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### Publication Information

Pub ID	Pub Date
054039	2005 ASAE Annual Meeting Paper

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*The Society for engineering  
in agricultural, food, and  
biological systems*

*An ASAE Meeting Presentation*

*Paper Number: 054039*

## **Adsorption Kinetics of Ammonia on a Dynamic Isolation Flux Chamber**

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**Written for presentation at the  
2005 ASAE Annual International Meeting  
Sponsored by ASAE  
Tampa Convention Center  
Tampa, Florida  
17 - 20 July 2005**

**Abstract.** A laboratory study dealing with the adsorption kinetics of ammonia on a flux chamber was performed to determine if adsorption onto the chamber walls was significant. The study took into account the system responses of all instrumentation. The remaining response was considered adsorption. The study detailed how adsorption can be measured in an open system. By knowing an estimate of the adsorption, the concentration obtained from the chamber may be corrected. The study found that the adsorption would not significantly change the concentration of the output flow 30 minutes after a clean chamber was exposed to ammonia concentrations. The adsorption was found to be more significant at lower concentrations. The mass adsorbed for 2.5 ppm of ammonia was found to be 14.7  $\mu\text{g}$ .

**Keywords.** Ammonia, adsorption kinetics, adsorption, flux chamber.

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## Introduction

Ammonia from animal feeding operations is emitted as a result of biological breakdown of animal waste. Confined animal feeding operations have come under scrutiny by environmental interest groups, the U.S. Environmental Protection Agency (EPA), and nearby residents. Ammonia is one of many odorants that contributes to the odor emissions from an animal feeding operation. Ammonia is known to have a pungent odor and may cause respiratory diseases in both animals and humans if breathed in large quantities. Particulate matter may form from ammonia by reacting with nitrogen oxides (NO<sub>x</sub>) and sulfur oxides (SO<sub>x</sub>) in the atmosphere causing further respiratory damage.

One method for measuring ammonia emissions from a surface is a flux chamber. A flux chamber measures the potential for a surface to emit a certain pollutant. The sampling protocol for a flux chamber is detailed in Eklund (1992), Gholson, et al. (1989), and Kienbusch(1986). Since the chamber isolates the surface from its natural environment, interferences may bias a measurement. One of the interferences of the flux chamber that affects the measurement of ammonia is adsorption. The focus of this study is to determine the kinetics of adsorption when the chamber is exposed to different concentrations of ammonia. The laboratory study focused on determining whether adsorption of ammonia on the chamber walls was significant.

The method used in sampling with a chamber involved flushing the chamber with a set flowrate while continuously sampling the headspace. The chamber was allowed to vent during the test. Studies done by Kienbusch (1986) indicated that the chamber acts as a continuously stirred tank reactor (CSTR) when used in this method. One of the characteristic properties of a CSTR is the first order response to a step change in input. Thus for a step function input of concentration, a chamber without interferences will have an output concentration that will be described by the first order equation:

$$C(t) = (C_f - C_i)(1 - \exp(-t/\tau)) + C_i \quad (1)$$

where  $\tau = V/Q$ . In the above Equation,  $C(t)$  is the concentration at time  $t$ ,  $C_f$  is the final concentration,  $C_i$  is the initial concentration,  $V$  is the volume of the chamber, and  $Q$  is the actual flow rate into the chamber. The flux chamber method assumes that the concentration leaving the chamber and the concentration in the chamber are equal, that is, the flux chamber acts as a well mixed reactor.

Adsorption involves ammonia molecules accumulating at the surface of the chamber. Physical adsorption is a result of van der Waals interactions between the surface and solute molecules (Perry and Green, 1997). Chemical adsorption results in a breakdown of a solid over time as a result of exposure to a gas (Perry and Green, 1997). Materials exhibit different adsorption potentials. Materials used in an ammonia measurement system are generally selected to have a low adsorption potential for ammonia and other chemicals often found when measuring the ammonia.

Adsorption isotherms describe the adsorption equilibrium behavior of a surface. Adsorption isotherms relate gas adsorption dependence to the gas partial pressure at a constant temperature. Several isotherms have been used to describe adsorption including the Langmuir isotherm, BET isotherm, and Freundlich isotherm. The Langmuir isotherm is used to describe monolayer adsorption on a homogeneous surface. The Langmuir isotherm is based upon the assumptions that all adsorption sites are equivalent, no horizontal interactions exist among adsorbed molecules, and the heat of adsorption is the same for all molecules to any site (Seinfeld and Pandis, 1998). The Langmuir isotherm may be described by:

$$n_i = \frac{n_i^s k_i p_i}{1 + p_i k_i} \quad (2)$$

where  $n_i^s$  is the adsorption capacity (mass),  $k_i$  is an isotherm parameter (1/partial pressure),  $n_i$  is the mass adsorbed (mass), and  $p_i$  is the partial pressure of the solute.

The BET isotherm may be used to describe multilayer adsorption on a homogeneous surface. The BET isotherm is an extension of the Langmuir isotherm with the additional assumptions that each adsorbed molecule provides a site for an additional layer and the heat of adsorption for each additional layer after the first is equal to the latent heat of evaporation for the bulk condensed gas (Seinfeld and Pandis, 1998). The Freundlich isotherm may be used to describe adsorption for a heterogeneous flat surface. The isotherm assumes an exponential distribution of heats of adsorption (Perry and Green, 1997). The Freundlich isotherm lacks the required linear behavior in the Henry's law region. Because of the low coverages resulting from low concentration typical in ammonia measurement, the Langmuir isotherm may be used to describe the adsorption characteristics.

Isotherms only describe the equilibrium behavior of adsorption. To understand adsorption in chamber, the kinetics of adsorption must be used. Kinetic theories that describe Langmuirian adsorption are often used in situations in which the solute is dilute. The Theory of Activated Adsorption, Absolute Rate Theory, the Elovich equation, and the Statistical Rate Theory (SRT) are four methods that describe Langmuirian adsorption. The Theory of Activated Adsorption contains parameters that are difficult to independently measure (Ward and Findlay, 1982). One other problem of the Theory of Activated Adsorption is that it predicts a linear function of coverage when the adsorption rate is actually highly nonlinear in the initial low coverage portion (Ward and Findlay, 1982).

The Absolute Rate Theory was suggested by Clark (1970) to elucidate discrepancies that occur when a surface is initially exposed to a gas (Ward and Findlay, 1982). With the Absolute Rate Theory, explicit functions for the surface coverage of adsorption and desorption cannot be found (Rudzinski and Panczyk, 2002). Additionally, the expression does not clearly show the dependence of the activation energies of adsorption and desorption on surface coverage (Rudzinski and Panczyk, 2002).

The Elovich equation has been more successful at correlating empirical results. However, the Elovich equation initially under predicts adsorption and does not contain a factor that limits the amount of adsorption (Ward and Findlay, 1982).

The SRT assumes that single molecular events result in the transport of molecules from one phase to another (Ward, Findlay, and Rizk, 1982). The transition probability is derived using a first order perturbation analysis of the Schrödinger equation (Ward, et al., 1982). The SRT may over predict in instances immediately after a bare surface is exposed to a gas (Ward and Findlay, 1982). In this case, the limiting factor is the collision rate of the gas molecule with the surface. The chamber is likely not to experience this phenomenon because the dynamics associated with the chamber are generally slow. Rudzinski and Panczyk (2002) give an expression for the SRT as shown below:

$$\frac{d\theta}{dt} = \left[ K_a p \frac{1-\theta}{\theta} \exp\left(\frac{\varepsilon}{kT}\right) - K_d \frac{1-\theta}{p} \exp\left(-\frac{\varepsilon}{kT}\right) \right] [1 - \theta^{(e)}] p^{(e)} \quad (3)$$

with

$$K_a = K_{gs} q_0^s \exp\left(\frac{\mu_0^g}{kT}\right) \quad (4)$$

and

$$K_d = \frac{K_{gs}}{q_0^s} \exp\left(-\frac{\mu_0^g}{kT}\right) \quad (5)$$

In the above equations,  $\theta$  is the coverage,  $p$  is the partial pressure,  $e$  is the activation energy for adsorption/desorption,  $k$  is the Boltzmann constant,  $T$  is the temperature,  $K_{gs}$  is a constant,  $q_0^s$  is the partition function of gas molecules, and  $\mu_0^g$  is the standard chemical potential for perfect gas. For the chamber, the volume of pollutant present in the chamber is much greater than the amount adsorbed in a short period of time. For this to be true, the partial pressure of the gas would not change much because of adsorption. When the chamber is initially exposed to the gas, this assumption does not hold true. For a volume dominated system, Rudzinski and Panczyk (2002), give:

$$\frac{d\theta}{dt} = \left[ K_a p^2 \frac{1-\theta}{\theta} \exp\left(\frac{\varepsilon}{kT}\right) - K_d \frac{\theta}{1-\theta} \exp\left(-\frac{\varepsilon}{kT}\right) \right] [1 - \theta^{(e)}] \quad (6)$$

The above equation may be simplified to

$$\frac{d\theta}{dt} = K_{gs} \left[ p^2 k_i \frac{1-\theta}{\theta} - \frac{1}{k_i} \frac{\theta}{1-\theta} \right] [1 - \theta^{(e)}] \quad (7)$$

The above equation must be changed into mass form to be applicable to the flux chamber. By applying the above equation after changing it into mass form, the amount adsorbed may be found as shown in equation 8.

$$\frac{dn}{dt} = K_{gs} \left[ p^2 k_i \frac{n_i^s - n}{n} - \frac{1}{k_i} \frac{n}{n_i^s - n} \right] [n_i^s - n_i] \quad (8)$$

The equation may then be fitted to the measured mass adsorbed. Adsorption kinetics has been traditionally measured in a closed system. Because the ammonia measurement instrumentation did not allow the measurement of adsorption using a closed system, the adsorption was measured using an open system. The adsorption may be found by performing a mass balance to the system. The modeled outlet concentration takes into account the system response of the chamber and instrumentation which may be measured separately to determine the entire system response. Equation 9 below shows the mass balance of the chamber

$$\frac{dm}{dt} = \dot{M}_{in} - \dot{M}_{out} - \frac{dn}{dt} \quad (9)$$

where  $dm/dt$  is the rate of change in mass of the chamber,  $\dot{M}_{in}$  and  $\dot{M}_{out}$  are the mass flow rates into and out of the chamber respectively, and  $dn/dt$  is the adsorption onto the walls of the chamber.

In order to account for system response, transfer functions were found for each component in the system. The method of Laplace transforms and system responses is detailed in *Feedback Control of Dynamic Systems* by Franklin, Powell, and Emami-Naeini (2002). By using transfer

functions instrument responses of each component may be found separately and then combined to form the transfer function of the entire system. Likewise, the single transfer function of a component in the system may be isolated by removing responses of the other components.

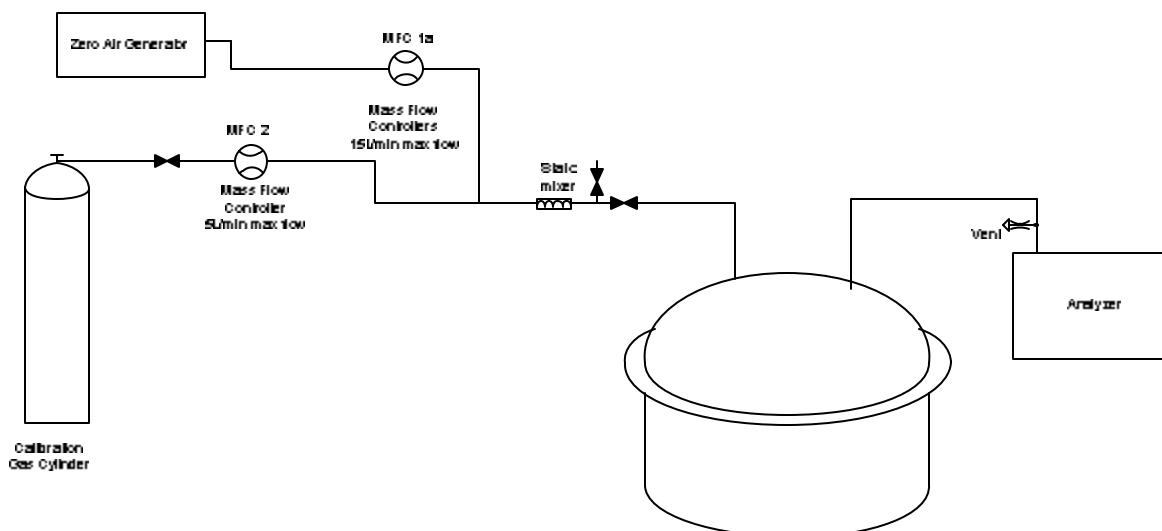
The objectives of this paper are to determine the system responses of the instrumentation, develop an isotherm model for adsorption, and develop a method for which adsorption may be estimated for a flux chamber.

## Materials and Methods

Adsorption was measured for the chamber by calibrating the instrumentation, measuring the system response without the chamber, measuring the system response with the chamber, and using transfer functions to both remove system response and obtain the chamber response function. The adsorption function was found by applying a mass balance on the chamber. Input concentrations of 5, 10, 20, and 50 ppm were studied to determine the effects of adsorption.

In order to measure the adsorption kinetics of the chamber, laboratory tests were performed under a controlled temperature ( $20 \pm 2^\circ\text{C}$ ) and pressure ( $1 \pm 0.01$  atm). The system setup is shown in Figure 1 with flowrate set points for each component. The laboratory setup consisted of one Thermo model 17C ammonia analyzer (Thermo, Franklin, MA), mass flow controllers (Aalborg, model GFC17-15L/m, Orangeburg, NY), flux chamber, zero air generator (Aadco Instruments, Inc., Model 737, Village of Cleves, OH), and PFA grade 3.2 mm (1/8 in.) inside diameter tubing as shown below in figure 1. The 17C ammonia analyzer has both an auto and manual mode of operation. In automatic mode, the analyzer can determine the concentrations of ammonia ( $\text{NH}_3$ ), nitric oxide (NO), and nitrogen dioxide ( $\text{NO}_2$ ). In manual mode, the analyzer can be set to measure the total nitrogen without speciation between the  $\text{NH}_3$ , NO, or  $\text{NO}_2$ . Since a specific calibration gas was used, no speciation was required by the analyzer. The analyzer was set up in  $\text{N}_t$  mode with a 1 s averaging time. This allowed for faster response times of the analyzer. The flux chamber skirting material was 304 grade SS with a diameter of 0.495 m (19.5 in.) and height of 0.241 m (9.5 in.). The flux chamber featured an acrylic dome top and sweep air tubes from Odotech Inc. (Montreal, Quebec, Canada). The volume of the chamber was 65 L. A static mixer (Koflo, model 1/2-80-PFA-12-2, Cary, IL) ensured that the calibration gas and zero air were well mixed before being measured. The chamber pressure was measured using a barometric pressure sensor (Vaisala, Inc., Model PTB100A, Woburn, MA). Temperature was measured using a HOBO model HO8-007-02 with TMC6-HC temp probe (Onset Computer, Pocasset, MA). LabVIEW with Field Point modules (National Instruments, Austin, TX) were used to control the mass flow controllers and to log data flow and pressure data.





**Figure 1.** Experimental apparatus consisting of mass flow controllers (MFC), flux chamber, calibration gas, and ammonia analyzers (TEI)

### **Experimental Protocol**

The experimental protocol consisted of the following steps:

- **Calibration:** Calibrations were performed according to the operator's manual of the analyzer. The calibration protocol consisted of zeroing the instrument, then calibrating the sensor with ammonia. The analyzers were calibrated using high purity calibration gases consisting of 100ppm ammonia and 50ppm ammonia (Praxair Inc, Danbury, CT) at the concentration at which the analysis was performed (2.5, 5, 10, 20, and 40 ppm, respectively). Two mass flow controllers were used to mix the calibration gas with purified (zero) air to the correct concentration. The calibration gases were mixed with at least 25% air to ensure sufficient oxygen for oxidation in the  $\text{NH}_3$  to NO catalytic converter. Calibrations were performed at the beginning of each day before the test was performed.
- **Determine system response:** Instrumentation response was determined by analyzing the output of the instrumentation to a step function with magnitude of the respective concentration measured when determining the chamber response. Transfer functions of each component were determined using Z-transform. The discrete transfer function is converted to a continuous transfer function by using the forward algorithm to calculate the Laplace transform. The forward algorithm is shown below as
 
$$z \rightarrow 1 + sT \quad (10)$$
- **Determine chamber response:** The chamber response was measured for 5 concentrations of ammonia (2.5, 5, 10, 20, and 40 ppm respectively). The dynamic response was measured for 1 hour for the upward concentration. The system responses of the flow controllers, analyzers, and tubing were much faster than the chamber so they did not need to be removed using transfer functions. The chamber responses were compared to a response to NO. A mass balance was performed to determine the mass adsorbed.
- **Determine Langmuir parameters:** The chamber dynamic response was measured until the system reached steady state conditions to determine the coefficients in the Langmuir

isotherm. No measurable mass is adsorbed when the system reaches steady state. The mass adsorbed for each concentration was determined by applying a mass balance to the chamber and comparing the actual chamber response to the Nitric oxide response. The Langmuir coefficients were determined by fitting the Langmuir equation using nonlinear regression.

## Results and Discussion

The chamber was found to follow a first order response for each test and the response was found to be a function of concentration. The change in response was primarily attributed to adsorption of ammonia to the walls of the chamber. Table 1 shows the change in the response of ammonia and the resulting mass adsorbed. The time constant for NO in the chamber is much smaller for the given flowrate and size of the chamber. The predicted time constant was 575 [s<sup>-1</sup>]. The chamber acts as a smaller volume possibly due to incomplete mixing.

**Table 1.** Chamber time constants and mass adsorbed onto chamber for various concentrations of ammonia. The time constants change as a result of adsorption onto the chamber walls.

Concentration [ppm]	Gas	time constant [s <sup>-1</sup> ]	Mass adsorbed [μg]
40	NO	470	*
2.5	NH <sub>3</sub>	518	14.7
5	NH <sub>3</sub>	508	27.5
10	NH <sub>3</sub>	502	46.3
20	NH <sub>3</sub>	492	79.8
40	NH <sub>3</sub>	485	135.7

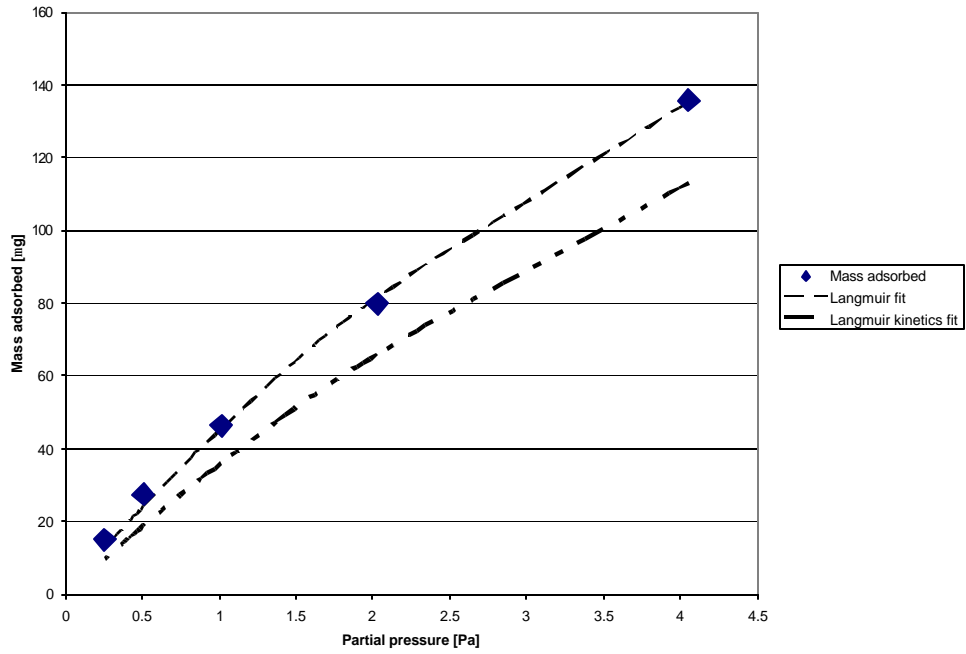
\* Nitric Oxide was considered a control for the tests

The Langmuir equation was fit to the data using non-linear regression, Levenberg Marquardt algorithm with SPSS 11.5 (SPSS, Chicago, IL). The solution to the regression was then used to find a solution to the Langmuir kinetics equation (equation 8). The Langmuir kinetics equation was fit to data presented after 750 s. The Langmuir results are presented in Figure 2. The kinetics results are presented in Figure 3.

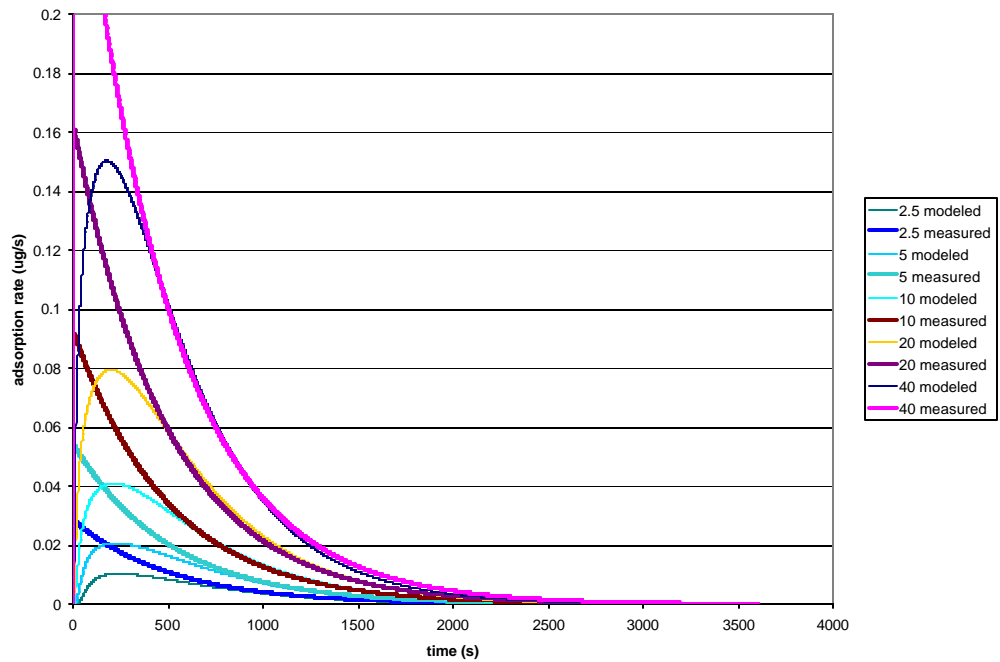
The Langmuir parameters found are:

- Langmuir isotherm  $k_i = 0.128$
- Langmuir kinetics  $k_i = 0.099$
- $K_{gs} = 1.9 \times 10^{-4}$
- $n_i^s = 395$
- Measured  $t = 441$
- Theoretical  $t = 575$

After 1800 seconds, almost no adsorption occurs. When the chamber is used to measure concentrations in the field, the chamber is allowed to flush for 1800 seconds for a flowrate of 7 L/min. Thus, essentially no adsorption occurs while the chamber is being used to measure the concentration. Thus the adsorption term is a storage term. The error in the kinetics equation occurs because of diffusion that must take place in the CSTR. In order for adsorption to occur, the ammonia molecules must come in contact with the surface. Because of the inherent characteristics of the system, measured adsorption is overestimated. The chamber does show to have some incomplete mixing. This provides areas which the chamber provides additional storage.



**Figure 2.** Original Langmuir equation fit and Langmuir kinetics fit. The equilibrium mass adsorbed is very small when compared to the total mass of the system.



**Figure 3.** Langmuir kinetics fit. After 30 minutes the adsorption rate is very small and does not affect the output concentration.

## Conclusion

Several conclusions can be drawn from the work presented.

- The Langmuir method may be used to assess the adsorption of the chamber. The Langmuir kinetics equation for a volume dominated system models the adsorption of the chamber after the initial system response. The kinetic equation for volume dominated systems assumes that there is a significant volume of ammonia such that the concentration is not affected by adsorption. Because of the dynamics of the measurement system, this is true only after approximately one time constant when the concentration change is relatively small.
- The mass adsorbed is relatively small and does not need to be taken into account after a 30 minute flush that take place before sampling. After 1800 seconds the concentrations are basically unaffected by the adsorption.
- The time constant for the chamber did not match with the theoretical time constant. Further work in this area must be performed to identify why the time constants are different.
- Adsorption does not need to be taken into account for the tested concentrations above 2.5 ppm when used for field measurements.

## Acknowledgements

Funding for this research was provided in part by grants from the United States Department of Agriculture - Cooperative State Research, Education, and Extension Service (CSREES) and the Texas State Air Quality Initiative. The Texas Agricultural Experiment Station (TAES) is the lead agency for this project.

## References

- Eklund, B. 1992. Practical Guidance for Flux Chamber Measurements of Fugitive Volatile Organic Emission Rates. *J. Air Waste Manage. Assoc.* 42: 1583-1591.
- Clark, C.A. 1970. *The Theory of Adsorption and Catalysis*. New York, N.Y.: Academic Press.
- Franklin, G.F., Powell, J. D., Emami-Naeini, A. 2002. *Feedback Control of Dynamic Systems*, 4<sup>th</sup> ed. Upper Saddle River, N.J.: Prentice Hall.
- Gholson, A. R., Albritton, J. R., and Janyanty, R.K.M. 1989. Evaluation of the Flux Chamber Method for Measuring Volatile Organic Emissions from Surface Impoundments. EPA/600/S3-89/08. Research Triangle Park, N. Carolina: US EPA, Office of Research and Development
- Kienbusch, M.R. 1986. Measurement of Gaseous Emission Rates From Land Surfaces using an Emission Isolation Flux Chamber. EPA/600/8-86/008. Las Vegas, Nevada: US EPA, Office of Research and Development.
- Perry, R. H. and Green, D.W., ed., 1997. *Perry's Chemical Engineering Handbook*, 7<sup>th</sup> ed. New York, N.Y.: McGraw-Hill
- Seinfeld J. H. and Pandis S. N. 1998. *Atmospheric Chemistry and Physics*, 735-738. New York, N.Y.: John Wiley & Sons.
- Rudzinski, W. and Panczyk, T. 2002. The Langmuirian Adsorption Kinetics Revised: A Farewell to the XXth Century Theories? *Adsorption*. 8:23-34
- Ward, C.A. and Findlay, R.D. 1982. Statistical rate theory of interfacial transport. III. Predicted Rate of Nondissociative Adsorption. *J. Chem. Phys.* 76(11): 5615-5623.
- Ward, C.A., Findlay, R.D., and Rizk, M. 1982. Statistical rate theory of interfacial transport. I. Theoretical development. *J. Chem. Phys.* 76(11): 5599-5605.