nanocellulose/filter paper. | [35] |
| Stable in water | Reducing bio-fouling of nanocellulose. This is important for application in water filter. | [36] |

## 3 Cationic Nanocellulose

Cationic nanocellulose has been widely described and recently tested for applications in non-viral gene delivery, ion-exchange, drug delivery and non-leaching antibacterial fibers. The cationic nanocellulose are rarely been studied to filter the viruses. Leung *et al.* [3] had recently developed the electrostatically charged polyvinylidene fluoride (PVDF) nanofibers to filter the COVID-19. The electrospinning method was used in their study in order to positively charged the PVDF nanofiber. The PVDF nanofiber filters were successfully capturing 100 nm airborne COVID-19 with over 90% efficiency.

There are several compounds such as small organic molecules, polymers, dendrimers and porphyrin that can be functionalized with nanocellulose to make it positively charged [29]. Functionalization of nanocellulose can be done by oxidation, esterification and etherification, which would introduce new functional groups. Conventional 2,2,6,6-teramethylpiperidinyloxy

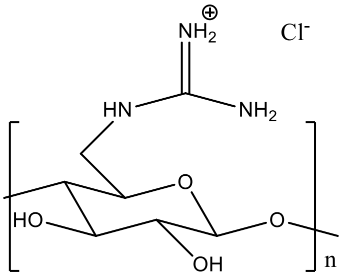


**Figure 4**: The guanidine functionalized nanocellulose.

(TEMPO) or acid treatments are most often approach to functionalized the nanocellulose [37]. For example, the aldehyde groups are usually functionalized on nanocellulose through an oxidation process by oxidants such as periodate sodium and TEMPO [6]. TEMPO can link to nanocellulose under aqueous condition, and then the hydroxyl group at the C6 position of nanocellulose will convert to aldehyde and carboxyl functional groups.

Here are some examples of cationic nanocellulose developed to filter the negatively charged viruses. Mi *et al.* [38] had functionalized the nanocellulose with a positively charged guanidine group to adsorb the porcine parvovirus and Sindbis virus. The cationic nanocellulose as shown in Figure 4 was completely filtered those viruses from water and exceeded the Environment Protection Agency (EPA) virus removal requirement. There were found that, the cationic nanocellulose was able to remove more than 4 logs of non-enveloped porcine parvovirus and enveloped Sindbis virus. This is due to the protonated of guanidine groups on the cationic nanocellulose can form ionic and hydrogen bonding to the proteins and lipids on the virus surface [39]. From this research also showed that advantage of this cationic nanocellulose can allocate to both electrostatic interaction between guanidine cations and negatively charged viruses existed, but also hydrogen bonding could occur between the guanidine group and virus surface protein or envelope.

Besides, Rosilo *et al.* [40] had prepared the cationic nanocellulose (known as nanocellulose-g-P(QDMAEMA)s) by surface-initiated atom-transfer radical polymerization of poly(N,N-dimethylaminoethyl methacrylate) and subsequent quaternization of the polymer pendant amino groups as shown in Figure 5. Addition of only a few weight percent of this cationic nanocellulose in water dispersions was efficiently

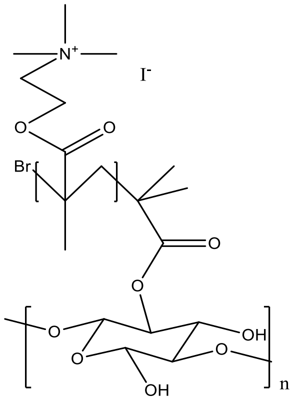


**Figure 5**: The nanocellulose-g-P(QDMAEMA)s.

bound with the cowpea chlorotic mottle virus and norovirus-like particles with high affinity. The addition of only a few weight percent of the functionalized nanocellulose in contaminated water sufficed to fully bind the virus capsids to form micrometer-sized assemblies.

Besides that, the quaternary amine is suggested to be functionalized with nanocellulose. This is due to the interesting findings reported by Riviere *et al.* [41]. They had functionalized lignin particles with quaternary amine to facilitate the removal of anionic cowpea chlorotic mottle viruses (CCMVs). They were found that CCMVs managed to form agglomerated complexes with cationic lignin particles. The CCMVs concentration was reduced by 79% when viruses were mixed with the functionalized lignin particles.

Besides that, polyglutamic acid (PGA) and mesoporous silica nanoparticles (MSNs) also been functionalized with nanocellulose in order to filter the Enterovirus (EV71) [42]. Based on the aforementioned studies, the successful removal of EV71 is mainly due to the surface proteins of the virus that contain two exposed positively charged amino acids (His10 and Lys14), which then interact with negatively charged MSNs on functionalized nanocellulose. Based on the statistical analysis, the functionalized nanocellulose adsorbed highest levels of EV71 (>80%) after 2 h. Time dependent experiment further showed that the adsorption capacity increased with increase in incubation time, and reached >95% after 4 h. Moreover, even after 5 operating times, the functionalized nanocellulose kept the adsorption capacity >65%, indicating its good reusability.

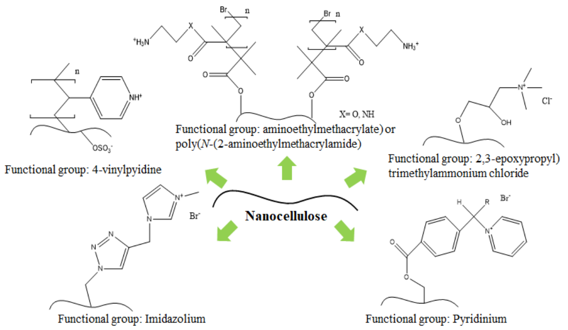


**Figure 6**: The example of cationic nanocellulose.

Figure 6 shows the other examples of cationic nanocellulose that have been developed for several purposes. However, not all of them have been tested to filter the viruses.

## 4 Challenges and Future Recommendation

All in all, development on cationic nanocellulose based filter as presented here provides the urgently needed technology for protecting the general public from the deadly airborne COVID-19 and other viruses. Some reviews had proved that the positively charged nanofiber can greatly entrap the negatively charged viruses. Besides that, nanocellulose based filter does not cause harmful to the environment because it is biodegradable and renewable. The cationic nanocellulose will not only can replace the current material of filtrations, but it also can be used for other systems such as s filters, packed columns, or flocculants in order to remove the air-borne COVID-19.

However, there are several challenges were also need to be tackled. The side effects towards environment as a result of the functionalization of nanocellulose are also important to be considered. For example, functionalization of nanocellulose with TEMPO can cause harmful to the environment. This is because, the synthesis of TEMPO can generate a chemical which toxic to aquatic life after been released into waste effluent [43]. In the future, research should also be focused on this matter to determine the feasibility of developed functionalized nanocellulose towards the environment.

Multiple challenges regarding the use of nanocellulose as filtration materials have been identified. Currently, nanocellulose requires high production cost. The energy consumption related to the production of nanocellulose is still an issue hampering the scale-up production of nanocellulose. A reliable and reproducible production techniques for nanocellulose is essential to pave way of using nanocellulose as a virus filtration material. Low-energy and affordable production cost to produce nanocellulose at a commercial scale should also be developed as it would diversify their usage in numerous industries. To the best of our knowledge, progress has been accomplished in this field and numerous pilot-scale productions are now available worldwide. Moreover, there is an issue regarding biodegradability of nanocellulose. Studies must be carried out in evaluating the lifespan on nanocellulose as adsorbent. Many factors could contribute to the degradability of nanocellulose such as types of water and the presence of certain microbes that may degrade the cellulose.

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