

2024年臺灣國際科學展覽會 優勝作品專輯

作品編號	200019
參展科別	環境工程
作品名稱	Silver nanoparticles-loaded titanium dioxide coating towards immobilized photocatalytic reactor for water decontamination and bacterial deactivation under natural sunlight irradiation
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SECTION 1: INTRODUCTION

The environmental implications of rapid industrialization, including rising pollution, depleted resources, the effects of climate change brought on by global warming, and unrestrained groundwater extraction, are contributing to a growing water scarcity crisis [1-3]. The improvements in quality of life are largely attributable to the innovations in manufacturing technology made possible by the Industrial Revolution, but these innovations also pose risks to the natural world and human health [1-3]. The textile business uses a wide variety of raw materials, including natural fibers like cotton as well as synthetic and woolen fibers, and the chemical components of dyes are just one example. The annual output of synthetic dyes is around 700,000 tons, and there are over 10,000 different varieties available. As much as 200,000 tons of synthetic dyes are released into the environment every year due to the inefficient dyeing technique commonly employed in the textile industry. According to the World Bank, the processing of textiles for dyeing and finishing accounts for between 17 and 20 percent of industrial wastewater [1-3].

Textile wastewaters contain a high biological oxygen demand (BOD), chemical oxygen demand (COD), nitrogen, color, acidity, high suspended particles, high dissolved solids, surfactants, dyestuffs, heavy metals, and other soluble chemicals [3] due to the variety of dyes used to color textile items. In particular, water-soluble reactive and azo dyes are employed to obtain the required color. Ten to twenty percent of the dyes used end up in the effluents, where they might harm wildlife and the ecosystem (carcinogenic or mutagenic). Headaches, nausea, skin irritation, respiratory difficulties, and congenital deformities are only some of the health problems linked to exposure to textile wastewater. There are repercussions for aquatic ecology, environmental

biodiversity, and the quality of receiving water bodies. New, low-cost, and highly effective water treatment methods are needed to deal with polluted wastewater. Adsorption and coagulation, two common water purification methods, just concentrate pollutants by shifting them to other phases; they do not "eliminate" or "destroy" them. Sedimentation, filtration, chemical oxidation, and biotechnology are all examples of conventional water treatment methods, but they all have their drawbacks. These include insufficient removal, high chemical reagent consumption, high treatment costs, long treatment times, and the creation of toxic secondary pollutants. New water treatment procedures are needed to improve the quality of treated effluent [1-3]. The use of semiconductor particles in photocatalysis is gaining appeal as a solution to global pollution problems due to its shown efficiency in degrading a wide variety of contaminants.

Photocatalyst-coated surfaces-based reactors have proven to be practical for long-term operation over photocatalytic powder-based reactors (i.e., slurry-based reactors) [4-5]. As a promising photo-electrode and photocatalyst, titanium dioxide (TiO_2) has enjoyed wider applicability in photocatalytic hydrogen generation, solar cells, and remediation of organic contaminants among other photo-catalytic applications [4-6]. TiO_2 has been recognized as one of the low-cost, most effective, and fascinating photo-catalyst as a result of its interesting thermal and chemical stability, desirable electronic features, others, and environmental benignity [6-8]. Pristine TiO_2 semiconductor is characterized by a wide band gap that can only utilize the UV part of the light spectrum with a wavelength of less than 385 nm, which is just 5% of the sunlight energy capacity. Spectrum usability extension to visible regions warrants further and extensive research study [8-10]. Additionally, the quickness of the recombination of photo-generated holes and electrons further restricts the practical applicability of the semiconductor [10-12]. It is highly desirable to develop a cost-effective scalable strategy to overcome these drawbacks toward sustainable development

and a clean environment using only natural sunlight irradiation [5-11]. In addition, it is preferred to fabricate them as films rather than powders as photocatalytic immobilized reactors are more practical than powder-based reactors [4-8].

Dye sensitization, supports, magnetic separation, and surface modification by doping with non-metals, metals, and transition metals and coupling with other semiconductors have all been used to enhance the photocatalytic activity of TiO_2 photocatalyst. Higher photonic efficiency can be attained through the synergistic fine-tuning of features such as physical, chemical, and electronic, and these composites and hybrid materials based on TiO_2 are creating a big trend. Doping has been widely studied as a means of altering the surface of TiO_2 . Rare earth metals, noble metals, and transition metals are all discussed in the existing literature on the surface modification of TiO_2 doped with cations [4-12].

In this study, for the first time, Ag nanoparticles loaded mesoporous TiO_2 coating was prepared and applied as an immobilized photocatalytic reactor for water decontamination and bacterial deactivation under natural sunlight irradiation.

SECTION 2: METHODOLOGY

Aims and objective

- To fabricate photocatalytic TiO₂ mesoporous coating as UV-responsive material.
- To fabricate Ag nanoparticles loaded TiO₂ (Ag-TiO₂) coating as visible light-responsive material.
- To apply the fabricated photocatalytic TiO₂ and Ag-TiO₂ coated surfaces for water decontamination and bacterial deactivation under sunlight irradiation.

Background

Photocatalytic metal-oxide nanomaterials such as titanium dioxide are promising green solutions for current environmental pollution issues under light irradiation [5,6]. However, their wide band gap energy and high recombination rate of the photo-induced electron-hole pairs limit their practical application for self-cleaning antibacterial surfaces, air purification, and water decontamination under abundant natural sunlight [7,8]. It is highly desirable to develop a cost-effective scalable strategy to overcome these drawbacks toward sustainable development and a clean environment using only natural sunlight irradiation [9, 10]. In addition, it is preferred to fabricate them as films rather than powders as photocatalytic immobilized reactors are more practical than powder-based reactors [10-13]. Thus, in response to this orientation, we developed visible light-responsive silver nanoparticles-loaded titanium dioxide-coated (Ag-loaded TiO_2) surfaces using a cost-effective and scalable method and then apply them as photocatalytic immobilized surfaces for water purification and to deactivate bacteria found in the Saudi environment under the abundant natural sunlight irradiation. The fabricated films showed outstanding photocatalytic activity under visible light irradiation making them a promising candidate as self-cleaning antimicrobial surfaces that can be applied on tables and door handles in public places reducing the spread of infectious diseases such as Covid-19 without any chemical additives. This study is in the line with **the ambitious Saudi 2030 Vision** which encourages the global transfer from full dependence on fossil fuels to green renewable energy for sustainable development and a clean environment.

Hypotheses

- The Ag nanoparticles will improve the optical properties of TiO₂ mesoporous film to absorb visible light.
- If the Ag nanoparticles loaded TiO₂ mesoporous coating is visible light responsive, then the Ag nanoparticles loaded TiO₂ coated surfaces will work for water decontamination and bacterial deactivation under sunlight irradiation.

Variables:

Dependent variables

Optical properties of TiO₂.

Independent variables

Ag concentration.

Constant variables

All other experimental parameters.

Methods

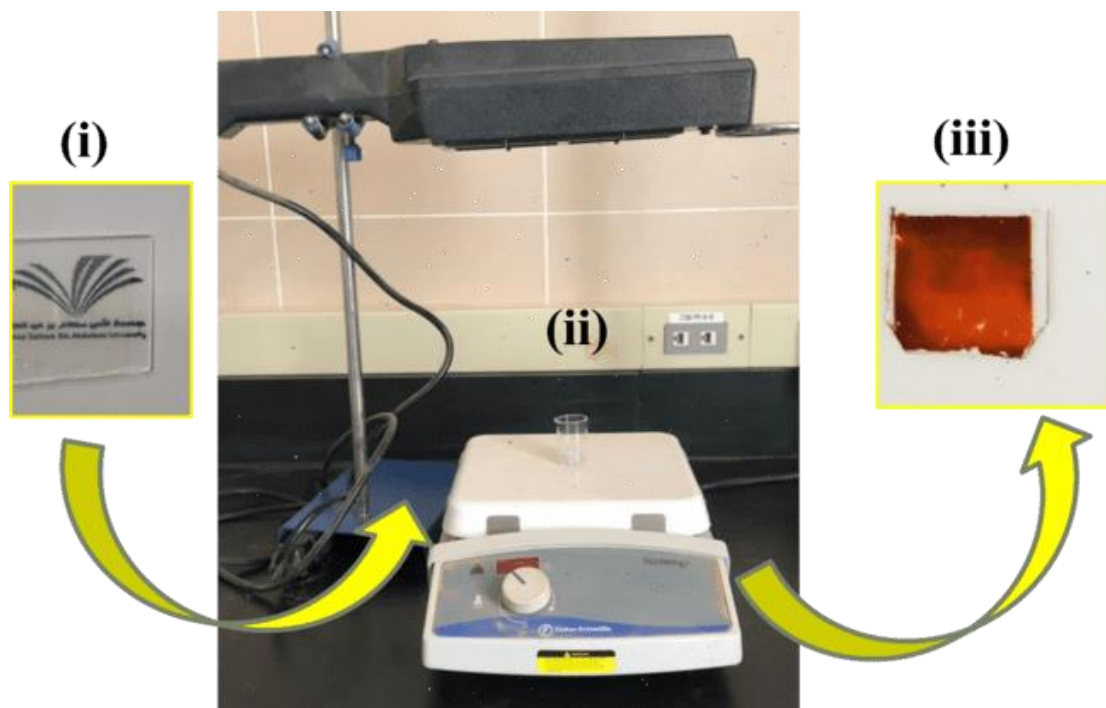


Figure 1: A schematic illustration of the fabrication procedure followed to fabricate sunlight-responsive photocatalytic surfaces.

TiO₂ paste was used to fabricate TiO₂-coated glass using doctor blade coating as shown in **Figure 1 (i)**. The fabricated TiO₂-coated glass was immersed in silver nitrate aqueous solution and subjected to 15 minutes of UV light irradiation, **Figure 1 (ii)**, to fabricate silver nanoparticles-loaded titanium dioxide (Ag NPs loaded TiO₂) films as immobilized photocatalytic reactors under natural sunlight irradiation as presented in **Figure 1 (iii)**. The fabricated TiO₂ and Ag NPs loaded TiO₂ films were characterized using a scanning electron microscope (SEM) and x-ray photoelectron spectroscopy (XPS) and then applied to degrade methylene blue dye (MB dye) as a

pollutant model from MB dye-contaminated water under natural sunlight irradiation in Al Kharj, Saudi Arabia.

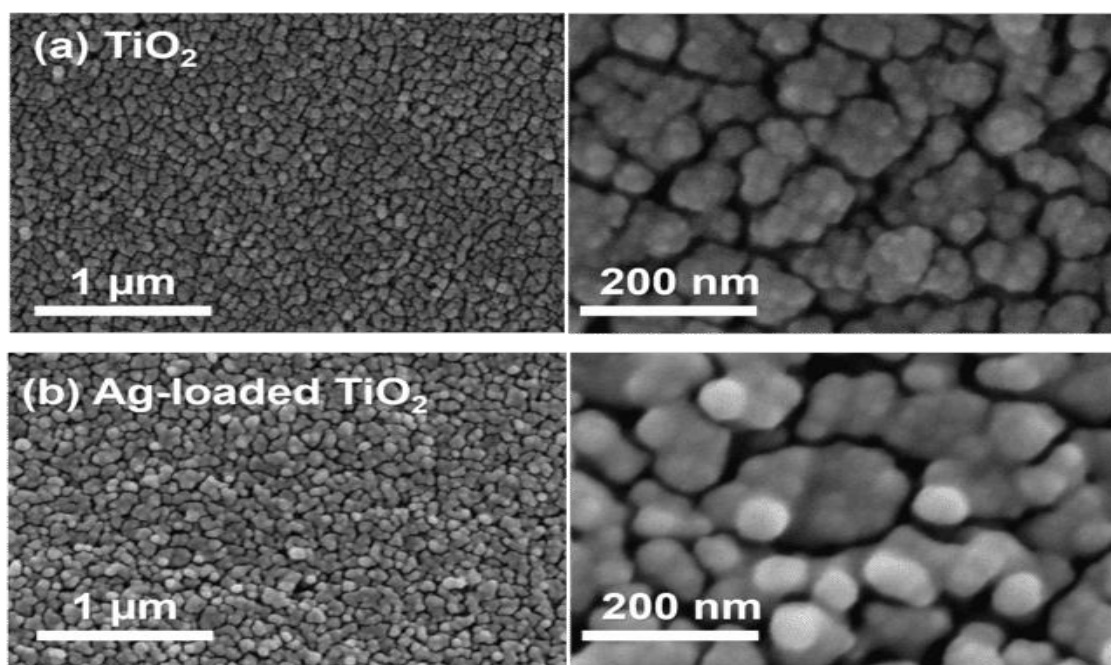


Figure 2: SEM images at different magnifications of the pristine TiO_2 and the Ag-loaded TiO_2 surfaces as indicated.

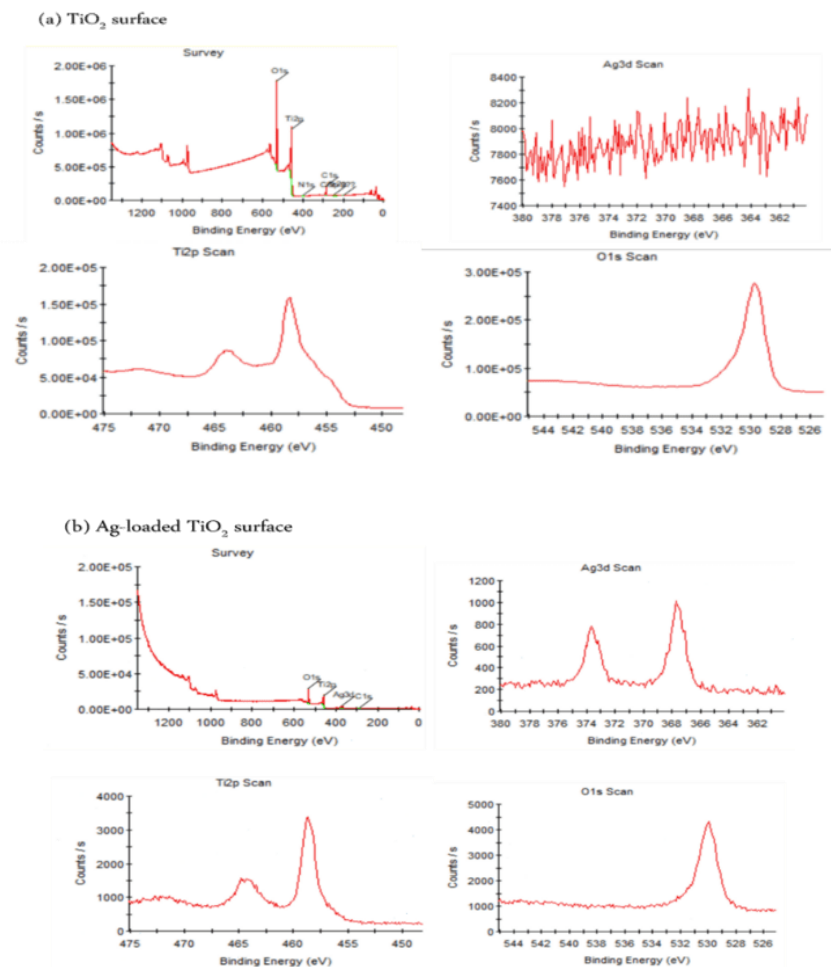


Figure 3: XPS spectra of the (a) pristine TiO_2 and (b) Ag NPs loaded TiO_2 film.

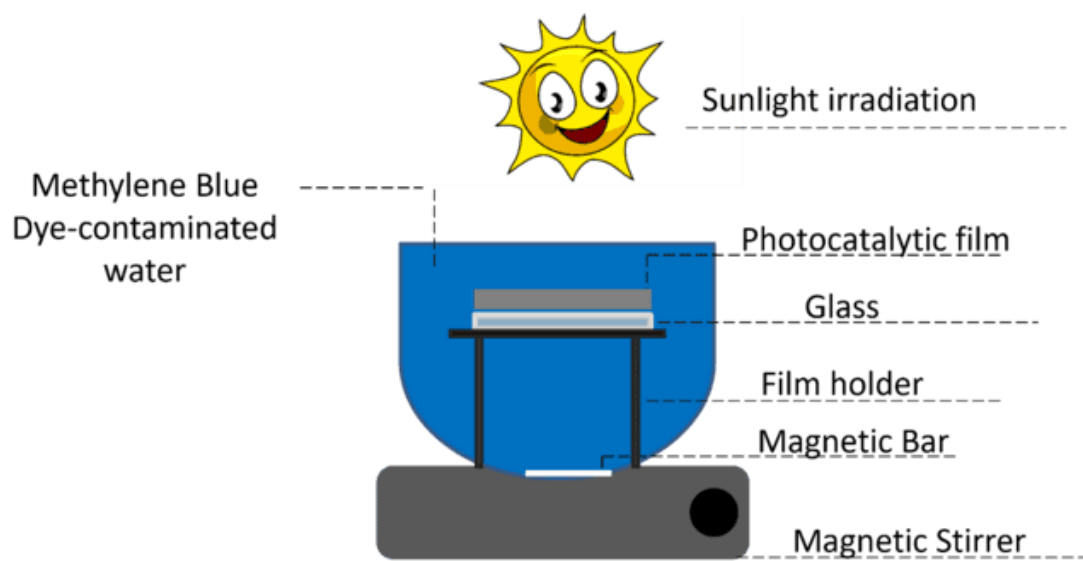


Figure 4: Home-made photocatalytic reactor used to degrade MB dye from MB dye-contaminated water under natural sunlight irradiation in Al Kharj, Saudi Arabia by the pristine TiO_2 and Ag NPs loaded TiO_2 films.

SECTION 3: RESULTS

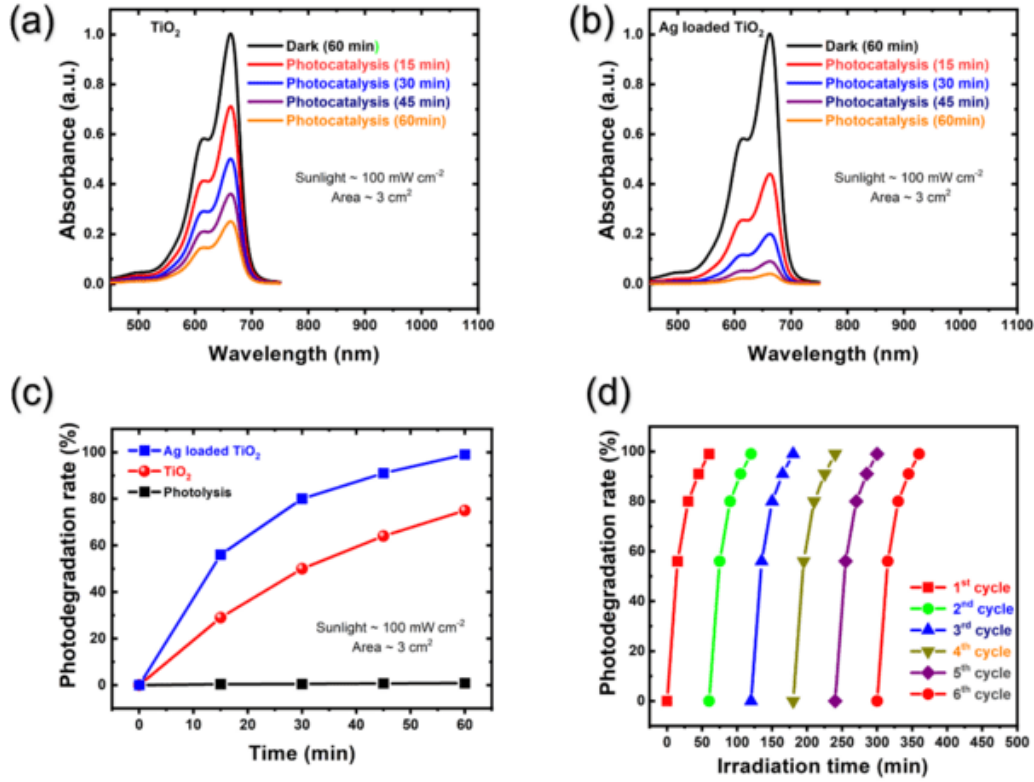


Figure 5: (a) and (b) the change in the concentration of MB dye upon natural sunlight irradiation using the pristine TiO_2 and Ag NPs loaded TiO_2 films respectively as indicated. (c) the photodegradation rate (%) of MB dye using both films was calculated from (a) and (b) as indicated. (d) the robustness test of the Ag NPs loaded TiO_2 film.

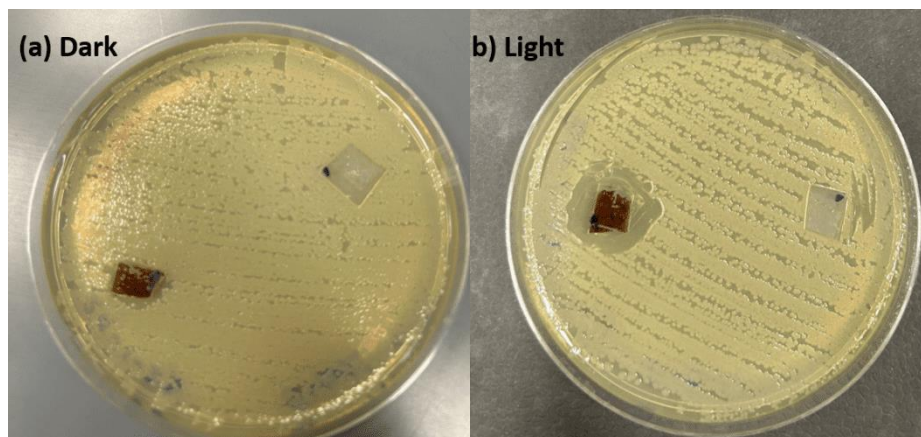
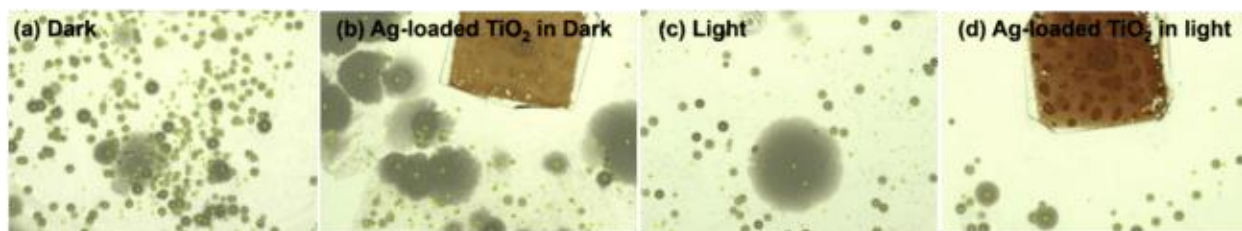


Figure 6-7: The **initial result** of the antibacterial activity test in dark and under visible light irradiation of the prepared coating as indicated. (**Note: this experiment is still in progress**).

SECTION 4: INTERPRETATION & CONCLUSIONS

The SEM images in **Figure 2** show the excellent quality of the coating and the nanostructured morphology of both fabricated TiO₂ and Ag NPs loaded TiO₂ films as they have spherical nanoparticles on their surfaces in uniform distribution. This observation indicates that both films have a high surface area and could be used effectively for photocatalytic reactions. XPS analysis confirms the successful loading of Ag nanoparticles on the TiO₂ surface as presented in **Figure 3**. The XPS spectra of TiO₂ film show the presence of Ti and O and there is no peak for Ag in Ag 3d spectrum, **Figure 3 (a)**. The oxidation state of Ti is Ti⁺⁴ forming TiO₂ [9, 14]. On the other hand, there is a clear peak for Ag in the Ag 3d spectrum of Ag-loaded TiO₂ film highlighting the presence of Ag NPs on its surface, **Figure 3 (b)**.

This result indicates that Ag-loaded TiO₂ film will demonstrate outstanding photocatalytic performance under natural sunlight irradiation compared to TiO₂ film as Ag NPs improve the absorption of metal oxides in the visible region of the solar spectrum and reduce the recombination rate of the photogenerated electron-hole pairs¹¹. Encouraged by this observation, a special homemade photocatalytic reactor was designed to test the fabricated film for water purification under natural sunlight irradiation as shown in **Figure 4**.

The designed photocatalytic reactor consists of a glass beaker to hold the contaminated water and a sample holder to hold the photocatalytic film at a depth of 3 mm below the surface of the contaminated water. The advantage of the film holder is to minimize the effect of light attenuation by water and gives space for the magnetic bar present at the bottom of the beaker to rotate and produce a homogenous solution during the photocatalytic process. The entire photocatalytic reactor was placed on a magnetic stirrer working at 500 r.p.m and exposed to natural sunlight in Al Kharj, Saudi Arabia.

The concentration of MB dye in the contaminated water was checked every 15 minutes by spectrophotometer as shown in **Figure 5 (a)** and **(b)**. As expected, the Ag-loaded TiO₂ film demonstrates outstanding photocatalytic performance in degrading MB dye over the pristine TiO₂ under the same operating conditions. The photodegradation rate ($1 - (\text{final concentration} / \text{initial concentration}) \times 100 \%$) of MB dye with a concentration of 5 ppm was $\sim 99 \%$ using the Ag-loaded TiO₂ film and $\sim 65 \%$ using the pristine TiO₂ film only in 60 minutes as shown in **Figure 5 (c)**. The excellent outstanding photocatalytic performance of the Ag-loaded TiO₂ film is attributed to the presence of Ag NPs on its surface which has a synergetic effect on improving the absorption of visible light and reducing the recombination rate of the photogenerated charge carriers [15]. Furthermore, it was found that Ag-loaded TiO₂

film has excellent stability under harsh operation conditions achieving an almost constant photodegradation rate (%) for six different samples as demonstrated in **Figure 5 (d)**.

To the best of our knowledge, for the first time, highly efficient photocatalytic Ag-loaded TiO_2 **films** were successfully fabricated by **the integration of doctor blade coating and UV irradiation methods**. The fabricated films were used as immobilized photocatalytic reactors for water purification under **natural sunlight irradiation in Al Kharj, Saudi Arabia**. The Ag-loaded TiO_2 films demonstrated outstanding photocatalytic activity and excellent robustness over six cycles under the same operating conditions. This study is one of the unique works that target utilizing abundant solar energy in Saudi Arabia for environmental protection and achieving the goals of the **Saudi vision 2030**.

The fabricated Ag-loaded TiO_2 surfaces are chemically robust and exhibit outstanding antibacterial activity under visible light irradiation in **Figure 6-7**.

Application

We anticipate that this approach will provide a promising pathway for versatile applications such as water decontamination systems, antibacterial coating, and antiviruses surfaces.



***Figure 8-9:** Photographs of surfaces that we are targeting for the practical application of our research in our environment.*

Future Work

The developed photocatalytic Ag-loaded TiO_2 coating will be used to fabricate immobilized **antivirus** surfaces under natural sunlight without any chemical additives towards a healthy environment in Saudi Arabia by outstanding utilization of the abundant solar energy and achieving the sustainable development targeted by **Vision 2030**.

SECTION 5: REFERENCES

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This project investigated the photocatalytic performance of Ag-loaded TiO₂ film under natural sunlight irradiation. The Ag-loaded TiO₂ films were fabricated by the integration of doctor blade coating and UV irradiation methods. This Ag-loaded TiO₂ films can be used to degrade MB in solution and bacterial deactivation under sunlight. This study prepared Ag nanoparticles loaded mesoporous TiO₂ coating and applied as an immobilized photocatalytic reactor for water decontamination and bacterial deactivation under natural sunlight irradiation. This project is interesting, but need more tests to nfirm its application, especially for real samples. The results presented on the application of AgNPs loaded TiO₂ for water decontamination look good. Field application tests are recommended for further study.