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Development of Air Filter by Porous Glass Filter Coated With Nano Titanium Dioxide

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Abstract **–** This study aims at producing porous glass coated with Nano Titanium dioxide. The photocatalytic activity of porous glass coated with Nano Titanium dioxide was evaluated by the degradation of methylene blue solution under UV-A light. The air filter was made by coating porous glass with Nano Titanium dioxide and then applying it to indoor applications for particulate matter (PM2.5) removal from simulated pollution sources. The antimicrobial activity of a porous glass coated with Nano Titanium dioxide was investigated with a gram-negative bacteria *Escherichia coli* and virus Influenza A (H3N2) inhibition assay by real-time reverse transcription polymerase chain reaction (RT-PCR). The result showed that porous glass coated with Nano Titanium dioxide revealed higher photocatalytic efficiency compared to porous glass without Nano Titanium dioxide. The developed air filter, which consisted of a porous glass filter coated with Nano Titanium dioxide, reduced particulate matter by 63% at the origin and continued to remove 13% after 30 minutes of UV-A illumination. The antimicrobial activity of the porous glass coated with Nano Titanium dioxide against gram-negative bacteria *E. coli*, along with disinfected H3N2 99.30% and still disinfected 99.91% after 120 minutes of UV-A irradiation.

Keywords**:** Nano Titanium dioxide, Photocatalytic, Porous glass, Air filter, *Escherichia coli*., H3N2

1. Introduction

Air pollution is a problem that has a wide impact on people and the environment. Open burning is the primary source of particulate matter emissions in the Southeast Asian Region [1]. Moreover, this environmental issue is the cause of varying impacts on the economy and human health, such as increased risk of cancer and respiration problems [2]. Indoor air pollution can be transported from one place to another as indoor air pollution and air purification via filter coated nano-TiO_2 are studied to remove indoor air pollutants [3]. Titanium dioxide (TiO_2) is a photocatalyst for air purification and for the degradation of organic pollutants, and it can be coated on the surface of a material or air filter. For this technology is used for organic pollutant removal that may have occurred from open burning [1], [4]. The properties to remove organic pollutants, disinfect, and antimicrobial for air treatment of titanium dioxide led to the decoration of porous glass, which is prepared from glass powder as solid waste [4-5].

This study aimed to produce porous glass using a powder method coated with Nano Titanium dioxide synthesized by the sol-gel method. The photocatalytic activity of porous glass coated with Nano Titanium dioxide was investigated by the degradation of methylene blue solution. Furthermore, particulate matter removal was studied from an air filter developed by a porous glass coated with Nano Titanium dioxide. Finally, antimicrobial activity was tested with *Escherichia coli* and the virus Influenza A (H3N2).

2. Materials and methods

2.1. Preparation of the porous glass coated with Nano Titanium dioxide and characterization

The glass powder contained SiO_2 72.40 wt%, Al_2O_3 0.70 wt%, Fe_2O_3 0.11 wt%, CaO 8.60 wt%, MgO 4.00 wt%, Na_2O 13.60 wt%, K_2O 0.30 wt%, TiO_2 0.02 wt%, and SO_2 0.20 wt% was mixed with dolomite and diatomite in a ratio of 8:7:5. Then, all the of mixture was homogenised by a ball mill instrument and made into a rod shape. Next, melted in a furnace at 800 degrees Celsius for 5 hours. Then, TiO_2 was synthesized by a sol–gel method at room temperature using tetra-n-butyl orthotitanate $Ti(OBu)_4$ (99% Merck, Germany) 20 mL and 500 mL of ethanol (C_2H_5OH, Merck, Germany) were homogenised via ultrasonic wave at about 30 min, 32 kHz (called solution A). While mixture containing 60 mL of ethanol and 1 mL of nitric acid (65% Merck) was mixed by ultrasonic wave at about 30 min, 32 kHz (called solution B). Solution B was then dropwise added into solution A under stirring for 30 minutes. Following this process, porous glass was added into the solution to absorb titanium and left for 1 day. The pH of the mixture was 4 and controlled with HNO_3. To obtain porous glass coated with TiO_2 nanoparticles, the porous glass was coated with $Ti(OH)_4$ gels, which were then dried at 60 °C for 24 hours before being calcined for 3 hours at 450 °C. Morphology and size of the Nano Titanium dioxide was characterized using LV-Scanning Electron Microscope (JSM 5910 LV), and XRD. Pore size and structure of porous glass were also investigated via LV-Scanning Electron Microscope (JSM 5910 LV), EDS and BET

2.2. The photocatalytic activity

The photocatalytic activities were studied by the degradation of methylene blue solution under UV-A irradiation using 4Wblack lamps, wavelength 365 nanometres. The porous glass coated Nano Titanium dioxide was immersed into a 50 mL methylene blue solution with a concentration of 1×10^{-5} M. Afterwards, kept in a system under UV-A irradiation for 0, 1, 2, 3, 4, 5, and 6 hours. Next, solutions were measured for methylene blue absorption at 665 nm using a UV-Vis spectrophotometer. The concentration of the methylene blue was calculated by formula at the below

$$A = \varepsilon cl \tag{1}$$

where A = absorbance

ε = molar absorptivity (L mol^{-1} cm^{-1}) at 665 nanometres = 74,021 L mol^{-1} cm^{-1}

l = Optical path length (cm)

c = Molar concentration (M)

Finally, the degradation of methylene blue was reported by the ratio as follow

$$\text{Degradation} = C/C_0 \tag{2}$$

where C_0 is the concentration of methylene blue aqueous solution at the beginning (1×10^{-5} M) and C is the concentration of methylene blue aqueous solution after illumination.

2.3. Performance of the air filter from porous glass coated with Nano Titanium dioxide

The air filter size of 10 x 10 x 2.5 centimeters was developed from porous glass coated with Nano Titanium dioxide and it was placed in a system which simulated pollution sources. Pollutants were generated from burning biomass in the first chamber, which contained a sensor and UV-A light wavelength of 365 nanometres. Then an air filter was placed between the first chamber and the last chamber, and the last chamber carried the second sensor and monitor to check particulate matter value. The particulate matter removal was evaluated by the decrease of particulate matter value in two chambers. The removal efficiency of particulate matter equations can be written as follows:

$$\text{Efficiency} = \frac{N_1 - N_2}{N_1} \times 100 \tag{3}$$

where N_1 and N_2 are the initial and final number of particulate matters inside the chamber.

2.4. The antimicrobial activity

E. coli cells (Chiang Mai University, Thailand) were cultured at 37 °C for at least 24 hours in a 250 mL nutrient broth containing 3 g/l beef extract, 5 g/l peptone, and 5 g/l NaCl, with the bacterial concentration adjusted by dilution with the NaCl solution (0.85%) to require a cell density of 10^8 cells/mL. Cells density was measured from optical density value

0.1±0.02 (OD_{600}=0.1±0.02) at the wavelength 600 nanometres or compared with turbidity of 0.5 McFarland standard. The antibacterial activity of porous glass coated with titanium dioxide was investigated in a box which contained the illuminating UV-A light source (wavelength 365 nm) was placed at the top of the test tube. Bacteria in 3 mL was pipetted into a test tube. After that, added 1 grams of the porous glass coated with Nano Titanium dioxide and test tube was carried porous glass and bacteria were irradiated to UV-A light also. Porous glass coated with Nano Titanium dioxide was inoculated with the bacterial suspension and placed in a dark chamber. Four irradiation durations of 0,60,120, and180 minutes were employed to examine the efficiency of the photocatalytic inhibition. After exposed of light, bacterial solutions was pipetted in a sterile bottle for serial dilution 10^{-5}, 10^{-6} and 10^{-7}. Then, plated on LB-agar. Plates were then incubated at 37 °C and colony counts were taken after 24 hours of incubation. The activity was reported as survival curves, equation can be written as follows:

$$\text{Survival curves} = \text{Log}\left(\frac{N_t}{N_0}\right) \tag{4}$$

where N_t is bacterial number at time t, N_0 is germ number at time 0

Not only gram-negative was evaluated, but influenza virus A (H3N2) was also treated with porous glass coated titanium dioxide to test inactivation of influenza virus by Virus Inhibition Assay and Real Time Reverse Transcription Polymerase Chain Reaction (RT-PCR) and it was analysed by service for bioassay, cell toxicity assay and lyophilization (The Department of Microbiology and Immunology in the Faculty of Tropical Medicine, Mahidol University, Thailand)

3. Results and discussions

3.1. Characterization of TiO_2 synthesized

Figure 1 shows the SEM of titanium dioxide prepared by the sol–gel method. It can be indicated that the size of the particles is in the range of nanometres. The particles have a spherical form and a uniform size an average 97±11.5 nanometres.

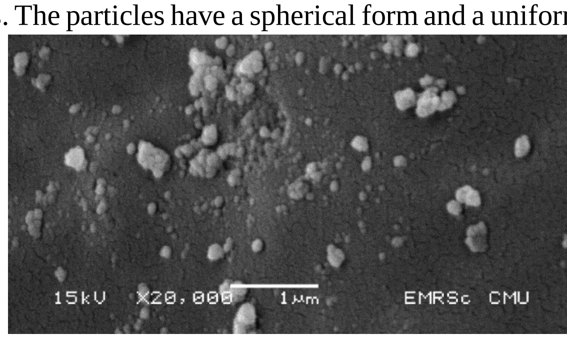


Fig. 1: SEM picture of nano titanium dioxide.

The XRD patterns of the Nano Titanium dioxide represented in Figure 2 discovered the strongest peak at 2θ =25.57° or anatase phase reflections (JCPDS No. 21-1272). The average crystallite size of the nano titanium dioxide is calculated from the XRD data following to Scherrer's equation:

$$\text{L} = \frac{K\lambda}{(FWHM)cos\theta} \tag{5}$$

where L is particle size, θ is peak position (2θ/2) in radian. λ is the wavelength of the X-ray used for the diffraction is 0.15418 nanometres. K is a constant, called shape factor is 1.0 and FWHM (full width at half maximum) obtained from XRD data. In terms of crystallite size, it was calculated to be at 5.83 nm and the percentage of anatase phase was 100%.

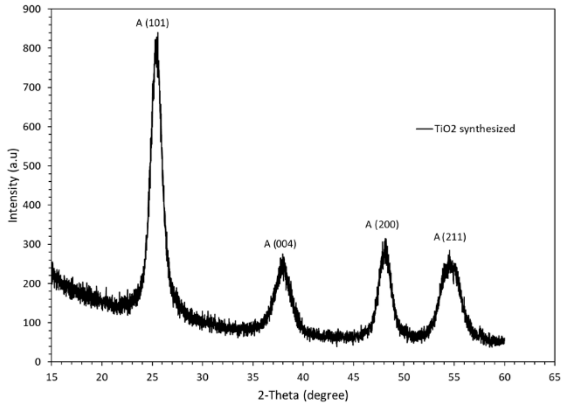


Fig. 2: XRD pattern of nano-titanium dioxide.

3.2. Properties of porous glass

The density and surface area of porous glass are shown in Table 1. The porous glass prepared from soda-lime glass mixed with dolomite and diatomite can generate pores which occur by the action of gas generation agents as carbonaceous substances (dolomite and diatomite) and when it heated, gas led to bubbles within melted glass [6] and structure can be seen from figure 3

Table 1: Physical properties of porous glass from BET analysis

Specific surface area (m^2/g)	50.820
Pore volume (cm^3/g)	0.053
Density (g/cm^3)	18.860
Radius (nm)	2.108
Diameter (nm)	4.216
Average pore size (nm)	96.407±3.622

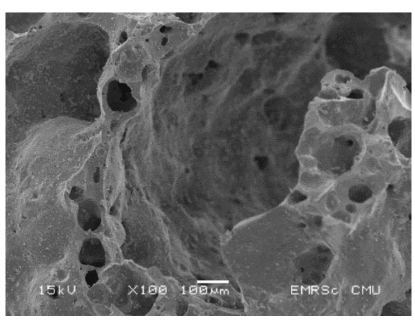
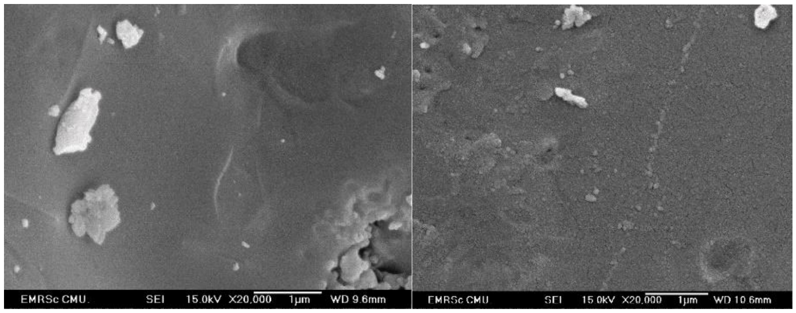


Fig. 3: Pore in the porous glass from SEM.

Nano Titanium dioxide was coated on porous glass during the sol-gel happened. Figure 4 indicates particles of titanium dioxide on the surface of porous glass from SEM. And an Energy Dispersive X-ray Spectrometer (EDS) also confirmed that the surface of porous glass contained elements of titanium dioxides from figure 5



(a) **(b)**

Fig. 4: SEM image of porous glass (a) and SEM of porous glass coated TiO_2 (b)

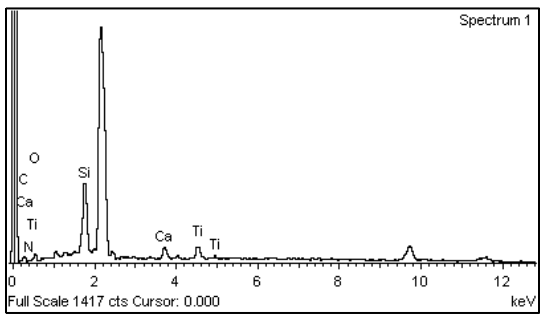


Fig. 5: EDS shows elements of titanium on porous glass.

3.3. Photocatalytic activity

The photocatalytic degradation of methylene blue solution by using porous glass coated with Nano Titanium dioxide experimented under UV-A irradiation is represented in figure 6. It was revealed that porous glass coated with Nano Titanium dioxide has a significant effect on photocatalytic reaction under UV-A illumination compared with uncoated porous glass. The methylene blue degradation under UV-A was reported. Porous glass coated with Nano Titanium dioxide is the best treatment for the decolorization of methylene blue. Because of distinct properties, the fundamental dye destruction was effective, and pollutant elimination was achieved using photocatalysis under light irradiation [7].

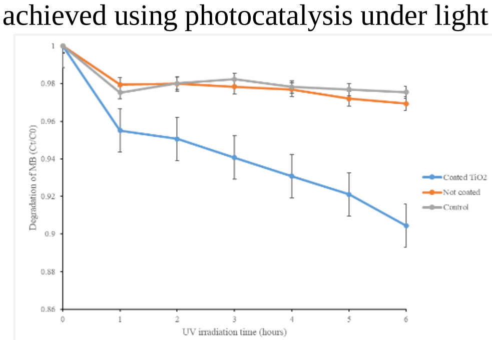


Fig. 6: Degradation of methylene blue solution under black light irradiation.

3.3. Performance of the air filter

Figure 7 shows the removal efficiency of particulate matter 2.5 (PM2.5) under UV-A light and without light in simulated pollutant sources. It was established that air filter from porous glass coated Nano Titanium dioxide degrade pollutants by 63.3% and continued to work 13.8% when 30 minutes.

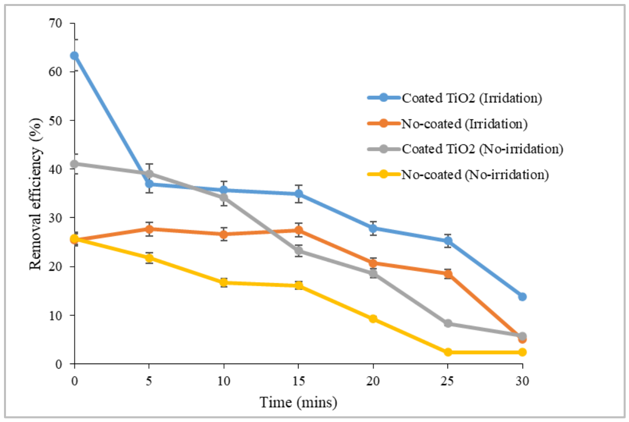
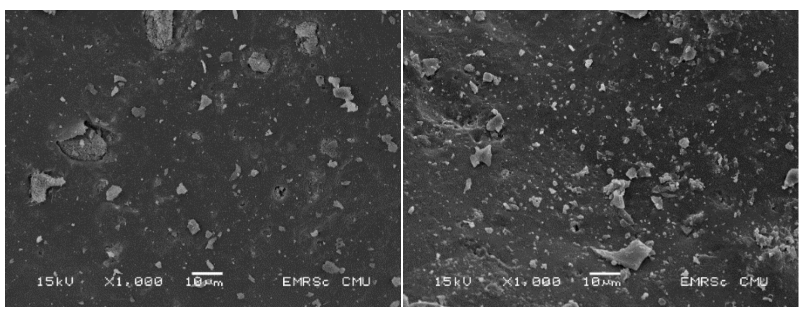


Fig. 7: Removal efficiency of particulate matter 2.5 (PM2.5).

Particulate matter 2.5 (PM2.5) represented organic pollutants from the burning of biomass, and it was degraded via porous glass coated Nano Titanium dioxide from the big particles to smaller particles. Figure 8 shows the particles of PM2.5 inside the porous glasses that coated titanium dioxide and without coating from SEM.



(a) **(b)**

Fig. 8: PM2.5 inside the porous glasses without coating TiO_2 (a) coating TiO_2 (b).

3.4. The antimicrobial activity

The photocatalytic bacterial inactivation experiments were performed with 10^8 CFU·mL^{-1} in 0.85% NaCl as the nonsubstrate enrichment condition. Figure 9 shows the *E. coli* inactivation performance of porous glass coated with Nano Titanium dioxide under UV-A light, with a decreasing population of *E. coli*, whereas porous glass without coating can adsorb bacteria cells on its surface. In the absence of light, porous glass coated with Nano Titanium dioxide cannot inhibit *E. coli*.

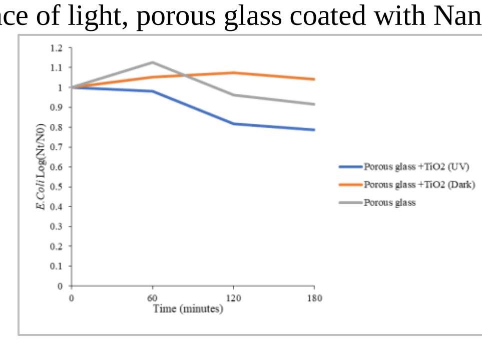
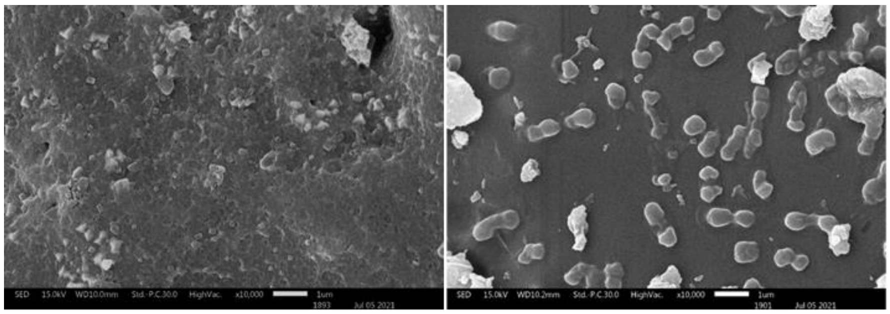


Fig. 9: The photocatalytic bacterial inactivation of *E. coli*.

Figure 10 confirmed that photocatalytic activity occurred when porous glass coated with Nano Titanium dioxide worked under illuminated UV-A light. The photocatalytic activity under UV-A causes damage or even destruction of the outer cell membranes of bacteria [8].



(a) **(b)**

Fig. 10: SEM images of *E. coli* after 180 minutes with porous glass coated TiO_2 (a) and porous glass without coating (b).

The influence of titanium dioxide on porous glass on the influenza virus was studied by the Virus Inhibition Assay and Real Time Reverse Transcription Polymerase Chain Reaction (RT-PCR). The virus was destroyed (Table 2). After 120 minutes of experiment, nano particles of titanium dioxide on porous glass attacked the external surface of the virus envelope. Surface spinules of the virus were aggregated together, and the envelope was broken after 120 minutes [9].

Table 2: The result of testing disinfects activity of porous glass coated Nano Titanium dioxide.

Treatment	**Testing concentration**	**Contact time**	**Efficiency (%)**
The porous glass coated Nano Titanium dioxide under UV-A irradiation	0.2 g/ 300 µL	0 mins	99.30 ± 0.04
		120 mins	99.91 ± 0.00

4. Conclusion

The purpose of this research is to produce porous glass coated with Nano Titanium dioxide synthesized by the sol-gel method and an anatase phase has size of particles 5.83 nm. The photocatalytic reaction of porous glass coated with Nano Titanium dioxide under UV-A irradiation can be caused by the degradation of methylene blue solution. For the air filter, porous glass coated with Nano Titanium dioxide was used in indoor applications, which can remove particulate matter (PM2.5) 63% at the source and 13% continuously after 30 minutes in a simulated pollution system with UV-A illumination and organic pollutants from burning biomass. Furthermore, population of *E. coli* was decreased when porous glass coated with Nano Titanium dioxide was conducted to investigate the antimicrobial activity and the virus Influenza A (H3N2) inhibited 99.30% and still disinfected 99.91% at 120 minutes under UV-A irradiation.

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