

# Investigating the potential of chitosan, polyvinyl alcohol and activated carbon combinations for antibacterial electrospun fibers

Zulkarnain Ghazali<sup>1</sup>, Nor Shahirul Umirah Idris<sup>1,2</sup>, Nur Hanisah Abdul Malek<sup>3</sup>, Suganthi Appalasamy<sup>1</sup> and Nurul Syazana Abdul-Halim<sup>1,2\*</sup>

<sup>1</sup>Faculty of Earth Science, Universiti Malaysia Kelantan, 17000 Jeli, Malaysia

<sup>2</sup>Tropical Climate Resilience Research Group, Faculty of Earth Science, Universiti Malaysia Kelantan, Jeli Campus, 17600, Jeli, Kelantan, Malaysia

<sup>3</sup>Mathematical Sciences Studies, College of Computing, Informatics and Mathematics, Universiti Teknologi MARA Terengganu, 23200 Dungun, Terengganu, Malaysia

**Abstract.** Electrospun fibers have attracted a lot of attention in industries due to their exceptional properties and diverse applications. Chitosan (CS) is a promising polymer for electrospun fibers because it is a natural polymer that can easily biodegraded and has antibacterial compound. Whereas, activated carbon (AC) has been demonstrated as a powerful adsorbent. Thus, this study investigated the optimal concentration of polymer solutions made from combination of CS, polyvinyl alcohol (PVA) and AC for antibacterial electrospun fibers. The results show that all polymer solutions with CS and PVA combination have antibacterial properties for *E. coli* and *S. aureus* bacteria but showed stronger bactericidal effects with *E. coli*. Results also revealed that polymer solution with AC have higher inhibition zone compared to polymer solution without AC for both bacteria strains. It can be concluded that the additional of AC into the polymer solution has improved the antibacterial efficiency of CS-PVA solution.

## 1 Introduction

*Staphylococcus aureus* (*S. aureus*) and *Escherichia coli* (*E. coli*) are two infectious bacteria that can be found in water and air under certain conditions which are harmful to human. These microorganisms can cause renal failure, diarrhoea, fever, headache and can be fatal [1, 2]. *S. aureus* has an ability to survive and colonize in water and wastewater, air, animals, and humans. Meanwhile, the presence of *E. coli* is particularly concerning as it may indicate the presence of other pathogenic microorganism such as *Shigella*, *Cryptosporidium*

---

\* Corresponding author: [syazana@umk.edu.my](mailto:syazana@umk.edu.my)

and *Giardia*. Thus, the development of new technology for treating microbes in our environment is necessary. Recently, electrospun fibers fabricated using electrospinning method has gain more attention [3]. This method has successfully obtained nanofibers with high surface area and high porosity using various type of polymer based. Besides, the diameter of the electrospun fibers can be adjustable by varying parameters such as applied voltage, flow rate, distance between metal collector and needle tips, polymer concentration and its viscosity [3].

Chitosan (CS) is a natural polysaccharide and a non-acetylated derivative of chitin [4]. Since chitosan is a natural polymer, it is non-toxic and biocompatible. It is also known to have good antibacterial activity [5]. However, electrospinning CS alone shows a poor mechanical property and thus need to be blended with other polymer such as polyvinyl alcohol (PVA) which strongly interacts with CS through hydrogen bonding on a polymer molecular level. According to Zheng et al. [6] combination of CS and PVA can easily produce electrospun fibers from an aqueous medium. Besides, PVA is also biodegradable, biocompatible and water soluble. However, PVA is lack of antimicrobial activity. Therefore, by introducing a functionalize materials such as activated carbon can enhance the adsorption capabilities of CS-PVA electrospun fibers. Besides, activated carbon has been used to treat water system containing *E. coli* and *P. aeruginosa* due to interesting antimicrobial properties [7].

In our previous research we incorporated CS-PVA electrospun fibers with activated carbon and the results shows potential in capturing total suspended particulate from air [8]. However, the potential of this electrospun fibers as an antimicrobial agent has not been explored. Therefore, this research aims to determine the antimicrobial activity of CS-PVA electrospun fibers incorporated with activated carbon against *S. aureus* and *E. coli* for potential uses in air filter. The characterization of CS-PVA electrospun fibers with activated carbon was also observed using scanning electron microscopy (SEM) and Fourier Transform Infrared analysis (FTIR).

## **2 Material and methods**

Chitosan (CS, low molecular weight from Sigma Aldrich), polyvinyl alcohol (PVA from R&M), activated carbon were used as received. Throughout the experiments, deionized water (DI) water was used.

### **2.1 The fabrication of electrospun fibers**

The CS/PVA suspension was first prepared according to Abdul-Halim et al. [8]. Then, in three separate beakers, the solution was mixed with 5, 10 and 15 wt.% of activated carbon respectively. Each of the solutions were placed inside the syringe and electrospun with electrospinning voltage of 20 kV. The flow rate of solution was ejected from 26 G needle tips at 2.0 mL/min. The gap between needle tips and metal collector was set at 15 cm. After 10 hours, the fibers were collected from metal collector kept dry for further used.

### **2.2 The characterization of electrospun fibers**

The morphological of electrospun fibers were examined using Scanning Electron Microscopy (Shimadzu Corporation) at 10 kV. All the samples were sputtered with gold

prior to examination. Meanwhile, the basic chemical compounds of the electrospun fibers were analysed over a wavelength range of 500 to 4000  $\text{cm}^{-1}$  using Fourier Transform Infrared Analysis (FTIR) (Shimadzu Corporation).

### 2.3 Antimicrobial properties test

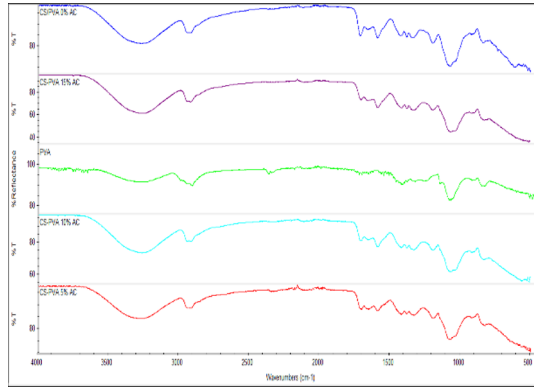
*S. aureus* and *E. coli* as a gram positive and gram-negative bacterium respectively were chosen for antimicrobial properties study. In two different agar plates, these bacterial strains were evenly distributed by swabbing it across the agar plate. Six sterile filter papers with 0.6 cm diameter each were treated with the 100  $\mu\text{l}$  of CS/ PVA-0, CS/PVA-5, CS/PVA-10, CS/PVA-15, PVC100 and PVA100 respectively. The PVC100 and PVA100 were used as a negative control groups. All treated filter papers were carefully placed onto the agar plates and incubated for 24 hours at 37  $^{\circ}\text{C}$ . After the incubation period, the agar plates were examined and the diameter of inhibitory zones surrounding the filter paper were measured. This procedure was repeated three times for each bacterial strains and the results were statistically analysed.

## 3 Results and discussion

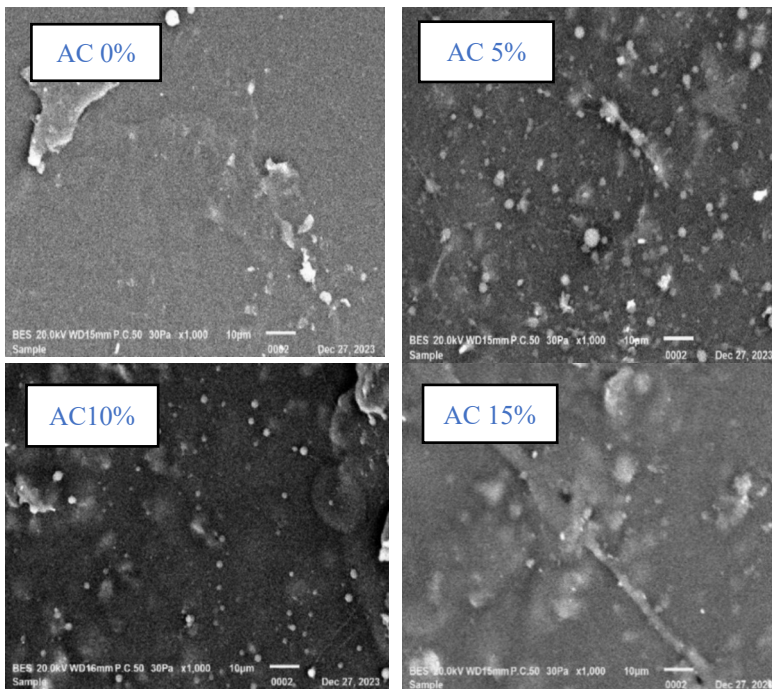
### 3.1 Characterization analysis

The result of FTIR spectra in Figure 1 shows an insight of plain CS-PVA and CS-PVA with activated carbon at various concentrations. Overall, all the CS-PVA result shows similar absorption bands at 3269, 2913, 1651, 1350 and 1099  $\text{cm}^{-1}$ . The characteristics band observed within 3200  $\text{cm}^{-1}$  to 3600  $\text{cm}^{-1}$  is related to stretching vibration of O-H in PVA [9]. The vibration at 1651  $\text{cm}^{-1}$  attributed to the C=O stretching bond correspond to remaining acetate group in PVA [10]. The peak at 1099  $\text{cm}^{-1}$  is correspond to the stretching vibration of CO group in CS-PVA [11] while 2913  $\text{cm}^{-1}$  peak is assigned to the stretching motions of C-H alkyl in the mixture of CS-PVA [12]. The peak at 1350  $\text{cm}^{-1}$  is belong to weakest amino structure in CS which accordance to [13] CS shows strong band at 1450-1350  $\text{cm}^{-1}$ .

Meanwhile, the morphologies image of various CS-PVA electrospun fibers at 1000x magnifications are shown in Figure 2. CS-PVA without activated carbon has smoother surface, uniform structure with less bead's formations. When 5% of activated carbon content was added, the formation of beads was observed. But at higher activated content, the beads size started to shrink and decrease.



**Fig. 1.** The FTIR spectra of CS-PVA electrospun fibers at various activated carbon content.



**Fig. 2.** The morphologies image of electrospun fibers at 1000x magnifications.

### 3.2 Antibacterial properties

Table 1 shows the measurement of inhibition zones for *S. aureus* and *E. coli* on the tested filter paper treated with CS-PVA, polyvinyl chloride (PVC100) and PVA100 solutions. Result show there are no inhibition zones observed for filter paper treated with PVC100 and PVA100 solutions which were used as negative control. The study revealed that all filter paper treated with CS/PVA with activated carbon solutions at different concentrations exhibited antibacterial properties for both bacteria strains. However, CS/PVA (without activated carbon) only effective in prohibiting *E. coli* but does not show any antibacterial

effect against *S. aureus*. Result shows that the additional of activated carbon, has increased the antibacterial efficacy. For *S. aureus* the CS-PVA 5 shows the highest inhibition zone whereas CS-PVA 10 shows highest inhibition zones for *E. coli*. Overall, the study indicates that *E. coli* has better bactericidal effects compared to *S. aureus*. This probably because *E. coli* has a thinner membrane wall which make it more susceptible than *S. aureus* [14].

The Kruskal-Wallis test was run to determine whether there were statistically significant difference between CS/PVA at various activated carbon content to antibacterial efficacy. Result is insignificant if the *P*-value is above 0.05. Based on the *P* values tabulated in Table 2, the varying concentration of activated carbon in CS/PVA solution has no significant effect on the antibacterial properties for both bacteria strains since the significance value exceeded 0.05.

**Table 1.** The inhibition zones for *S. aureus* and *E. coli* at different CS/PVA content.

Sample	Inhibition zone (mm)	
	<i>S. aureus</i>	<i>E. coli</i>
CS/PVA	0±0	3.67±1.0
CS/PVA-5	2.83±4.91	5.17±3.02
CS/PVA-10	1.83±3.18	5.58±2.75
CS/PVA-15	2.43±4.31	3.17±1.0
PVC100	0±0	0±0
PVA100	0±0	0±0

**Table 2.** The *P*-values obtained from Kruskal-Wallis test for CS-PVA at various activated carbon.

Bacteria	Significant, <i>P</i>
<i>S.aureus</i>	0.734
<i>E.coli</i>	0.453

## 4 Conclusion

Activated carbon was incorporated to CS-PVA electrospun fibers to enhance its absorption functionality and antimicrobial properties against *S. aureus* and *E. coli*. The FTIR results of the CS-PVA electrospun fibers have confirmed the existence of various functional groups that is related to the CS and PVA compound. Meanwhile, the SEM images showed that the cooperation of 5% activated carbon has increased the surface roughness and formation of beads on CS-PVA electrospun fibers surfaces. However, additional of higher activated carbon content (15%) has decreased the formation of beads.

The antibacterial properties was assessed by observing the inhibition zones around filter paper treated with CS-PVA/AC solutions and exposed with *S. aureus* and *E. coli*. It was revealed that the CS-PVA electrospun fibers has bactericidal effects with *E. coli* but not with *S. aureus*. Only CS-PVA with activated carbon (CS-PVA/AC) showed bactericidal effects for both bacteria strains. Thus, our future study will be tested the actual CS-PVA electrospun fibers against *S. aureus* and *E. coli* in actual water or air sample.

The authors would like to acknowledge the financial assistance from the Universiti Malaysia Kelantan (UMK-FUND: R/FUND//A0800/00453A/002/2022/01035) and technical support from laboratory assistance Faculty of Earth Science.

## References

1. R. E. Besser, S. M. Lett, J. T. Weber, M. P. Doyle, T. J. Barrett, J. G. Wells, P. M. Griffin, *J. Am. Med. Assoc.*, 269, 2217-2220 (1993)
2. T. K. Chang, T. M. Cheng, H. L. Chu, S. H. Tan, J. C. Kuo, P. H. Hsu, C. Y. Su, H. M. Chen, C. M. Lee, T. R. Kuo, *ACS Sustain. Chem. Eng.*, 7, 15479-15486 (2019)
3. H. Ziyadi, M. Baghali, M. Bagherianfar, F. Mehrali, R. Faridi-Majidi, *Adv. Compos. Hybrid Mater.*, 4, 768-779 (2021)
4. C. H. Jou, *Colloids Surf. B. Biointerfaces*, 88(1), 448-454 (2011)
5. S. Liang, L. Liu, Q. Huang, K. L. Yam, *Carbohydr. Polym.*, 77(4), 718-724 (2009)
6. H. Zheng, Y. Du, J. Yu, R. Huang, L. Zhang, *J. Appl. Polym. Sci.* 80, 2558 (2001)
7. S. L. Percival, L. Suleman, *World J Gastrointest Pathophysiol*, 5, 122–132 (2014)
8. N. S. Abdul-Halim, N. S. U. Idris, N. Shamsudin, N. K. Dzaifuzzaman, N. F. A. Mohamad-Fouzi, *BIO Web of Conferences* 73, 05006 (2023)
9. T. H. N. Vu, S. N. Morozkina, M. V. Uspenskaya, *Polymers* 14(4), 811 (2022).
10. Y. Cheng, B. R. Far, M. Jahanbakhshi, S. Bahrami, P. Tamimi, M. Sedaghat, E. Ghazizadeha, *RSC Adv* 13, 18450-18460 (2023)
11. M.W. Sabaa, H. M. Abdallah, N/ A. Mohamed, R. R. Mohamed, *Mater. Sci. Eng. C* 56, 363-373 (2015)
12. X. Jiao, Y. Gutha, W. Zhang, *Colloids Surf. B Biointerfaces* 149, 184-195 (2017)
13. P/ I. Campa-Siqueiros, T. J. Madera-Santana, J. F. Ayala-Zavala, J. Lopez-Cervantes, M. M. Castillo-Ortega, P. J. Herrera-Franco, P. Quintana-Owen, *Polym. Bull.* 80 (4), 3611-3632 (2023)
14. R. C. Goy, S. T. B. Morais, O. B. G. Assis, *Brazilian Journal of Pharmacognosy*, 26(1), 122-127 (2016)