Purification of Ambient Air by Novel Green Plant with Titanium Dioxide Nanoparticles

Abstract

**Background:** Indoor air pollution is an important environmental health problem. Nanotechnology is one of the most important methods to reduce the indoor air pollution. Titanium dioxide (TiO₂) is generally accepted as one of the most effective photoinduced catalysts. It is frequently used to oxidize organic and inorganic compounds in the air due to its strong oxidative ability and long-term photostability. The aim of this study was to determine the effectiveness of nanotechnology in the purification of ambient air by using Saudi myrtle plants treated with TiO₂. **Methods:** Experiments were conducted in two academic departments of the laboratories at the Public Sector University. Concentration of formaldehyde, nitrogen dioxide (NO₂), sulphur dioxide (SO₂) and other toxic gases was measured in the environment of the laboratories. Myrtus plant was growing in the growth media which contained TiO₂. After 8 hours of exposure of the plant, concentration of NO₂, SO₂ and other toxic pollutant gases in the air was measured. The total duration of the experiment was 4 days. **Results:** It was found that the levels of formaldehyde, volatile organic compounds (VOCs) and other pollutants were significantly reduced the concentration from 10% to 98% in the air. After intervention, air containing the concentration of formaldehyde, TVOCs, NO₂, SO₂ and carbon monoxide (CO) on the fourth day reduced from 0.251, 401, 0.032, 0.009 and 0.99 to 0.014, 54,0.0003, 0.003 and 0.01 after exposure of Myrtus plant to ambient air. **Conclusions:** Significant reduction of air pollutants in the air after application of TiO₂ in the green plant (Myrtus communis). It is a novel approach and economically feasible for purification of indoor air.

**Keywords:** Air pollution, environment, health, purification, viridiplantae

Introduction

Environmental pollution is an important public health problem.[1] Indoor air environment has a high level of pollutant concentration. Common places such as homes, schools, offices, public places and hospitals are commonly affected.[1] In the developed countries, people spend most of their time indoors and they are exposed to polluted air that may lead to adverse health effects. There are various health effects due to polluted air from mild disease to severe disease such as carcinogenic effects on human body.[2] The most common hazards are particulate matter (pm), VOCs and CO.[3] Nitrous oxide (N₂O) and VOCs are a group of air contaminants that deteriorate the air quality. Benzene, toluene, ethylbenzene and xylene (BTEX) are important components of VOCs and NOx. The NOx and VOCs have carcinogenic abilities, which produce various cancers in the human body. They also cause respiratory diseases, eyes and skin irritation as well as memory loss.[4]

The most common method to remove air contaminants is photocatalytic oxidation (PCO) of organic matter which removes air contaminants from air.[5] TiO₂ is generally accepted as one of the most effective photoinduced catalysts and it is frequently used to oxidize organic and inorganic compounds in the air due to its strong oxidative ability and long-term photostability.[6] TiO₂ is non-expensive and non-toxic material. It can effectively be used to reduce VOCs and NOx.[7]

In this photocatalyst process, TiO₂ traps and absorbs pollutant molecules from the air and converts them to harmless inorganic anions in the presence of ultraviolet (UV) sunlight.[8] TiO₂ is the ideal photocatalyst to incorporate into the existing infrastructure for improved air quality.[8] Educational institutions are the building blocks of nations, specifically, universities

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

For reprints contact: WJHLPReprints@wolterskluwer.com
where young people are trained. High levels of VOCs and formaldehyde were major causes of deterioration in indoor air quality (IAQ) at the university; resulting in adverse health disorders among staff and students. The most common health disorders were mental and respiratory disorders which lead to low performance of staff and students.\[10,11\]

There is a growing interest among different universities concerning public awareness regarding improved quality of environment. IAQ in teaching laboratories is a serious health hazard problem which directly affects the students’ ‘health and overall performance and satisfaction’.\[15,16\] PCOs processes can be used effectively in indoor air purification by getting rid of gaseous pollutants.\[12-14\]

Myrtus communis is an evergreen tree with dense flora in the Mediterranean regions and Middle East nations. These regions mostly have sunny and humid weather which is perfect for the cultivation of this tree.\[14-17\]

No previous study was conducted to determine the effectiveness of green plant treated with TiO$_2$ for purification of ambient air. In this study, IAQ and indoor environment were investigated in research laboratories of two departments at a university. Formaldehyde, VOC and toxic gases concentrations were measured in the presence and absence of myrtle plant treated with TiO$_2$. The main aim of the study was to determine the effectiveness of myrtle plant which was treated with TiO$_2$ to reduce the indoor air pollution at teaching laboratories.

**Methods**

The study was conducted in the laboratories of two academic departments at Public Sector University.

**Study Design: It is an experimental study**

**Indoor air quality assessment**

Levels of all gaseous air pollutants

Levels of the selected gaseous air pollutants were measured directly by the Gray Wolf’s Directness mobile PC-based products advanced Sense TM with Wolf Pack TM area monitor. This monitor is composed of multi-gas detectors equipped with a wireless radio frequency modem which allows the unit to communicate and transmit readings and other information on a real-time basis with a remotely located base controller. At each measuring point, several readings in parts per million (ppm) were recorded for each gaseous pollutant during the 2-h period (a reading per 15–30 min). For quality assurance, the instruments were calibrated and adjusted to record and save directly a reading every 30 min.

Application of different concentrations of TiO$_2$ nanoparticles sprayed on the Myrtus communis L. (Arabic name: Aas or Hadas) or added with the growth media and fertilizers to the plant root at controlled variables such as temperature and relative humidity.

**Preparation of TiO$_2$ nanoparticles**

TiO$_2$ nanoparticles (NPs) were P25 (80% anatase, 20% rutile, Sigma-Aldrich, USA, Art. No. 718467) were prepared in different concentrations as 1,3,5,7, ppm in water suspension after sonication. Different concentrations of TiO$_2$ NPs (40-10 nm) were prepared and applied to the Myrtus communis L. applying TiO$_2$-containing growth media to at least one of a Myrtus communis plant root, stem and leaf. The growth media has a concentration of TiO in the range of 0.5-10 ppm. Myrtus plant in the growth media, which is a liquid and gel growth media, or both, then exposing the plant to contaminant-containing air.

**Measurements of gaseous air pollutants**

Gaseous air contaminants CO, VOCs, formaldehyde, SO$_2$ and NO$_2$ were measured in different locations around the control and intervention laboratories. The temperatures, air speed and relative humidity were recorded with the measurement of air contaminants using special Kestrel 4500 equipment.

**Procedure of intervention**

The experiment was conducted over four working days in the selected laboratories. One laboratory was control and the other laboratory was intervention with TiO$_2$. Days 1-4, TiO$_2$ NPs were applied in different concentrations in the intervention laboratory. Over 8 h per day, multi readings were recorded. Every hour reading was calculated, and after every day, the average reading was calculated.

The data were collected under controlled levels of humidity, temperature and air flow exchange. However, other toxic air pollutants such as CO, NO$_2$ and SO$_2$ were tested and indicated different removal efficiency when recorded under similar settings.

**Statistical analysis**

Data were analyzed in the SPSS software. Descriptive analysis was done. Frequency was calculated for different pollutant concentrations.

**Results**

TVOCs and formaldehyde air pollutants removal by Myrtus treated with different concentrations of TiO$_2$ NPs with humidity, temperature, air velocity and air change per hour [Table 1 Intervention] and [Table 2 Control]. The concentration of formaldehyde was measured before the intervention and the range was from 0.2 to 0.3 ppm. After the intervention, the concentrations range from 0.1 to 0.2 ppm. The concentration of NO$_2$, SO$_2$, formaldehyde, TVOCs and CO reduced from the range of 0.3 to 0.4 ppm to the range of 0.1 to 0.3 ppm. Contaminant concentration in the air is reduced to 0.25 ppm from 50 ppm.

Toxic gaseous air pollutants removal by Myrtus treated with different concentrations of TiO$_2$ NPs with humidity,
temperature, air velocity and air change per hour [Table 3 Intervention] and [Table 4 Control]. Significant decrease in the concentration of toxic gaseous air pollutants after intervention of TiO₂ NPs. As an interpretation of continuous stable control performance of the Myrtus communis tree against such harmful gases with increasing the concentrations of TiO₂ from 1 to 7 ppm, the mean efficiencies of removal about 99% for CO, NO₂ and SO₂ gases, respectively, in regards to sight variation of air change per hour rate and other confounding factors such as temperature, humidity and air velocity.

Mean levels of TVOCs and formaldehyde removed by Myrtus communis treated with different concentrations of TiO₂ [Figure 1].

Discussion
The result of this study found that PCO is effective for reducing pollutants in the indoor air. This reaction can produce hydroxyl and superoxide radicals resulting in oxidation of the VOCs into CO₂, water and some intermediate compounds. Coating a photocatalyst, e.g., commercial P25 TiO₂ onto a substrate and irradiating it with UV light is the most popular method for purification of indoor air.[17]

This study found that the NO concentration reduced to 50% compared to before intervention. This result is consistent with other studies. A previous study using TiO₂ to coat an activated carbon filter found that the NO removal increased to 66%, and that BTEX was removed by more than 60%.[18,19] In the other study, toluene removal efficiency was increased from 32 to 78% when using a combination of PCO.[20]

The source of gaseous pollutants such as nitrogen, carbon and Sulphur oxides are from various commercial and industrial units due to the use of fossil fuels as power.[21-23]
It is a concern for environmental experts that there is a need for an alternative to fossil fuels which counters the hazards due to them, which is a major step for the implementation of global sustainability.\textsuperscript{[23]}

The result found that VOC concentration significantly reduced which is the same as in the previous study.\textsuperscript{[24]} The burning of fuels such as gasoline, wood, coal or natural gas is the main contributor to global VOC emissions.\textsuperscript{[25-27]} The major possible restriction of the use of plants for the control of outdoor gaseous emissions was their durability against high temperatures that are related to various power sources/consumers. Hence, it is essential to search for proper kinds of plants that are either naturally durable such as Myrtus communis or artificially made to be so.

TiO$_2$ is incorporated into various types of coatings which can be applied in many situations as an effective tool to remove VOCs and other toxic compounds from the surrounding environment, among other benefits.\textsuperscript{[28]} Any compound containing carbon is considered an organic compound, and substances which evaporate easily are described as volatile. As such, VOCs are organic compounds which eventually are converted to gases and vapor. Once the surface of the TiO$_2$ comes into contact with UV rays, it is able to react with VOCs in the air and convert them into non-toxic substances such as water and carbon dioxide. These are superior in relation to other pollution-control methods which often simply collect contaminants and store them elsewhere, essentially relocating the toxins instead of disposing them. TiO$_2$-photocatalysis is favorable in that the VOCs are legitimately eliminated and transformed into harmless substances.\textsuperscript{[28,29]}

Utilization of the TiO$_2$-containing dried plant portion substantially increases the capability of the dried plant material to reduce contaminants in comparison to dried plant material that has not been treated with a TiO$_2$-containing growth media. Preferably, the TiO$_2$-containing dried plant material is able to reduce contaminants with an efficiency of more than 5%, more than 10%, more than 20%, more than 30%, more than 50% or more than 100% in comparison to dry plant material made from a plant which has not been contacted with a TiO$_2$-containing growth media. Efficiency of contaminant removal is measured based on the molar concentration of contaminants present in the contaminant-containing air prior to and after contact with the TiO$_2$-containing dried plant.

**Conclusion**

Application of TiO$_2$ in green plants especially Myrtus communis is a novel approach for reduction of concentrations of harmful gaseous toxic and carcinogenic air pollutants in indoor and even outdoor environments.

**Acknowledgment**

The authors would like to thank Deanship of scientific research at Imam Abdulrahman Bin Faisal University for data collection.

**Financial support and sponsorship**

The authors would like to thank Deanship of scientific research at Imam Abdulrahman Bin Faisal University for the financial support given during this study, which was a part of the research project No. 2017-411-CPH.

The research project was published as US patent with number: US 2018/0279623 A1 date Oct. 4, 2018. And granted from US patent with grant number: US 10,244,764 B2 date, Apr. 2,2019.

**Conflicts of interest**

There are no conflicts of interest.

**Received:** 28 Sep 20 **Accepted:** 17 Mar 21

**Published:** 08 Apr 22

**References**

1. Wang S, Ang HM, Tade MO. Volatile organic compounds in indoor environment and photocatalytic oxidation: State of the art. Environ Int 2007;33:694-705.

2. De Witte K, Meynen V, Mertens M, Lebedev OI, Van Tendeloo G, Sepulveda-Escribano A, et al. Multi-step loading of titania on mesoporous silica: Influence of the morphology and the porosity on the catalytic degradation of aqueous pollutants and VOCs. Appl Catal B: Environ 2008;84:125-32.

3. Jones AP. Indoor air quality and health. Atmos Environ 1999;33:4555-64.

4. Park J, Lee L, Byun H, Ham S, Lee I, Park J, et al. A study of the volatile organic compound emissions at the stacks of laboratory fume hoods in a university campus. J Clean Prod 2014;66:10-8.

5. Alshuwaikhat HM, Abubakar I. An integrated approach to achieving campus sustainability: Assessment of the current campus environmental management practices. J Clean Prod 2008;16:1777-85.

6. Strini A, Cassese S, Schiavi L. Measurement of benzene, toluene, ethylbenzene and O-xylene gas phase photodegradation by titanium dioxides dispersed in cementitious materials using a mixed flow reactor. Appl Catal B-Environ 2005;61:90-7.

7. Ochiai T, Fujishima A. Photocatalytic properties of TiO2 photocatalyst and its applications for environmental purification. J Photochem Photobiol C Photochem Rev 2012;13:247-62.

8. Fujishima A, Zhang X. Titanium dioxide photocatalysis: Present situation and future approaches. Comptes Rendus Chimie 2006;9:750-60.

9. Hassan Mm, Dyilla H, Mohammad LN, Rupnow T. Effect of
Application Methods on the Effectiveness of Titanium Dioxide as a Photocatalyst Compound to Concrete Pavement. Paper presented at the 89th Transportation Research Board Annual Meeting, 2010.

10. Hussin M, Ismail MR, Ahmad MS. Air-conditioned university laboratories: Comparing CO2 measurement for centralized and split-unit systems. J King Saud Uni-Eng Sci 2017;29:191-201.

11. Godwin C, Batterman S. Indoor air quality in Michigan schools. Indoor Air 2007;17:109-21.

12. Sofuoglu SC, Aslan G, Inal F, Sofuoglu A. An assessment of indoor air concentrations and health risks of volatile organic compounds in three primary schools. Int J Hyg Environ Health 2011;214:38-46.

13. ASHRAE Standard 62-2007. Ventilation for acceptable indoor air quality. Atlanta: American Society of Heating and Refrigerating and Air-Conditioning Engineers Inc.

14. Ma X, Geiser-Lee J, Deng Y, Kolmakov A. Interactions between engineered nanoparticles (ENPs) and plants: Phytotoxicity, uptake and accumulation. Sci Total Environ 2010;408:3053-61.

15. Ochiai T, Fujishima A. Photoelectrochemical properties of TiO2 photocatalyst and its applications for environmental purification. J Photochem Photobiol C Photochem Rev 2012;13:247-62.

16. Rackes A, Waring MS. Using multiobjective optimizations to discover dynamic building ventilation strategies that can improve indoor air quality and reduce energy use. Energy Building 2014;75:272-80.

17. Sulaiman Z, Mohamed M. Indoor air quality and sick building syndrome study at two selected libraries in Johor Bharu, Malaysia. Environ Asia 2011;4:67-74.

18. Syazwan AL, Juliana J, Norhafizalina O, Azman ZA, Kamaruzaman J. Indoor air quality and sick building syndrome in Malaysian buildings. Glob J Health Sci 2009;1:126-35.

19. Toprak M, Gursoy G, Demiral Y, Cinmir AH, Sofuoglu S. Indoor air quality and occupational risk factors in university laboratories. Hava Kirliliği Arastirmaları Dergisi 2013;2:87-95.

20. USEPA. An Office Building Occupant’s Guide to Indoor Air Quality. US Environmental Protection Agency, USA; 2003.

21. Han Z, Chang VWC, Zhang L, Tse MS, Tan OK, Hildemann LM. Preparation of TiO2-coated polyester fiber filter by spray-coating and its photocatalytic degradation of gaseous formaldehyde. Aerosol Air Qual Res 2012;12:1327-35.

22. Mendes A, Pereira C, Mendes D, Aguiar L, Neves P, Silva S, et al. Indoor air quality and thermal comfort-results of a pilot study in elderly care centers in Portugal. J Toxicol Environ Health A 2013;76:333-44.

23. Song JE, Kim YS, Sohn JY. The impact of plants on the reduction of volatile organic compounds in a small space. J Physiol Anthropol 2007;22:599-603.

24. Wood RA, Orwell RL, Tarran J, Torpy F, Burchett M. Potted-plant/growth medium interactions and capacities for removal of volatiles from indoor air. J Hortic Sci Biotechnol 2002;77:120-9.

25. Orwell RL, Wood RA, Tarran J, Torpy F, Burchett MD. Removal of benzene by the indoor plant/substrate microcosm and implications for air quality. Water Air Soil Pollut 2004;157:193-207.

26. Alessio GA, De Lillis M, Fanelli M, Pinelli L, Loreto F. Direct and indirect impacts of fire on isoprenoid emissions from Mediterranean vegetation. Func Ecol 2004;18:357-64.

27. Bita CE, Gerats T. Plant tolerance to high temperature in a changing environment: Scientific fundamentals and production of heat stress-tolerant crops. Front Plant Sci 2013;4:273. doi: 10.3389/fpls.2013.00273

28. Çakir A. Essential oil and fatty acid composition of the fruits of Hippophae rhamnoides L. (Sea Buckthorn) and Myrtus communis L. from Turkey. Biochem Syst Ecol 2004;32:809-16.

29. Yau YH, Chew BT, Saifullah AZA. Studies on the indoor air quality of pharmaceutical laboratories in Malaysia. Int J Sustain Built Environ 2012;1:110-24.