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Original Article

Process modeling of NH_3 contaminated waste air treatment in photocatalytic reactor using TiO_2 coated glass tubes

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Abstract

Ammonia (NH_3) is a noxious gas that can cause serious damage to human health and to the environment. Thus, elimination of NH_3 in waste air by treating before releasing to the atmosphere is necessary. In this study, titanium dioxide (TiO_2) nanoparticle Degussa P25 coating on glass cylindrical tube supporters was synthesized and used as photocatalytic in a continuous photoreactor device. UV light source was vertically installed around the photoreactor in a stainless steel chamber. Experiments were designed and conducted based on central composite design (CCD) and analyzed using response surface methodology (RSM). This RSM was used to evaluate the effects of process variables and their interactions towards attainment of their optimum conditions. Three significant variables, light intensity (23-114W/m^2), waste air flow rate (1-5 l/min), and TiO_2 loading (1.18-5.90 g) were fitted in a quadratic model to the response of NH_3 treatment efficiency. R^2 of 0.9783 was satisfactorily evaluated for correlation coefficient of the quadratic model on the photocatalytic reactor. Based on statistical analysis, the NH_3 treatment model has been proven to be highly significant with very low probability values (<0.0001). The optimum conditions obtained were 114 W/m^2 in light intensity, 1 l/min waste air flow rate, and 5.90 g TiO_2 loading. This resulted in 91.45% treatment of NH_3 at 300 ppmv as obtained from the predicted model, which fitted well with the laboratory results (90.02%). According to the study, TiO_2 coated on glass tube supporter can effectively be used for the treatment of NH_3 from waste air and could possibly be applied at an industrial scale.

Keywords: RSM, ammonia, photocatalytic, TiO_2, UV light

1. Introduction

Ammonia (NH_3) is a caustic volatile compound and it is toxic. It is produced in nature by a variety of organisms, human, industrial, agricultural, and social activities. Although NH_3 contributes significantly to the nutritional needs of plants and biological systems, the gas itself can create odors and have negative impacts to animal and human health (Wu *et al.*, 2008). The Occupational Safety and Health Administration (OSHA) has set a 15 min exposure limit for gaseous NH_3 of 35 ppmv in environmental air and an 8 h- exposure limit of 25 ppmv. Many chemical industries use NH_3 as reactants and/or produce NH_3 from various processes. The 'NH_3 slip' is now a significant problem to be solved urgently to reduce NH_3 pollution (Yamazoe *et al.*, 2007). Indirect NH_3 emissions into the atmosphere as nitrous oxide (N_2O) contribute to the destruction of the ozone layer which is a cause of global warming (Philippe *et al.*, 2011).

Many technologies have been used to eliminate NH_3 in emission air, such as catalytic oxidation, biological filtration, liquid absorption, and solid adsorption (Guo *et al.*, 2009). Photocatalytic oxidation of NH_3 into nitrogen (N_2), carbon dioxide (CO_2) and water (H_2O) is a potentially available method to reduce NH_3 pollution proceeds at room

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temperature and atmospheric pressure as shown in Equation 1- 6. A photocatalytic system consisting of catalyst with photo-active properties and light source in the UV light wavelength has been used for UV induced photocatalysis of pollutants. Titanium dioxide (TiO_2) has drawn much attention from the industry as a good candidate in the form of a large band-gap semiconducting oxide or optical semiconductor material for pollutant treatment. TiO_2 powder has favorable physical/chemical properties, low cost, ease of availability, and high stability to be coated as thin films on media. TiO_2, however, is only photoactive under UV irradiation (< 405 nm), which accounts for less than 95% of solar light energy (Kuo et al., 2011). Glass is an interesting medium to be used as a supporter of TiO_2 catalytic species since it is economical and corrosion resistant. Glass tube substrate can be coated with TiO_2 powder suspension using dip coating method and applied to increase the contact area with gas emission stream. The photocatalytic oxidation has been prevalently applied as techniques for degradation of toxic organic and inorganic compounds in air streams due to its non-toxic, inexpensive, and highly reactive characteristics.

$$TiO_2 + h\nu \rightarrow e^- + h^+ \quad (1)$$

$$h^+ + OH^- \rightarrow OH^\bullet \quad (2)$$

$$e^- + O_2 \rightarrow O_2^{\bullet -} \quad (3)$$

$$NH_3 + OH^\bullet \rightarrow NH_2^\bullet + H_2O \quad (4)$$

$$NH_2^\bullet + OH^\bullet \rightarrow NH + H_2O \quad (5)$$

$$NH + OH^\bullet \rightarrow \tfrac{1}{2} N_2 + H_2O \quad (6)$$

Response surface methodologies (RSM) have long been used to design and evaluate physical, chemical, and biological experiments in which the outcomes are influenced by various input factors or process variables (Shahsavani *et al.*, 2009). RSM has been applied to optimize and evaluate interactive effects of independent factors in numerous chemical and biochemical processes. This methodology arises from experiments which include interactive effects among the variables and, eventually, it depicts the overall effects of the parameters on the process (Amini *et al.*, 2008). The responses of the experiment can be simply related to the chosen independent factors by quadratic models. The model is fitted using multiple regressions and used to plot 3D-response surfaces. This method could effectively be used to form a process model and prediction for achieving the optimal NH_3 treatment efficiency of the photocatalytic reactor performance. Analysis of variance (ANOVA) has been employed to further justify the significance of the models.

The aim of this research is to treat NH_3 in waste air using TiO_2 thin film photocatalyst on glass tube supporters synthesized from TiO_2 nano-powders with polyethylene glycol binder in a solvent suspension. The laboratory scale of the continuous up-flow photocatalyst fix-bedded column system was constructed together with UV light irradiation installation. Waste gas stream was generated and forced to flow through the continuous photoreactor to contact with TiO_2 photocatalyst. The system was set to study the operating parameters of light intensity, waste air flow rate, and TiO_2 loading for the response of NH_3 treatment efficiency. RSM for experimental design and ANOVA analysis were used to respectively perform surface plots and mathematical model formations. A quadratic equation was obtained from the regression analysis in the design-expert program for the NH_3 treatment system and solved to seek the optimization performance. The optimum condition was validated by testing the NH_3 treatment efficiency in the photocatalytic reactor.

2. Materials and Method

2.1 Chemicals and apparatus

Commercial-grade titanium dioxide powder (TiO_2, Degussa P25) consisting of 80% anatase and 20% rutile phase was used as the starting material. Ethanol (99.9%; Merck Germany) was used as a solvent in TiO_2 suspension preparation. Nitric acid (HNO_3) (J. T. Baker, Thailand) was employed for pH adjustment and polyethylene glycol (PEG) was chosen as binder. UV fluorescence light lamps (8W, F20T12-BLB, USA) with wavelengths of 315-400 nm were used as a light source for photocatalytic performance in this work. 25% NH_3 analytical-grade solution was obtained from Merck. NH_3 solution was applied to generate NH_3 vapor to produce simulated NH_3 gas contamination by mixing with the air stream from the air compressor. Cylindrical glass tube 0.8x2.0 cm in size was used as medium supporter for catalyst coating.

2.2 TiO_2 photocatalyst preparation

TiO_2 suspension was prepared by dissolving 6 g of TiO_2 nanoparticles in 150 ml ethanol solvent and vigorously stirred for 1 hr at room temperature. Polyethylene glycol was used as catalytic binder by adding to the prepared TiO_2 suspension and served as the precursor (Yu, 2000). The suspension was kept in a refrigerator (4°C) for 24 hrs until the suspension turned into a clear low viscosity solution. The suspension was then coated on the 0.8x2.0 cm cylindrical glass tube by dip coating method. The coated substrates were dried at temperature of 100°C for 1 hr and calcined at 600°C for 2 hrs. The calcined procedure was performed in flowing air at a heat rate increase of 10°C/min until the final temperature was reached. The obtained TiO_2 thin film catalyst on the cylindrical glass media is as shown in Figure 1. Morphology of the synthesized TiO_2 coating glass tube was characterized by scanning electron microscope (SEM).

Figure 1. Synthesized TiO_2 on cylindrical glass tubes photocatalysts.

2.3 Photocatalytic reactor and experimental set-up

The photocatalytic system with TiO_2 on glass tube medium supporter was set up in a laboratory scale. Continuous up-flow fixed-bed glass columns (5 cm internal diameter and 30 cm column height) were packed by the raschigring typed catalytic packing media. The columns were installed in a cylindrical stainless steel chamber ($\pi \times 20^2 \times 50$ cm^3) with vertically fixed UV lights at the chamber wall. UV lights (23-114 W/m^2) at 315-400 nm wavelengths (power consumption of 8 W per lamp) were chosen as the light source to create photocatalytic reaction. Air stream flowed through the reactor chamber to regulate a constant temperature in the system. The diagram of NH_3 contaminated waste air flow and the photocatalytic system is depicted in Figure 2.

The NH_3 contaminated air stream was continuously generated for the NH_3 treatment testing by photocatalytic system. Air flow from the air compressor was passed through a NH_3 tank (25% w/w) to pick up vaporized NH_3 gas and moisture at room temperature (28-29°C). The mixed-gas stream was forced to the NH_3 mixing tank under steady flow to the photocatalytic reactor. The waste air contaminated with NH_3 at concentration of 300 ppmv was constantly used to investigate the system capacity. NH_3 concentrations of the inlet waste air stream were measured every 15 min to monitor and regulate a constant concentration throughout the experiment.

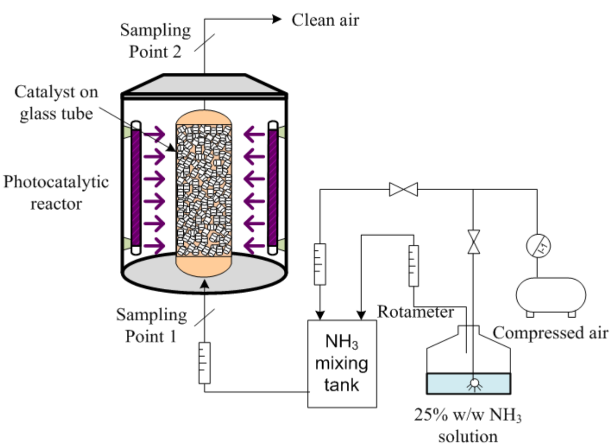

Figure 2. Schematic diagram of NH_3 contaminated waste air generation process and the photocatalytic reactor treatment system.

2.4 System performance analytical methods

NH_3 treatment efficiency (*% eff*) by photocatalytic continuous system performance was calculated employing Equation 7 through concentration of NH_3 in the inlet and outlet waste air streams. The ammonia gaseous sample from the treatment system was bubbled for 3 min through a glass bottle containing 50 ml boric acid solution. NH_3 concentrations in the waste air were determined by titration method (Rodrigues *et al.*, 2007).

$$\%eff = \frac{C_i - C_f}{C_i} \times 100 \tag{7}$$

where *%eff* is the percentage of NH_3 treatment efficiency, C_i and C_f are NH_3 concentrations (ppmv) in the waste air at the inlet and outlet points of the photocatalytic reactor, respectively.

2.5 Experimental design and analysis

Process experimental design for model formation of NH_3 in the waste air treatment was carried out using response surface methodology. RSM encompasses mathematical and statistical techniques that are useful for optimization performing and experimental designs (Ye *et al.*, 2009; Ling *et al.*, 2010). In this study, RSM was used to assess the relationship between the response (NH_3 treatment efficiency, *% eff*) and the independent variables, as well as to optimize the relevant conditions of variables in order to predict the best value of the responses. Central composite design (CCD), the most widely used approach of RSM, was employed to determine the effect of operational variables on the NH_3 treatment efficiencies. CCD allows reasonable amount of information to test lack of fit when a sufficient number of experimental values exist (Guven *et al.*, 2008). CCD and RSM were established with the help of the Design Expert software program. The three significant independent variables considered in this study were light intensity (X_1) in the range of 23-114 W/m^2, waste air flow rate (X_2) in the range of 1–5 l/min, and TiO_2 loading (X_3) in the range of 1.18-5.90 g. The responses can be simply related to the independent factors by a quadratic model consisting of linear, two factorial, and quadratic terms as given in Equation 8.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \left(\sum_{i=1}^{k-1} \sum_{j=i+1}^{k} \beta_{ij} x_i x_j\right)_{i<j} \tag{8}$$

where y is the predicted response evaluated; x_i and x_j are the independent variables; β_0 is the constant coefficient; β_j, β_{jj}, and β_{ij} are the interaction coefficients of linear, quadratic and second-order terms, respectively; and k is the number of studied factors.

Analysis of variance was used for graphical analyses of the data. The quality of the fit was expressed by the value of correlation coefficient (R^2), and its statistical significance was checked by F-value (Fisher variation ratio). Model terms were evaluated by the P-value (probability) with 95%

confidence level (Sahoo *et al.*, 2010). Three-dimensional plots and their respective contour plots were obtained for NH_3 treatment based on the effects of the three variables at five levels.

3. Results and Discussions

3.1 Scanning electron micrographs of TiO_2 films

A dip coating method on the small glass tubes described in Section 2.2 was employed to effectively perform the catalytic preparation with suspension of pure TiO_2 nano powder, ethanol solvent, and polyethylene glycol as binder. Figure 3 shows the scanning electron microscope of the surface of the synthesized TiO_2 on one of the glass tubes. It is observed that TiO_2 nanoparticles were well dispersed on the surface of the glass tube substrate. TiO_2 surface is rough and large size particles are formed on the surface.

3.2 Stability of TiO_2 photocatalyst on NH_3 treatment

TiO_2 photocatalyst coated on glass tubes was used for the treatment of NH_3 in contaminated waste air at NH_3 concentration of 300 ppmv. The glass tubes were packed in a raschig-ring typed packing media in a series of three glass columns to increase the contact area among the catalyst, UV light, and the waste gas. The efficiency and stability of TiO_2 catalyst on NH_3 treatment from the waste air using photocatalytic reactor were investigated by plotting between %NH_3 treatment efficiency and irradiation time, as shown in Figure 4. Experimental conditions of 3 l/min waste air flow rate and TiO_2 loading of 3.54 g were set. Tests were performed three times under the same testing conditions to verify stability of the synthesized catalyst and the system. Efficiency of the NH_3 treatment was monitored for consistency of the system every 15 minutes for 2 hours.

The results show that TiO_2 catalyst on the raschigring typed glass packing media performed effectively in the NH_3 treatment with constant efficiency throughout the operating time of 2 hours. After repeated operations, similar performance of the system with 60% efficiency was obtained. This indicates stability of the TiO_2 coated catalysts packed in the photoreactor column exposing to waste air flow and UV light irradiation. Also the TiO_2 catalyst, under constantly and continuously high activity UV light exposure, can effectively be regenerated after reacting with NH_3 in the waste air.

3.3 Model fitting and statistical analysis

Process and parameters of the NH_3 treatment in the photocatalytic reactor were designed and investigated by RSM and CCD design. Table 1 shows the coded value ranges of the three operating variables (X_1, X_2, and X_3) that were set at five coded levels: -α, -1, 0, +1, +α (Sahoo *et al.*, 2010). The coded values for the variable parameters were used to facilitate regression with -α as the minimum level and +α as the maximum level. The center runs (0, 0, and 0) were repeated three times, leading to 20 experimental runs as they contribute to the estimation of the quadratic terms in the process model.

Experimental design parameters by CCD and the response of NH_3 treatment efficiency in the TiO_2 photocatalytic reactor are given in Table 2. Relationships between the three variables (light intensity, waste air flow rate and TiO_2

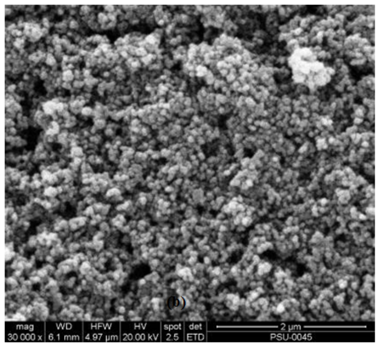

Figure 3. SEM image of the surface of TiO_2 on glass tube substrate of TiO_2 suspension.

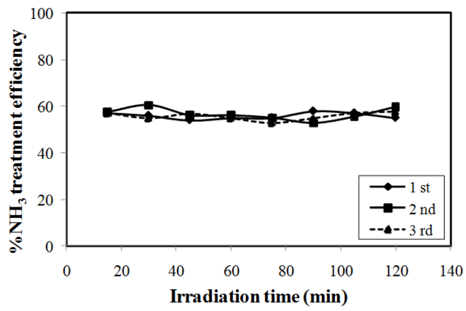

Figure 4. Stability of TiO_2 photocatalyst, indicated by slight changes under repeating irradiation.

Table 1. Experimental range and level of the independent variable.

Variable	Range and level				
	-α	-1	0	+1	+α
X_1: light intensity (W/m^2)	23	45	68	92	114
X_2: waste air flow rate (l/min)	1	2	3	4	5
X_3: TiO_2 loading (g)	1.18	2.36	3.54	4.72	5.90

Table 2. Experimental condition of CCD and response of NH_3 in waste air treatment efficiency by the photocatalytic system.

Run no.	Variable			NH_3 treatment eff. (%)
	X_1 Light intensity (W/m^2)	X_2 Waste air flow rate (l/min)	X_3 TiO_2 loading (g)	
1	23	3	3.54	47.40
2	45	4	2.36	35.00
3	45	2	2.36	46.20
4	45	2	4.72	75.30
5	45	4	4.72	60.10
6	68	3	3.54	56.55
7	68	3	3.54	55.77
8	68	1	3.54	63.20
9	68	3	3.54	56.10
10	68	2	3.54	58.90
11	68	3	4.72	68.80
12	68	5	3.54	49.78
13	68	3	1.18	49.63
14	68	3	5.9	87.00
15	92	2	4.72	75.60
16	92	4	4.72	73.50
17	92	2	2.36	62.99
18	92	4	2.36	53.00
19	92	3	3.54	58.70
20	114	3	3.54	70.20

Table 3. ANOVA for adequacy of the quadratic model of NH_3 treatment in TiO_2 photocatalytic reactor.

Source	Sum of squares	DF	Mean Square	F-value	Prob > F	Remarks
Model	2,809.44	6	468.24	97.66	< 0.0001	significant
X_1	542.19	1	542.19	113.08	< 0.0001	significant
X_2	273.33	1	273.33	57.01	< 0.0001	significant
X_3	1,709.47	1	1,709.47	356.55	< 0.0001	significant
X_1X_2	25.33	1	25.33	5.28	0.0388	significant
X_1X_3	54.83	1	54.83	11.44	0.0049	significant
X_3^2	243.49	1	243.49	50.78	< 0.0001	significant
Residual	62.33	13	4.79			
Lack of Fit	62.02	11	5.64	36.78	0.0268	significant
Pure Error	0.31	2	0.15			
Correlation Total	2,871.77	19				
Standard deviation	2.09					
R^2	0.9783		Adjusted R^2	0.9683		
Predicted R^2	0.9306		Adequate Precision	41.48		

loading) and the responses were analyzed using regression analysis of the Design Expert software.

Fitting of the process data and the response to the quadratic models were performed. Their subsequent ANOVA analyses showed that the photocatalytic of NH_3 treatment was most suitably described by a quadratic model as shown in Table 3. Regression coefficients of the model describing the NH_3 treatment were determined by F-value and P-value. Corresponding P-values suggest that, among the test variables used in this study, X_1, X_2, X_3, X_1X_2, X_1X_3, and X_3^2 are significant model terms. Other model terms are not significant (with a probability value less than 0.05). The effects of the terms on the response could be easily seen from the normalized coefficients. Based on the results, the response surface constructed in this study for predicting NH_3 treatment efficiency was considered reasonable. The final regression model, in terms of their coded factors, is expressed by the following reduced quadratic Equation 9.

$$y = 38.33 + 0.39X_1 - 8.04X_2 - 0.44X_3 + 0.06X_1X_2 - 0.09X_1X_3 + 2.18X_3^2 \quad (9)$$

ANOVA results of the reduced quadratic model in Table 3 indicated that the model could adequately be used to describe the NH_3 treatment under a range of operating conditions. Data given in this Table demonstrate that the quadratic model was significant at 5% confidence level since P-values (0.0001) were less than 0.05. Values of P>F less than 0.0500 indicate that model terms are significant, while values greater than 0.1000 indicate that the model terms are not significant (Korbahti *et al.*, 2008). The value of correlation coefficient (R^2=0.9783) obtained in the present study for NH_3 treatment indicated that only 1.66% of the total dissimilarity might not be explained by the empirical model. The quadratic equation obtained by multiple variables can be used to predict the NH_3 treatment efficiency. Figure 5 plots between predicted responses and actual values reveal that the predicted responses of the reduced quadratic model agree well with the actual ones in the range of the operating variables.

3.4 Effect of independent variables on NH_3 in waste air treatment

Individual and interaction effects of the three factors consisting of light intensity, waste air flow rate, and TiO_2 loading on the NH_3 treatment efficiency were presented by the quadratic model (Equation 3). Three-dimensional surface plot of the NH_3 treatment by the fitting quadratic model from the regression analysis are given in Figure 6-8. These plots illustrate the response of different experimental variables of the photocatalytic system. All 3D plots can be used to explain and identify the effect of each variables and major interactions between the variables. The variables: light intensity, waste air flow rate and TiO_2 loading, were tested on the treatment of NH_3 individually. It was also important to check the interaction effect of these variables, especially the two factor interaction effects.

3.4.1 Effect of light intensity and waste air flow rate

The 3D plot in Figure 6 indicates significant interaction between light intensity (X_1) and waste air flow rate (X_2) on the NH_3 treatment efficiency. It is observed that treatment efficiency significantly increases with increasing light intensity and decreasing waste air flow rate. As can be seen in Figure 6 at NH_3 concentration of 300 ppmv, the highest % of treatment efficiency is reached at 114 W/m^2 of light intensity and waste air flow rate of 1 l/min. Interaction of light intensity at 23 W/m^2 and the same waste air flow rate, however, presented very low efficiency of NH_3 treatment (%). The photonic nature of the photocatalysis reaction has emphasized the dependency of the overall photocatalytic rate on the light source used. Light intensity is major factor that affect the degree of photocatalytic reaction on organic substrates because electron–hole pairs can be produced more by light energy (Li *et al.*, 2008). There is more photon activation per unit time and unit area at higher light intensity.

3.4.2 Effect of light intensity and TiO_2 loading

In Figure 7, the two-factor interaction of light intensity and TiO_2 loading was investigated when NH_3 concentration was fixed at 300 ppmv. This interaction (X_1X_3) exemplifies the real importance of TiO_2 loading on the NH_3 treatment. As shown in this figure, the highest value of treatment (83.5%) was observed at the highest light intensity (114 W/m^2) with highest TiO_2 loading (5.9 g). However, there is a significant decrease on the treatment efficiency in the presence of low

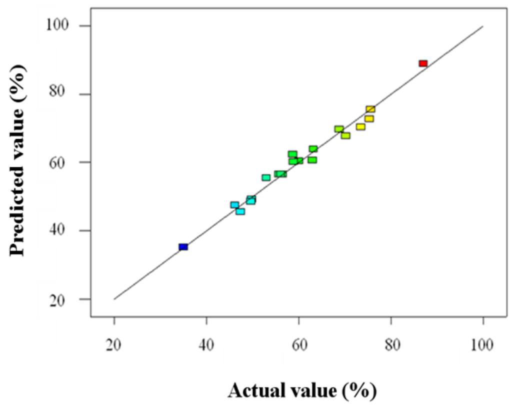

Figure 5. Plot of predicted response vs. actual value for NH_3 treatment response from reduced surface quadratic model.

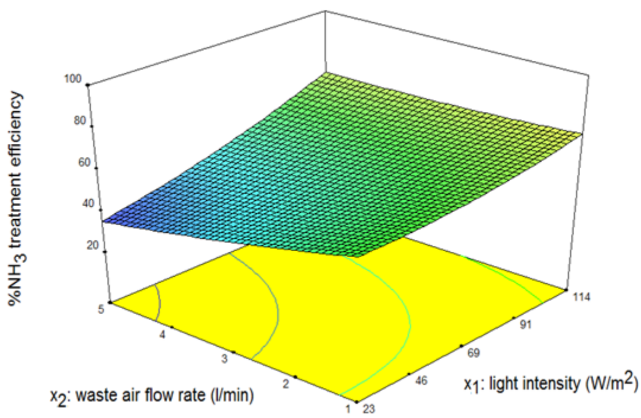

Figure 6. 3D-surface plot on the effect of light intensity (X_1) and waste air flow rate (X_2) on the NH_3 treatment efficiency under 3.54 g TiO_2 loading at 300 ppmv NH_3 concentration.

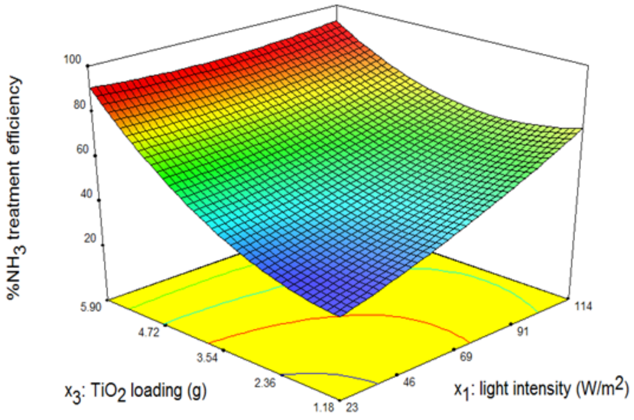

Figure 7. 3D surface plot on the effect of light intensity (X_1) and TiO_2 loading (X_3) on the NH_3 treatment efficiency under 3 l/min waste air ow rate at 300 ppmv NH_3 concentration.

light intensity, especially at low TiO_2 loading (1.18 g). Higher TiO_2 loadings in the photocatalytic reactor generally lead to higher efficiency of NH_3 removal from the waste air. The TiO_2 photocatalyst generates a lot of active sites on the surface which leads to •OH radicals generation. The increase in the amount of active sites in accordance with the increase in TiO_2 photocatalyst loading consequently lead to enhancement of the production of •OH radicals (Abdollahi *et al.*, 2012). The figure clearly shows that higher NH_3 treatment efficiency depends on the higher amount of TiO_2, as well as higher light intensity. The strong interaction between the light intensity and the TiO_2 loading (X_1X_3) indicates an important inter-dependence in the response of treatment.

3.5 Optimization of NH_3 treatment conditions

An optimization process was carried out to determine the optimum value of NH_3 treatment efficiency using the Design Expert software. Parameters used in the software for each operational condition (light intensity, waste air flow rate, and TiO_2 loading) were set as constraints within the upper and lower limit ranges. The NH_3 treatment model (Equation 9) was employed as objective function for the response of NH_3 treatment efficiency at "maximum" to achieve the highest performance. The program combines the constraints into the objective function, and then searches for the best combination to maximize this function. Accordingly, the optimum working condition and respective percent treatment efficiencies were established. As presented in Table 4, a maximum 91.45% NH_3 treatment efficiency was predicted according to the objective function and constraints under optimum operational conditions at light intensity of 114 W/m^2; 1 l/min of waste air flow rate; and TiO_2 loading of 5.9 g.

An experiment was then performed to validate and confirm the optimum results of the optimization performance. Efficiency of the system was monitored for consistency and stability of the system every hour for six hours. Figure 8 shows the NH_3 treatment efficiency along with irradiation time using the optimum conditions derived earlier. An average NH_3 treatment efficiency of 90.02%, shown also in Table 4, was obtained from the experiment which agrees well with the predicted response value (91.45%). The effectiveness of TiO_2 photocatalytic supporting on glass cylindrical tubes for continuous NH_3 pollutant treatment at laboratory scale is certain, as shown here, with a great potential to be proven in an industrial scale waste air treatment system.

Compared to literature data, reasonably successful results were obtained in this study under conditions from process modeling of NH_3 contaminated waste air treatment in photocatalytic reactor using TiO_2 coated glass tubes. This treatment system could be regenerated by UV light and continuously run with more efficiency than other traditional waste air treatment methods (Rodrigues *et al.*, 2007; Guo *et al.*, 2009). A simple and efficient design of catalyst preparation and photo reactor system was applied to accommodate and support for high waste gas flow treatment.

4. Conclusions

In the present study, NH_3 contaminated waste air treatment using TiO_2 nanoparticle coating on glass tubes

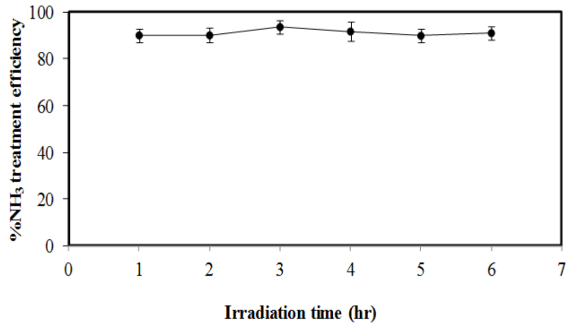

Figure 8. NH_3 treatment efficiency versus irradiation time under optimum condition using TiO_2 photocatalyst (conditions: 114 W/m^2; 1 l/min waste air flow rate; 5.9 g. TiO_2 loading). Error bars denote standard deviation.

Table 4. Model validity of response surface for NH_3 treatment under optimal condition.

Light intensity (W/m^2) (X_1)	Waste air flow rate (l/min) (X_2)	TiO_2 loading (g) (X_3)	NH_3 treatment efficiency (%)	
			Predicted	Experimental
114	1	5.9	91.45	90.02

inside a continuous photocatalytic reactor was investigated. The treatment process focused on the interaction effects of operating variables such as light intensity, waste air flow rate and TiO_2 loading using RSM with CCD. The multiple correlation coefficient of determination R^2 obtained was 0.9783, indicating that the acquired data fitted well with the predicted data from the quadratic model. Regression analysis, ANOVA, and response surface were carried out and plotted using Design Expert software for the prediction of experiment responses. The optimum result derived from the model indicated that 114 W/m^2 of UV light intensity together with a waste air flow rate of 1 l/min and a TiO_2 loading of 5.9 g was most suitable to achieve 91.45% of NH_3 treatment at 300 ppmv, and was verified by an actual experimental result of 90.02%. Thus, TiO_2 coated on glass tubes can be effectively used for efficient treatment of NH_3 from waste air with high potential to be applied in industrial-scaled NH_3 contamination remedies.

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