Design of wastewater treatment system using 3-D printed structure incorporated with TiO_2

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Abstract

With the high population in the world, it is added challenges to the current water treatment in conjunction with the increase in antibiotic-resistant bacteria. One of the promising solutions is to utilize nanoparticles in water treatment on their strong oxidative properties in removing wide range of contaminants. It is difficult to separate or remove nanoparticles from the liquid state system, this is not practical as the treatment system is non-reusable and possible release of toxins into the water. Most of the nanoparticles separation are in templates of film, sheets, tube and etc, in which there are still limitations in term of surface area, sustainability and cost which lower the efficiency of the treatment system. In this paper, a three-dimensional (3-D) structure is designed to achieve high surface area for the incorporation of TiO_2 nanoparticles as a separation system. The surface areas of different 3-D shapes were measured using the software of Meshmixer. Results concluded that spherical shaped of 3-D printed structure has the highest surface area. Among all structures, sphere structure has the highest surface area which was 40%, 61%, 2% and 30% higher compared to cube, prism, hexagonal prism and cylinder structure respectively. Sphere structure was proposed to be the most suitable structure to be applied in the degradation of organic pollutants and antimicrobial test.

Keywords: *Additive manufacturing; Separation system; Treatment system; Photocatalysis; Antibacterial*

1. INTRODUCTION

Wastewater derived from household, industrial, agriculture and hospitals. Wastewater contains various chemical and biological wastes that can be harmful to humans and other organisms. Increasing population in worldwide deteriorates the water quality and triggers the demand of higher volume of clean water (Olvera et al., 2017; Singh & Mishra, 2020; Kamali et al., 2019). At the current stage, water treatment techniques are still dependent on the conventional water treatment method such as activated sludge, trickling filter and membrane bioreactor. The conventional method are multi-steps and inefficient in removing toxins and heavy metals completely in the wastewater (Keerti et al., 2021). Due to these disadvantages, nanotechnologies are found to be a promising way to treat wastewater.

Nanoparticles are nano-sized particles that lies between the sizes of 1nm to 100nm. Due to its nanoscale size, the properties of electrical, mechanical, magnetic and optical are higher in which improve and increase its capability and efficiency in conductivity, photocatalysis, antibacterial activity and etc (Xu et al., 2012; Hot et al., 2017). In the application of water treatment, semiconductor-based nanoparticles are most widely explored such as Fe_2O_3, TiO_2, SiO_2, Al_2O_3, Cds and $BaTiO_3$ (Hdidar et al., 2018; Zhang et al., 2019).

Titanium dioxide (TiO_2) has been greatly studied in many researches due to their outstanding properties such as high photocatalytic performance, low cost, non-toxicity, chemically stable and photostability (Guesh et al., 2016; Rawal et al., 2013). In addition to these advantages, TiO_2 can degrade most of the pollutants such as organic compounds, inorganic compounds, heavy metals, dyes, pesticides, cyanide, arsenic and phenols (Guo et al., 2015; Nguyen et al., 2016; Chen et al., 2016). However, the drawback to exploiting TiO_2 in water treatment is the non-recyclability. Nanoparticles when suspended in liquid or solution, are difficult to trace back hence inhibiting its reusability, while the overall treatment cost will also be increased. Recent studies had placed effort in producing nanoparticles embedded in membrane form as a separation system (Meng et al., 2014; Evyan et al., 2017), which is more sustainable than direct exposure of nanoparticles powder into the water treatment system.

The viscosity of a composite material is important to ensure printability of a 3-D structure. Most composite material suffers from non-homogeneity, aggregation and sedimentation of additives dispersion in the polymer material. This is due to incorporation of additives or nanoparticles in the polymer can introduce some bubble traps in the mixture. (Falahati et al., 2020). Such parts are usually mechanically weak to withstand pressure and requires more time to print. A suitable selection of viscosity shall be considered in 3-D printing composite material. The viscosity should be low enough to ensure printability while it should also be high enough to ensure structural support (Wang et al., 2017).

In this study, a 3-D printed nanocomposite incorporated with TiO_2 with high surface area was designed in terms of the study on 3-D shapes and the effect of viscosity on 3-D printing. In addition, a low-cost photoreactor is proposed.

2. EXPERIMENTAL

2.1 Design of 3-D structure using software

Meshmixer software was used to design structures with different shapes. This software was used in designing and manipulating 3-D files for 3-D printing. The design of the structures was based on a fixed volume to compare the strength and total surface area of the proposed structures.

2.2 Printing of 3-D structure incorporated with TiO_2

The two chosen 3-D structures from the previous step which were designed using Meshmixer software were printed in spherical and cubic shapes. For each printing of the structure, 5%wt. of P25 (Sigma Aldrich) was mixed with acrylic resin (Anycubic) solution using a homogenizer. The P25 powder was added in few batches, with each batch homogenized for 1 minute. The resulting mixture was poured onto the resin vat for printing using Anycubic Photon Series printer. The printed structure was washed with alcohol in an ultrasonic bath for 10 minutes. The structure was further cured in a UV light chamber (15W).

2.2 Design of low-cost photoreactor

A photoreactor was designed using unused oven as the main structure. It was designed according to the standard criteria in designing a photoreactor. The photoreactor was consist of light bulb holder, light bulb, ventilation fan, magnetic stirrer, mirror sheets and power source. The surface of the oven was cut according to the size of the parts and masking tape was used to attach the parts into the photoreactor.

3. RESULTS AND DISCUSSION

3.1 The influence of shapes on surface area

The 3-D structures were designed using Anycubic Photon Series as in Fig. 1. The strengths were measured and compared as shown in Table 1using Meshmixer.

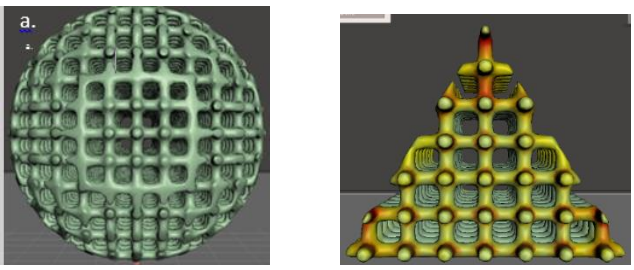

Fig. 1. The appearance of 3-D models: (a) Sphere; (b) Cube.

Table 1: The study of dimention, volume, surface area and strength of designed 3-D models.

Shape	Dimention (X/Y/Z) (mm)	Volume (mm^3)	Surface Area (mm^2)	Strength
Sphere	24.94/25.14/24.95	2680.29	8952.55	Strong
Cube	20.66/20.58/20.58	2682.98	5336.37	Weak

In the application of water treatment, the surface area of the proposed 3-D structure is an important factor to be concerned for degradation of pollutants and killing of microbes effectively. The designed structure should also be durable and mechanically strong in order to withstand the force produced during the magnetic stirring when undergone the photocatalysis. The strength of the structure is particularly important in the application of water treatment under stirring mechanism. The recyclability and efficiency of the antibacterial activity will be affected if the printed samples broken during the treatment. Fig. 2 shows the 3-D printed sphere nanocomposite which has been re-used for five cycles. The sphere structure still appeared in good condition after using it for more than five cycles while the cubic structure was broken even after the first treatment as shown in Fig. 3(b).

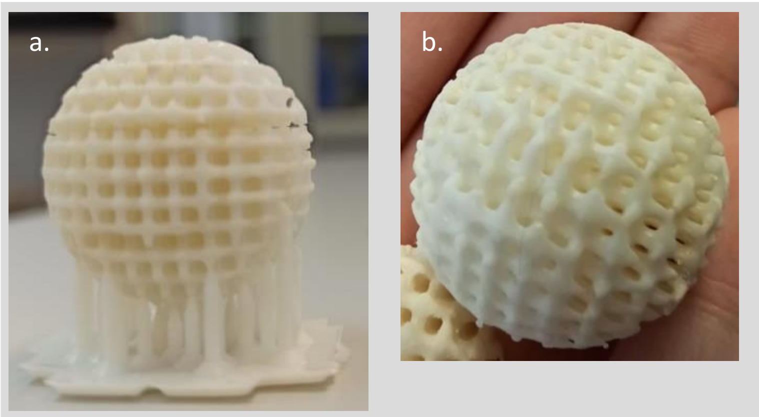

Fig. 2. The 3-D printed sphere nanocomposite incorporated with TiO_2. (a) Before treatment; (b) After treatment.

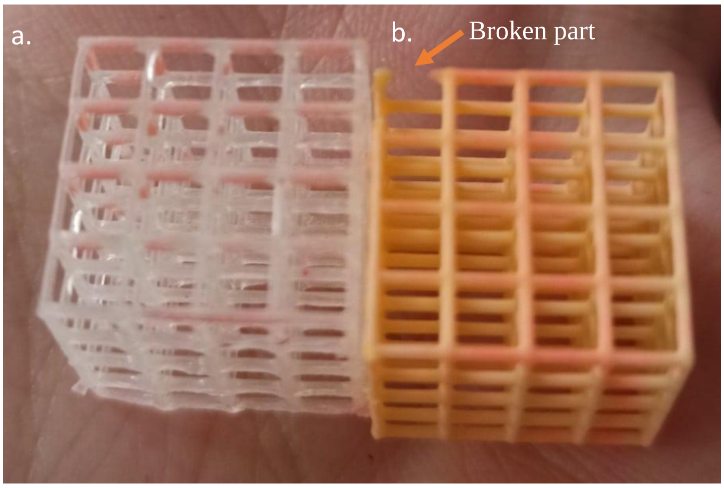

Fig. 3. The cubic structures: (a) before magnetic stirring (b) after treatment magnetic stirring.

3.2 Photoreactor

In this study, a photoreactor was built with simple component yet low cost. Conventional methods such as filtration, coagulation, enzymatic, and adsorption are most widely used. However, these methods often result in incomplete mineralization of organic pollutants (Li et al., 2021). One of the most promising way is to make use of photocatalytic reactors to treat wastewater as advanced oxidation process (AOP). Bacteria are generally destroyed by hydroxyl radical generated by TiO_2 nanoparticles. The hydroxyl radicals are able to disrupt the covalent bond of the bacteria's peptidoglycan resulting in lysis of the cell wall, making them unstable (Ge et al., 2015). Upon exposure to UV light, conduction band and valence band produce e^- and h^+ which then reacts with water and oxygen in the surrounding (Evyan et al., 2021), promoting the production of reactive oxygen species (ROS).

One of the main criteria in building a photoreactor is the presence of light source, since it is the main driving force for photocatalysis to occur. Light intensity, types of light and radiation source are some important aspects to consider in designing a photoreactor. In addition, a light source must be correlated with the type of photocatalyst used to suit their band gap. For instance, TiO_2 with 3.2eV is only activated upon the exposure of UV light. Apart from the light source, the design of a photoreator is also crucial to determine the photocatalytic performance (Pu et al., 2019). The self-setup of a photoreactor is shown in Fig. 4 with the addition of mirror sheets on the inner surface of the photoreactor. This enables light to reflect in all directions, giving exposure to the sample as much as possible. The setup of this photoreactor is relatively simple and can be a reference for the large-scale water treatment system.

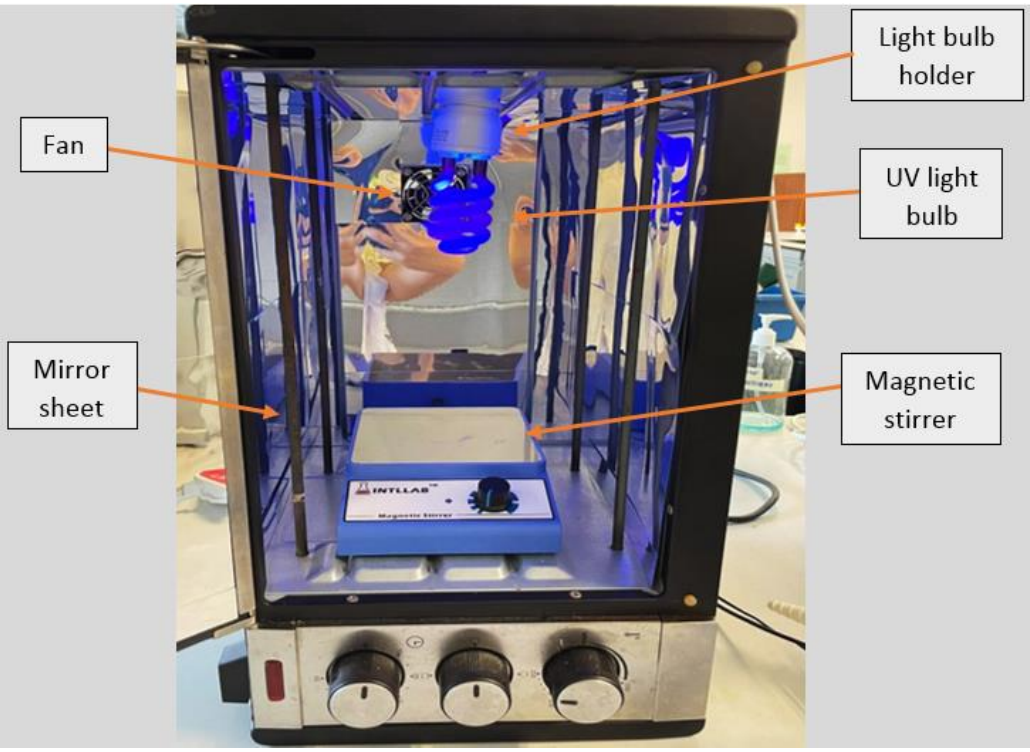

Fig. 4. Design of a low-cost photoreactor equipped with UV light.

4. CONCLUSION

In this study, the study of 3-D geometries has been achieved to select the best structure for the antimicrobial test. The spherical 3-D printed samples are high in surface area and strength. A total of 5% in weight of TiO_2 powder was successfully incorporated into the structure. This proposed mechanically strong 3-D printed nanocomposite which is a good candidate in water treatment applications. A study on the effect of viscosity of the printing ink was also elaborated. A low-cost yet effective photoreactor was proposed in this study. The treatment system was cost-effective with recyclable and reusable properties. Future study will be carried out to determine the effectiveness of the system in wastewater treatment.

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