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MODELING AND SIMULATION OF ATMOSPHERIC AMMONIA EMISSION FROM WATER BY NATURAL WIND

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ABSTRACT

Ammonia is classified as a hazardous air pollutant. In southern part of Thailand, ammonia is widely used as a preservative for rubber latex in concentrated rubber latex industries. The wastewater from this plant contains high total nitrogen and total ammonia nitrogen which lead to water and air pollution problems. This study emphasized the emission of ammonia from wastewater due to natural wind. The mass transfer coefficients of ammonia as a function of wind speed were experimentally determined. The relationship between mass transfer coefficient of ammonia and the wind speed were obtained and incorporated into a simple emission rate model. The model was modified for the field wind speed application using power law profile. The simulation on emission rate of ammonia using wastewater characteristic from actual plant was performed. The model revealed that the emission rate of ammonia from water increases with increasing wind speed. The influence of wind speed on emission rate was extremely enhanced by increasing pH. The model can be used to estimate ammonia emission from wastewater at interested wind speed, pH and water temperature. The predicted result may be used as a guideline for determining an appropriate mean to air pollution regarding ammonia emission from wastewater.

KEYWORDS

Ammonia, Ammonia emission, Mass transfer coefficient of ammonia, Air pollution

I. INTRODUCTION

Ammonia (NH_3) is a primary air pollutant. According to the nation air quality standard, the amount of ammonia in air is controlled not to exceed 35 ppm. When airborne, NH_3 reacts with acidic species, such as sulfuric acid, nitric acid, or hydrochloric acid to form ammonium sulfate, ammonium nitrate, or ammonium chloride, respectively. In the US, the largest contributor of ammonia to the global budget is domestic animal waste and the other important source of ammonia emission are from fertilizer and biomass burning. In southern part of Thailand, ammonia is being used in many industries, such as concentrated latex industries, rubber glove industries and frozen seafood industries. The emission of ammonia via waste air and wastewater from these plants is concerned. The wastewater from concentrated latex industries contains high level of total nitrogen and ammonia nitrogen (Maheswaran and John, 1991). Ammonia emission from wastewater treatment plant can be substantial due to a number of factor such as large surface area to volume ratio, high temperature, high surface wind, and high pH. The measurement or prediction of ammonia emission from wastewater treatment facility is then necessary not only to confine with air pollution regulation, but also useful for performing nitrogen balance of the treatment plant. Although, the ammonia emission flux model, which relates the ammonia emission flux to water temperature and pH, has been proposed (Aneja et. al., 2001), no model that includes the wind speed has been reported.

The aims of this study were to (1) determine the influence of the wind speed on mass transfer coefficient of ammonia, (2) develop ammonia emission rate model, which incorporates the effect of wind speed, and (3) simulate the model to predict ammonia emission from wastewater of concentrated latex industries. The model obtained from this work can be used to estimate ammonia emission from wastewater at interested wind speed, pH and water temperature. The predicted result may be used as a guideline for determining an appropriate mean to prevent air pollution regarding ammonia emission from wastewater.

2. THEORY

The emission of ammonia from water to the atmosphere is a physical process. The emission rate of ammonia from water can be represented, simplistically by (Bunyakan et.al., 2003):

$$R_{NH_3} = \frac{K_{OL}aC_t}{1 + 10^{(0.09018 + \frac{2729.92}{T} - pH)}} \quad (1)$$

where R_{NH_3} is ammonia emission rate (g/s), C_t is the concentration of total ammonia nitrogen in the solution (g/m^3), T is absolute temperature (K), and $K_{OL}a$ is an overall mass transfer coefficient (m^3/s). The $K_{OL}a$ can be obtained by combining mass balance and the film theory. The relationship between $K_{OL}a$ and C_t can be expressed as equation (2) (Bunyakan et. al., 2003):

$$\ln \frac{C_t}{C_{t0}} = \frac{-K_{OL}a}{V} t \quad (2)$$

where t is emission time (s), C_t is the concentration of total ammonia nitrogen in the solution at time t (g/m^3), and C_{t0} is the concentration of total ammonia nitrogen in the solution at time 0 (t=0) (g/m^3), and V is the volume of solution (m^3).

3. EXPERIMENTAL SETUP AND PROCEDURE

3.1 Experimental set up

A series of emission experiments of ammonia from water at various wind speeds were carried out using a wind tunnel-water tank system. The detail of the wind tunnel-water tank used in this investigation and the procedure to measure the wind speed within the tunnel was detailed elsewhere (Bunyakan et. al., 2001). The reference wind speed was measured at 10 cm above water surface (U_{10cm}). The U_{10cm} in the range of 0-4.8 m/s were investigated. The air and the water temperature were monitored for all experimental run and they were 27±2 and 27±2 °C, respectively.

3.2 Experimental Procedure

The ammonia solution was prepared by dissolving ammonia hydroxide in water to desire concentrations and 120 L of the prepared solution was charged into the water tank. The content in the water tank was circulated at the rate of 15 L/min to maintain a uniform concentration throughout the water volume. The emission experiment was begun by turning on the blower, setting the wind speed to the desire value and taking the solution sample at initial emission time. After that, liquid samples were then taken periodically at predetermined time interval, usually every 1 hr. The emission time was varied between 4.5-14 hr depending on the emission rate of ammonia. The liquid samples were analyzed for concentration of the total ammonia nitrogen by using UV-vis spectrophotometer (Model 8453, Hewlett Packard) according to Phenate Standard Methods (APHA, AWWWA, and WPCF, 1995). Provided that the solution is uniform, the change in ammonia concentration with time can be described by equation (2). Thus $K_{OL}a$ at various wind speeds can be determined directly from the concentration-time data for each run. The experimental conditions are summarized in Table 3.1.

Table 3.1 Summary of experimental conditions.

Run No.	U_{10cm} (m/s)	T_{water} (°C)	C_t (g/m^3)
1	0.00	27±2	399
2	0.46	27±2	342
3	1.52	27±2	379
4	2.58	27±2	492
5	3.37	27±2	514
6	4.21	27±2	433
7	4.80	27±2	415

4. RESULTS AND DISSCUSION

4.1 Effect of wind speed on $K_{OL}a$

Results of overall mass transfer coefficient at various wind speeds are shown in Figure 4.1. From Figure 4.1, as expected, the wind speed was found to influence the mass transfer coefficient of ammonia significantly as compared to zero wind speed. Moreover, a linear relationship, equation (3), with a significant correlation (R^2 =0.95) was found between $K_{OL}a$ and U_{10cm}.

$$K_{OL}a = 3.02x10^{-6}U_{10cm} + 1.19x10^{-6} \quad (3)$$

where $K_{OL}a$ is expressed in m^3/s, U_{10cm} is average wind speed at 10 cm above water in m/s.

The $K_{OL}a$ of ammonia in this study was higher than those predicted from two-film model using k_Ga and k_La based on volatile organic compounds (VOCs) (Bunyakan et. al., 2001) as shown in Figure 4.2. It appears that the difference may attribute to the difference in the pH which was found to enhance the ammonia emission rate and mass transfer coefficient significanly (Bunyakan et al, 2003). Thus, for the prediction of ammonia emission rate from water, the mass transfer coefficient based on ammonia, equation (3), is then recommended.

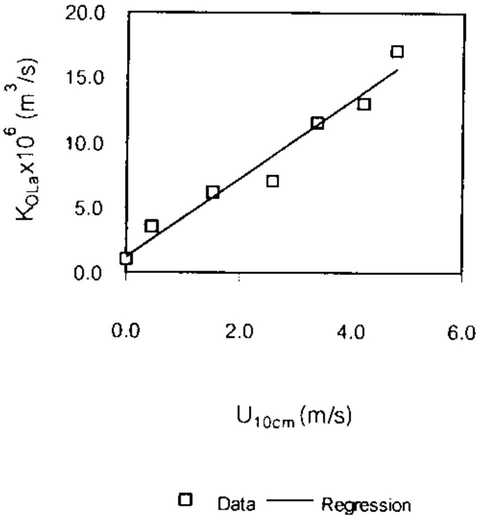

Figure 4.1 Overall mass transfer coefficient of ammonia at different wind speeds (pH =10, T_{water} =27±2 °C).

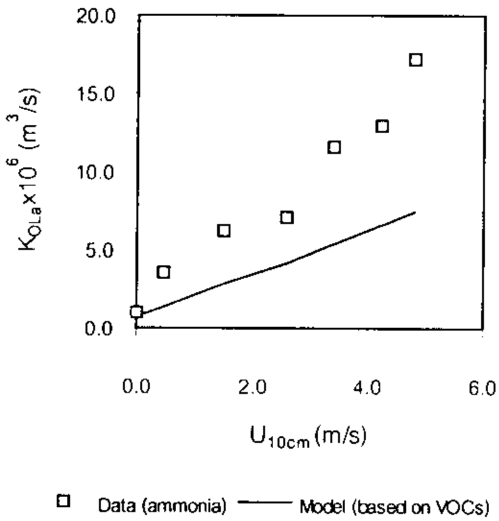

Figure 4.2 The comparison of $K_{OL}a$ of ammonia from this work to the predicted value using mass transfer coefficient based on VOCs.

4.2 Emission rate model of ammonia for field application

The emission rate of ammonia as function of wind speed can be obtained by substituting $K_{OL}a$ from equation (3) into equation (1).

$$R_{NH_3} = \frac{(3.02x10^{-6} U_{10_{cm}} + 1.19x10^{-6})C_t}{1 + 10^{(0.09018 + \frac{2729.92}{T} - pH)}} \quad (4)$$

To make use of equation (4) for field application, the wind speed appeared on the right hand side of equation (4) needed to be adjusted t10 m height, which is usually measured at meteorological station. This can be done by using the power-law profile, which is frequently used in air pollution applications (Arya, 1999).

According to power-law profile, when the wind speeds at reference height is known, the wind speeds at other height is given by equation (5) (Arya, 1988)

$$\frac{U}{U_r} = \left[\frac{Z}{Z_r}\right]^{0.1} \quad (5)$$

where U_r is the wind speed at a reference height Z_r and U is the wind speed at any interested height Z. The relation between $U_{10_{cm}}$ and U_{10_m} according to equation (5) is

$$U_{10_{cm}} = 0.63\, U_{10_m} \quad (6)$$

Through the power-law above, the laboratory wind speed used in this study, 0 to 4.8 m/s, equates to wind speed at 10 m height between 0 to 25 km/hr which is in the normal range of natural wind. By substituting $U_{10_{cm}}$ with $0.63\, U_{10_m}$, the emission rate of ammonia for the field application was obtained.

$$R_{NH_3} = \frac{(1.90x10^{-6} U_{10_m} + 1.19x10^{-6})C_t}{1 + 10^{(0.09018 + \frac{2729.92}{T} - pH)}} \quad (7)$$

4.3 Simulate ammonia emission rate from wastewater of concentrated latex industries

The wastewater from latex concentrated industry usually contains high total nitrogen and high total ammonia nitrogen. The wastewater treatment facility of this industry is exposed to the wind, thus it is high potential of ammonia emission from water due to the wind over water surface. However, no actual emission data has been reported. The figure of ammonia emission rate from such plant can be estimated by using emission rate model as expressed by equation (7).

In this study, the emission rate model was employed to estimate the ammonia emission from concentrated latex industry using the wastewater characteristic as shown in Table 4.1 (Maheswaran and John, 1991). For simulation purpose, the wind speed at 10 m height and water temperature were assumed as listed in Table 4.1. The predicted ammonia emission rates from wastewater , source I and source II, are shown in Table 4.2.

Table 4.1 The wastewater characteristic and the environmental conditions used in simulation.

Parameters/characteristic	Wastewater	
	Source I	Source II
TKN (mg/L)	602	202
Total NH_3 concentration (c_t, mg/L)	466	134
pH	4.8	7.8
Water temperature (°C)*	30	
Wind speed* (at 10 m height)	0-25 km/hr	

*Assumed value for simulation purpose

Table 4.2 Predicted ammonia emission rate as function of wind speed.

Wind speed (km/hr)	Ammonia Emission Rate x10^6 (kg/day)	
	Source I	Source II
0	2.40	657.84
5	7.73	2117.79
10	13.07	3577.74
15	18.39	5037.69
20	23.73	6497.65
25	29.02	7947.10

From table 4.2, we can see that the ammonia emission rates increase significantly with increasing wind speed. As the wind speed increased from 0 to 5, 10, 15, 20, and 25 km/hr, the ammonia emission rates were increased, as compared to zero wind speed, by a factor of 3.2, 5.4, 7.7, 9.9, and 12.1, respectively. The dependency of wind speed on ammonia emission rate from wastewater is also shown in Figure 4.3.

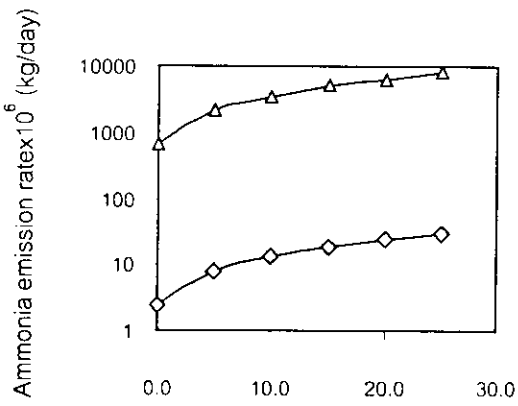

Figure 4.3 Predicted ammonia emission rate from wastewater from concentrated latex industry.

From Figure 4.3, it was found that the ammonia emission rate of the source II was about 273 times that of the source I. This was attributed to the different in pH. For source I , the pH was very low (pH=4.8). Most of ammonia was in an ionized form, which could not volatilize, thus the emission rate was extremely low even at high ammonia concentration (466 mg/L). As pH of wastewater increased to 7.8 as in source II , most of ammonia was in unionized form (gas form). The emission rate was high, even at low concentration of 134 mg/L as shown in this simulation.

5. CONCLUSIONS

The wind speed is an important parameter influencing the mass transfer coefficient of ammonia. Empirical model correlating the wind speed, through mass transfer coefficient, pH and water temperature, through pKa correlation, has been proposed to predict the ammonia emission rate from wastewater. The simulation on emission rate of ammonia using wastewater characteristic from actual plant was performed. The model revealed that the emission rate of ammonia from water increases with increasing wind speed. The influence of wind speed on emission rate was extremely enhanced by increasing pH. The model can use to estimate ammonia emission from wastewater at interested wind speed, pH and water temperature. The predicted result can be used as a guideline for determining appropriate mean to prevent air pollution regarding to ammonia emission from wastewater.

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