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Environmental Air Pollution Control by New Egyptian Ward El Nile Based Filter

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Abstract

Air pollution is a complex problem involving particles, asbestos, gaseous contaminants, aldehydes and volatile organic compounds. Indoor air pollution is a very real and dangerous problem because indoor air is typically 2 to 5 times more polluted than the outdoor air (EPA publication, Indoor Air Quality, 2003). Indoor air pollutants not only cause discomfort but also can cause diseases by its accumulation, such as respiratory & heart diseases, asthma and cancer. It's estimated that 2.2 million deaths each year are due to indoor air pollution. Indoor air pollution problem is more complicated on developing countries than on developed ones due to fuel combustion (such as wood, charcoal and animal dung) is burned inside homes for cooking and heating. Therefore, indoor air quality improvement is paid more and more attention to preserve human health and the environment. A major aim in the air pollution control is finding economic ways of treating gas containing low levels of pollutants.

The present study is directed to provide an economic activated carbon air purifier that can conveniently installed with small volume and has high gas contaminants removal efficiency. The air purifier made from activated carbon prepared in our laboratory at National Research Center using Ward El Nile (Water Hyacinth) as raw material through chemical activation. This aspect has two benefits: the first one is presenting a technology that aims to recycle and disposal Ward El Nile (water hyacinth) and solving the problem of this water plant. The second benefit is producing cheap and local porous structure activated carbon with high surface area (S_{BET}, 1100 m^2/g). The results showed that the total mesoporous and microporous volumes of the prepared AC were 0.230 and 0.113 cm^3, respectively. The performance test of the new air purifier filter for SO_2 gas removal from kitchen indoor air environment indicated that the new filter has high SO_2 adsorption removal efficiency (90%).

In particular, the present filter concerns in promoting the development of an economically feasible air purifier system (hundred percent manufacturing in Egypt) capable of eliminating odors, Volatile Organic Compounds (VOCs) and other indoor air contaminants at ambient temperature with saving the energy consuming.

Key words: Air pollution, Environmental Protection, Ward El Nile, Activated carbon.

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1. Introduction

Ward El Nile (water hyacinth) is a free floating water plant. It has been called the world's worst invasive aquatic weed and is continuously creating environmental problems. The plant extremely rapid proliferation and overcrowd growth present serious challenges in navigation, irrigation and power generation. Water hyacinth causes many problems including blocking irrigation channels and impeding the flow of water in large rivers. It may also have adverse effects on human health by enabling the breeding of mosquitoes, bilharzias and other human parasites. In addition, water hyacinth affects the water quality by reducing water temperature, pH, bicarbonate content and increasing biological oxygen demand and free carbon dioxide. It may also reduce water nutrients level which ultimately makes water remarkably less useful for livestock and humans. The flowers of water hyacinth were first seen wild in the River Nile in Egypt in the 1890s. Prior to the construction of the Aswan Dam, the main Nile channel was relatively free of water hyacinth, as the annual floods flushed it downstream. The presence of the dam caused the flow of water to be much slower, and water hyacinth found its way into the irrigation and drainage canals fed by the Nile. In Egypt, people are highly dependent on the River Nile for transportation, fishing, drinking and tourism. Introducing water hyacinth in the River Nile has resulted in severe socio-economic problems. For example, El-Sawaf (1998a, b) reported that water lost due to the presence of water hyacinth in the River Nile branching channels and drainage system was about 47,523,000 m^3 /year. Exploring new ways of water hyacinth treatment, disposal and utilization is very important for solving its significant problem. Attempts to mechanically and manually control the plant reproduction were proven to be costly and results were negligible. The possible uses of water hyacinth include: (1) Biogas plants, heating, lighting and generation of electricity (Ofoefule1 *et al.*, 2009); (2) Composting units (ADESINA *et al.*, 2011); (3) Animal/fish food (Aboud *et al.*, 2005); (4) Using dried water hyacinth stems to make crafts, furniture and writing paper (De Groote *et al.*, 2003); (5) Phytoremediation agent and bio-sorbent for several heavy metals and other pollutants (Mahamadi and Nharingo, 2010a, b). Growing concerns about the environment have resulted in the development of new environmental technologies, new materials, and new ways to reduce; minimize and solve the environmental wastes problem. Consequently, many research works have been carried out with the main objective of utilizing water hyacinth especially that the plant has shown considerable ability to absorb and concentrate many toxic metals from aquatic environments.

On the other hand, indoor air quality (IAQ) remains a very important issue today because it can significantly affect people's health, comfort satisfaction and productivity. The health effects of indoor air pollution are important because individuals spend large fractions of their time in indoor environments and frequently have little control over exposure time or indoor air quality (IAQ). Exposure to air contaminants such as the gaseous byproducts (sulfur dioxide, SO_2; nitrogen dioxide, NO_2; ozone, O_3) and the volatile organic compounds (VOCs) has been a recent subject of concern because of the prevalence of these compounds in indoor as well as outdoor environments and because of their adverse health effects. They include aliphatic and aromatic hydrocarbons, chlorinated hydrocarbons, various ketones, acetaldehydes, and formaldehyde. Many technologies for indoor air treatments have been developed during the last years such as bio-oxidation and adsorption (Mohamed *et al.*, 2015b).

Activated carbon adsorption is an effective technology for environmental remediation, industrial processing and to remove trace contaminants from both air and water in general. Its economical drawback has stimulated the interest to utilize cheaper raw materials for the production of activated carbon (Mohamed *et al.*, 2011). Consequently, a wide variety of agricultural by-products and wastes have been investigated as cellulosic precursors for the production of activated carbon. Due to the high carbon content of water hyacinth and its ubiquity, preparing activated carbon from water hyacinth can help in utilizing the plant for air and water treatment purposes.

The present study aimed to encourage the valorization and recycle water hyacinth by producing activated carbon via chemical activation process. Another goal of the research study was to establish the technical and economic feasibility of adsorption technology, providing a new filter system for the first time to remove the indoor air contaminants in Egypt at ambient temperature and at low cost.

2. Materials and Methods

2.1 Reagents

All chemicals used were analytical grade reagents supplied by Sigma Aldrich. Phosphoric acid, Methylene Blue (MB), Sodium tetra chloromercurate, Mercuric chloride and Sodium chloride were used.

2.2 Collection of Ward El Nile

Ward El Nile (water hyacinth) samples have been collected from the River Nile (Cairo-Egypt). Samples have been washed with boiled water to remove dust and other impurities, air-dried in sunlight until all moisture was evaporated, cut into short pieces and crushed to coarse grains.

2.3 Preparation of Activated Carbon from water hyacinth

In this study, the activated carbon was produced through the chemical activation process. 50g of the dried raw materials were treated with 50% analytical grade phosphoric acid for 24 hr and then separated by decantation. The impregnated raw material was transported to a stainless steel tubular furnace system admitted to a controller temperature (Fig. 1). The soaked sample was firstly heated at 170˚C at a rate of 10˚C/min and kept at this temperature for 30 min to remove water. The activation temperature was then raised slowly until 500˚C with a heating rate of 10˚C/min under its own atmosphere for 2hr. The produced carbon was cooled and then it was subjected to thorough washing with hot water until neutral pH. Then the samples were dried in an oven at 110˚C overnight.

2.4 Characterization of prepared activated carbon

2.4.1 Specific surface area and pore volume

Surface area of the water hyacinth based activated carbon (WHAC) was determined using nitrogen as the sorbate at 77K in a static volumetric apparatus (Quantachrome NOVA Automated Gas Sorption System). Specific total surface areas were calculated using the BET equation.

2.4.2 Fourier Transform Infrared Spectroscopy (FTIR) analysis

A known mass (1 mg) of water hyacinths based activated carbon was grinded and milled with 100 mg KBr to form a fine powder. This powder was then compressed into a thin pellet under 7 tons for 5 minutes. The sample was analyzed using spectrometer and the spectrum was recorded in a spectral range.

2.4.3 Adsorption isotherm of Methylene blue by the prepared activated carbon

The adsorption capacity of the prepared activated carbon was investigated by batch adsorption experiment of Methylene Blue (MB). 100 mL of MB solution of various initial concentrations were agitated with 0.05 g of the prepared activated carbon into several small flasks using water bath shaker at 25C˚ for 72hr to attain equilibrium concentration. Then, solutions were filtered and MB concentrations were measured using a UV/VIS spectrophotometer (NOVASPEC 4049 Spectrophotometer LKB BIOCHROM) at 625 nm.

2.5 Removal of sulfur dioxide from indoor air by WHAC air purifier

The new WHAC air purifier (EG patent, application number 2015/1979) made from activated carbon prepared in our laboratory at National Research Center using water hyacinth as raw material through chemical activation. The performance of this air purifier filter was investigated for SO_2 removal from a kitchen indoor air environment. The indoor air samples from kitchen area were collected during cooking times from a house situated in Helwan industrial area. The choice of Helwan area due to the fact that sulfur dioxide (SO_2) is one of the major emitted pollutants in Helwan from several air pollution sources (motor vehicles exhaust, power generation and industrial activities). Samples were collected by drawing air with constant flow (1L/ min for 24 hours) through bubbler containing absorbance solution for SO_2. The indoor air samples had been collected before and after using the new air purifier filter.

2.5.1 Sulfur dioxide determination method

The concentration of sulfur dioxide was determined colorimetrically using West and Geake method (Harrison and Perry, 1986). The method sensitivity is reported to be in the range of 0.005 to 5 ppm SO_2 in air. Sulfur dioxide gas was collected from the kitchen indoor by using a glass bubbler sampler containing 50 mL of absorbing solution (0.1 M. Sodium Tetra-chloromercurate) with constant flow (1L/min for 24 hours). Acid bleaching pararosaniline hydrochloride solution and dilute aqueous formaldehyde were added to the complex ion. Samples were measured using an ultraviolet/visible (UV/VIS) spectrophotometer (NOVASPEC 4049 Spectrophotometer LKB BIOCHROM) at 560 nm.

3. Results and Discussion

3.1 Characterization of the activated carbon

Figure 2 shows N_2 adsorption –desorption isotherms of water Hyacinth activated carbon at 77K. The first part of the isotherm represents micropores and the second part at high relative pressure is due to multilayer adsorption in mesopores. The BET surface area (S_{BET}) of the prepared AC was about 1100 m^2 /g. Pore size distribution of the prepared water Hyacinth activated carbon by density functional theory is represented in Figure 3. It was noticed that two different peaks at 15 nm and 35 nm correspond to the micropore and mesopore, respectively. The total mesoporous and microporous volumes of the prepared AC were 0.230 and 0.113 cm^3/g, respectively. FTIR analysis was carried out to identify the functional groups present in the prepared activated carbon surface. FTIR analysis showed the presence of phenols, carboxyl and carbonyl groups. Functional surface groups affect the adsorption mechanism of the activated carbon (Zheng et al., 2014). The prepared activated carbon exhibits carbonyl functional groups (C=O at 1740 cm^{-1}). The bands observed in the range of 1000 to 1260 cm^{-1} indicating C-O single bond of the carboxylic acids and alcohols. The prepared activated carbon exhibits also hydroxyl functional groups, including hydrogen bonding (O-H, stretching at 3000-3500 cm^{-1}).

3.2 Methylene blue adsorption studies

The adsorption capacity of WHAC for MB was represented in Figure 4. The results indicated that WHAC has a maximum dye adsorption elimination capacity of 45 mg/g. This proved that the prepared activated carbon is mesoporous since the methylene blue is used to characterize mesoporous activated carbons. Mohamed et al. (2015a) reported that the sugarcane bagasse-based activated carbon was used successfully as adsorbing agents for the removal of MB dye (around 90%) from aqueous solutions. The isotherms of MB adsorption were evaluated according to the major two parameter models, Langmuir and Freundlich. The isotherms of MB adsorption were evaluated according to the major two parameter models, Langmuir model which is given by equation (1) and Freundlich model which is given by equation (2).

$$q_e = \frac{q_{max} \cdot K_L \cdot C_e}{1 + K_L \cdot C_e}, \qquad (1)$$

Where:
q_e is the amount of adsorbed MB on the prepared activated carbon at equilibrium ($mg.g^{-1}$), C_e is the concentration of the MB at equilibrium ($mg.L^{-1}$),q_{max} is the maximum adsorption capacity ($mg.g^{-1}$), and K is the adsorption intensity or Langmuir coefficient ($L.mg^{-1}$).

$$q_e = K_F \cdot C_e^{\,1/n}, \qquad (2)$$

Where K_F is the Freundlich constant and *n* is related to the magnitude of the adsorption driving force and to the adsorbent site energy distribution.
From the correlation coefficient values (R^2=0.998 and 0.997, for Langmuir and Freundlich model, respectively) and from Figure 5a, b it is noticed that the experimental adsorption isotherms fit very well to the Langmuir model. The maximum adsorption capacity, q_{max} and the adsorption equilibrium constant, K are obtained from the intercept and the slope of the linearized form of Langmuir isotherm model, respectively. The values of different parameters of Langmuir adsorption model at 25C° for MB on the prepared activated carbon are as follows: q_{max} = 45.5 $mg.g^{-1}$ and K =3.84 mg. L^{-1}.

3.3 Performance of WHAC for sulfur dioxide Removal from indoor air

The performance of WHAC air purifier for the SO_2 removal is depicted in Figures 6 and 7. Figure 6 shows that SO_2 concentration in kitchen indoor gas concentration after using WHAC filter decreased to 0.344 µg /m^3 as compared to the kitchen indoor gas concentration before using the filter (3.99 µg/ m^3) in the first day (24hr of filter application). In the second exposure day, the SO_2 concentration values in the treated and untreated samples were approximately the same that obtained in the first day (3.44 and 0.356 µg/ m^3, respectively). In the third treatment, the results showed that the SO_2 concentrations in both samples were slightly lower than that in the previous treatments. This result can be explained by the fact that SO_2 gas concentration depend on the human activities during the study. The results illustrated in Figure 7 indicated that the filter removal efficiency by studying the difference in SO_2 concentration before and after using the filter. The results showed that more than 90% SO_2 removed in the first treatment by filter. Similarly, Akbar *et al.* (2013) reported that the adsorption of SO_2 onto commercial activated carbon produced from coal was found to be 100%. Iyobe *et al.* (2004) also cited that ammonia removal efficiency by granular activated carbon was 80% at 20 C°. The removal efficiency in the second and third using of WHAC filter was slightly decreased to 89%. This high removal percentage of the filter indicated that it is still capable of removing additional SO_2 gas. Consequently, the performance of WHAC air purifier in the field-scale shows that the filter is effective as indoor air adsorbent treatment system.

4. Conclusions

This research work proves the effectiveness of water hyacinths activated carbon prepared by using chemical activation process. The WHAC has BET surface area (S_{BET}) of 1100 m^2/ g and the total mesoporous and microporous volumes of WHAC are 0.230 and 0.113 cm^3/g, respectively.
For economic cost , it was assumed that there is a considerable cost differential between the production costs of activated carbon from water hyacinth by chemical activation and the selling price for the activated carbon in the commercial marketplace. Indeed, the adsorption capacity of the prepared activated carbon should be considered. Moreover, the economic significance of large scale production is also important. The low cost and high availability of water hyacinth would be minimized the manufacture costs.
The economic water hyacinth activated carbon air purifier (EG patent application number 2015/1979) can conveniently installed with small volume and has high gas contaminants removal efficiency. The performance test of the new air purifier filter for SO_2 gas removal from kitchen indoor air environment indicated that the new filter has high SO_2 adsorption removal efficiency (90%). The SO_2 removal results confirmed that the new WHAC air purifier can be used as an effective applicable filter for treating a variety of gas pollutants from the indoor environment.

5. Acknowledgement

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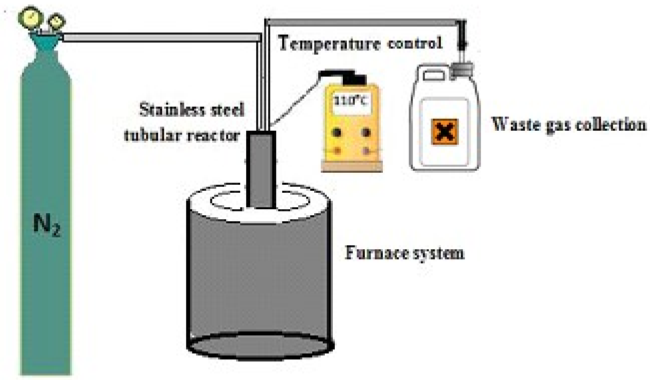

Figure 1. Diagram of the stainless steel tubular furnace system used for the preparation of activated carbon from water hyacinth

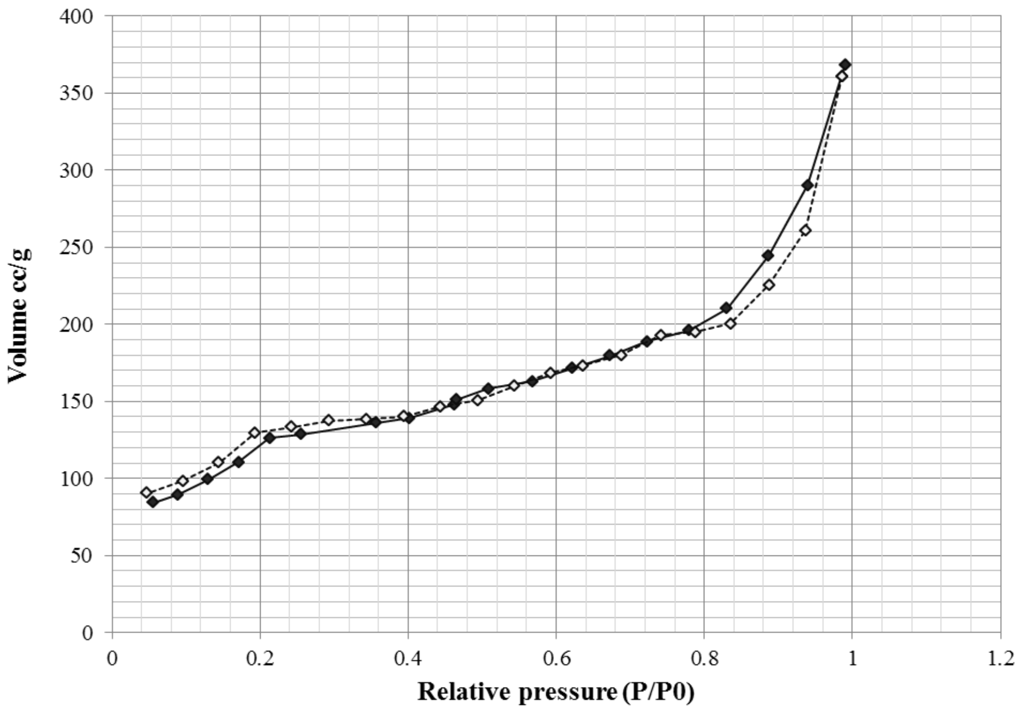

Figure 2. Adsorption –desorption isotherm of N_2 of the prepared WHAC at 77K.

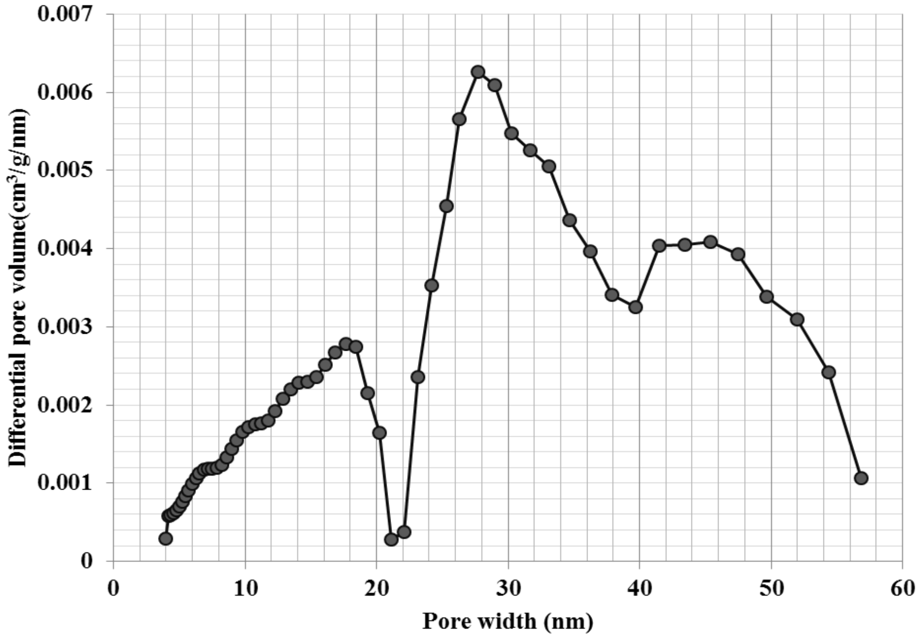

Figure 3. Pore size distribution of the prepared WHAC determined by density functional theory.

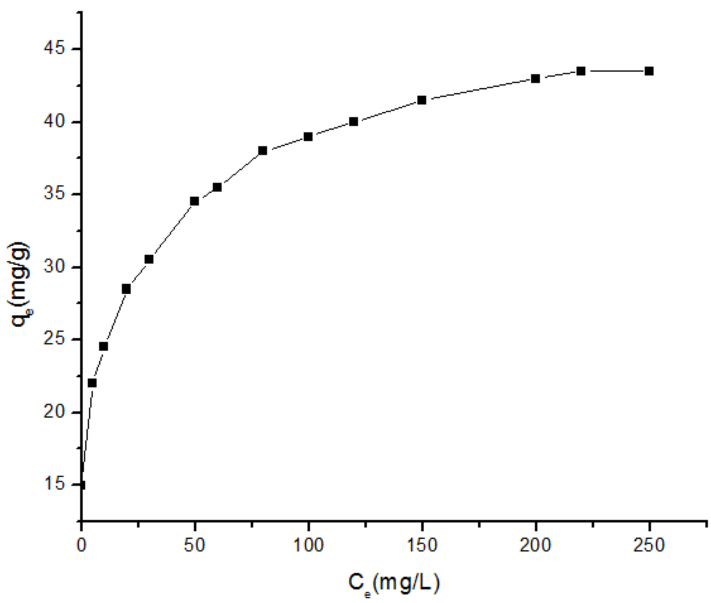

Figure 4. Adsorption isotherm of Methylene Blue using WHAC at 25°C

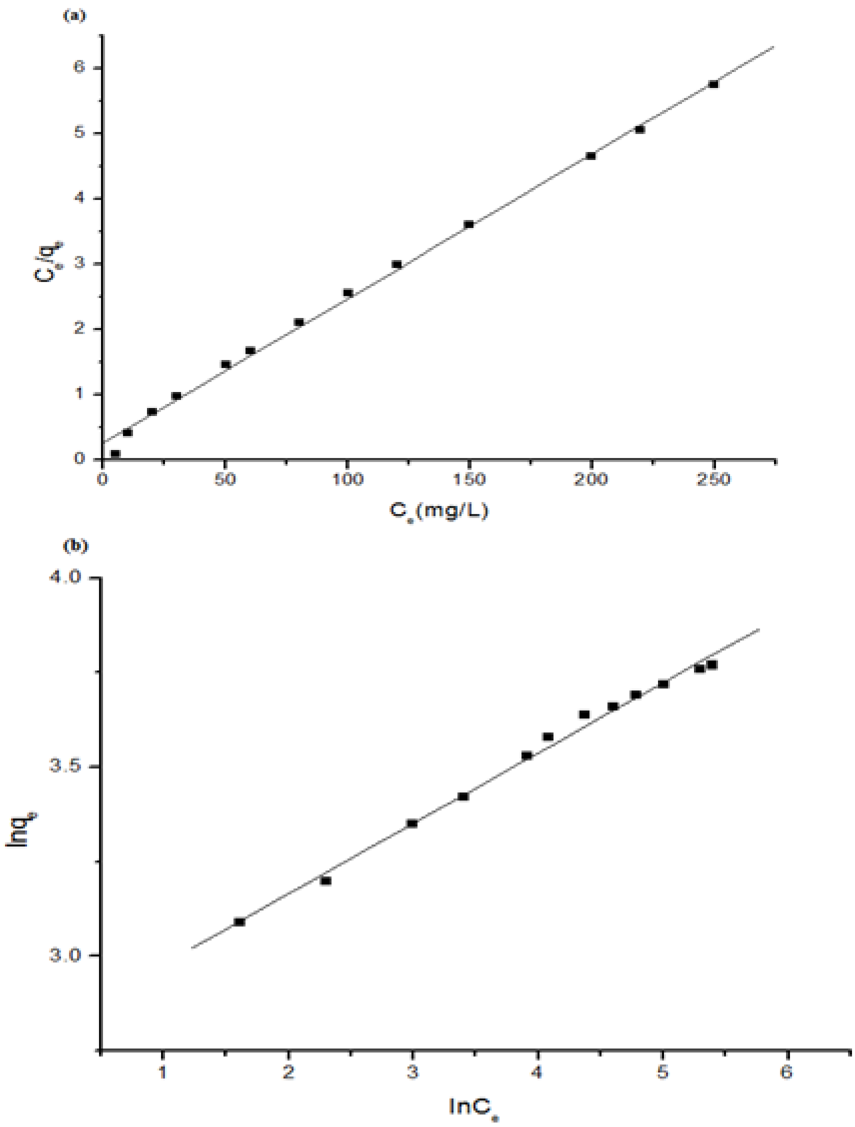

Figure 5. Langmuir isotherm (a) and Freundlich isotherm (b) for MB adsorption of WHAC

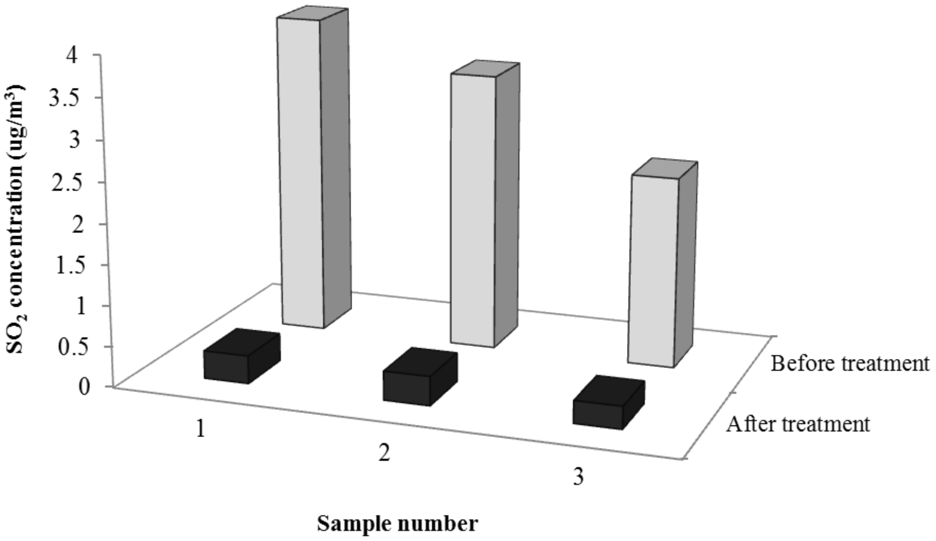

Figure 6. SO_2 gas concentration in the kitchen indoor air with and without WHAC filter

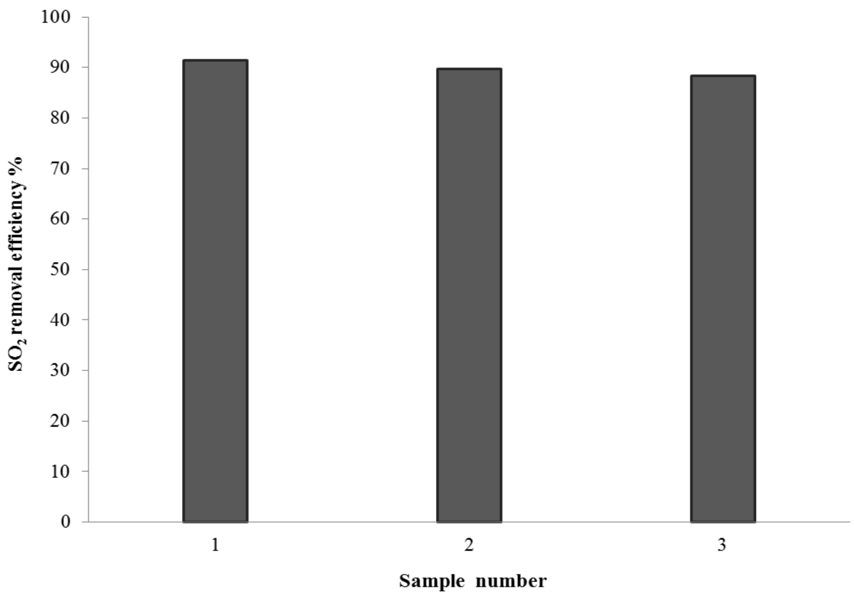

Figure 7. SO_2 removal efficiency by using the new WHAC air purifier filter