Update on Ammonia Emission Mitigation for Egg Facilities

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Summary and Implications

Ammonia emissions from laying hen facilities may be reduced via pre- and/or post-excretion pathways. Our lab-scale tests to date have shown the following: a) reducing surface to volume ratio of manure stacks leads to reduced ammonia emission; b) an experimental diet (Ecocal) for W36 laying hens showed a 41% reduction in manure ammonia emission, as compared to the control diet, over a 14-d manure storage period; c) topical application of zeolite to laying hen manure at 2.5 to 5% (by weight) reduced ammonia emission by as much as 66-91% within one day of application; d) topical application of alum to layer manure at 0.5 kg/m^2 (0.1 lb/ft^2) reduced ammonia emission by 63-90% during seven days after the application, and emission reduction rate for application rate of 1.0 or 1.5 kg/m^2 (0.2 and 0.3 lb/ft^2) was at about 93% during the 7-d post-application period. Cost effectiveness and practicality of each mitigation option remain to be examined.

Introduction

Understanding and mitigating air emissions from production facilities is an important issue facing the U.S. livestock and poultry industries. A comparative summary of ammonia emission rates for laying hen houses in different countries is given in Table 1. Based on the recent ammonia emission data for U.S. broiler houses (Wheeler et al., 2004) and layer houses (Liang et al., 2005a), the approximate numbers of birds taken to emit 100 lb of ammonia per day[1] for various housing and manure handling schemes are listed in Table 2.

While baseline emission data are important, devising practical means to mitigate air emissions is the ultimate goal of the industry. It is based on this need that we are conducting emission mitigation studies. This report gives an update of our work concerning emission mitigation for egg facilities.

[1] 100 lb/day of ammonia emission is the reportable quantity under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Materials and Methods

We have been conducting emission mitigation studies using two research lab facilities. One consists of four individually environment-controlled air emission chambers and the measurement system (Fig. 1a,b). The other consists of eight emission vessels and the measurement system located in an environment-controlled room (Fig. 2a,b). The potential mitigation strategies that we have been examining include a) physical configuration of the manure storage stack, b) dietary manipulation, and c) topical application of mineral or chemical agents, i.e., zeolite and aluminum sulfate [$Al_2(SO_4)_3$] or alum.

To evaluate the effects of manure stacking profile on ammonia emission, five surface-area-to-volume ratios (SVRs, m^{-1}) of 1.23, 2.5, 5, 10, and 20, were examined using the air emission chamber facility. The five SVRs were achieved by stacking manure at 2, 4, 8, 16 and 31 inches high with the same base (floor) area of 5 x 6 ft of each emission chamber. The chamber was held at 77°F air temperature near the manure surface and ventilation rate was held at 20 air changes per hour (ACH). The manure storage and emission measurements lasted 40 d. A separate study was conducted to evaluate the effect of air exchange rate (10 vs. 20 ACH) on ammonia emission and the results showed no effect.

The effect of dietary manipulation was evaluated using the emission vessel system. Nearly fresh manure samples from hens fed either the industry standard or control diet (Ctrl) or an experimental diet (Ecocal[2]) were collected and shipped frozen to our lab where the manure samples were thawed and randomly allotted to the eight emission vessels. Each 2.5 kg manure sample was placed in a 1-gallon (3.8 L) container that was placed inside a 5-gallon (19 L) emission vessel. The manure storage and emission measurements lasted 14 d. Four replicates were tested per dietary regimen.

The effects of topical application of zeolite (grade 14×40, Bear River Zeolite Company, Thompson Falls, MT) at various dosages on ammonia emission from hen manure also were examined in two experiments using the emission vessel system. In both experiments, nearly fresh hen manure was collected from a commercial belt layer house and transported to our lab. In Expt 1, 2.5 kg of manure sample was loaded into a 1-gal (3.8 L) container with a 0.2 ft^2 (0.02 m^2) manure surface area. Different quantities of zeolite, 62.5, 125 or 250 g, were topically applied to the

[2] Ecocal is a custom-formulated diet by the cooperative producer, consisting of gypsum (calcium sulfate, to partially replace limestone) and zeolite.

manure, resulting in an application rate of 0.64, 1.28 and 2.60 lb·ft^{-2} (3.125, 6.25, or 12.5 kg·m^{-2}) manure surface. Each 1-gal container was placed in the 5-gal vessel. Two trials were conducted to obtain four replicates of each regimen. The storage and measurement lasted 14 d. In Expt 2, equal amount of fresh manure (2.5 kg per layer of 2 inch or 5 cm) was added to all vessels every two days for four layers, simulating manure removal from belt hen houses into manure storage. Zeolite of 125 g (5% by weight) was topically applied to each layer in four vessels while the other four served as control. Manure was loaded directly into the 5-gal emission vessel, resulting in an application rate of 0.52 lb·ft^{-2} (2.55 kg·m^{-2}) over the 0.5 ft^2 (0.05 m^2) manure surface. Airflow rate through the emission vessels ranged from 11 to 21 ACH, as a result of increasing manure volume. Ammonia emission was monitored for eight more days after the last layer of manure and zeolite addition, a 14-d trial.

Results and Discussion

Effect of Manure Stacking Profile on NH_3 Emission

The cumulative ammonia emissions during the 40-d storage from the manure stacks with the same base area of 30 ft^2 but different height of 2, 4, 8, 16, or 31 inches are shown in figure 3. The difference in ammonia emission per unit weight of manure over the 40-d storage period between the 2-inch stack and the 31-inch stack was more than six folds. This substantial difference arose from the fact that it is the top sub-layer of the manure stack that was primarily responsible for the ammonia emission. The crust formed near the surface was speculated to provide a physical barrier to ammonia escape from the stack. Table 3 shows the manure properties before and after the 40-d ventilated storage. Hence, the results indicate when stocking manure, reducing surface to volume ratio will lead to reduction in ammonia emission. Details of the experimental procedure and results were given in Li et al. (2005).

Effect of Dietary Manipulation on NH_3 Emission

Figure 4 shows the daily ammonia emissions from the manure samples of either the standard (Ctrl) diet or the experimental Ecocal (Trt) diet, along with the manure and air temperatures. The mean daily ammonia emission over the 14-d storage period was 0.29 g·kg^{-1} d^{-1} for the Ctrl diet and 0.17 g·kg^{-1} d^{-1} for Trt diet, i.e., a reduction of 41%. Daily ammonia emission of the Trt manure after day 2 was significantly lower than that of the Ctrl manure ($P<0.01$). The emission reduction for the Trt presumably resulted from a combination of acidogenic (gypsum) and ammonia adsorbing (zeolite) effects. Details of the experimental procedures and results were given in Liang et al. (2005b).

Effect of Topical Application of Zeolite on NH_3 Emission

Topical application of zeolite on hen manure reduced ammonia emission and the magnitude of emission reduction was generally proportional to the application rate (Fig. 5). Adsorption of ammonia seemed to take effect right after the application, resulting in the largest emission reduction on day 1, 66%, 91% and 96% for the application rate of 2.5%, 5% and 10%, respectively. Daily NH_3 emission of the Ctrl vessels became stabilized after day 3, whereas emissions of the Trt vessels continued to increase with the Trt2.5 being most obvious. Ammonia emissions of Trt5 and Trt10 were significantly lower than that of the Ctrl ($P<0.01$) throughout the 14-d trial period, whereas this was true for the Trt2.5 regimen during the first 7 d ($P<0.01$). Table 4 summarizes the effects of single or multiple topical applications of zeoilite at the three dosages on NH_3 emission reduction.

Effect of Topical Application of Alum on NH_3 *Emission*

The ammonia emission profiles of the Ctrl and three application rates of 0.1, 0.2 and 0.3 lb·ft^{-2} (0.5, 1.0, and 1.5 kg·m^{-2}) and the reduction rates are shown in figure 6. Ammonia emission from each of the treatment regimens was significantly lower than that of the control ($P<0.0001$). There was no significant difference between the 0.2 lb·ft^{-2} (1.0 kg·m^{-2}) and 0.3 lb·ft^{-2} (1.5 kg·m^{-2}) application rates ($P = 0.884$). During the 7-d trial period, ammonia emission reduction for the 0.1 lb·ft^{-2} regimen changed from 91% to 63%, whereas it remained nearly 93% for the 0.2 and 0.3 lb·ft^{-2} regimens.

Conclusions

- Reducing surface to volume ratio of manure stacks will lead to reduced ammonia emission.
- The dietary manipulation showed a 41% reduction in ammonia emission over a 14-day trial period from laying hen manure using the experimental diet (Ecocal), as compared to the control diet.
- Topical application of zeolite to laying hen manure at 2.5 to 5% showed ammonia emission reduction of as much as 66 to 91% within one day of application. It remained effective for at least 7 days.
- Topical application of alum to laying hen manure at 0.1 lb/ft^2 reduced ammonia emission by 91% to 63% during 7 days of post application. Emission reduction for application rate of 0.2 and 0.3 lb/ft2 was about 93% during the same period.

Future Work

- Analysis of costs and practicality of each potential mitigation strategy/technique.
- Field verification of dietary manipulation with regards to hen production performance and feed costs as well as ammonia emission reduction.

Acknowledgements

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Table 1. Summary of ammonia emission rates (ER, g NH_3 $AU^{-1}d^{-1}$) of laying hen houses with different housing and management schemes in different countries as reported in the literature and current study (1 AU or animal unit = 500 kg live weight).

Country	House Type (season)	Manure Removal Interval	NH_3 ER	Reference	Year
England	Deep pit (winter)	info not available	192	Wathes et al.	1997
England	Deep pit (summer)	info not available	290	Wathes et al.	1997
England	Deep pit (N/A)	info not available	239	Nicholsen et al.	2004
U.S.A (Ohio)	High-rise (March)	Annual	523	Keener et al.	2002
U.S.A (Ohio)	High-rise (July)	Annual	417	Keener et al.	2002
U.S.A (Iowa & Pennsylvania)	High-rise (all year) – *standard diet*	Annual	298	Liang et al.	2005
U.S.A (Iowa)	High-rise (all year) – *1% lower CP diet*	Annual	268	Liang et al.	2005
The Netherlands	Manure Belt (N/A)	Twice a week with no manure drying	31	Kroodsma et al.	1988
The Netherlands	Manure Belt (N/A)	Once a week with manure drying	28	Kroodsma et al.	1988
Denmark	Manure Belt (all year)	info not available	52	Groot Koerkamp et al.	1998
Germany	Manure Belt (all year)	info not available	14	Groot Koerkamp et al.	1998
The Netherlands	Manure Belt (all year)	info not available	39	Groot Koerkamp et al.	1998
England	Manure Belt (all year)	Weekly	96	Nicholsen et al.	2004
England	Manure Belt (all year)	Daily	38	Nicholsen et al.	2004
U.S.A (Iowa & Pennsylvania)	Manure Belt (all year)	Daily with no manure drying	17.5	Liang et al.	2005
U.S.A (Iowa & Pennsylvania)	Manure Belt (all year)	Twice a week with no manure drying	30.8	Liang et al.	2005

Source: Liang et al. (2005a)

Table 2. Estimated number of birds taken to emit 100 lb of ammonia (NH_3) per day for broilers at different market age and laying hens under different housing and manure handling systems.

Poultry Type	Market age (broilers) or Housing/Manure Handling Schemes	Emission Rate g NH_3/bird-day	# birds to emit 100 lb NH_3/day
Broilers	Mean of broiler houses	0.93	48,817
	Hi of 40-day old broilers	1.45	**31,310**
	Hi of 49-day old broilers	1.73	**26,243**
	Hi of 63-day old broilers	2.16	**21,019**
Laying Hens	Mean of high-rise houses	0.90	50,444
	Hi of high-rise houses	1.61	**28,199**
	Mean of belt houses-1d removal	0.054	840,741
	Hi of belt houses-1d removal	0.132	**343,939**
	Mean of belt houses -3-4d removal	0.094	482,979
	Hi of belt houses -3-4d removal	0.28	**162,143**

The emission rate values are based on one-year field monitoring of commercial broiler houses in Kentucky and Pennsylvania (Wheeler et al., 2005) and laying houses in Iowa and Pennsylvania (Liang et al, 2005).

Table 3. Initial and post (40-d) storage compositions of laying hen manure stacked at a surface to volume ratio (SVR) of 20, 10, 5 or 2.5 (base area of 30 ft^2 at stack height of 2, 4, 8 or 16 inches) and ventilated at 20 air changes per hour (ACH) (Top layer refers to top 2 inch of the stack and bottom layer to sub layer of stack) (mean and standard deviation, n=2).

	Property	Fresh Manure	After 40-day Ventilated Storage			
			SVR20	SVR10	SVR5	SVR2.5
Top Layer	Dry matter (%)	28.1 (1.7)	68.4 (13.4)	54.1 (4.6)	54.9 (1.8)	56.6(11.7)
	Total N, g/kg (as-is)	16.2 (0.3)	19.9 (5.1)	19.9 (3.1)	15.5 (4.1)	20.1 (3.9)
	Total N, g/kg (dry base)	57.7 (2.5)	28.9 (1.8)	37.2 (8.9)	28.4 (8.4)	37.0(14.5)
	Total Ammoniacal N, g/kg (as-is)	8.8 (1.0)	4.6 (1.5)	6.0 (1.0)	6.0 (0.1)	5.9 (2.6)
	Total Ammoniacal N, g/kg (dry base)	31.3 (1.6)	7.1 (3.6)	11.3 (2.7)	10.9 (0.5)	11.2 (7.0)
	pH	7.4 (0.4)	8.6 (0.0)	8.6 (0.1)	8.5 (0.2)	8.6 (0.2)
Bottom Layer	Dry matter (%)	28.1 (1.7)	68.4 (13.4)	32.5 (3.0)	23.7 (1.6)	23.3 (2.4)
	Total N, g/kg (as-is)	16.2 (0.3)	19.9 (5.1)	12.2 (3.0)	16.7 (0.4)	15.9 (1.0)
	Total N, g/kg (dry base)	57.7 (2.5)	28.9 (1.8)	38.1(12.6)	70.8 (6.7)	64.6 (0.7)
	Total Ammoniacal N, g/kg (as-is)	8.8 (1.0)	4.6 (1.5)	8.2 (2.2)	10.5 (1.6)	10.8 (0.2)
	Total Ammoniacal N, g/kg (dry base)	31.3 (1.6)	7.1 (3.6)	25.5 (9.1)	44.3 (3.5)	44.2 (3.6)
	pH	7.4 (0.4)	8.6 (0.0)	8.5 (0.1)	8.0 (0.0)	8.0 (0.2)

Table 4. Effects of topical application of zeolite at different rates on reduction of ammonia emission from laying hen manure storage. The application rates, expressed in % of manure weight, were 0% (Ctrl), 2.5% (Trt2.5), 5% (Trt5), and 10% (Trt10), respectively.

		Single Application (in 1-gal emission vessels)				Four Layers (5-gal vessels)		Single Application (in chambers)	
		Ctrl	Trt2.5	Trt5	Trt10	Ctrl	Trt5	Ctrl	Trt5
Amount of manure, kg		2.5				2.5 kg x 4 = 10		136 kg x 7 = 952	
Surface area of the manure, m^2 (ft^2)		0.02 (0.22)				0.05 (0.54)		2.8 (30)	
Application rate	$kg \cdot m^{-2}$	0	3.125	6.25	12.5	0	2.55	0	2.55
	$lb \cdot ft^{-2}$	0	0.639	1.277	2.555	0	0.52	0	0.52
Number of zeolite application		Once - at the beginning				4 - once per layer		Once - after 3 weeks of manure loading & storage	
Trial/treatment duration, day		14				14		14 (w/o) + 4 (with trt)	
Avg. daily ER per unit of manure weight or surface area over trial period	$g \cdot kg^{-1} d^{-1}$	0.231	0.185	0.116	0.053	0.137	0.069	0.086	0.052
	$g \cdot m^{-2} d^{-1}$	29.9	24.0	15.0	6.9	16.1	9.7	25.9	15.6
7-d cumulative emission, $g \cdot kg^{-1}$		1.6	1.0	0.62	0.14	-	-	-	-
7-d cumulative emission reduction		-	**68%**	**81%**	**96%**	-	**33%** [b]	-	-
Total cumulative emission, $g \cdot kg^{-1}$ [a]		3.0	2.5	1.4	0.7	1.7	1.0	0.34	0.21
Total cumulative emission reduction		-	**20%**	**50%**	**77%**	-	**44%**	-	**40%**
8-d cumulative emission reduction [c]		-	-	-	-	-	**54%**	-	-

[a] comparison tests lasted 14 days for vessel trials, but four days for the LEAP Lab trial (last four days of an 18-day trial)
[b] represents cumulative emission reduction over 7 days following the last-layer addition of hen manure
[c] represents cumulative emission reduction during first 8 days of manure additions

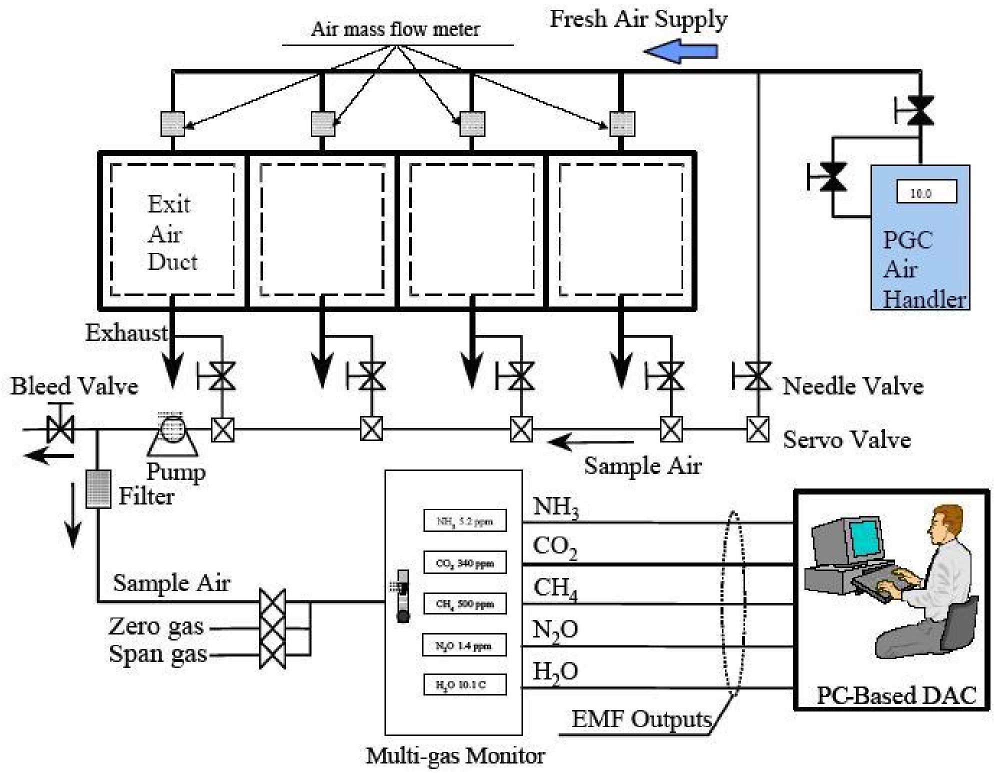

Figure 1a. Schematic representation of environmentally controlled air emission chambers (5 x 6 x 8 ft each) and data acquisition system used in our air emission measurement and mitigation studies.

Figure 1b. Photographical views of the air emission chambers and data acquisition system used in our air emission measurement and mitigation studies.

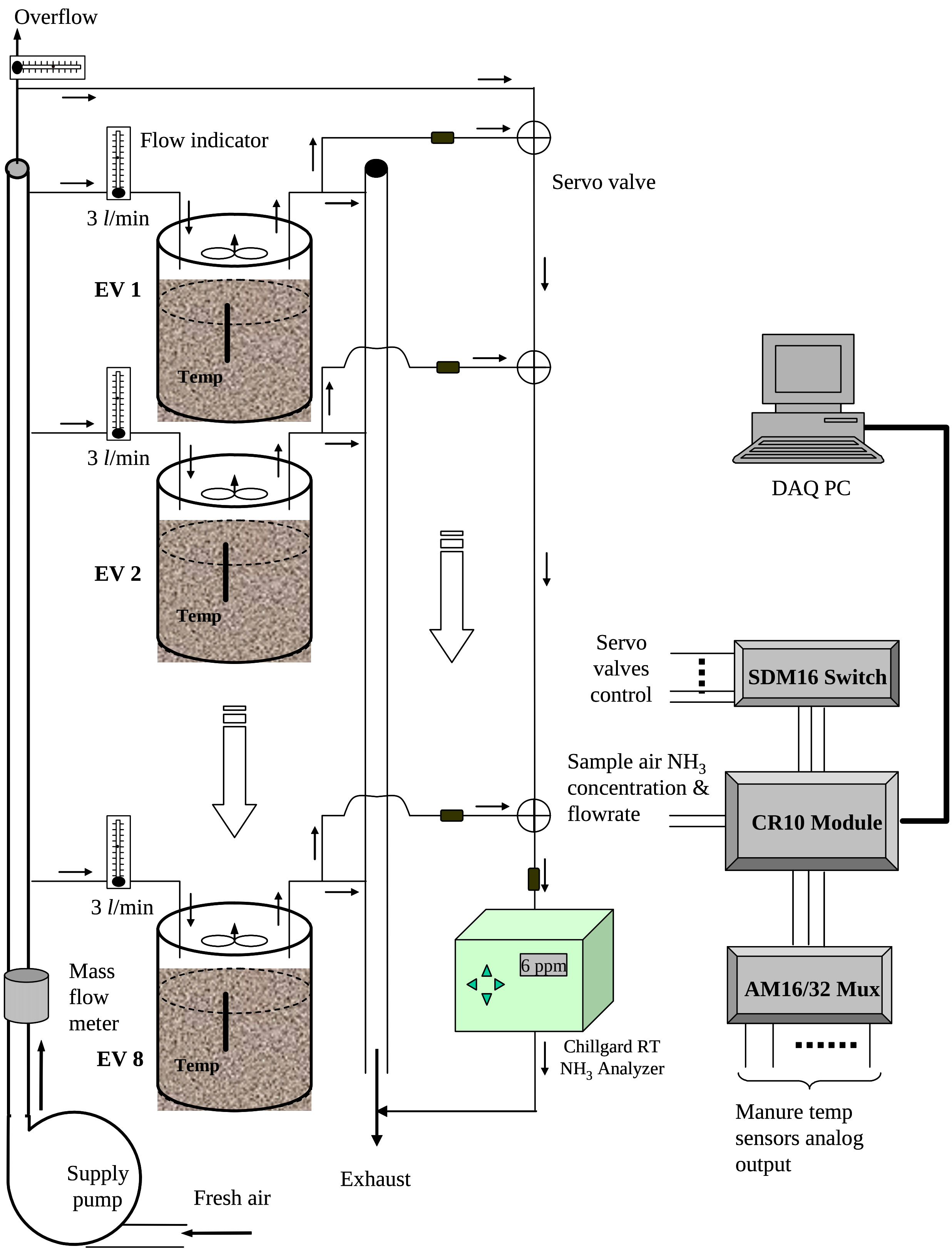

Figure 2a. Schematic representation of the experimental setup for evaluating efficacy of treatment agents on ammonia emission reduction from animal (poultry) manure (EV = emission vessel, 5 gal or 19 liter each).

Figure 2b. Photographical views of the lab-scale setup for evaluating efficacy of air emission mitigation strategies. Pictured (right) is topical application of Zeilite on laying hen manure at various dosages.

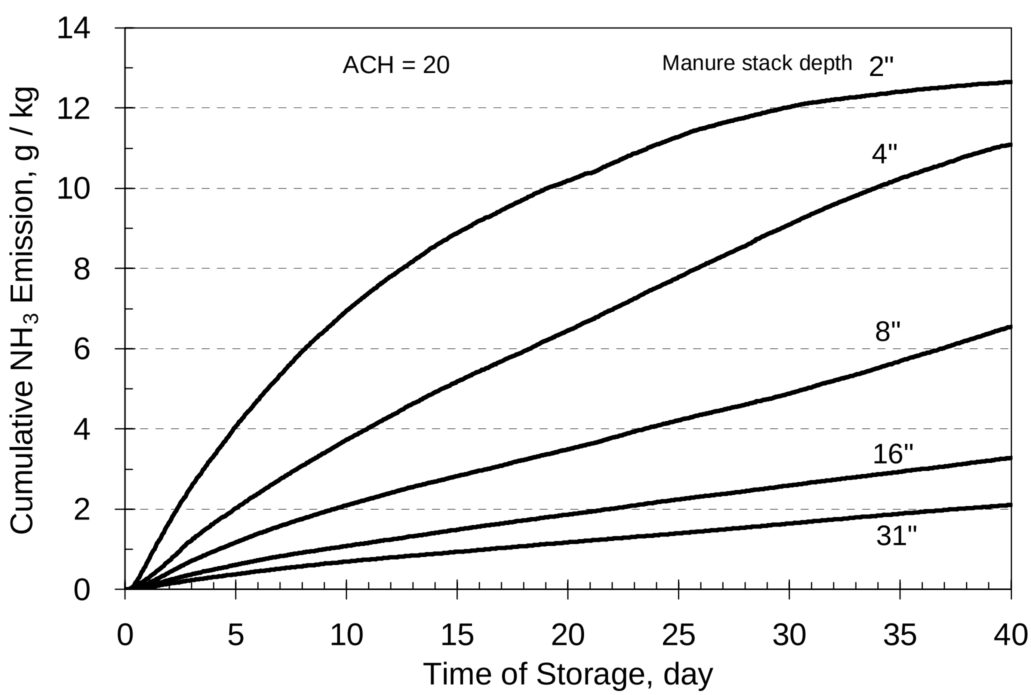

Figure 3. Ammonia emissions from laying hen manure storage as affected by surface area to volume ratio of the manure stack. All stacks had the same base area of 30 ft^2 but with different heights of 2 to 31 inches. Air temperature in all chambers was held at 77^{o}F, with an airflow rate of 20 air changes per hour (ACH).

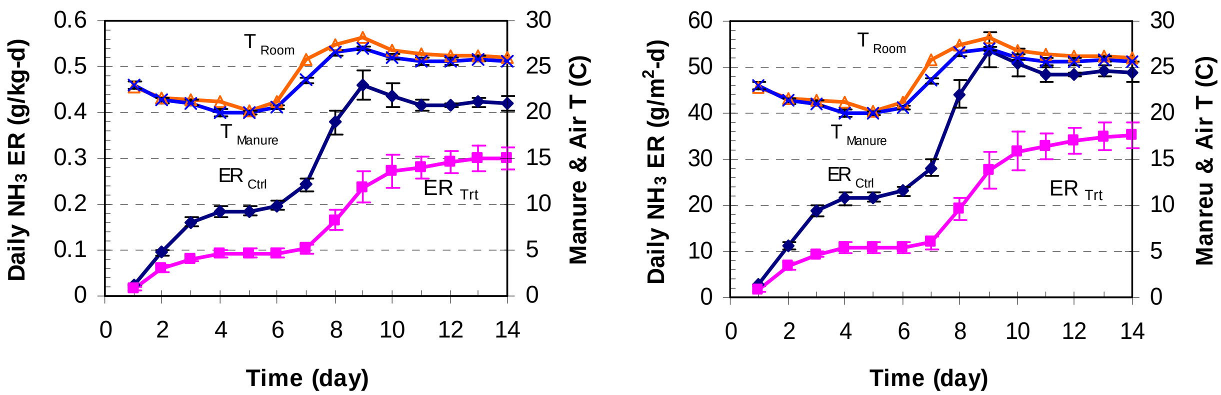

Figure 4. Daily ammonia emission rate (ER) and manure or air temperatures of stored laying hen manure using either standard ration or the experimental Ecocal ration.

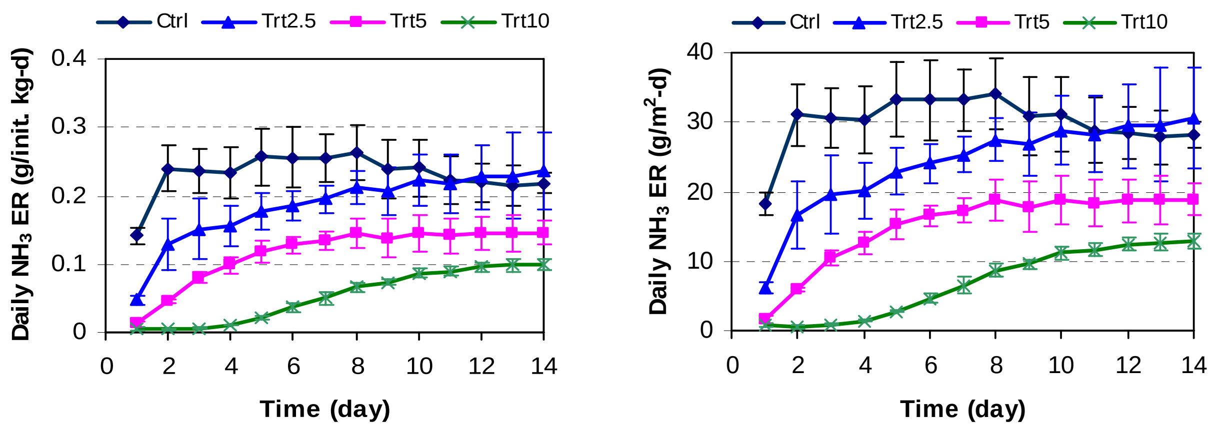

Figure 5. Daily ammonia emission rate (ER) of ventilated storage of laying hen manure with different rates of topical application of zeolite on day 0. Ctrl = no zeolite; Trt2.5 = 2.5% zeolite by weight; Trt5 = 5% zeolite by weight; Trt10 – 10% zeolite 10% .

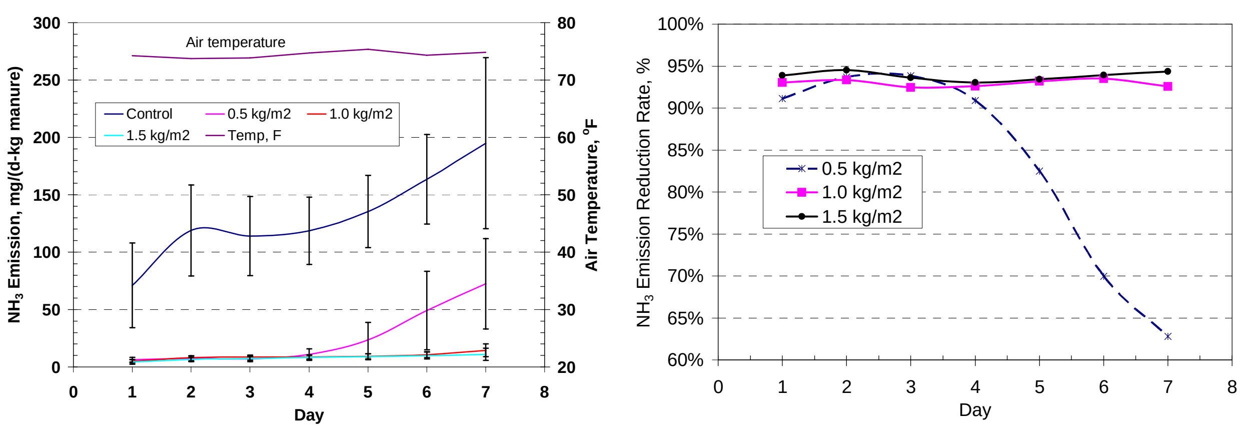

Figure 6. Effect of topical application of alum powder at different rates on ammonia emissions from laying hen manure. The application rates were 0, 0.1, 0.2 or 0.3 lb/ft^2 (0, 0.5, 1.0 or 1.5 kg/m^2). The vertical bars represent the standard deviations.