Antimicrobial hollow fiber polypropylene/ZnO membrane for effective air filtration

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Abstract. Air pollution has become an environmental problem since it poses a serious effect on human health. In addition, circulation of air containing airborne particles including pathogens in an enclosed building like a hospital may lead to more severe health effects. Therefore, an air purifier is needed to prevent the spreading of those particles through air circulation. To address the issue, an antimicrobial membrane was prepared by embedding ZnO nanoparticles onto hollow fiber polypropylene (PP) membrane. Results showed that the prepared PP/ZnO membrane had a high air filtration performance as well as antibacterial properties. The membrane also showed a high filtration capacity or permeability with a relatively low-pressure drop. With those interesting features, the newly developed PP/ZnO membrane can be applied in air filtration, in particular for indoor spaces and other medical applications.

Keywords: air filter, air pollution, clean air, fine particles, membrane

1. Introduction
Worsening air quality has become one of the environmental problems due to their adverse effects on human health. This is associated with various activities, such as industry, transportation, forest fire, and fuel usage [1]. Airborne particles such as fine particles and bio-aerosols are among the important pollutants which gain increasing attention due to their negative impacts on human health. Since they have a small size, those pollutants may from one place to another easily and can be suspended in the atmosphere for a long time due to its stability [2–4].

Those airborne particles can be removed for producing clean air by employing technologies, such as electrostatic precipitation, cold plasma, wet scrubbing, cyclonic air filtration, and filters [5–7]. Among the technologies, filtration is the most widely used because it is easy to operate, less energy consumption, and low cost.
Recently, membrane technology has been applied in almost industrial sectors which were driven by interesting features of the smaller footprint, easy to scale-up, and lower operating cost [8–11]. In air filtration, membranes show superior filtration efficiency than conventional filter due to the ability to perform a filtration in the molecular level. Membranes allow the passes of clean air while rejects fine particles via sieving mechanism. With the high removal efficiency of fine particles, the membrane may be used as an effective air filtration replacing the conventional ones [12,13].

Even though the airborne particles can be effectively retained, the airborne microorganism may be accumulated on the membrane surface becoming secondary bioaerosols polluting source [14]. For a long-term application, a membrane with antimicrobial properties should be used. An antimicrobial membrane can be prepared by introducing antimicrobial agents in its structure. Metal oxide particles, silver, and natural extracts are usually employed as antimicrobial agents [15–19]. ZnO is one of the materials known to have antimicrobial functionality. ZnO antimicrobial activities are derived from its chemical and physical interaction with bacterial cells [20]. The antibacterial functionality of ZnO in an air filter has been demonstrated by Zhong et al. [21] by growing ZnO nanorods on expanded polytetrafluoroethylene. In this study, the excellent antimicrobial activity of ZnO is utilized to prepare the antimicrobial polypropylene (PP) membrane for effective air filtration. PP hollow fiber membrane was chosen since it has high mechanical strength, high chemical and thermal stability, and low cost [22]. Hollow fiber membrane also provides a high packing density and is easy to fabricate. To introduce ZnO nanoparticles, a simple permeation method is used. Combining simple fabrication and the low-cost material is expected to produce membrane air filter with low cost.

2. Materials and methods

PP membrane module and ZnO particles used in this study were obtained from GDP Filter Indonesia. Properties of PP membrane were summarized in Table 1. Technical grade ethanol (obtained from a local supplier, 96%) was used for the preparation of ZnO suspension.

ZnO particles were dispersed in ethanol with a concentration of 4 g/L (2.5 L). The suspension was mixed until optically homogeneous. The suspension was pumped into the shell side of the membrane module. The solvent was permeated through the membrane in a dead-end mode (at 0.2 bar operating pressure; 9 L/h flow rate) while the permeate was recirculated into the feed tank. Permeation was conducted for 30 minutes. The membrane was then allowed to dry for 24 hours. To remove the remaining ethanol, air scouring was applied for 30 minutes.

| Table 1. Properties of PP membrane |
| Parameter | Value |
| Outside diameter (mm) | 2.2 |
| Inside diameter (mm) | 1.8 |
| Pore size (nm) | ~50 |
| Membrane surface area (m²) | 3 |

An air filtration was performed by filtering synthetic polluted air prepared by combusting papers in a 100 L combustion chamber. The chamber was connected to a blower. The polluted air was transferred into the module in a dead-end mode and outside-in flow configuration. Permeate quality was measured immediately by laser-based light scattering detector (Origins Technology, 1-999 μm/m3). Microbial filtration test was conducted by using a mixed culture solution (EM4; PT. Songgolangit Persada, Indonesia; total plate counts = 2.8 x 106; Lactobacillus = 3.0 x 105; Phosphate dissolving bacteria = 3.4 x 105; Yeast = 1.95 x 103). A 20 mL mixed culture was diluted into demineralized water until the final volume of 2 L was obtained. The solution was then filtered by PP membrane (at 1 bar operating pressure). The feed and permeate were analyzed by microscope. For the antimicrobial test, fibers of PP and PP/ZnO membrane were cut and wound into a circle with a diameter of 2 cm. The fiber was placed on nutrient agar which was previously added microbes obtained from the mixed culture. After 5 days, the membrane was observed.
FTIR analysis of the membrane was carried out by The PerkinElmer SpectrumTwo™ while SEM analysis was performed using scanning electron microscopy (JEOL JSM 6510 LA, Tokyo, Japan).

3. Results and discussion

3.1. SEM and FTIR analysis
SEM images of PP and PP/ZnO membrane are shown in Figure 2 a and b. It can be seen that ZnO particles were successfully deposited on the membrane indicated by bright spots. It was obvious since the ZnO particles have an average size (about 300 nm, Figure 2 c) which was larger than the membrane pore size. Consequently, ZnO particles were retained on the membrane due to the sieving mechanism.

![Figure 1. Experimental set-up for ZnO deposition.](image1)

![Figure 2. SEM Image of (a) PP and (b) PP/ZnO membranes, (b) digital microscope image of ZnO particles, (d), (e) IR spectra of PP and PP/ZnO membranes.](image2)
FTIR analysis was also conducted to ensure the presence of ZnO on the membrane surface. Wang et al. [23] observed a peak of around 450 cm\(^{-1}\) in their FTIR analysis of ZnO particles. The peak was attributed with the stretching mode of crystal ZnO. Meanwhile, Zhu et al. [24] found the stretching mode of Zn-O bond spanning at the wavenumber of 540-570 cm\(^{-1}\). FTIR analysis of PP and PP/ZnO membranes are shown in Figure 2 d and e. Two peaks were found in PP/ZnO, i.e. wavenumber of ~450 cm\(^{-1}\) and ~600 cm\(^{-1}\) which may indicate the presence of Zn-O bond.

3.2. Membrane performance

The performance of PP membrane during filtration of microbial containing solution is depicted in Figure 3a and b. As shown in Figure 3 b, complete removal of the microbes was observed. This was due to the small pore size of the PP membrane (see Table 1).

Figure 3 c shows that the membrane could remove PM2.5 particles (particulate matters with the size of less than 2.5 \(\mu\)m) almost completely (~99.9%). In addition, the membrane exhibited relatively low-pressure drops which are beneficial for their application. The lower pressure drop will result in lower energy consumption.

![Figure 3](image-url)  
**Figure 3.** (a) Feed and (b) permeate of PP membrane, (c) pressure drop and PM2.5 removal efficiency (feed: 990 \(\mu\)m/m\(^3\)), (d) PP membrane, (e) PP/ZnO, and (f) ZnO on microbial culture.
3.3. Antimicrobial activity of PP/ZnO membrane

Results of the antimicrobial test of PP, PP/ZnO, and ZnO particles were shown in Figure 3 d-e. As can be seen in Figure 3 f, the inhibition zone of ZnO (0.06 g ZnO/cm2) when it is placed on a medium with microbial culture. ZnO particles are known as the antimicrobial agent. Antimicrobial activity of ZnO particles has been demonstrated in several studies [20,25–27]. Antimicrobial activity of ZnO in composite membranes was also reported in literature [25,28]. The antimicrobial property of ZnO was derived from its oxidative activity. It was found that the death of bacteria due to the presence of ZnO particles was associated with the high generation rate of oxygen on ZnO surface and its activity increased with the decreasing size of ZnO [26]. The antimicrobial activity of the prepared PP/ZnO membrane was also observed in this study. As shown in Figure 3 d and e, the presence of ZnO (estimated to be 0.33 mg ZnO/cm2 membrane) resulted in lower growth of the microbial indicated by the cleaner area surrounding the PP/ZnO membrane. This may imply that the antimicrobial membrane is successfully prepared.

4. Conclusion

In this study, an antimicrobial air filter was prepared by depositing ZnO nanoparticles onto hollow fiber PP membrane. The ZnO was deposited on the membrane surface by a simple permeation method. Results showed that ZnO particles were successfully coated on the membrane surface showed by SEM and FTIR analysis. The prepared PP/ZnO membrane had a high air filtration performance as well as antimicrobial properties. The membrane also showed a high filtration capacity or permeability with a relatively low-pressure drop. With those interesting features, the newly developed PP/ZnO membrane can be potentially applied in air filtration, particularly for indoor spaces and other medical applications.

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