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Photocatalytic Removal of Toluene from Gas Stream using AgI-ZnO/Chitosan Nanocomposite Fixed on Glass Bed under UVA Irradiation

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ABSTRACT

In this study, AgI-ZnO/chitosan nanocomposite was synthesized and then was coated on 2×40×200 glass plates under UVA irradiation for the removal of toluene from air streams. The AgI-ZnO/chitosan Nanocomposite was characterized using XRD, SEM, FTIR and BET techniques. The analyses showed Zn and Ag were added to the composite structure with weight percentages of 32.02 and 7.31, respectively. The results confirmed that the AgI-ZnO/chitosan nanocomposite was successfully synthetized. According to the results, the photocatalytic process was able to remove 74.6% of toluene at an air flow rate of 1 L/min after 3.3 min. Also, by increasing the passing flow rate from 0.3 to 1.5 L/min through the photocatalytic reactor, the process efficiency for toluene removal increased. The toluene removal efficiency decreased with increasing relative humidity with respect to time. Moreover, increasing relative humidity decreased the photocatalyst capacity for the removal of the target pollutants. The results implied that the initial toluene concentration in the inlet stream played a key role on the photocatalysis of toluene and by further increase in the pollutant concentration higher than 20 ppm, its performance decreased dramatically. Therefore, the proposed process can be used and an effective technique for the removal of toluene from the polluted air stream under UV irradiation and increasing temperature up to 60 °C could increase its performance.

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1. INTRODUCTION

Nowadays, the quality of indoor air in residential and occupational environments has become an important issue around the world [1]. Toluene as an aromatic hydrocarbon is widely found in coal tar that can pose a major threat to human health. Toluene (methylbenzene or phenyl methane) is a colorless, odorless, water-insoluble and flammable liquid, which is commonly used as a solvent in various industries such as paints, resins, solvents, thinners, silicone sealants, chemical reagents, plastics, printing inks, adhesives, lacquers and disinfectants. It can also be used in the manufacture of foam and TNT [2]. Toluene exposure is associated with many adverse effects on human health. Low-level exposure to toluene can cause fatigue, dizziness, weakness, unbalanced behavior, memory impairment, insomnia, anorexia, and blurred vision and hearing loss. Toluene can also cause damage to liver and kidney [3]. There is no evidence at present that toluene causes cancer in humans [4]. Occupational Safety and Health Administration (OSHA) standard concentration has established a maximum exposure limit of 3 ppm for the workplace and EPA has recommended 14.3 mg/L for drinking water [5]. Due to the adverse effects of toluene on human health, it must be removed from polluted air streams before being released into the ambient air. In recent years, there has been a growing interest in the use of heterogeneous photocatalytic oxidation for indoor air purification, especially gaseous pollutants such as benzene, toluene, ethylbenzene, zylene isomers, and

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ethylene trichloride. Because the indoor pollutants can pose a serious health risk to human [6]. The use of Nano-crystalline semiconductors as photocatalysts to initiate surface reduction-oxidation reactions has gained much interest due to their unique physicochemical properties such as nano-dimensions and high specific surface area. Until now, numerous photocatalysts have been used in photocatalytic degradation of different pollutants from air and water media. Among them, zinc oxide (ZnO) nanoparticle is one of the most widely used inorganic nanoparticles, which offers good physical and chemical properties like high chemical stability, low dielectric constant, low toxicity, high electromechanical coupling coefficient, high optical absorption thresholds and high ability to degrade some organic compounds, and high catalytic activity [7-9].

ZnO as a semiconductor (type II–VI) has a band gap of 3.37 eV and an excitation binding energy of 60 eV at room temperature. Due to its non-toxicity and low-cost, it offers high potential to be used as photocatalyst. However, some limitations of ZnO such as low quantum efficiency and low visible light absorption limit its practical applications as photocatalyst. AgI is a plasmonic semiconductor that offers a narrow band gap, and hence provides excellent visible light sensitivity and photocatalytic performance. So that the combined composite of this photocaalyst can make it a more practical catalyst and boosts its application under different types of light sourses [10].

Nowadays, in order to enhance the adsorption and condensation of gaseous compounds, various stabilizers such as activated carbon, bone ash, silica, alumina, zeolites are applied. In this regard, chitosan as a natural polysaccharide provides many advantages such as hydrophilicity, biocompatibility, biodegradability and antibacterial properties. Chitosan is also capable of absorbing many metal ions because its amino groups can act as a chelating site [11]. In a review study on the applicability of chitosan based nanocomposite materials as a photocatalyst, it was found that the use of natural organic materials such as chitosan in the synthesis of nano-sized material causes an interface for the charge transfer, resulting in an increase of photocatalytic efficiency [12]. Therefore, the use of chitosan as supporting material in photocatalytic process can increase the adsorption rate of pollutant molecules, and consequently increase the photocatalytic process efficiency. Recent studies have showed that Ag-based semiconductors exhibits strong visible light absorption and high photocatalytic activity under visible light due to its narrow band gap energy [13]. Until now, there has been no study investigating the performance of AgI-ZnO/chitosan nanocomposite for the removal of toluene from polluted air stream.

Therefore, this study aimed at investigating the performance of AgI-ZnO/chitosan nanocomposite fixed on glass bed in photocatalytic degradation of toluene from polluted air stream under UVA irradiation. For this reason, on the proposed photocatalytic efficiency, the effects of various parameters, such as volumetric flow Rate, TiO_2/chitosan ratio, volumetric flow rate, and toluene concentration were investigated. Moreover, in order to evaluate the applicability of the proposed system under visible light as a cost effective and available energy, the experiments were conducted under UVA and visible light.

2. MATERIALS AND METHODS

2. 1. Materials Toluene with >99% purity were analytical grade and purchased from Merck (Darmstadt, Germany). AgI powders were purchased from Sigma Aldrich Co (USA). Chitosan was provided from tiger or pink shrimp shells that is available in the domestic markets and shrimp shops in Ahwaz city of Khuzestan province.

2. 2. Preparation of Chitosan from Chitin Chemical and biological methods are commonly used for the production of chitin and chitosan from the shrimp shell including. In this study, the chemical method was used for the production of chitosan from tiger or pink shrimp shells that is available in the domestic markets and shrimp shops in Ahwaz city of Khuzestan province. For this reason, chitin was first extracted in four steps including: 1) size reduction: In this step, the pink shrimp shells were rinsed with distilled water and stored in 0.5% sodium hydroxide solution for 4 h. Next, the resulting shells were rinsed with distilled water, dried in open air and grinded machine, 2) protein removal: 2% caustic soda solution with a weight ratio of 1:30 was used at 90 ° C for 24 h. Then, the resulting shells were rinsed and washed with distilled water until the sample pH reached near neutral and dried at 70 ° C, 3) demineralization: the shell residues were poured in 2% hydrochloric acid, mixed in 5% hydrochloric acid solution at 60 ° C for 24 h, filtered, washed to reach neutral pH and finally dried, and 4) decolorization: the obtained chitin was kept in acetone-ethanol solution (1: 1 ratio) for 24 h until the color became clear, washed to reach neutral pH, and then dried. Eventually, chitosan was obtained the deacetylation of the prepared chitin from the previous stages.

2. 2. Preparation of AgI-ZnO Nanocomposite In order to prepare 0.188 mol of silver iodide crystal, 0.578 g of zinc nitrate and 506.08 g of silver nitrate were dissolved in 100 mL of distilled water and stirred at room temperature. Then, NaOH solution (5 M) was added dropwise to the resulting solution at room temperature to reach pH of 9.5. Then, the aqueous sodium iodide

solution (0.076 g of sodium iodide dissolved in 50 mL of distilled water) was slowly added into the light brown suspension until the solution turned yellow. The resulting yellow suspension was then refluxed for 60 min at approximately 196 °C. The formed olive product was centrifuged. The obtained precipitate was removed and washed twice with distilled water and ethanol to remove unreacted reagents and dried at 60 ° C for 24 h.

2. 3. Synthesis of AgI-ZnO/Chitosan Nanocomposite In the present study, AgI-ZnO/chitosan nanocomposite was synthetized in three different ratios of 0.5: 1, 1: 1, and 1: 2 chitosan: AgI-ZnO. For preparing AgI-ZnO/chitosan nanocomposite with a ratio of 1: 1, 2 g of AgI-ZnO powder was poured into 100 mL of distilled water, and then placed in an ultrasonic bath for 5 h to form a suspension. Next, 2 g of the chitosan powder was added into 100 mL of 5% acetic acid solution and placed on a shaker at 60 rpm. Afterward, the resulting mixture was added into the AgI-ZnO suspension until white gel was formed

2. 4. Characterization of AgI-ZnO/Chitosan Nanocomposite In this step, the prepared AgI-ZnO/chitosan nanocomposite was characterized using XRD technique (to identify crystalline compounds or phases), (to study surface morphology), FTIR (to determine functional groups) and BET (to measure specific surface area).

2. 5. Experiments In this research, AgI-ZnO/chitosan nanocomposite was first synthetized and then was coated on 2×40×200 glass plates. Next, the glass containing harmonious nanocomposite was placed inside a plexiglass chamber with a useful volume of 1 L (5 ×8× 25 mm). All experiments were conducted in this set-up as continuous–flow reactor. The airflow was generated using the air pump (BioLite High-volume Sample Pump, SKC) and passed through the chamber containing toluene (37% toluene was used to provide various concentrations of toluene in the gas phase) and a humidifier (containing water) to provide the desirable humidity. Afterward, the humid air stream containing toluene was entered into a mixing chamber and the photocatalytic reactor. The air stream containing the compounds of interest was entered into the reactor and passed on the photocatalytic glass containing photo catalyst under UV irradiation at a wavelength of 365 nm, which provided by two UVA lamps (6 watt). The concentration of toluene in the inlet and outlet of the reactor was measured by sampling valves embedded in the inlet and outlet of the reactor using a direct-reading monitor (PhoCheck TIGER). In order to evaluate the effects of visible light on the process performance, a 30-watt fluorescent tube was applied in the reactor. A schematic illustration of the reactor used is shown in Figure 1.

In order to determine the optimum conditions of the various parameters affecting the photocatalytic process, the experiments were performed at three different levels of each parameter under UV irradiation (Table 1). In order to determine the effect of irradiation type on process efficiency, the experiments were conducted under UV and visible irradiation. The parameter were optimized by the one-factor-at-a-time method as presented in Table 1. Moreover, in order to investigate kinetics and thermodynamics of the process, the effects of time and temperature variables under optimal conditions were also investigated. Table 2 shows how the experiments were performed. Sample size determination was based on the simplicity of the design of the experiment (combining factors to perform the experiments) based on the one-factor-at-a-time method. It should be noted that in the present study, the effect of irradation time was evalauted by changing the duration of the use of UVA lump in the reactor. Because, increasing the irradiation time may affect on the photocatalyst. Moreover, the effects of temperature and time (in a specific range) on the process efficiency were investigated (see Table 3).

3. RESULTS AND DISCUSSION

3. 1. Nano-composite Characterization The AgI-ZnO/chitosan nanocomposite was characterized using XRD, FTIR and BET techniques. Figure 2 a presents the FTIR spectrum of the synthetized AgI-ZnO/chitosan nanocomposite. As observed here, the broader and stronger peak at 3425 cm^{-1} is attributed to the NH_2 and OH group stretching vibration, which may be due to the interaction between these groups and ZnO. Moreover, the presence of peaks at 2924 and 2859 cm^{-1} may be assigned to asymmetric stretching OH, CH_3 and CH_2 of chitosan polymer in the structure of the Nan-composite [14]. Moreover, the presence of peak at 1647 cm^{-1} may be assigned to addition of silver nanoparticles to the

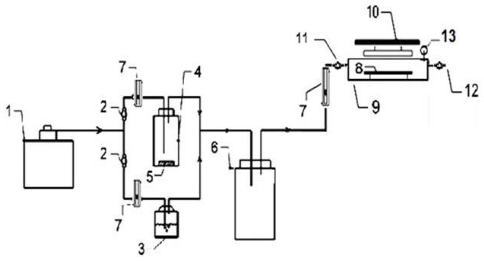

Figure 1. A schematic illustration of the reactor used (1-Air Pump, 2- Flow adjustment valve, 3- Humidifier, 4- Toluene chamber, 5- Toluene solution, 6- Mixing chamber, 7- Flowmeter, 8-Photocatalyst, 9- Reaction reactor, 10- Ultraviolet lamp, 11- Input sampling valve, 12- Output sampling valve, 13- Humidity meter)

TABLE 1. Determination of optimum parameters under UV irradiation

Volumetric flow rate (L/min)	**Toluene concentration (ppm)**	**Relative humidity (%)**	**TiO_2/chitosan ratio**	**Volumetric flow rate (L/min)**		
	4	60	1:1	0.2	0.6	1
Relative humidity (%)	Toluene concentration (ppm)	Volumetric flow rate (L/min)	TiO_2/chitosan ratio	Volumetric Flow Rate (L/min)		
	4	Optimum	1:1	20	50	80
AgI-ZnO/chitosan ratio	Toluene concentration (ppm)	Volumetric flow rate (L/min)	Relative humidity (%)	TiO_2/Chitosan Ratio		
	4	Optimum	Optimum	1:0.5	1:1	2:1
Total runs with 2 replicates			18			

TABLE 2. Effect of toluene concentration under optimum operating conditions on process efficiency

Irradiation source	**Optimal conditions**	**Toluene concentration (ppm)**				
UV-A	Flow, Relative humidity and Chitosan /Agi-Zno ratio	1	2	4	6	8
Visible Light	Flow, Relative humidity and Chitosan /Agi-Zno ratio	1	2	4	6	8
Total runs with 2 replicates				20		

TABLE 3. Effect of temperature and time on process efficiency

Optimal conditions	**Irradiation source**	**Parameters**	**Levels**				
Concentration, relative humidity and chitosan /AgI-ZnO ratio	UV-A	Irradiation time* (s)	60	75	100	150	300
		Temperature (˚ C)	25		45	65	
	Visible light	Irradiation time (s)	60	75	100	150	300
		Temperature (˚ C)	25		45	65	
Total runs with two replicates					32		

*irradiation time: Duration of use of UV lamp before sampling

proposed composite. According to the XRD analysis of the synthetized nanocomposite (Figure 1b), the peaks observed at 2θ values of 37.9002 °, 47.3018 °, 56.1889 °, and 76.8833 ° that are assigned to (111), (200), (220) and (311) planes of pure silver based on the face-centered cubic structure (JCPDS, file No. 04-0783) [15,16]. Figures 2c and 2d show the EDAX analysis results of the synthetized nanocomposite. As can be see here, Zn and Ag was added to the composite structure with weight percentages of 32.02 and 7.31, respectively, which confirmed that the AgI-ZnO/chitosan nanocomposite was successfully synthetized. Figure 2e demonstrates the SEM images of the AgI-ZnO/chitosan nanocomposite. The SEM analysis indicated spherical shape of Ag nanoparticles that the size of most particles are more than 100 nm.

3. 2. Effect of Flow Rate In this study, in order to investigate the performance of the photocatalytic process under different flow rates, the experiments were conducted under 5 flow rates (0.3, 0.5, 1, 1.5 and 2 L/min). Figure 3 presents the changes of process efficiency with increasing flow rates with respect to time. As observed, by increasing passing flow rate from 0.3 to 1.5 L/min through the photocatalytic reactor, the process

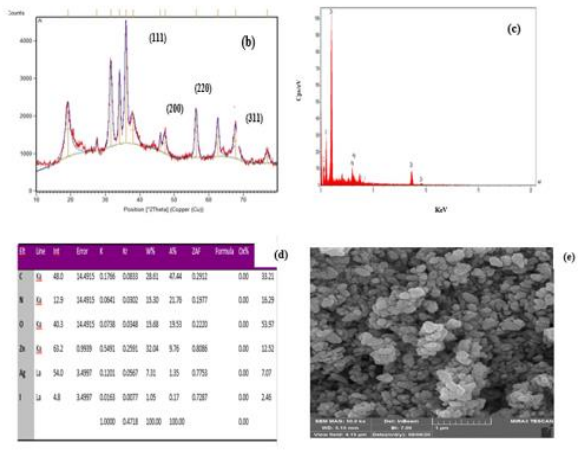

Figure 2. (a) FTIR analysis, (b) XRD, (c and d) EDAX, and (e) SEM analyses of AgI-ZnO/chitosan Nanocomposite

efficiency for toluene removal increased. Flow rate of the entrance stream to a photocatalytic reactor plays a key role in the photocatalysis of the target pollutant, due to its role in the determination of irradiation time of pollutant in the reactor. It is suspected that increasing flow rate up to certain amount provides enough irradiation time of the pollutant and sufficient mixing for the photocatalytic process. While further increasing the air flow rate can decrease the residence time of the pollutant, and thereby decreases the process efficiency. As can be seen in Figure 2, the process efficiency of the proposed photocatalytic process increased with increasing air flow rate up to 1.5 L/min, while by further increasing the air flow rate to 2 L/min, a dramatic decrease was observed in the process performance. This phenomenon may be attributed to the high speed of the air stream inside the reactor, which decreases the UV irradiation time in the reactor. According to the results, photocatalytic process increased with increasing UV irradiation time from 0 to 0.6 min and then a constant efficiency was observed with respect to time. The photocatalytic process was able to remove 74.6% of toluene in at an air flow rate of 1 L/min after 3.3 min of irradiation time. This finding indicated that the proposed process requires low contact time to remove the pollutant in the air stream and further increasing in the contact time did not have an obvious effect on increasing process efficiency. In a recent study, the synergistic effect of pollutant initial concentration and air flow rate on the plasma-photocatalytic process for ethylbenzene removal was investigated. It was found that the flow rate had a negative effect on the ethylbenzene removal efficiency. The highest performance was observed at the lowest air flow rate. This difference with our findings may be attributed to the difference in the volume of entrance air and the dimensions of the used reactor. In the present study, the effect of air flow rate was investigated in the range 0.3-2 L/min, while in the mentioned study, the effect of air flow rate was very lower (15-45 mL). On the other hand, the simultaneous effect of increasing the pollutant concentration can also be related to decrease in overall process efficiency in the mentioned study in compared to the present study [17].

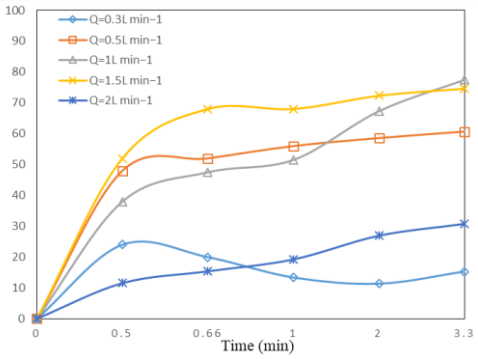

Figure 3. Effect of air flow rate on photocatalysis of toluene

3. 3. Effect of Relative Humidity Water vapor is generated as a byproduct in the most of reactions in industries such as burning in petroleum and gas refineries. The content of water vapor is measured as relative humidity in contaminated air stream. It is recommended to measure the relative humidity along with other parameters in the exhaust air flow from many industries due to its effects on the control processes. In this regard, it is necessary to evaluate relative humidity on the performance of control processes. For this reason, in the present study, the influences of different levels of relative humidity in the range 30-80% on the proposed process efficacy were investigated. Figure 4 illustrates the effects of the relative humidity on the photocatalysis of toluene with respect to time. As can be seen here, the performance of the photocatalytic process with the AgI-ZnO/chitosan nanocomposite fixed on glass bed decreased with increasing relative humidity level. Moreover, this decreasing effect increased with respect to time. Based on the results, the highest removal efficiency was obtained at 30% of relative humidity, which was about 70%. This phenomenon is clearly attributed to the competition of water molecules at higher humidity to absorb on the vacant sites on the photocatalyst surface, which decreases the available vacant sites of the photocatalyst for the target pollutant [18]. These results are in agreement with the findings of Jiancai et al. [19] study on the catalytic combustion of toluene over copper based catalysts with different supports in presence of water vapor.

3. 4. Effect of AgI-ZnO/Chitosan Ratios In this step, the effect of different ratios of Ag-ZnO/chitosan (0.5:1, 1:1 and 2:1) on the process performance in the removal of toluene from air stream was investigated. As can be seen in Figure 5, at the Ag-ZnO/chitosan ratio of 0.5:1, the photocatalytic efficiency reached about 70%. This result is due to the photocatalytic activity of the AgI-ZnO at this ratio, which can generate higher active species such as •OH and $•O_2$-. Various photocatalysts generate different main active species because of the difference in their band structure or phase composition.

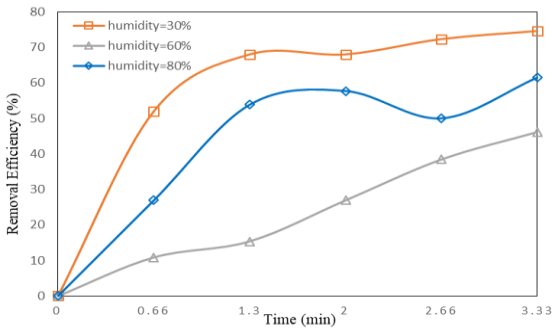

Figure 4. Effect of relative humidity on photocatalysis of toluene

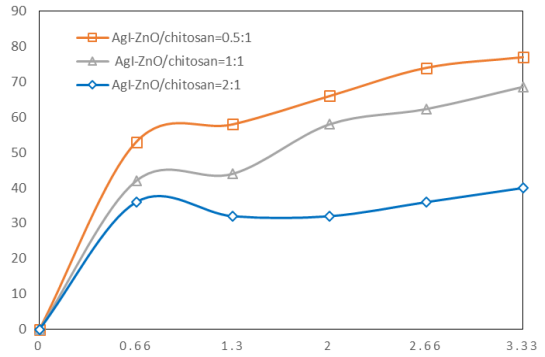

Figure 5. Effects of different ratios of AgI-ZnO /chitosan in the process performance

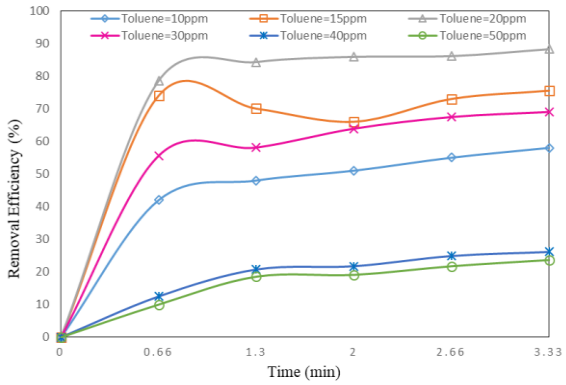

Figure 6. Effects of different toluene concentration on the process performance

Therefore, the different ratio of the proposed photocatalyst can affect its photocatalytic activity. So that the process efficiency decreased by increasing AgI-ZnO/chitosan ratio and the most removal efficacy was observed at 0.5:1 ratio [9,10]. On the other hand, chitosan as supporting material in photocatalytic process can increase the adsorption rate of the pollutant molecules and consequently increase the photocatalytic process efficiency, which is consistent with our findings, because increasing chitosan with a specific ratio of AgI-ZnO in the proposed nanocomposite could increase the photocatalytic efficiency for the removal of toluene from air stream. While, further increase of AgI-ZnO could reduce the light transmittance and decrease the light penetration. Therefore, a high dosage of AgI-ZnO limits the photocatalysis of toluene in the air. This result is consistent with the finding of Xie et al. [20] study, on the enhanced photocatalytic activity of Se-doped TiO_2 under visible light irradiation. They reported that further increasing the doping concentration decreased the photocatalytic activity of the photocatalyst.

3. 5. Effect of Toluene Concentrations The efficiency of photocatalytic process for the removal of pollutants is obviously dependent to the pollutant concentration. In air purification processes using photocatalytic, due to short UV irradiation time of the pollutant inside the reactor, the pollutant concentration plays a key role in the process efficiency. For this reason, in the present study, the effects of various toluene concentration on the process performance were investigated. As observed in Figure 6, the efficiency of the proposed photocatalytic process reduced with increasing toluene concentration from 20 to 50 ppm. This is clearly due to the limited capacity of the nanocatalyst used in the process, which by increasing the pollutant concentration from a certain amount, the empty sites available on the nanocomposite surface is reduced, and hence there is no enough capacity in the nanocomposite to decompose the high concentration of the pollutant molecules. This result is consistent with the findings of previous studies [1-3]. In contrast, the highest removal efficiency was obtained at 20 ppm of toluene in the inlet stream into the reactor. Indeed, the process efficiency increased with increasing toluene concentration from 10 to 20 ppm. This phenomenon can be due to the absence of the minimum concentration of contaminants at low concentrations for the reaction in the process. This result implied that this process can efficiency used for different concentrations of air pollutants up to a certain concentration without decreasing its performance. Binas et al. [21] in a similar study on the removal of toluene along with other organic and inorganic pollutants, reported that the photocatalytic process with modified TiO_2 decreased with increasing toluene concentration; however, this decreasing effect was negligible at low concentrations of toluene in the range 10-20 ppm, which is in agreement with our findings.

3. 6. Comparison of Effect of Ultraviolet Light and Visible Light In this study due to the use of Ag in the synthesis of photocatalyst it was expected to be applicable under visible light in addition to UV irradiation. For this reason, the performance of the AgI-ZnO/chitosan nanocomposite fixed on glass bed under the UV irradiation was compared to visible light for the photocatalytic removal of toluene from gas stream. The results are presented in Figure 7. As can be see here, the photocatalytic process offered a better efficiency under UV irradiation at different temperatures compared to visible light. This result can be attributed to the high photocatalytic acitivity of AgI-ZnO/chitosan nanocomposite under UVA, which generates higher active species such as $^{\bullet}OH$ and $^{\bullet}O_2^-$[9,10]. Therefore, our findings implied that the proposed photocatalyst showed higher photocatalyst activity under UVA irradiation compared to visible light, because of higher degradation rate of toluene under UVA irradiation. According to the results, the highest removal efficiency of toluene was

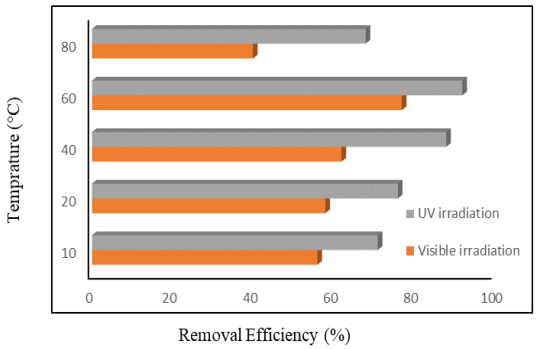

Figure 7. Effects of ultraviolet irradiation and visible light on photocatalytic removal of toluene from gas stream using AgI-ZnO/chitosan Nanocomposite fixed on glass bed

observed at 60 °C under UV irradiation. Therefore, the photocatalytic process has high performance at higher reaction temperature that can be attributed to the increase in the rate of chemical reactions at high temperatures. This result is consistent with the findings of Hu et al. [22] on the effect of reaction temperature on the photocatalytic degradation of methyl orange under UV-Vis light irradiation. In the mentioned study, it was reported that the photo catalytic efficiency increased five times by increasing reaction temperature in the range 30-100 °C [22-24]. This finding emphasize the role of solar energy in such photocatalytic processes that can be used for activation of the used catalyst simultaneously with increasing the reaction temperature.

4. CONCLUSION AND FUTURE PERSPECTIVE

In this study, AgI-ZnO/chitosan nanocomposite was first synthetized and used for photocatalytic degradation of toluene from polluted air. The laboratory experiments indicated that the process efficiency of the proposed photocatalytic process increased with increasing air flow rate up to 1.5 L/min, while by further increasing the air flow rate to 2 L/min, a dramatic decrease was observed in the process performance, and obviously decreased with increasing relative humidity. Moreover, the process efficiency was also decreased by increasing *AgI-ZnO/chitosan* ratio and the most removal efficacy was observed at 0.5:1 ratio. The results implied that the initial toluene concentration in the inlet stream played a key role on the photocatalysis of toluene and by further increase in the pollutant concentration higher than 20 ppm, its performance decreased dramatically. Our findings also indicated that the proposed process offered a better performance under UV irradiation compared to visible light and increasing temperature up to 60 °C could increase its performance. It can be concluded that the AgI-ZnO/chitosan nanocomposite fixed on glass bed can effectively remove toluene from air stream under UV light, and given the synergetic effect of high temperature on the process efficiency, it is recommended to perform further study on the application of such process under sunlight as a natural and cost-effective source for UV and temperature rise. Lack of analysis of the production of by-products during photocatalytic process to determine the quality of the outlet gase and lack of investigation of the effect of other contaminants on the process efficiency are considered as the main limitations in conducting this research. Further studies are requred to investigate the effect of some other parameters such as other polutants on the AgI-ZnO/chitosan photocatalyst under UVA irradiation as well as by-products in the outlet gas of the proposed process in order to determine the quality of the process exhaust gas.

5.ACKNOWLEDGMENT

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6. REFERENCES

1. Samarghandi, M. R., Daraee, Z., Shekher Giri, B., Asgari, G., "Reza Rahmani, A.and Poormohammadi, A., Catalytic ozonation of ethyl benzene using modified pumice with magnesium nitrate from polluted air", ***International Journal of Environmental Studies,*** Vol. 74, (2017) 486-499. DOI: 10.1080/00207233.2017.1316042.
2. Zhu, B., Zhang, L.-Y., Li, M., Yan, Y., Zhang, X.-M.andZhu, Y.-M., "High-performance of plasma-catalysis hybrid system for toluene removal in air using supported Au nanocatalysts" ***Chemical Engineering Journal,*** Vol. 381, (2020), 122599. DOI: 10.1016/j.cej.2019.122599.
3. Samarghandi, M.R., Babaee, S.A., Ahmadian, M., Asgari, G., Ghorbani Shahna, F.and Poormohammadi, A., Performance catalytic ozonation over the carbosieve in the removal of toluene from waste air stream, ***Journal of Research in Health Sciences***, Vol. 14, (2014), 227-232.
4. Pitarque, M., Vaglenov, A., Nosko, M., Hirvonen, A., Norppa, H., Creus, A., Marcos, R., "Evaluation of DNA damage by the Comet assay in shoe workers exposed to toluene and other organic solvents, Mutation", ***Research/Genetic Toxicology and Environmental Mutagenesis,*** Vol. 441, (1999) 115-127. DOI: 10.1016/s1383-5718(99)00042-x.
5. Hsieh, G. C., Sharma, R. P., Parker, R. D., "Immunotoxicological evaluation of toluene exposure via drinking water in mice", ***Environmental Research,*** Vol. 49, (1989) 93-103. DOI: 10.1016/S0013-9351(89)80024-6.
6. Poormohammadi, A., Bahrami, A., Ghiasvand, A., Shahna, F. G. and Farhadian, M., "Preparation of Carbotrap/silica composite for needle trap field sampling of halogenated volatile organic compounds followed by gas chromatography/mass spectrometry determination", ***Journal of Environmental Health Science and Engineering***, (2019) 1-9. DOI: 10.1007/s40201-019-00418-2.

7. Salehi, R., Arami, M., Mahmoodi, N. M., Bahrami, H., Khorramfar, S., "Novel biocompatible composite (chitosan–zinc oxide nanoparticle): preparation, characterization and dye adsorption properties", ***Colloids and Surfaces B: Biointerfaces***, Vol. 80, (2010), 86-93. DOI: 10.1016/j.colsurfb.2010.05.039.
8. Scharnberg, A. A., de Loreto, A. C., Alves, A. K. "Optical and structural characterization of Bi2FexNbO7 nanoparticles for environmental applications", ***Emerging Science Journal***, Vol. 4, (2020) 11-17. DOI: 10.28991/esj-2020-01205
9. Gharibshahian, E. "The Effect of Polyvinyl Alcohol Concentration on the Growth Kinetics of $KTiOPO_4$ Nanoparticles Synthesized by the Co-precipitation Method", ***High Tech and Innovation Journa***l. Vol. 1, (2020), 187-193. Doi: 10.28991/HIJ-2020-01-04-06
10. Lu, J., Wang, H., Dong, Y., Wang, F., Dong, S., "Plasmonic AgX nanoparticles-modified ZnO nanorod arrays and their visible-light-driven photocatalytic activity", ***Chinese Journal of Catalysis,*** Vol. 35, (2014), 1113-1125. DOI: 10.1016/S1872-2067(14)60055-3.
11. Yaghmaeian, K., Jaafarzadeh, N., Nabizadeh, R., Rasoulzadeh, H., Akbarpour, B., "Evaluating the performance of modified adsorbent of zero valent iron nanoparticles–Chitosan composite for arsenate removal from aqueous solutions", ***Iranian Journal of Health and Environment,*** Vol. 8 (2016) 535-548.
12. Nithya, A., Jothivenkatachalam, K., Prabhu, S., Jeganathan, K. "Chitosan based nanocomposite materials as photocatalyst–a review", ***In Materials Science Forum***, Vol. (2014), 79-94. DOI: 10.4028/www.scientific.net/MSF.781.79.
13. Li, J., Fang, W., Yu, C., Zhou, W., Xie, Y., "Ag-based semiconductor photocatalysts in environmental purification", ***Applied Surface Science***, Vol. 358, (2015). DOI: 46-56. 10.1016/j.apsusc.2015.07.139
14. Abbasipour, M., Mirjalili, M., Khajavi, R., Majidi, M. M., "Coated cotton gauze with Ag/ZnO/chitosan nanocomposite as a modern wound dressing", ***Journal of Engineered Fibers and Fabrics***, Vol. 9, (2014) 155892501400900114.
15. Meng, Y., "A sustainable approach to fabricating Ag nanoparticles/PVA hybrid nanofiber and its catalytic activity", ***Nanomaterials***, Vol. 5, (2015) 1124-1135. DOI: 10.3390/nano5021124.
16. Samadi, M. T., Shokoohi, R., Poormohammadi, A., Azarian, G., Harati, M., Shanesaz, S., "Removal of bisphenol, using antimony nanoparticle multi-walled carbon nanotubes composite from aqueous solutions", ***Oriental Journal of Chemistry,*** Vol. 32, (2016) 1015-1024. DOI : 10.13005/ojc/320227
17. Parvari, R., Ghorbani-Shahna, F., Bahrami, A., Azizian, S., Assari, M. J., Farhadian, M., "Core-Discontinuous Shell Nanocomposite as an Indirect Z-Scheme Photocatalyst for Degradation of Ethylbenzene in the Air Under White LEDs Irradiation", ***Catalysis Letters***, (2020) 150, 3455-3469. DOI: 10.1007/s10562-020-03236-6.
18. Bose, R., "Methane gas recovery and usage system for coalmines, municipal land fills and oil refinery distillation tower vent stacks", ***Google Patents,*** 2010.
19. Jiancai, F., Xiao, C., Qibin, X., Hongxia, X., Zhong, L., "Effect of relative humidity on catalytic combustion of toluene over copper based catalysts with different supports", ***Chinese Journal of Chemical Engineering***, Vol.17, (2009) 767-772. DOI: 10.1016/S1004-9541(08)60275-X.
20. Xie, W., Li, R. Xu, Q., "Enhanced photocatalytic activity of Se-doped TiO_2 under visible light irradiation", ***Scientific Reports***, Vol. 8, (2018) 8752.
21. Binas, V., Venieri, D., Kotzias, D.andKiriakidis, G., "Modified TiO_2 based photocatalysts for improved air and health quality", ***Journal of Materiomics,*** Vol. 3, (2017) 3-16. DOI: https://doi.org/10.1016/j.jmat.2016.11.002.
22. Hu, Q., Liu, B., Song, M., Zhao, X., "Temperature effect on the photocatalytic degradation of methyl orange under UV-vis light irradiation", ***Journal of Wuhan University of Technology-Materials Science Edition***, Vol. 25, (2010) 210-213. DOI: 10.1007/s11595-010-2210-5.
23. Priscilla, S. J., Judi, V. A., Daniel, R., Sivaji, K. "Effects of chromium doping on the electrical properties of zno nanoparticles", ***Emerging Science Journal***, Vol. 4, (2020), 82-88. DOI: 10.28991/esj-2020-01212
24. Sohrabi, S., Akhlaghian, F., "Fe/TiO_2 catalyst for photodegradation of phenol in water", ***International Journal of Engineering, Transactions A: Basics, Vol.*** 28 (2015) 499-506. DOI: 10.5829/idosi.ije.2015.28.04a.02

Persian Abstract

چکیده

در این مطالعه، نانوکامپوزیت AgI-ZnO/کیتوزان سنتز شد و روی صفحات شیشه ای 2 × 40 × 200 تحت تابش UVA پوشانده شد، سپس برای از حذف تولوئن از جریان هوا به کار برده شد. نانوکامپوزیت کیتوزان/AgI-ZnO با استفاده از تکنیک های XRD، SEM، FTIR و BET بررسی شد. تجزیه و تحلیل نشان داد که Zn و Ag به ترتیب با درصد وزنی 32/02 و 7/31 درصد به ساختار کامپوزیت اضافه شدند که تأیید کرد که نانوکامپوزیت AgI-ZnO/ کیتوزان با موفقیت سنتز شده است. با توجه به نتایج، فرآیند فوتوکاتالیستی توانست 74/6 درصد تولوئن را با سرعت جریان هوا 1 لیتر بر دقیقه پس از 3/3 دقیقه حذف کند. همچنین ، با افزایش میزان جریان عبوری از 0/3 به 1/5 لیتر در دقیقه از طریق راکتور فوتوکاتالیستی، راندمان فرآیند حذف تولوئن افزایش یافت. راندمان حذف تولوئن با افزایش رطوبت نسبی با گذشت زمان کاهش می یابد. علاوه بر این، افزایش رطوبت نسبی ظرفیت فوتوکاتالیست را برای حذف آلاینده هدف کاهش می دهد. نتایج حاکی از آن است که غلظت اولیه تولوئن در جریان ورودی نقش اساسی در فتوکاتالیز تولوئن داشته و با افزایش بیشتر غلظت آلاینده بالاتر از 20ppm ، عملکرد آن به طرز چشمگیری کاهش می یابد. بنابراین، فرآیند پیشنهادی می تواند و یک تکنیک موثر برای حذف تولوئن از جریان هوای آلوده تحت تابش اشعه ماورا بنفش مورد استفاده قرار گیرد .و افزایش دما تا 60 درجه سانتیگراد عملکرد آن را افزایش دهد.