ASSESSMENT OF AMMONIA ADSORPTION ONTO TEFLON AND LDPE TUBING USED IN POLLUTANT STREAM CONVEYANCE

by
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ABSTRACT

The adsorption of ammonia onto polymer tubing used in pollutant stream conveyance was assessed for possible systematic losses. An experimental design with three replications of 32 trials was completed to investigate the adsorption of ammonia based on two nominal temperatures (25 and 37 ^{o}C), two nominal tubing lengths (15 and 46 meters), six nominal inlet concentrations (2, 5, 10, 15, 25, and 35 parts per million), and two tubing materials, (Teflon and low density polyethylene,LDPE). For a given length, mean ammonia adsorption on Teflon tubing was found to be statistically less than that from LDPE. The effect of tubing length on ammonia adsorption was not significant for Teflon, but was significant for LDPE. There were significant differences between inlet and outlet concentrations of LDPE at nominal inlet concentrations of 5 and 15 ppm ($\alpha=0.05$). Overall, ammonia adsorption to Teflon was approximately 1 ppm regardless of the magnitude of inlet concentration. This loss on to the Teflon surface was well within the measurement sensitivity of the ammonia analyzer. Ammonia adsorption onto LDPE tubing increased with increasing inlet concentration, temperature and length of the tubing.

Keywords. Ammonia, Adsorption, Teflon, LDPE

INTRODUCTION

Atmospheric ammonia (NH_3) is a pollutant of increasing interest. Along with sulfur dioxide (SO_2) and nitrogen oxides (NO_x), it is a major primary pollutant leading to acidic deposition (Singh et al., 2001). In addition, atmospheric nitrogen deposition alters the species composition and biodiversity of ecosystems and causes acidification and eutrophication of soils as well as leaching of nitrogen to surface and ground waters (Kangas and Sanna, 2001). Measurement of SO_2 and NO_X had been done for many decades but ammonia measurements have not been well defined. One technique for quantifying ambient ammonia concentrations in the field uses isolation flux chambers (Aneja et al., 2001). Several meters of polymer tubing such as Teflon and LDPE are used together with the flux chambers in ambient air sampling to afford portability. Teflon and LDPE materials have a high chemical stability but adsorption of ammonia is still possible (Kosmulski, 2001). Current research has not quantified the amount of ammonia that is lost through adsorption onto different polymers under field conditions.

The polarity of the N-H bonds and the geometry of its structure make ammonia a polar molecule with considerable dipole moment. Having the nitrogen atom at the apex of a pyramidal

molecular structure, makes ammonia highly adsorbable onto surface sites (Appl, 1999). Although the structure of polymers is such that adsorption sites are relatively rare, ammonia is reactive enough to noticeably adsorb on polymers (Kosmulski, 2001).

Analysis of the gas – solid physical adsorption equilibrium is important to design separation and purification processes as well as description of conveyance effects on materials. The equilibrium between the fluid phase and the adsorbent phase may be expressed by adsorption isotherms. An isotherm is defined by the amount of gas adsorbed per unit mass of solid at constant temperatures at varying pressures. The derivation of a scientifically based adsorption isotherm was first achieved by Langmuir in 1918 (Kosmulski, 2001).

The Langmuir adsorption isotherm is presented in the following equation:

$$\frac{X}{M} = \frac{b*Q*C}{1 + b*C} \tag{1}$$

where:

X = mass of adsorbate (e.g. ammonia, mg)
M = mass of dry adsorbent (e.g. Teflon, LDPE, g)
b = constant (units of reciprocal of concentration, l/mg)
Q = maximum capacity (assumed to be monolayer coverage of adsorbent surface, mg/g)
C = solution concentration at equilibrium (mg/l)

Another adsorption isotherm equation is given by Freundlich (Montgomery, 1985) and is written as:

$$\frac{X}{M} = k * C^{(1/n)} \tag{2}$$

Where k and n are constants and X, M, and C are defined as before.

The constants k and n define both the nature of the adsorbent and the adsorbate. High k and n values indicate high adsorption throughout the concentration range of studies. A low value of n (steep slope) indicates high adsorption at strong solute concentrations and poor adsorption at dilute concentrations.

Different polymers possess different properties of adsorbate activity, so the amount of full adsorption sites will vary with each polymer. This is the thermodynamic basis for polymer resistance to substances such as ammonia, and the reason why the resistance of each polymer to each fluid is unique.

Several recent studies have attempted to quantify the amount of ammonia present in livestock waste (Sommer et al, 2001; Erisman et al, 2001; Aneja et al, 2001). The research of Sommer et al., (2001) focused on the volatilization of ammonia from sow manure on grassland. To conduct this research a mobile dynamic chamber was constructed. This chamber utilized approximately 6 meters of Teflon tubing and an air pump to convey the pollutant stream through denuder tubes.

Roelle, et al. (1999) and Roelle and Aneja (2002) conducted research to detect nitrogen oxide emissions from agricultural soil. This research utilized a dynamic chamber system and a mobile laboratory up to 10 meters in distance from the chamber. Teflon tubing was used to span the required distance from area source to mobile laboratory. The chamber was also lined with 5 millimeters of fluorinated ethylene propylene (FEP) Teflon. None of the previously mentioned studies specifically addressed the potential loss of ammonia through adsorption, whether in steady state conditions or in start-up.

The overall objective of this study was to model ammonia adsorption and desorption in Teflon and LDPE tubing. By experimenting with different concentrations at the inlet of the tubing being tested, tubing types, temperatures and lengths, a relationship may be established to predict the amount of ammonia that may be adsorbed onto tubing under these conditions. The results could also be fitted in an adsorption isotherm curve to evaluate the maximum adsorption capacity of the adsorbate. Once these parameters are established, the amount of ammonia that could be adsorbed onto different types of tubing material under several operating parameters can be estimated with accuracy.

The specific objectives of this research work are as follows:
1. To determine the level of ammonia adsorption onto Teflon and LDPE tubing;
2. To determine the collective effects of inlet ammonia concentrations, tube length and temperature on the behavior of adsorption for a given material; and
3. To develop an equation to estimate adsorption as a function of inlet concentration, temperature and length of tubing used.

MATERIALS AND METHODS

Ammonia concentration at the inlet and outlet of Teflon and LDPE tubing was measured using a chemiluminescence analyzer (Thermo Environmental Inc. (TEI) Model 17C, Franklin, Ma.). The chemiluminescence analyzer utilizes the reaction of nitric oxide (NO) with ozone (O_3) as its basic principle. Specifically:

$$NO + O_3 \rightarrow NO_2 + O_2 + h_v \qquad (3)$$
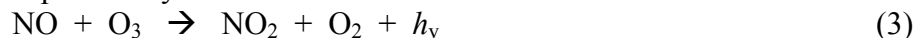
A sample is drawn into the analyzer where it mixes with ozone (generated internally) in a reaction chamber. The reaction creates a luminescence proportional to the concentration of NO. NH_3 gas sample must first be transformed through a converter chamber into NO prior to reaching the reaction chamber.

The experiment began with the calibration of the TEI for the range of concentrations that will be used for the tests. This was followed by setting up of a particular length of the polymer material

inside a temperature controlled incubator. Finally, the initial concentration used for the experiment was measured directly by the TEI. Figure 1 shows the schematic of the process.
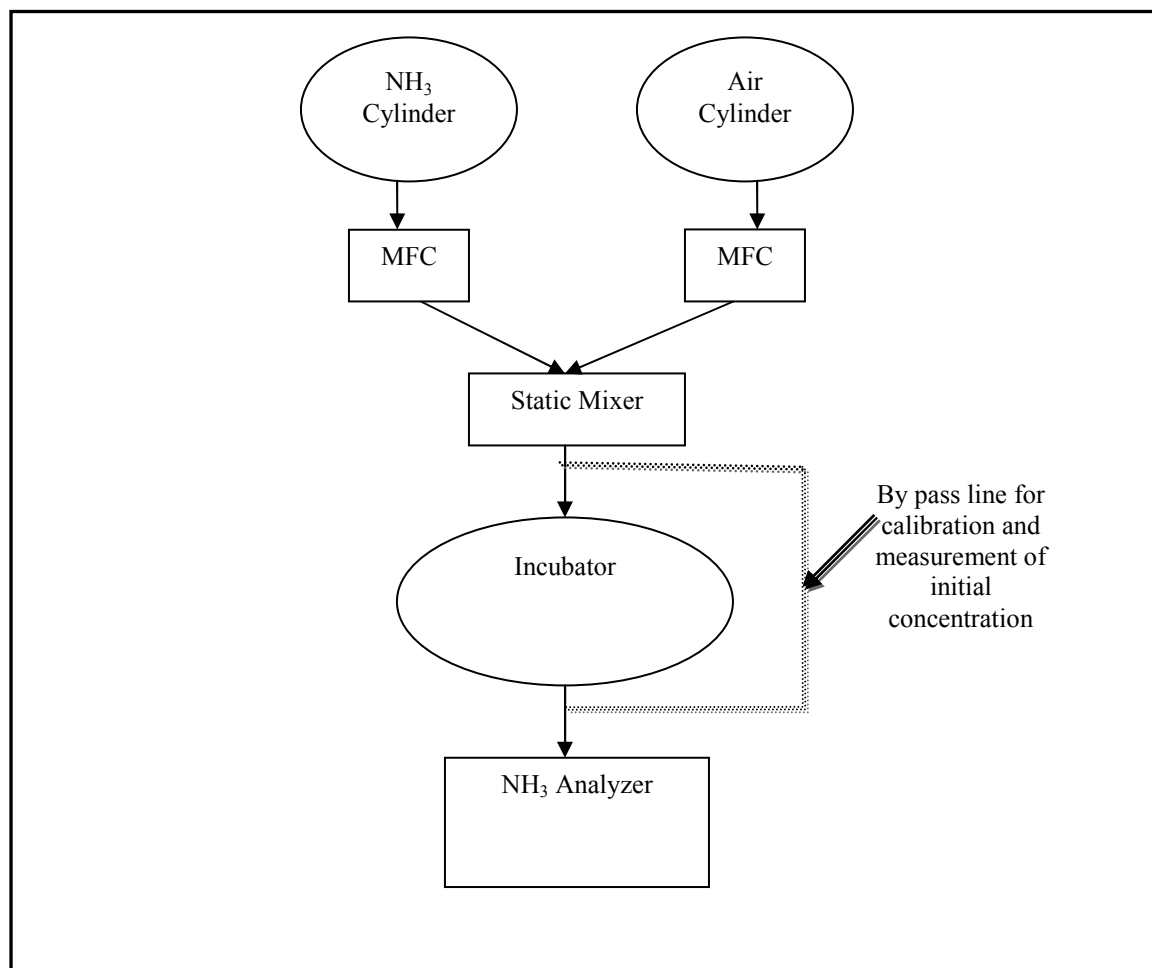

Figure 1. Schematic of the test setup to measure ammonia adsorption onto polymer tubing.

A National Instruments LabVIEW (Version 5.1.1) program was used to control and regulate the flow and concentration of ammonia by using two programmable mass flow controllers (MFCs). One MFC controlled the amount of ammonia (ultra high purity grade) released from a cylinder (Scott Specialty Gases, Houston, Texas) and the other controlled the amount of ammonia-free air needed for dilution to achieve the correct NH_3 concentration for a given test. The gases were mixed well in a static mixer. The correct concentration was then conveyed through the corresponding tubing length in each experiment. Both tubing materials were manufactured to

have 0.32-cm inner diameter. The inside surface area of each treatment was therefore equal. The LabVIEW program allowed for the inlet ammonia concentration to be varied, but the allotted times used to change gas flows were constant for these experiments.

Three sequences were used: warm up, adsorption, and desorption. First, 100% of the flow at 2 liters per minute (LPM) was ammonia-free air (zero grade air). This ammonia-free air allowed the analyzer to stabilize and provide a reference zero ammonia concentration for the treatment. In tests, a system start up and stabilization time of 10 minutes was sufficient to let the system warm up. There were no detectable temporal concentration changes. After 10 minutes, the appropriate ammonia and air mixture was formed. The mixing ratio of ammonia and ammonia-free air was set by the user based on a selected concentration in the trial. This ratio was maintained for an additional 60 minutes, after which, the flow returned to 100% ammonia-free air to test for desorption. The desorption sequence lasted 20 minutes, allowing any residual ammonia in the system (tubing, flow controllers, etc.) sufficient time to be depleted. After the 90 minute test period, the tubing used in the trial was removed, the calibration system was connected and the same concentration was drawn through the TEI. The resultant concentration was recorded as the tubing inlet concentration (C_{in}) in the prior trial. The difference (C_{Diff}) between the outlet concentration and the inlet concentration was used to determine adsorption of ammonia onto each type of tubing being tested. After the trial was completed, the appropriate physical factors (length, temperature, program concentration) were modified for the next trial. The software was reset, and the next experiment was started. As an illustration of this experiment, Figure 2 details the output of one of the experiments. In this trial the treatments were Teflon tubing, $37^{o}C$ nominal temperature, 46 meters nominal length, and 15 ppm ideal concentration. For this trial the outlet concentration averaged 13.8 ppm while the inlet concentration was 14.63 ppm. The difference, or amount of ammonia adsorbed from the tubing, was 0.83 ppm (5.6% less than the inlet concentration).
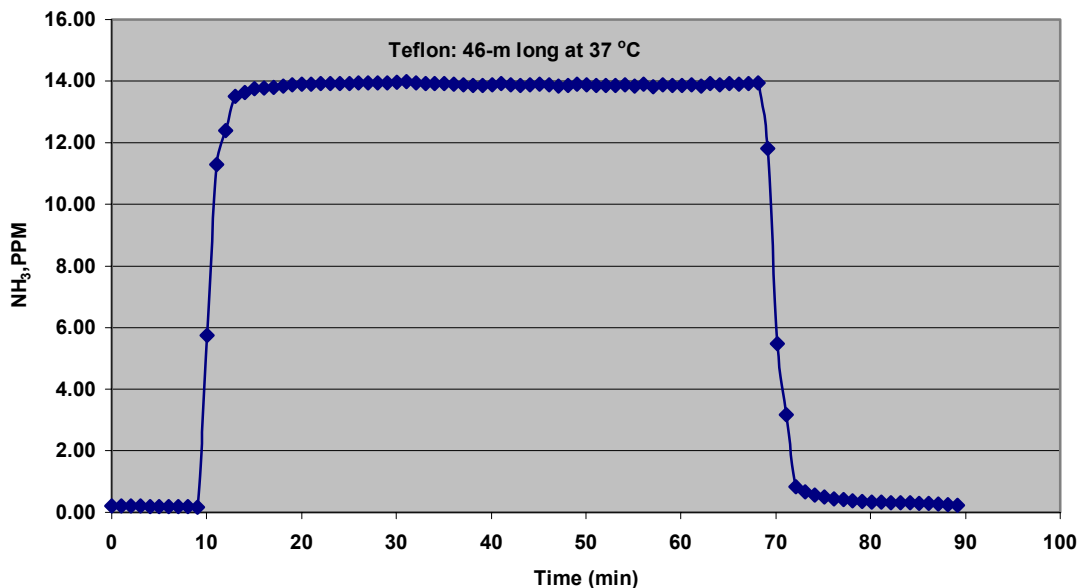
Figure 2. Profile of NH$_3$ concentration during warm-up (0-10 min), adsorption (11-70 min) and desorption (71-90 min) stages during one trial for a nominal 46-m long Teflon tubing maintained at 37°C.

The LabVIEW program updated and recorded data every five seconds. This was twice the update rate of the analyzer and 12 times the logging rate of the analyzer. The faster update rate ensured that every point from the analyzer was recorded. The five second data were averaged over one minute. In addition to the ammonia concentration, the logging program stored the date, time, ammonia flow rate, and air flow rate. The variables tested in this experiment with their nominal values are given in Table 1.

Table 1. Ammonia adsorption variables tested and their nominal values.

Material	Temperature (^{o}C)	Length (m)	NH$_3$ Inlet Concentrations (ppm)
Teflon	25, 37	15, 46	2, 5, 10, 15, 25, 35
LDPE	25, 37	15, 46	5,15

Temperature range for nominal values: 25=(25.2-25.6); 37=(36.7-37.7)

For Length: 15m nominal = (14.8 -15.5) m and 46m nominal = (45.3 - 46.6) m.

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For this study, three replications per trial were used, bringing the total number of experiments to 96. As shown in Table 1, more concentrations were used for Teflon to model ammonia adsorption over a larger range, since Teflon is typically used to convey ammonia more frequently (Kosmulski, 2001). The ideal (nominal) concentration is used for display purposes only.

To change the temperature for each experiment, the entire length of tubing (not including inlets or outlets) was placed in an incubator. To ensure accuracy in these experiments the temperature inside the tubing was determined by using stainless steel temperature probes (TMC6-HC, Onset Computer Corp.) inserted into the tubing exiting from the incubator. The accuracy of the probes are within $\pm$ 0.5% at 20°C using an ONSET TH8 data logger. Warm air was drawn through the bottom of the incubator and across a heating element. The air was then passed across the different lengths of tubing, warming the interior mixture. After determining the internal temperature and respective incubator setting, the temperature controls could be accurately described. A data logger (Onset Communications, Bourne, Ma.) was used to record the temperature information as well as the time required to attain each temperature. Software created by Onset Communications (BoxCar Pro 4.0) was used to read the temperatures from the data loggers. The actual and not the ideal output temperatures, lengths, and inlet and outlet ammonia concentrations were used in the statistical analysis.

RESULTS AND DISCUSSION

Tables 2 and 3 present the results of ammonia adsorption tests using Teflon and LDPE tubing material, respectively. Actual ammonia inlet and outlet concentrations and their differences (adsorption) along with their standard deviations are also reported. For Teflon, adsorption of ammonia generally increased slightly within the same inlet concentration as the temperature of the tubing increased, regardless of the difference in the length of tubing (Table 2). Among Teflon inlet concentrations, regardless of different temperatures and lengths of the tubing, ammonia adsorption was generally within one ppm or less, well within the measurement sensitivity ($\pm$ 2% of the 0-100ppm measuring scale) of the ammonia analyzer. On the other hand, ammonia adsorption onto LDPE tubing (Table 3) increased with increasing inlet concentration, temperature and length of the tubing. The lowest adsorption (0.84 ppm) was observed for the inlet concentration that corresponded to the ideal concentration of 5 ppm at the lower temperature (25^OC) and the shorter tubing length (15-m), while the highest adsorption (3.58 ppm) was observed for the inlet concentration that corresponded to the ideal concentration of 15 ppm at the higher temperature (37^OC) and the longer tubing length (46m).

Table 4 presents the analysis of variance results for mean values of ammonia adsorption (C_{Diff}) as a function of inlet concentrations, tubing lengths, temperatures and tubing material of Teflon. Fisher's least significant difference statistics test was used to compare the mean adsorption. For Teflon, ammonia adsorption for 15 ppm ideal inlet concentration was significantly higher than those for 5, 25 and 35 but statistically similar to all other ideal inlet concentrations. Also Teflon ideal inlet concentrations of 2, 5, 10, 25, and 35 ppm had statistically similar mean adsorptions. For LDPE, mean adsorption at ideal inlet concentration of 15 ppm was

significantly higher than that for the ideal inlet concentration of 5ppm (Table 5). Generally, longer Teflon and LDPE tubing at higher temperatures resulted in higher ammonia adsorption but none of the means for either tubing were statically different due to higher temperatures or greater lengths. Mean adsorption (compared at 5 and 10 ppm ideal inlet concentrations) for LDPE was higher than that for Teflon. Adsorption isotherm curves could not be developed for LDPE because of the fewer number of concentration values used for the test. Likewise for Teflon, concentrations in the ppb level should be used to describe adsorption behavior and whose concentration difference between the inlet and outlet should be above equipment sensitivity.

Table 2. Ammonia adsorption results for Teflon

C_{ideal} (ppm)	Temp. ^oC	Length (m)	Inlet C ppm	(S.D.)*	Outlet C ppm	(S.D.)*	Difference ppm	(S.D)*
2	25	15	2.30	(0.04)	1.10	(0.08)	1.20	(0.09)
2	25	46	1.80	(0.01)	0.96	(0.10)	0.84	(0.10)
2	37	15	2.30	(0.05)	1.09	(0.04)	1.21	(0.08)
2	37	46	2.00	(0.01)	0.98	(0.06)	1.02	(0.07)
5	25	15	5.00	(0.10)	4.81	(0.16)	0.19	(0.14)
5	25	46	4.80	(0.07)	4.12	(0.15)	0.68	(0.22)
5	37	15	5.40	(0.09)	4.72	(0.04)	0.68	(0.06)
5	37	46	4.60	(0.10)	3.75	(0.21)	0.85	(0.20)
10	25	15	10.20	(0.32)	9.12	(0.07)	1.08	(0.33)
10	25	46	9.60	(0.21)	8.94	(0.09)	0.66	(0.25)
10	37	15	10.50	(0.33)	9.13	(0.12)	1.37	(0.33)
10	37	46	9.80	(0.03)	9.05	(0.16)	0.75	(0.14)
15	25	15	15.10	(0.27)	14.24	(0.79)	0.86	(1.00)
15	25	46	14.40	(0.13)	13.27	(0.84)	1.13	(0.75)
15	37	15	15.30	(0.33)	13.10	(0.58)	2.20	(0.34)
15	37	46	14.60	(0.27)	13.38	(0.52)	1.22	(0.78)
25	25	15	24.50	(0.27)	24.15	(0.26)	0.35	(0.23)
25	25	46	24.20	(0.06)	24.08	(0.07)	0.12	(0.04)
25	37	15	25.30	(0.50)	24.35	(0.11)	0.95	(0.40)
25	37	46	24.90	(0.29)	24.07	(0.15)	0.83	(0.44)
35	25	15	34.40	(0.41)	34.27	(0.46)	0.13	(0.05)
35	25	46	35.60	(0.33)	33.70	(0.26)	1.90	(0.44)
35	37	15	34.43	(0.20)	34.28	(0.07)	0.15	(0.19)
35	37	46	35.20	(0.92)	34.19	(0.19)	1.01	(0.92)

Temperature range for nominal values: 25 (25.2-25.6); 37 (36.7-37.7)

For Length: 15m nominal = (14.8 -15.5)m and 46m nominal = (45.3 - 46.6)m.

*n=3

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Table 3. Ammonia adsorption results for LDPE

C_{ideal} (ppm)	Temp. ^oC	Length (m)	Inlet C ppm	(S.D.)*	Outlet C ppm	(S.D.)*	Difference ppm	(S.D.)*
5	25	15	5.1	(0.14)	4.26	(0.10)	0.84	(0.22)
5	25	46	4.8	(0.07)	3.5	(0.36)	1.30	(0.31)
5	37	15	5.4	(0.10)	4.05	(0.08)	1.35	(0.16)
5	37	46	4.9	(0.10)	3.16	(0.12)	1.74	(0.16)
15	25	15	15.1	(0.34)	12.71	(0.40)	2.39	(0.07)
15	25	46	14.4	(0.19)	11.72	(0.27)	2.68	(0.43)
15	37	15	15.4	(0.32)	12.43	(0.49)	2.97	(0.63)
15	37	46	14.7	(0.29)	11.12	(0.35)	3.58	(0.60)

*n=3

Table 4. Differences between the outlet and inlet concentrations of ammonia for Teflon tubing.

Nominal Inlet Concentrations (ppm)	Mean inlet Concentrations (ppm)	Mean Outlet Concentrations (ppm)	Difference* (ppm)		Effect of Temperature[2] C_{diff}(ppm)	Effect of Tubing Length[2] C_{diff}(ppm)
2[1]	2.10	1.03	1.07[ab]*		0.76[a] (@25^oC	0.86[a]@16m
5	4.95	4.35	0.60[a]		1.02[a]@37^oC	0.92[a]@45m
10	10.03	9.06	0.96[ab]			
15	14.85	13.50	1.35[b]			
25	24.73	24.16	0.56[a]			
35	34.91	34.11	0.80[a]			

[1]n=12 for difference in inlet and outlet concentrations
[2]n=36 for effect of temperature and tubing length.
*Mean C_{diff} values in columns followed by different letters are different at a 5% level

Table 5. Differences between the outlet and inlet concentrations of ammonia for LDPE tubing.

Ideal Inlet Concentrations (ppm)	Mean Inlet Concentrations (ppm)	Mean Outlet Concentrations (ppm)	Difference* (ppm)		Effect of Temperature C_{diff} (ppm)*	Effect of Length C_{diff}(ppm)*
5	5.05	3.74	1.31		1.90[a] (T=25)	1.80[a] (L=15)
15	14.9	12.0	2.9		2.32[a] (T=37)	2.41[a] (L=46)

[1]n=12 per treatment mean
*Mean C_{diff} values in columns followed by different letters are different at a 5% level

Table 6. Overall difference in outlet and inlet concentrations for Teflon and LDPE[1]

Material	Mean Inlet Concentrations (ppm)	Mean Outlet Concentrations (ppm)	Difference* (ppm)
Teflon	9.90	8.93	0.98[a]
LDPE	9.98	7.87	2.11[b]

[1]n=24 per treatment for Teflon vs LDPE
*Mean C_{Diff} values in columns followed by different letters are different at a 5% level

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Multiple linear regressions were performed for both materials to model the adsorption of ammonia. Tubing lengths of 15 and 46 meters did not statistically affect the adsorption of ammonia onto Teflon tubing. Tubing length was significant for LDPE within the experimental ranges tested (at $\alpha=0.05$). The inlet concentrations (C_{in}) used for the two different materials were also significant in explaining adsorption. While we can develop a model to predict adsorption of ammonia onto Teflon polymer tubing, the difference in adsorption through all parameters in the trials were within the systematic response of the TEI analyzer. This implies that within the time period set for the experiments (10 minute warm-up), adsorption sites have been filled up so that while we are having outlet concentrations readings below or above the set concentrations, the concentration difference are within the sensitivity of the equipment. In short, considering the standard deviation numbers from the mean, there were actually no systematic losses or adsorption that could be explained. The system loses for the LDPE however were above 2% and therefore may be worth modeling for future adsorption losses or corrections. This relationship is shown in Equation 6. The standard error and p-values for the variables are outlined in Table 7.

$$C_{LDPE} = -1.791 + 1.193 \cdot Cout + 0.058 \cdot T + 0.019 \cdot L \qquad (4)$$

Where:

C_{LDPE} = concentration from source of ammonia (ppm)
Cout = ammonia concentration at the outlet of tubing (ppm)
T = Temperature of fluid stream (^{o}C)
L = Tubing length (m)

It is important to note that the above predictive equation is only valid for the range of concentrations used in the experiment. At the highest concentration (15ppm), as much as 3.5 ppm of ammonia (Table 3) may be lost due to adsorption on LDPE material. For Teflon, no significant differences between the outlet and the inlet concentrations were observed. The differences recorded were within the sensitivity of the ammonia analyzer thus indicating equipment response rather than actual adsorption loses. It is therefore safe to use Teflon tubing in conjunction with ammonia measuring equipment like the TEI even for longer lengths (as much as 46 m) without accounting for systematic ammonia loss along the conveying tubes.

Table 7. Tests of significance for NH$_3$ adsorption onto LDPE material.

Variable	Estimate	Standard Error	t-Statistics	p-Value
Length (L)	0.019	0.003	5.791	b
Concentration (C)	1.193	0.012	98.777	a
Temperature (T)	0.058	0.008	6.816	b
Intercept	-1.719	0.305	-5.876	b

a: $\alpha \ll 0.001$; b: $\alpha \ll 0.001$

An interesting trend was observed from adsorption of ammonia onto Teflon for the wide range of concentrations used in the experiment. In Figure 3, the average inlet concentration is graphed against the percentage of the inlet concentration that is lost due to adsorption to Teflon material.

The curve shows that at lower concentrations of ammonia, as much as 50% ammonia could be lost due to adsorption onto this material. If a sufficiently high concentration is inputted into the tubing, then all of the adsorption sites are quickly filled with ammonia. The remaining concentration then passes through the tubing without any further adsorption providing minimal ammonia loss. The six data points plotted represent the average of three data sets in three replications for both the low (25°C) and high temperature (47°C) used in the tests and for the two tubing lengths used..
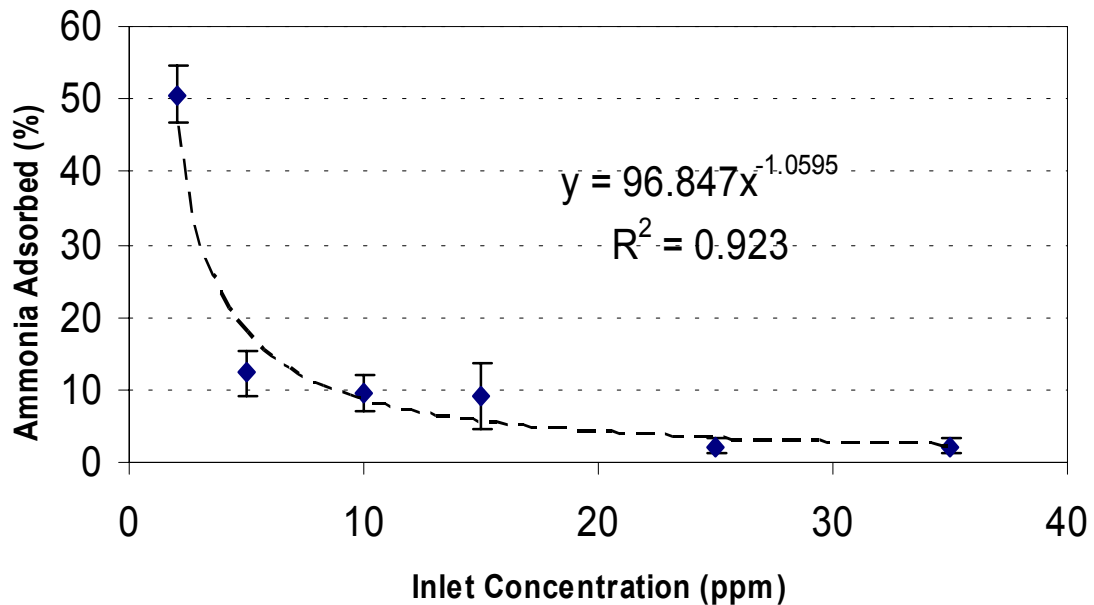
Figure 3. Relationship between ammonia adsorption and inlet ammonia concentration for Teflon tubing.

The implications of systematic losses in tubing could result in underestimation of ammonia inventory in ground level area sources. Table 8 shows an example of emission rate calculations for a lagoon (area=20,000m^2) in a 2,000-head dairy farm whose ammonia concentration was estimated using a flux chamber (area=0.193m^2) with a flow rate of 7 LPM at standard conditions (25°C and 1 atm). A 5 ppm difference in ammonia measurements or losses can be translated to about 3.6 kg/day emission rate change. The value will be doubled if area of the source is doubled.

Table 8. Emission rate calculations of ammonia from a typical dairy lagoon.

Ammonia Concentration (C_{ppm})	Mass Concentration* (C_{mass})	Flux**	Emission rate***	Emission rate	Emissions Inventory
(ppm)	($\mu g/m^3$)	($\mu g/m^2/sec$)	(kg/day)	(kg/1000HD/day)	(tons/year)
20	13,906	8.41	14.53	7.26	5.30
25	17,383	10.51	18.16	9.08	6.63

* C_{mass} ($\mu g/m^3$) = 40.9 x MW_{NH3} (g/mol) x C_{ppm}

**Flux ($\mu g/m^2/sec$)=C_{mass}($\mu g/m^3$)xFlow(LPM)/ Flux cross-sectional area (m^2) x conversion factor

***Emission rate (kg/day) = Flux ($\mu g/m^2/sec$) x Area of source (m^2) x conversion factor

SUMMARY AND CONCLUSIONS

This research quantifies the adsorption of ammonia onto Teflon and LDPE tubing under different length, temperature, and inlet ammonia concentrations. Ammonia adsorption onto LDPE material was found to be significantly higher than those for Teflon, signifying the higher resistance of Teflon to ammonia adsorption compared to LDPE. Tubing length was not significant in modeling ammonia adsorption onto Teflon, but was significant for LDPE. There were significant differences between inlet and outlet concentrations of LDPE at 5 and 15 ppm. The adsorption behavior of ammonia onto LDPE material was modeled and shown to increase as temperature and tubing length is increased. Overall, ammonia adsorption to Teflon was nearly 1 ppm regardless of the magnitude of inlet concentration, temperature or length of tubing. This loss onto the Teflon surface was well within the measurement sensitivity of the ammonia analyzer. Observed from the results of this research work is the increase in percent ammonia adsorption on Teflon material as the concentration is decreased and at the lowest concentration used in the test, the difference was as much as 50%. This was not evident at higher ammonia concentrations. The implications of this research work on future gas emissions sampling work is that, should there be evident adsorption loses on conveying tubes, they should be accounted for in reporting gas emissions inventory.

FUTURE WORK

The statistical analysis used in this study assumes that the changes in ammonia adsorption are a linear function of the different variables tested. This may not be necessarily true, but under the small range of values encountered in the field coupled with limited time, this assumption could be acceptable. The data from this study could not be fitted into an isotherm curve due to limited amount of concentration values used in the experiment. Other factors may play a role in determining the true variables that affect the adsorption of ammonia such as pressure, relative humidity, and gas flow rate. Future work should continue in this research to extend the knowledge base for ammonia adsorption.

ACKNOWLEDGEMENTS

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