The removal of total suspended particulates (TSP) using chitosan/PVA electrospun fibers

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Abstract. Total suspended particle (TSP) is the measurement of the amount of suspended particle with a diameter less than 100 micrometers. The exposure of particulate matter can be significant for human health and environment. It can cause respiratory and cardiovascular effects, reduce visibility, and reduce water quality. Electrospun fibers is a versatile technology that can produce large surface area, controllable fiber diameter and interconnected pore structure. In this study, the effectiveness of chitosan-polyvinyl alcohol (CS-PVA) fibers incorporated with activated carbon (AC) for capturing TSP in the air was investigated. The CS-PVA fibers was prepared by combining CS and PVA solutions at ratio of 30:70 with various AC concentrations ranging from 0-3 wt.%. The CS-PVA fibers prepared were fitted in the low-volume air samplers (LVAS) and placed nearby the main road of UMK Campus Jeli, for the collection of $PM_{2.5}$ and PM_{10}. Additionally, the weathering data during the sampling days was requested from My MET website to observe the influence of weather on TSP collection. Based on the results, as the AC concentration increased in the CS-PVA fibers, the concentration of PM_{10} and $PM_{2.5}$ also increased. The CS-PVA-3 showed the highest collection of PM_{10} and $PM_{2.5}$ compared to other CS-PVA fibers and standard quartz filter. However, the collection of TSP on the filter paper were also influence by the humidity, rainfall, and wind speed of the sampling day.

1 Introduction

Total suspended particles (TSP) are referring to solid and liquid particles of different sizes that are suspended in the air including PM_{10} and $PM_{2.5}$. However, $PM_{2.5}$ poses the greatest fear to public health [1] as these particles can easily enter people's lungs and some even penetrate the bronchi. As a result, it increases the probability of breathing-related illness, cardiovascular diseases, and lung cancer. Therefore, the removing of air particulate matter is considered as necessary for human health protection.

Nowadays, the electrospinning method has become popular due to its versatility in producing nanofibrous membranes with diameter in the nanoscale. These fibers are used in many applications due to their excellent features such as interconnected pore structure, remarkable surface area to volume ratio, controllable fibers diameter, and high porosity [2,

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3]. Recently, there are a few studies conducted on electrospun fibers using this method for air filtration using various types of polymers with some showing a great capability for $PM_{2.5}$ removal [4-8]. They have successfully produced ultrathin diameter fibers with adjustable porosity and interconnected pores. However, to our knowledge, there are no studies of electrospun fibers using natural polymers such as chitosan (CS) incorporated with polyvinylalcohol (PVA) and activated carbon (AC) for TSP removal. This is because CS is difficult to electrospun due to its high crystallinity and difficulty to solubilize in aqueous and organic media [9]. Yet, CS is the second most abundant natural biopolymer with good properties such as biocompatibility, biodegradability, antimicrobial activity, and non-toxicity [10]. Therefore, CS needs to be blended with other polymers and PVA was chosen for this study due to its strong interaction with CS, which can easily produce fibers in an aqueous medium [11]. In addition, to make a high functionality of electrospun fibers, (AC) will be added to increase the absorption of particulate matter and enhance the mechanical structure of bio-polymer.

Although AC is a well-known adsorbate, little is known about the suitability of AC on electrospun fibers for the removal efficiency of TSP. From a previous study [12], the combination of CS and PVA at a ratio of 30:70 can be electrospun. Therefore, this study will modify the CS-PVA (30:70) ratio by adding various AC content to investigate its functionality in absorbing PM_{10} and $PM_{2.5}$. The discovery knowledge from this research will facilitate the design and fabrication of new potential environmentally friendly air filters with high performance and good biocompatibility in reducing the effect of TSP.

2 Methodology

2.1 The preparation of CS-PVA solutions

The composition of polymer solutions was prepared as tabulated in Table 1. First, the PVA and CS solution was prepared according to the method described by Ohkawa et al. [12] where 9 wt.% of PVA was dissolved in distilled water and 7 wt.% of CS was dissolved in formic acid.

Table 1. The composition of chitosan, PVA and activated carbon in the solution.

Polymer solution	Chitosan (wt.%)	PVA (wt.%)	AC (wt.%)
CS-PVA-0	30	70	0
CS-PVA-1	30	70	1
CS-PVA-2	30	70	2
CS-PVA-3	30	70	3

These two solutions were mixed using magnetic stirrer and heated at 80 °C until both solutions become homogenous. Then, the solutions were left overnight at room temperature. Next, the chitosan and PVA solutions were mixed based on ratio of 30:70 respectively. To make a CS-PVA solutions at different AC content, the CS-PVA solution was combined with AC at 0, 1, 2, and 3 wt.%. The mixture was stirred until it was homogeneous. Then, the solutions were put into an ultrasonic bath for an hour to get rid of any air bubbles before proceed with electrospinning process.

2.2 The preparation of CS-PVA electrospun fibers

The CS-PVA electrospun fibers with and without AC were produced using electrospinning equipment which consist of high voltage supplier (BT-GP Series, UltraVolt Inc.), single syringe pump (KDS 100, KD Scientific Inc.) and metal collector. CS-PVA solutions prepared in section 2.1 was put into a syringe with a 26 G needle tip. Flow rate and voltage were set at of 1 mL/h and 21 kV respectively. The distance between the needle tip and the metal collector is maintained at 15 cm. The CS-PVA solution was electrospun for 10 hours to form fibers mat on the aluminum collector. Later, it was allowed to dry for one day before baked in an oven at 105 °C for 5 hours to eliminate organic pollutants contained in the fibres. The CS-PVA fibres were kept in a desiccator to absorb moisture before further used.

2.3 Collection and data analysis of total suspended particles (TSP)

In this study, the potential of CS-PVA fibers in capturing TSP were determined and the result was compared with the original quartz filter. For this purpose, a Low Volume Air Sampler (LVAS) (SIBATA model LV-20P) was used to gather PM_{10} and $PM_{2.5}$ samples from the air. The intake surface of PM_{10} and $PM_{2.5}$ was cleaned and lubricated with high vacuum grease to ensure the smooth operation of the TSP filtering process.

In order to test the performance of CS-PVA fibers, the CS-PVA fibres were cut to fit in the LVAS. Prior to TSP collection, the CS-PVA fibres were weighted to determine their initial weight. Then, the CS-PVA fibers was fitted in the LVAS and installed in front of the main road entrance of the Universiti Malaysia Kelantan, Jeli campus. All TSP samples were collected for 3 days each where the filter was changed new every 24 hours. After the TSP collection, all the filters were weighted to get the final weight. Finally, the average concentration of PM_{10} and $PM_{2.5}$ was calculated using Equation 1.

$$C = m/(Q \times T) \quad (1)$$

Where;

C = the particulate concentration in ambient air (m/v)
m = net mass of particle collected in the sampler filter
Q = the flow rate of ambient air pump to the sampler (v/t)
T = the total duration of particle collection

3 Result and discussion

3.1 The concentration of PM_{10} on CS-PVA fibers

The potential of all CS-PVA fibers for the collection of PM_{10} using LVAS was examined, and the results are shown in Figure 1. In the present study, the collection of PM_{10} was collected for three days where each day new CS-PVA fibers was used. In addition, the weather data including wind speed, relative humidity, temperature, and rainfall for the three days of sampling was obtained from the My Met Data in order to observe the weather's influence on the TSP concentration obtained in that day.

Based on Figure 1, the average PM_{10} concentrations collected on CS-PVA-0, CS-PVA-1, CS-PVA 2, CS-PVA-3 and Quartz filter were 9.83 x 10^{-4}, 1.05 x 10^{-3}, 1.12 x 10^{-3}, 1.38 x 10^{-3} and 9.83 x 10^{-3} g/L respectively. The result shows that CS-PVA fibers without activated carbon (CS-PVA-0) obtained similar PM_{10} concentration with the original filter used in LVAS. As the content of AC increased in the CS-PVA fibers, the concentration of PM_{10} increased. The results revealed that CS-PVA-3 has the highest PM_{10} concentrations. AC is known as a superior adsorbent and has been used as a catalyst because of its large number of micropores and high surface area. It has been widely applied for gas purification and separation, deodorization, and water purification [13]. Activated Carbon Filters (ACFs) prepared by Mochida et al. [14] showed higher adsorption of SOx and NOx. Therefore, the addition of activated carbon has a tendency to increase the accumulation of PM_{10}.

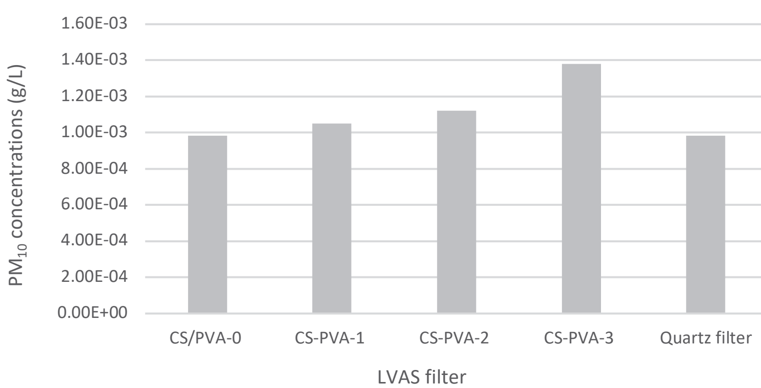

Fig. 1 The concentration of PM_{10} vs LVAS filters.

The weathering data can also influence the concentration of particulate matter on the filter. Previous study indicated that the variability of PM_{10} levels can be influenced by wind speed, temperature, rainfall, and humidity [15]. Study by Pushpawela et al. [16], showed that transport and dispersion of pollutants in the air are strongly influenced by wind speed and direction. Even though the area was not close to the air pollutant sources, but wind direction and speed can cause the pollutants to spread and thus causing higher concentrations of pollutants in that area.

Based on the meteorological data obtained during the sampling days of CS-PVA-3 (Table 2), the average humidity, (77.6%) and rainfall (2.2 mm) was among the lowest during the sampling days. Study by Styszko et al. [17] (2018), stated that a high concentration of TSP might be associated with low air humidity and little rain. Thus, contribute to the higher concentration of PM_{10} with CS-PVA-3. However, when sampling with CS-PVA-1, the rainfall data was lower and the wind speed was higher than the day sampling with CS-PVA-

3. But the PM_{10} concentration was little compared with CS-PVA-3 which received higher rainfall and wind speed. The CS-PVA-2 also attained a higher PM_{10} concentration than CS-PVA-1 despite having higher rainfall and humidity during the sampling day. This showed that, the AC content in the CS-PVA fibers could have some effects on the collection of particulate matter.

Although all CS-PVA fibers showed higher PM_{10} concentration than quartz filter, it is difficult to assume that they are better than quartz filter. This is because, the meteorological data obtained when sampling with quartz filter showed the highest wind speed, humidity and rainfall which may lead to a decrease in the concentration of PM_{10}.

Table 2. Weather data for the collection of PM_{10} for different filters.

Types of Filters	Wind Speed (m/s)	Relative Humidity (%)	Temperature (°C)	Rainfall (mm)
CS-PVA-0	0.6	85.9	26.0	16.2
CS-PVA-1	0.6	91.8	24.0	1.8
CS-PVA-2	0.5	92.9	24.0	4.0
CS-PVA-3	0.7	77.6	26.0	2.2
Quartz filter	0.9	90.2	24.8	28.4

3.2 The concentration of $PM_{2.5}$ on CS-PVA fibers

The potential of CS-PVA fibers for the collection of $PM_{2.5}$ was also observed and the results were displayed in Figure 2. The average $PM_{2.5}$ concentration for CS-PVA-0, CS-PVA-1, CS-PVA-2, CS-PVA-3 and quartz filter was 8.49×10^{-4}, 8.83×10^{-4}, 1.03×10^{-3}, 1.12×10^{-3} and 8.16×10^{-4} g/L respectively.

Similar to the PM_{10} collection, the concentration of $PM_{2.5}$ increased with the increasing concentration of AC in the fibers. Although the rainfall on the sampling day of CS-PVA-3 was 12 times higher than the sampling day of CS-PVA-1 (Table 3), the concentration of $PM_{2.5}$ was higher (1.12×10^{-3}). Besides, the weathering data for CS-PVA-2 which showed higher rainfall, humidity, and wind speed (Table 3) also show higher $PM_{2.5}$ collection than CS-PVA-1. Thus, proof that the content of AC in CS-PVA fibers plays a significant role in capturing particulate matter in the air. Moreover, CS-PVA-1 obtained a higher collection of $PM_{2.5}$ than quartz filter despite receiving the highest average rainfall and humidity with the lowest wind speed on the collection day. This result indicates that the CS-PVA fibers produced are capable of capturing particulate matter in the air.

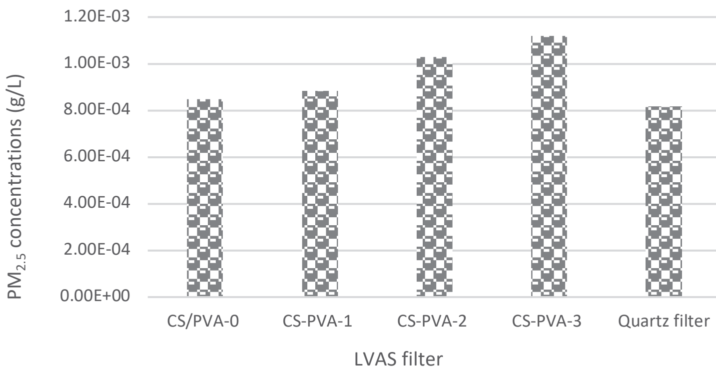

Fig. 2: The concentration of $PM_{2.5}$ vs LVAS filters.

Table 3. Weather data for the collection of $PM_{2.5}$ for different filters.

Types of Filters	**Wind Speed (m/s)**	**Relative Humidity (%)**	**Temperature (°C)**	**Rainfall (mm)**
CS-PVA-0	0.4	91.7	24.1	72.4
CS-PVA-1	0.6	89.8	24.6	3.5
CS-PVA-2	0.7	92.9	23.9	9.9
CS-PVA-3	0.5	88.7	24.6	40.5
Quartz filter	0.6	91.8	24.0	67.5

4 Conclusion

In this study, various types of CS-PVA fibers incorporated with AC were prepared and tested for TSP collection. The results revealed that the CS-PVA fibers have potential and are capable in capturing PM_{10} and $PM_{2.5}$. All collection of PM_{10} and $PM_{2.5}$ obtained with LVAS for CS-PVA fibers were higher than the original filter used in LVAS. Besides, the incorporation of AC into the CS-PVA fibers also improved the TSP collections. As the AC content increased in CS-PVA fibers, the concentration of PM_{10} and $PM_{2.5}$ increased. Overall, CS-PVA-3 obtained the highest TSP collections. The average concentrations of PM_{10} and $PM_{2.5}$ using CS-PVA-3 for three days were 1.38 x 10^{-3} and 1.12 x 10^{-3} g/L respectively. Meanwhile, the collection of PM_{10} and $PM_{2.5}$ using the quartz filter were only 0.98 x 10^{-3} and 0.81 x 10^{-3} g/L respectively.

Results also indicate that weather factors such as humidity, wind speed and rainfall can influence the concentration of particulate matter in the air and thus reduce the collection of TSP on the LVAS filters. However, in our study although the average rainfall was higher and the average wind speed was lower when sampling with CS-PVA-1 but, the concentration of $PM_{2.5}$ was higher compared to quartz filter where the weather condition received less rainfall and higher wind speed suggesting that CS-PVA fibers is a promising candidate for entrapping TSP in the air. For further studies, the collection of TSP for both CS-PVA fibers and quartz filter should be carried out at the same time to avoid any error and ensure precise judgement. Besides, the sampling of TSP should be designed free from weather factors in the future so that all the filter fibers are exposed to the similar concentration of PM_{10} and $PM_{2.5}$ in order to avoid the influences of weather factors during sampling collection.

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