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COVID-19 Prevention: Role of Activated Carbon

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Highlights:

- Prevention is a successful way to survive and fight against COVID-19
- Activated carbon can adsorb and filter the virus effectively
- AC can be used with a respirator and mask to enhance its performance

Abstract. Recently, Coronavirus Disease 2019 (COVID-19) has brought the whole world into a pandemic condition, where the number of infected cases and deaths is exponentially high. A number of vaccines are available for this novel virus, but these are in the preliminary stage and are also not available to everyone. As the virus is very contagious, protection and prevention are the best way to survive and get rid of this disease. The virus affects the human body by entering through the nose, mouth, and eyes, so face protection with an appropriate mask is highly advisable. Combined masks made with activated carbon (AC) can effectively adsorb the virus because of its high surface area and broad functional groups. Such combined masks can also control coronavirus transmission by capturing harmful gases and smoke as they help in decreasing the spread of the virus.

Keywords: *activated carbon/charcoal; coronavirus, COVID-19; protection/prevention; SARS-CoV-2.*

1 Introduction

The novel Coronavirus Disease 2019 (COVID-19) is an infective pneumonia illness that causes severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This previously unknown disease was first discovered in Wuhan City, Hubei Province, China, in December 2019 [1,2]. From China, the virus spread widely around the whole world within a short period of time. The number of patients increased so fast in different countries that the situation quickly got out of control,

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and the World Health Organization (WHO) declared a pandemic [3,4]. After the first infection on 1 January 2021, a total of 84,491,717 confirmed cases and 18,35,472 deaths had been reported for COVID-19 in the 220 countries of the world [5]. Figure 1 shows the exponential growth of the numbers of confirmed cases and deaths for COVID-19 up to 1 January 2021.

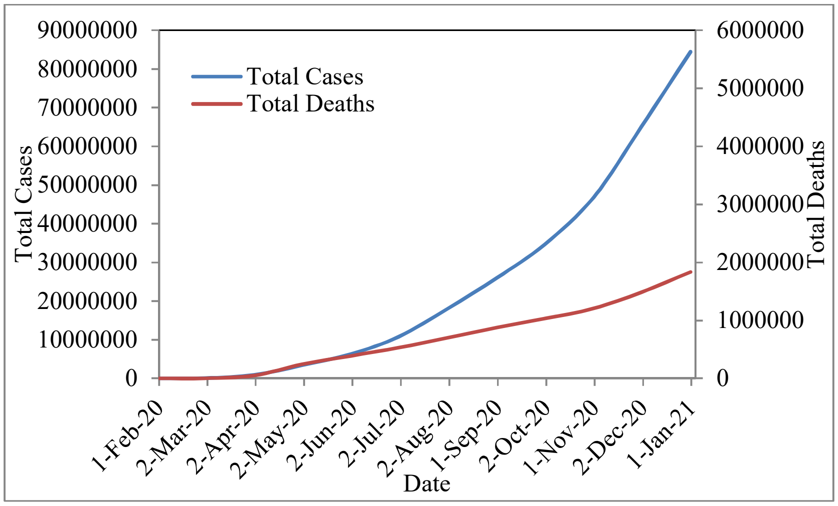

Figure 1 Worldwide status of COVID-19 from 1 January 2020 to 1 January 2021 [5].

SARS-CoV-2 is a novel beta RNA coronavirus (60-140 nm diameter) with spike-like projections forming a crown shape. The virus causes severe symptoms in the human respiratory system such as high fever, breathing problems, lung infection, dry cough, and gastrointestinal problems (diarrhea, vomiting, abdominal pain, etc.) [6]. The virus is mainly spread by coughing and sneezing through droplets of human-to-human conduction through the nose, mouth, and eyes. It can also exist in stool and contaminated water [7].

A number of vaccines have been developed against COVID-19, but these are in the preliminary stage and do not reach everyone. Prevention and protection are the best way to avoid and minimize transmission of the virus. Washing hands with soap and alcohol-based solutions, physical and social distancing, quarantining, and wearing face masks are the recommended remedies for the prevention. Proper indoor ventilation and exposure to sunlight can also destroy this virus [8].

Healthcare workers are at the highest risk of transmission towards patients and themselves because they cannot avoid physical contact with infected persons. As they are the soldiers that fight against this pandemic, they should get proper personal protective equipment (PPE) and airborne infection isolation rooms (AIIR) when on duty. Healthcare staff should wear a PPE gown, facemask, respirator, eye protector, and medical gloves. As the virus can enter the body through the nose, mouth, and eyes, proper facemasks and respirators are the most important for healthcare personnel and infected patients as well as the people in infected areas. Doctors and patients need to wear surgical masks and respirators and apply suitable cough hygiene [9]. In the COVID-19 pandemic situation, the surgical staff is at a huge risk during procedures such as laparoscopic surgery because of the strong relationship between surgical smoke and virus transmission. These surgical procedures generate carcinogen smoke of volatile organic compounds (VOCs), which are highly dangerous for the health of surgeons and operation theatre staff [10]. The generation of harmful smoke and polluted gases is also high in slum areas because of indoor smoking and cooking by burning waste biomass during the lockdown of COVID-19 [11]. In China, it has been reported that the death rate was fourteen times higher for smokers than for nonsmokers among COVID-19 patients [12].

In addition, for the COVID-19, there is a reliable connection between the infection and mortality rates and air pollution associated with smoke, gas, and dust. It has been stated that one of the most significant reasons for confirmed cases and deaths of COVID-19 are higher in the United States of America (USA) because of air pollution [13]. Pollutant gases can damage the cellular and immune system by causing respiratory stimulation, cough, throat irritation, and breathing problems in the human body [14]. It has also been found that the infection and death rates for COVID-19 were higher in Northern Italy because of higher air pollution levels [15]. To protect against COVID-19, people use several types of masks and respirators such as N95, surgical, and cotton cloth masks [16]. Similar to N-95, FFP-2 (Europe), KN-95 (China), P-2 (Australia and New Zealand), Korea 1st class (Korea), and DS-2 (Japan) masks are also used [17]. The performance of these masks is adequate, but some have limitations in protection from harmful gases, toxic vapors, and very tiny pathogens at higher breathing rates [18]. Thus, it is necessary to design a respiratory protector that can more effectively filter and absorb viruses, bacteria, dust, smoke, and toxic gases.

Activated carbon (AC) can be a very valuable solution in the fight against COVID-19, as it can filter and trap pathogens and toxic gases due to its high surface area and a large number of functional groups [19]. Combined masks with activated carbon can remove more poisonous pollutants and pathogens than ordinary or surgical masks. Activated carbon has unique properties that remove VOCs, odors, and other gaseous pollutants from the air. Combined activated-carbon masks are used in hospitals for surgery, filtering smokes, eliminating dust, and removing bacteria from droplets [20].

2 Activated Carbons

Activated carbons (ACs) are carbonaceous materials with a high degree of porosity and a large surface area [21-24]. Typically, they are called activated coal, activated charcoal, activated biochar, or carbo. They have a complex chemical formula and can contain 400-1000 square meters of surface area per gram. The most common uses of ACs are processing gases, air purification, virus and bacteria removal, water purification, reducing tank vent emissions, and odor control [19,25]. Different types of pores (micropores, mesopores, and macropores, as shown in Figure 2) and a large number of functional groups make ACs extremely versatile in purification applications [26].

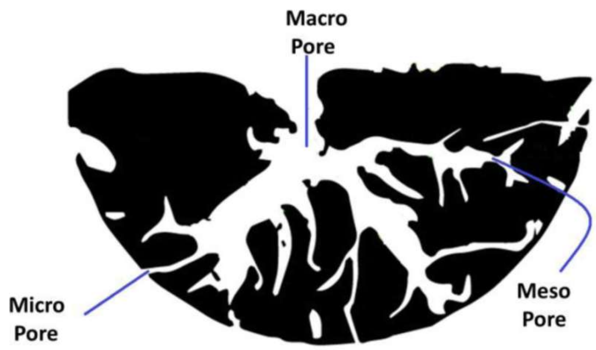

Figure 2 Activated carbon with pores [26].

ACs are generally produced by the pyrolysis of biomass into biochar and activation of that biochar through physical, chemical, and microwave processes [27,28]. Any materials with high carbon and low inorganic content can be used as the raw material for the production of activated carbons. Waste biomass and invasive species are mainly used to produce activated carbons with better adsorption capability and adequate mechanical power [29-31]. The removal efficiency depends mostly on the properties of the activated carbon and the characteristics of the pollutants. Pore size (macro: D > 50 nm, meso: 50 > D > 2 nm, and micro: D < 2 nm), surface area (~3000 sqm/gm), density (400~2100 kg/m^3), hardness (62 to 93.5%) are related to AC properties, and initial concentration, solubility in water, chemical/biological compositions, magnetism tendency toward the carbon surface involved with contaminated characteristics [2,32-35]. ACs are cheap, readily available, and environment-friendly adsorbents for specific purification applications [36].

3 Virus Removal by Activated Carbon

Various studies have used powdered activated carbon (PAC) and granular activated carbon (GAC) to effectively remove viruses. Considering all the facts related to the development of virus removal by AC, Table 1 provides an overview of the various conventional viruses associated with their host, activated carbon, and logarithmic reduction.

Table 1 Virus removal by activated carbons.

Activated Carbon	AC Pores	Host	Virus	Logarithmic Reduction	Ref.
Super-powdered activated carbon (S-PAC) of wood 1	20-50 nm	*Escherichia coli* F^+	Qβ (NBRC 20012)	4.1 log (contact time 8 hours, Ca^{2+} = 100 μM)	[33]
Super-powdered activated carbon (S-PAC) of wood 1	20-50 nm	*Escherichia coli* F^+	MS2 (NBRC 20015)	3.0 log (contact time 8 hours, Ca^{2+} = 100 μM)	[33]
Granular activated carbon (GAC) from palm coconut (GAC/Ag0.5%Cu1.0 %)	1.19 nm	*Escherichia coli*	Bacteriophage T4	>4 log (>1 mg mL^{-1} sample, 2 hours equilibrium time)	[39]
Biological activated carbon (BAC)	-	*Escherichia coli* K12A/ λ (*F^+*)	Pepper mild mottle virus (PMMoV)	3.80 ± 0.77 log_{10} for Plant A	[40]
Granular activated carbon (oil palm shells) with silver and copper oxide (GAC/Ag0.5%Cu1.0 %)	1.19 nm	*Escherichia coli*	Bacteriophage T4	>5 log	[37]
Granular activated carbon (GAC)	-	*Escherichia coli*	Bacteriophage MS2	~3 log[41]	[41]
Hybrid granular activated carbon (GAC)	-	*Escherichia coli* (*E. coli*)	-	4.6–5.1 log	[42]
Hybrid granular activated carbon (GAC)	-	Spores of *Clostridium perfringens* (SCP)	-	0.1–0.6 log	[42]
Hybrid granular activated carbon (GAC)	-	Somatic coliphages (SOMCPH)	-	3.2–3.3 log	[42]

The removal of pathogenic microorganisms is measured by a log reduction value, where a value of 1 log, 2 log, 3 log, 4 log, 5 log, and 6 log is equivalent to the removal of 90%, 99%, 99.9%, 99.99%, 99.999%, and 99.9999%, respectively [37]. Based on the literature, the efficient and rapid inactivation of virus (Bacteriophage T4) by GAC from oil palm shells with silver and copper oxide (GAC/Ag0.5%/Cu1.0%) achieved the highest reduction efficiency (>5 log) as reported by Shimabuku *et al*. [38]. Commercial super-powdered activated carbon (S-PAC) reduced the Escherichia virus Qbeta (Qβ) at 4.1 log, as reported by Matsushita *et al.* [33].

Masks equipped with activated carbon/charcoal can trap viruses by adsorbing moisture. Once a virus is caught, highly electropositive ions can disrupt the integrity of their membrane and vital proteins, degrading their cell capability. Masks with activated carbon may be a significant milestone in the control of the spread of COVID-19 [43]. Figure 3 shows the general arrangement of a mask with activated carbon to remove viruses, bacteria, and dust.

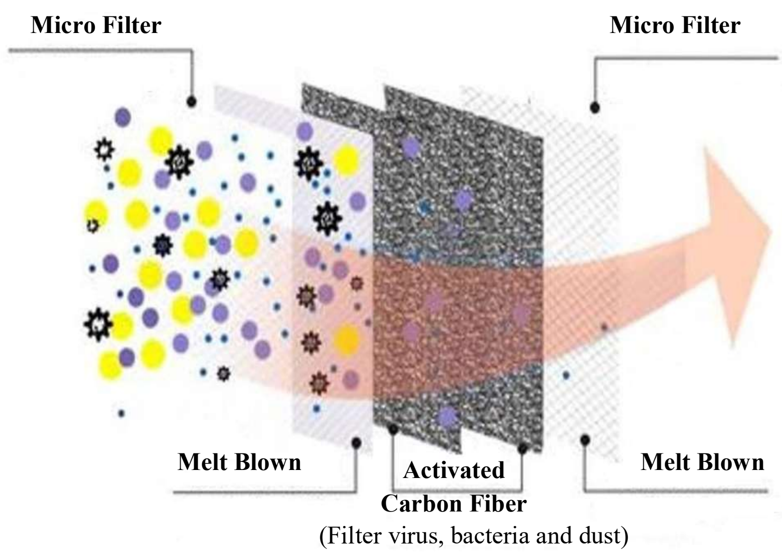

Figure 3 Typical activated carbon mask [44].

The removal of a virus through activated carbon depends on the hydrophobicity of the virus, the electrophoretic repulsive force, the pore size distribution, and the surface charge of the activated carbon. If the hydrophobicity of the virus surface is higher, the removal rate will be higher. A lower electrophoretic repulsive force between the AC and the virus can contribute to higher virus elimination. A large volume of AC with 20-50 nm pores can eliminate viruses effectively. AC can enhance virus removal efficiency with fewer negative charges on its surface [33]. SARS-CoV-2 has a spike protein with a hydrophobic character, so AC can be an efficient adsorbent for this virus [45].

Activated carbon leads to the best configuration and optimization for removing viruses and pathogens through a membrane filtering process [46]. The activated carbon can adsorb viruses and bacteria from polluted deposits due to the electrostatic attraction forces between the pathogens (viruses and bacteria) and the carbon structure. Adsorption occurs between the functional groups (carboxyl groups and amino groups) of the AC and the tails of the viruses. In this way, the virus can be removed from the environment through effective and cheap materials [19]. SARS-CoV-2 can create bondage with carbon atoms by hydrogen bonds at the first level, π-π interactions at the second level, and Van der Waals connections at the third level [47]. In the inhibition of SARS-CoV-2 by hydroxychloroquine, activated carbons play a significant role in eliminating pigments, tannins, and fatty acids [48].

Respirators and masks with activated carbon can filter out more than 95% of particles and reduce the odor nuisance level by removing toluene and benzene [49]. Activated charcoal filters can clean the environment of the operation theatre by adsorbing surgical smoke, harmful gases, and volatile organic compounds during smoke-generating surgical procedures. It can reduce the adverse effects of volatile organic compounds and coronavirus transmission [10]. Activated carbons filter toxic gases, vapor, and smoke due to the free carbon atoms in their amorphous structure, which can easily connect with pollutants [20].

Activated carbon air filter masks are very useful for filtering gases through a bed of activated carbon. They are used to combat volatile organics, bad smells, and fumes through the process of adsorption. Therefore, all healthcare workers can use activated carbon masks to avoid chemical inhalation [50]. To protect from COVID-19, proper ventilation and pure air are highly necessary [51]. The air quality inside the hospital and indoors should be suitable for patients and healthcare personal by reducing air pollution through proper filtration processes. Activated carbon combined masks can filter the air of hospitals and indoor spaces by removing contaminants in a better way [52].

Some companies claim that activated carbon combined masks can filter up to 95% to 99% of particles from the air when fitted tightly. These masks should comply with the requirements and standards of the Centers for Disease Control and Prevention (CDC), USA [53]. Activated carbon filters have some limitations in regeneration, resistance, and mineral processing. AC filters should be changed on time after being filled up by trapping pollutants [52].

There is no direct relationship between the source of COVID-19 and the activated carbon. Also, nobody has been infected with COVID-19 when handling products of activated carbons [54]. However, further investigation is needed before recommending people to use these AC masks, and care should be taken during the reuse of activated carbon filters according to handling rules and standards [55].

4 Conclusion

The whole world is facing an emergency situation because of the COVID-19 pandemic. The disease has a high negative impact on the human body and environment. Since there is no medicine for this disease and prevention is the only solution, proper health protection is highly necessary. Activated carbon can be a very valuable solution to protect the human body from COVID-19, as it has the ability to capture and eliminate viruses. Combined masks with activated carbon can filter and remove viruses, bacteria, dust, smoke, and toxic gases effectively. These masks can also protect healthcare personal by capturing surgical smoke. Activated carbon filters can minimize the transmission of SARS-CoV-2 by capturing smoke and toxic gases, which enhance the transmission of viruses. No one has ever been infected by COVID-19 while using or handling activated carbon products. Investigations and improvements are required to check the performance of activated carbon in COVID-19 prevention.

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