Original Article

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 (TiO_2) 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 TiO_2. **Methods:** Experiments were conducted in two academic departments of the laboratories at the Public Sector University. Concentration of formaldehyde, nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and other toxic gases was measured in the environment of the laboratories. Myrtus plant was growing in the growth media which contained TiO_2. After 8 hours of exposure of the plant, concentration of NO_2, SO_2 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, NO_2 SO_2 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 TiO_2 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*

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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 (N_2O) 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] TiO_2 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] TiO_2 is non-expensive and non-toxic material. It can effectively be used to reduce VOCs and NOx.[7]

In this photocatalyst process, TiO_2 traps and absorbs pollutant molecules from the air and converts them to harmless inorganic anions in the presence of ultraviolet (UV) sunlight.[8] TiO_2 is the ideal photocatalyst to incorporate into the existing infrastructure for improved air quality.[8,9]

Educational institutions are the building blocks of nations, specifically, universities

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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'.[5,6] 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 each 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_2NPs (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_2in 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 Mytrus 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_2NPs 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 TiO_2 NPs. As an interpretation of continuous stable control performance of the Myrtus communis tree against such harmful gases with increasing the concentrations of TiO_2 from 1 to 7 ppm, the mean efficiencies of removal about 99% for CO, NO_2 and SO_2 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 TiO_2 [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 CO_2, water and some intermediate compounds. Coating a photocatalyst, e.g., commercial P25 TiO_2, 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 TiO_2 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]

Table 1: TVOCs and formaldehyde air pollutants removal by Mytrus treated with different concentrations of TiO_2 nanoparticles with humidity, temperature, air velocity and air change per hour (Intervention)

Day	TiO_2 Treatment	TVOCs (avg ppb)	Formaldehyde (avg ppm)	Relative Humidity (%)	T (°C)	Air Velocity (m/s)	Air Change per Hour (ACH)
1	1 ppm	260	0.17	57	22.8	0.08	10
2	3 ppm	150	0.12	55	21.7	0.08	12
3	5 ppm	85	0.09	60	20.2	0.09	11
4	7 ppm	54	0.014	62	22.4	0.09	12

Table 2: TVOCs and formaldehyde air pollutants removal by Mytrus treated with different concentrations of TiO_2 nanoparticles with humidity, temperature, air velocity and air change per hour (Control Conditions)

Day	TVOCs (avg ppb)	Formalde-hyde (avg ppm)	Relative Humidity (%)	T (°C)	Air Velocity (m/s)	Air Change per hour (ACH)
1	410	0.275	56	22.2	0.08	12
2	359	0.28	55	21.9	0.09	11
3	510	0.31	60	21.2	0.08	10
4	401	0.251	62	22.7	0.07	11

Table 3: Toxic gaseous air pollutants removal by Myrtus treated with different concentrations of TiO_2 nanoparticles with humidity, temperature, air velocity and air change per hour (Intervention)

Day	TiO_2 Treatment	CO ppm	NO_2 ppm	SO_2 ppm	Relative Humidity (%)	T (°C)	Air Velocity (m/s)	Air Change per hour (ACH)
1	1 ppm	1.5	0.041	0.009	57	22.8	0.08	10
2	3 ppm	0.9	0.007	0.0014	55	21.7	0.08	12
3	5 ppm	0.3	0.001	0.002	60	20.2	0.09	11
4	7 ppm	0.01	0.0003	0.0003	59	21.5	0.08	12

Table 4: Carbon monoxide, nitrogen dioxide and sulphur dioxide air pollutants levels in absence of Mytrus treated with different concentrations of TiO_2 nanoparticles with humidity, temperature, air velocity and air change per hour (Control Conditions)

Day	CO ppm	NO_2 ppm	SO_2 ppm	Relative Humidity (%)	T (°C)	Air Velocity (m/s)	Air Change per hour (ACH)
1	1.5	0.041	0.009	56	22.6	0.07	11
2	1.1	0.038	0.008	57	21.8	0.08	12
3	0.98	0.039	0.008	59	22	0.08	10
4	0.99	0.032	0.009	57	21.8	0.09	11

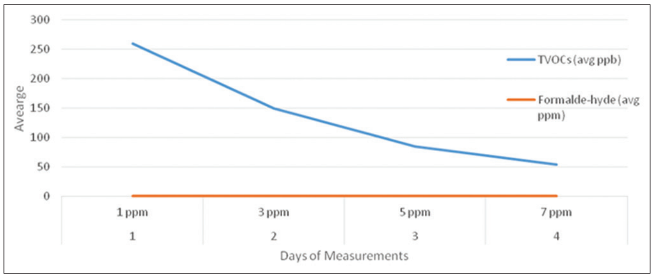

Figure 1: Mean levels of TVOCs and formaldehyde removed by Myrtus communis treated with different concentrations of TiO_2

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.[23]

The result found that VOC concentration significantly reduced which is the same as in the previous study.[24] The burning of fuels such as gasoline, wood, coal or natural gas is the main contributor to global VOC emissions.[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.[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_2comes 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_2photocatalysis is favorable in that the VOCs are legitimately eliminated and transformed into harmless substances.[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_2in green plants especially Mytrus communis is a novel approach for reduction of concentrations of harmful gaseous toxic and carcinogenic air pollutants in indoor and even outdoor environments.

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Conflicts of interest

There are no conflicts of interest.

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