

# **A Study of the Effects of Post-Combustion Ammonia Injection on Fly Ash Quality: Characterization of Ammonia Release from Concrete and Mortars Containing Fly Ash as a Pozzolanic Admixture**

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## Abstract

Work completed in this reporting period focused on the measurement of the rate of ammonia loss from mortar and concrete, and the measurement of ammonia gas in the air above the materials immediately after placement. The majority of mortar experiments have been completed, and testing has begun on concrete. The mortar experiments indicate that the rate of ammonia loss is greater in mortars prepared using a higher water content and water:cement (W:C) ratio, although the higher rate is primarily observed within the first 2 days, after which the loss rates are nearly the same. The source of low-calcium (Class F) fly ash exerted a negligible influence on the loss rate. However, mortar prepared using a higher-calcium fly ash evolved ammonia at a slightly slower rate than the Class F ash mortars. The data also indicate that an increase in ventilation increases the ammonia loss rate from mortar, and suggest that a well-ventilated space could substantially increase the loss of ammonia from mortar and, by inference, a concrete slab. Analysis of ammonia concentrations in the air above freshly-placed mortars in an enclosed space indicate that the fly ash ammonia concentration should not exceed 100 mg N/kg ash in confined space applications. For most other applications with some ventilation the maximum acceptable concentration would be approximately 200 mg/kg. Early results from experiments on concrete suggest that, under similar conditions, ammonia diffusion from concrete occurs at a higher rate than in mortar. In addition, increasing the slump of concrete through the use of chemical admixtures has only a minor effect on the ammonia loss rate.

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## **EXECUTIVE SUMMARY**

Work completed in this reporting period focused on the measurement of the rate of ammonia loss from mortar and concrete, and the measurement of ammonia gas in the air above the materials immediately after placement. The majority of mortar experiments have been completed, and testing has begun on concrete.

Mortar testing results indicated that the overall ammonia loss rate was greater for mortars prepared at a higher W:C ratio. Initially, within approximately 48 hrs, the loss rate was relatively high for both types of mortars. However, the Low W:C mortar exhibited a decrease in the rate sooner than the higher W:C material. The result was a greater loss of ammonia in the latter. This is possibly caused by a greater amount of bleed water coming to the surface of the High W:C mortar. Furthermore, the High W:C mortar will have a greater porosity and thus diffusivity. At the cessation of the experiments, greater than 80% of the ammonia remained within the mortars. These data indicate that ammonia could continue to evolve from mortar for a prolonged period after placement, although the diffusion rate would be very slow.

Mortars prepared using low-calcium Class F fly ash, exhibited similar ammonia loss rates, that is, the source of the ash had a negligible influence on the loss rate. However, mortar prepared using a higher-calcium (16% CaO) fly ash evolved ammonia at a slightly slower rate than the Class F ash mortars. This is probably related to the faster rate of strength development, with a corresponding porosity decrease, in mortar and concrete that occurs when high-calcium fly ash is used instead of Class F fly ash.

Over the course of the experiments it was found that the degree of air ventilation above a mortar slab has a pronounced effect on the ammonia loss rate from the mortar in both the fresh and hardened state. Compared with a 1 L/min air flow, ventilation of mortar with 8 L/min of fresh air for four weeks causes a loss of 35% of the total ammonia compared with only 15% for the 1 L/min ventilation. These data indicate that a well-ventilated space could substantially increase the loss of ammonia from mortar and, by inference, a concrete slab.

Measurement of ammonia concentration at different heights above freshly placed mortar within an enclosed cylindrical space (7.5 ft. high) revealed that during the first 2 hours the ammonia concentration was highest near the mortar surface. However, after 2 hours the ammonia concentration was homogeneous from top to bottom. The data also suggest that, under the conditions employed for the experiments, the maximum concentration of fly ash ammonia for confined-space applications is 100 mg N/kg fly ash, whereas for other applications with at least a modicum of ventilation the maximum concentration is approximately 200 mg/kg. It was also evident that increasing the slump of the mortar mix (through addition of water and/or chemical admixtures) can increase the ammonia concentration in the air. This effect was associated with an increase in the quantity of bleed water that occurred at the surface of the mortar, which would effectively carry ammonia to the surface. Furthermore, excessive bleeding can introduce channels in the mortar, thus providing a conduit for ammonia release.

Comparison of the results of mortar experiments with those from initial experiments on concrete suggest that ammonia diffusion from concrete occurred at a higher rate than from mortar. In addition, increasing the slump of concrete through the use of chemical admixtures had only a minor effect on the ammonia loss rate.

## **EXPERIMENTAL**

### **A. Mortar and Concrete Preparation**

#### **A.1. Mortar**

Mortars were prepared and mixed using the materials and procedures described in a previous technical progress report (10/12/00 to 04/11/01). The two mortar mixes used are provided in Table 1.

#### **A.2. Concrete**

Concrete studied in this project was prepared using Type I Portland cement (Quickcrete brand), graded sand, limestone aggregate, fly ash, and tap water. Slump was increased using Boral X20 mid-range water reducer, and air was entrained by addition of Boral Air 40. Concrete batch volumes of 0.02 m<sup>3</sup> were formulated following ACI 211.1-91 guidelines (ACI, 2000). Two water:cement + pozzolan (W:C) ratio mixes were designed and prepared in trial batches, and are presented in Table 2. Ammonia (expressed on a nitrogen basis) was introduced into the concrete by first dissolving ammonium sulfate in the mix water when non-ammoniated ash was used, and directly through the addition of ammoniated fly ash. The components were mixed for approximately 3 minutes in a 99 L (3.5 ft<sup>3</sup>) capacity mixer (Gilson Company), the opening of which was covered with a tight-fitting lid to prevent the escape of ammonia from the rotating mixing drum.

### **B. Measurement of Evolved Ammonia**

#### **B.1. Mortar**

The experimental design for measurement of ammonia loss from mortar is described in a previous technical progress report (10/12/00 to 04/11/01) and was used throughout the mortar testing program. During this reporting period, the effects of fly ash source, ammonia concentration and ventilation rate were studied. Ventilation rates that would be applicable for residential buildings (ASHRAE, 1999) were proportioned to the cross-sectional area of the cylindrical mortar slabs as described for the mortar experiments in the aforementioned technical report.

One of the major concerns regarding the use of ammoniated fly ash in mortar and concrete is the potential exposure of workers to high levels of ammonia. In this context, a key issue is the maximum concentration of ammonia allowable in fly ash, below which worker safety would not be jeopardized. Therefore, an experimental procedure was designed to address this issue. An 11 cm thick layer of ammonia-laden mortar was placed into a vertical 15.2 cm (6 in.) i.d. diameter section of PVC pipe that was capped on the bottom. A 213 cm (7 ft) tall section of identical pipe (capped at the top) was then placed over the bottom section and sealed to it using a rubber-lined pipe clamp (Figure

1). Holes were drilled at several locations (10, 40, and 70 in. above the mortar) along the length of the upper pipe section to allow measurement of ammonia concentration inside the pipe (between measurements the holes were plugged). Two of these holes were sometimes used as an inlet and outlet for air ventilation through the pipe. Ammonia concentration of the air within the pipe was measured using Sensidyne and GasTec ammonia detection tubes at specific intervals.

## **B.2. Concrete**

After mixing the concrete was placed and compacted into a cylindrical section of a cardboard concrete form (Sonotube) that was 40.6 cm (16 in.) in diameter and 15.2 cm (6 in.) high. Prior to concrete placement, this section was fastened to a circular polyethylene base and then coated with a silicone spray. After placement of the concrete a longer section of Sonotube measuring 213 cm (7 ft.) in length was fitted over the base section (containing the concrete) and secured to it using a rubber-lined stainless steel band clamp (Figure 2). This assembly was designed to represent a cylindrical section of a larger room with a 7.5 ft ceiling height. Ventilation rates were then calculated for the surface area of the concrete slab. For example, ASHRAE recommends a minimum ventilation rate of 450 L/min-person for a residential building. Applied to a basement with 5 persons and a floor area of 35 m<sup>2</sup>, the standard would require a ventilation of 64.3 L/min-m<sup>2</sup> of floor area. It then follows that for our cylindrical concrete slab, with an area of 0.13 m<sup>2</sup>, the proportional ventilation rate is 8.3 L/min. However, for this project a range of ventilation rates will be studied. The experimental design also allowed for the measurement of ammonia concentration in the space above the concrete over time.

Ammonia that evolved from the concrete was collected in an acetic acid-magnesium acetate aqueous solution and measured using an Orion ammonium ion-selective electrode (Figure 2). This apparatus is a scaled-up version of the apparatus used in the mortar experiments.

## **RESULTS AND DISCUSSION**

### **A. Ammonia Loss from Mortar**

#### **A.1. Effect of Fly Ash Source**

In this series of experiments six different fly ash samples were used in the preparation of mortar. Although the properties of these samples have been reported previously, for convenience Table 3 provides chemical data for the ash samples. The rate of ammonia loss from mortars prepared using the six different fly ashes are presented in Figure 3. These data were obtained using the Low W:C mortar mix and a ventilation rate of 1 L/min. Ammonia was added to the mortars prepared using non-ammoniated fly ash at a concentration of 400 mg NH<sub>3</sub>/kg ash. It is evident from the graphs that, in the case of low-calcium Class F fly ash, the source of the ash exerted a negligible influence on the loss rate: all of the mortars contained greater than 80% of the initial ammonia concentration after 3 weeks. However, mortar prepared using the higher-calcium (16% CaO) Rockport fly ash evolved ammonia at a slightly slower rate than the

Class F ash mortars (Figure 3). This is probably related to the faster rate of strength development (and thus porosity decrease) that occurs when high-calcium fly ash is used in mortar and concrete than when Class F fly ash is used (Thomas et al., 1999).

The data also indicate that the origin of the ammonia within mortar exerts a negligible influence on the loss rate. Mortar prepared using non-ammoniated fly ash, with ammonia added to the water as  $(\text{NH}_4)_2\text{SO}_4$ , behaves similarly to mortar prepared using ammoniated fly ash (Figure 3).

### **A.2. Effect of Ammonia Concentration**

The loss of ammonia from mortar as a function of ammonia concentration is presented in Figure 4. As is expected, the loss rate is greater for mortar containing a higher initial ammonia concentration than for one with less ammonia (Figure 4, top). However, if the same concentration data are plotted as a fraction of the initial ammonia concentration (of the water component, i.e. mg/L  $\text{H}_2\text{O}$ ) it is evident that the rates, expressed in this way, are similar. This is similar to what is observed in aqueous solutions containing ammonia. Figure 5 presents ammonia loss curves for water containing three different concentrations of ammonia, calculated from the empirical equation of Weiler (1979) using the area:volume ratio of our cylindrical mortar slabs, a temperature of  $18^\circ\text{C}$ , and negligible wind speed. It can be seen from the figure that, because the rate constant is independent of concentration, the loss rate on a fractional basis is the same for all initial ammonia concentrations, similar to our data. It is also interesting to note that, under these conditions, nearly all of the ammonia is lost from water after several days. This is in sharp contrast to our mortar experiments wherein several months and a high ventilation rate would be required to remove even 50% of the ammonia from the mortar.

### **A.3. Effect of Ventilation Rate**

According to work by Weiler (1979) the rate of ammonia loss from water to the atmosphere is a function of pH, temperature, the area:volume ratio of the water body, and the wind speed passing over the water body. It has been found for seawater that the loss rate to the atmosphere of gases that are reactive in water, such as  $\text{SO}_2$  and  $\text{NH}_3$ , is limited by the gas concentration in the air layer immediately overlying the seawater. Thus, for water with a high pH (i.e. 12), and a constant temperature and area:volume ratio, the ammonia loss rate should be limited by the air ventilation rate over the water. This has practical implications for this project since concrete will experience a wide range of ventilation conditions during and after placement and finishing. For example, whilst some concrete slabs in residential applications are placed after basement walls have been constructed, in many other cases the slab is poured on-grade prior to construction. The result is that ventilation in the former case would be significantly less than in the latter. It is therefore of interest to this project to study a range of ventilation rates in order to ascertain the effect on ammonia loss rate.

Figure 6 depicts the effect of ventilation rate on ammonia loss from Low W:C mortar containing 400 mg  $\text{NH}_3$  per kg of fly ash, at  $18^\circ\text{C}$ . The data indicate that an increase in ventilation did indeed substantially increase the ammonia loss rate from mortar.

Ventilation of the cylinder with 8 L/min of fresh air for four weeks caused a loss of 35% of the ammonia compared with only 15% in the case of the 1L/min ventilation. These data indicate that a well-ventilated space could substantially increase the loss of ammonia from mortar and, by inference, a concrete slab. An additional experiment is currently being conducted using a 16L/min air flow through a mortar cylinder in order to further investigate and quantify the influence of ventilation rate.

#### **A.4. Ammonia Concentration in the Space Above Mortar**

Table 4 provides the measured concentrations of ammonia at different heights above a Low W:C mortar prepared using Bowen fly ash and an ammonia concentration equivalent to 100 mg NH<sub>3</sub>/kg ash, with no ventilation in the pipe (apparatus described in the Experimental section above). During the first 2 hours of measurement the ammonia concentration was highest near the mortar surface. However, after 2 hours the ammonia concentration was homogeneous from top to bottom. This trend was observed for all of the experiments without ventilation. The maximum concentration was 17 ppm which is below the 25 ppm TWA and 35 ppm PEL limits recommended by NIOSH.

Increasing the ammonia concentration to 200 mg/kg (using non-ammoniated Bowen ash) and 245 mg/kg (using ammoniated Yates ash) resulted in air concentrations as high as 35 ppm and 38 ppm, respectively (Table 5), which exceed NIOSH limits. A flow of 0.5 L/min air (representing a low degree of residential ventilation) lowered the maximum ammonia-in-air concentration for the Bowen ash mortar to 20 ppm. However, in the case of the Yates ash mortar a high ventilation rate of 2 L/min (equivalent to 1.85 L/sec-m<sup>2</sup>, or 2.86 air changes/hr) was required to lower the ammonia-in-air concentration below the NIOSH TWA limit (Table 5). These data suggest that, under the conditions employed for the experiments (i.e. 0.485 W:C ratio, 20% cement replacement with fly ash, 20°C) the maximum concentration of fly ash ammonia for confined-space applications is 100 mg NH<sub>3</sub>/kg, whereas for other applications with at least a modicum of ventilation the maximum concentration would be about 200 mg/kg.

The effect of mortar slump on ammonia-in-air concentration is shown in Table 5, which provides the results of two experiments where the slump of the mortar was increased in two ways. For the first mortar, prepared using Bowen fly ash and ammonia added at a concentration of 100 mg NH<sub>3</sub>/kg ash, the W:C ratio was increased to 0.66 (High W:C mix), while the total water content was increased as well. In the second case, Yates ammoniated fly ash was used in the preparation of the Low W:C and High W:C mortars, as well as the Low W:C mortar mix to which a mid-range plasticizer was added at a rate of 667 ml per 100 kg of cement + fly ash (10 oz/100 lbs). From the data in Table 5 it is evident that increasing the slump of the mortar mix can increase ammonia evolution from the fresh mortar into the air, even though the High W:C Bowen ash mortar contained a lower ammonia concentration in the water than its Low W:C counterpart (from dilution). This effect seems to be associated with an increase in the quantity of bleed water that occurs at the surface of the mortar, which would effectively bring ammonia with it. Furthermore, excessive bleed can introduce channels in the

mortar which would provide a conduit for ammonia release.

## **B. Ammonia Loss from Concrete**

### ***B.1. Evaluation of Experimental Set-Up***

In order to accurately measure the loss rate of ammonia from concrete, the scaled-up version of the experimental design used for mortar was evaluated to ensure that ammonia could be efficiently trapped at the higher flow rates (nearly an order of magnitude) required to study concrete. In this test, a 1 L Erlenmeyer (“source”) flask was filled with a 0.1 M aqueous NaOH solution containing 500 mg/L of ammonia as N. A 15 L/min flow of air was passed through the flask and then through an ammonia trap flask containing 3.5 L of the acetic acid trap solution. After 5 days the test was completed, and it was found that 96% of the ammonia was trapped in the acetic acid solution, with less than 1% remaining in the source flask. Given that the error of the ammonium electrode is approximately 4-5%, this level of recovery was considered acceptable.

In a related experiment, the Sonotube apparatus was evaluated for significant leakage of ammonia out of the system. To accomplish this task, 3.46 L of water was placed into a polyethylene pan that was 29 cm (11.4 in) in diameter by 10 cm (3.9 in) deep. To this water was added 1.92 g of  $(\text{NH}_4)_2\text{SO}_4$ , which produced a concentration of 118 mg  $\text{NH}_3/\text{L}$  water, and sodium hydroxide to produce a concentration of 0.1 M. The apparatus was then assembled and 8.3 L/min (equivalent to 1 L/sec- $\text{m}^2$ ) flow of air was passed through the assembly for 9 days. Each day during the test, the ammonium ion concentration in the acetic acid trap flask was measured, whilst the remaining ammonia in the “source” pan was measured once at the end of the test. The two sets of data were then combined to calculate the percentage of initial ammonia that could be accounted for after the experiment was complete. Table 7 lists the results of the test and shows that 96% of the ammonia could be accounted for as ammonium ion in the trap flask and as ammonia in the source pan. Figure 7 provides the ammonium ion data (from the trap flask) graphically.

### ***B.2. Comparison of Concrete and Mortar Data***

The first series of experiments conducted to measure ammonia release from concrete was designed with the objective of comparing the data with those collected using mortar. Figure 8 shows a comparison of data collected from concrete and mortar. The concrete was prepared using the Low W:C mix proportions, Bowen fly ash, no chemical admixtures, and 400 mg  $\text{NH}_3/\text{kg}$  fly ash. The ventilation rates were 8.3 L/min (1 L/sec- $\text{m}^2$ ) and 1 L/min (0.9 L/sec- $\text{m}^2$ ) for the concrete and mortar, respectively. Although the concrete data are scattered to a greater degree than the mortar data, they indicate that ammonia diffused from concrete at a faster rate than from mortar. Although the reason for this is not known yet, the rate difference is possibly caused by porosity at the cement paste-coarse aggregate interface that is not present in mortar. However, it is also possible that the results from the smaller-scale mortar experiments did not “scale-up” proportionally to the larger-scale concrete experiments which utilized a larger surface area slab, a different mixer, and a higher air ventilation rate.

### **B.3. Effects of Concrete Slump on Ammonia Loss**

As is described above, the proportioning of the concrete mixes was done in accordance with ACI 2000 guidelines. However, the mix proportions were not re-calculated when water reducing and air entraining reagents were added to the concrete. Instead, these admixtures were simply added at the rates shown in Table 2 to achieve the desired air content (6%) and slump (127-152 mm) without increasing the water + cementitious material content.

Comparison of the data collected from concrete prepared with and without the chemical admixtures revealed that the increase in slump resulted in only a minor increase in the rate of ammonia loss from the concrete (Figure 9). These data are seemingly inconsistent with those from the mortar experiments in which the High W:C (and high slump) mortar lost ammonia at an overall greater rate than the Low W:C mortar. However there exist several differences in the experimental conditions. The High W:C mortar contains a higher water and cement content, with less sand, than the Low W:C mortar, whereas the high slump concrete is identical to the low slump mix with the exception of chemical admixtures in the former. Consequently, the High W:C mortar contained a noticeably larger amount of bleed water than the Low W:C mix, whereas the amount of bleed water observed in the high-slump and low-slump concrete mixtures was essentially the same. As was discussed above, a higher degree of bleeding might provide an easier pathway for ammonia to escape the mortar and concrete. In this context, increasing the degree of compactive effort applied to the concrete could increase the bleed water content and thus increase the rate of ammonia loss. Consequently, an experiment will be conducted with the objective of investigating the effects of compaction on ammonia loss from concrete.

### **CONCLUSIONS**

Based on the experimental results to-date, the following conclusions can be made that relate to ammonia loss from mortar and concrete:

1. Mortar containing a high calcium fly ash loses ammonia at a slightly slower rate than mortar prepared using low-calcium fly ash. This is probably caused by the more rapid strength gain that occurs when high-calcium ash is used.
2. The source of Class F ash has no effect on ammonia loss from mortar.
3. In a confined space application, mortar data (@ 20% cement replacement with fly ash) suggest that the fly ash ammonia concentration should not exceed 100 mg NH<sub>3</sub>/kg ash in order to ensure worker safety. For most other applications, the maximum concentration is approximately 200 mg/kg. However, this conclusion must be verified for concrete.
4. The rate of ventilation over mortar has a pronounced effect on the ammonia loss rate, with a higher ventilation rate causing ammonia to diffuse out of mortar at a faster rate. The implication is that proper ventilation will not only result in a lower ammonia concentration in the air, but also can cause ammonia to be depleted from a concrete slab at a faster rate than in a poorly ventilated space. Additional experiments will be conducted with concrete to verify this conclusion.

5. The loss of ammonia from concrete occurred at a faster rate than from mortar, even though the W:C ratio was lower for the concrete mix than for the mortar. This is possibly caused by porosity in the concrete that occurs at the coarse aggregate-paste interface.
6. Increasing the slump of concrete through the addition of chemical admixtures resulted in only a slight increase in the ammonia loss rate.

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**Table 1. Proportions of Mortar Mixes Used in this Study**

Property/Component	Low W:C Mix	High W:C Mix
Cement (g/L)	429	392
Fly Ash (g/L)	107	98
Sand (g/L)	1,475	1,349
Water (g/L)	260	324
W:C (cement + ash)	0.485	0.661
Yield (L) <sup>1</sup>	1.000	1.000

<sup>1</sup>Assumes component specific gravities: cement = 3.15, fly ash = 2.40, sand = 2.64, water = 1.00

**Table 2. Proportions of Concrete Mixes Used in this Study**

Property/Component	Low W:C Mix	High W:C Mix
Cement (kg/m <sup>3</sup> )	429	392
Fly Ash (kg/m <sup>3</sup> )	107	98
Fine Aggregate (kg/m <sup>3</sup> )	1,475	1,349
Coarse Aggregate (kg/m <sup>3</sup> )	260	324
Water (kg/m <sup>3</sup> )	190	173
Water:Cement + Fly Ash	0.43	0.68
Slump (mm, in.) no admixtures with admixtures <sup>1</sup>	76, 3 127, 5	76, 3 178, 7
Air Content (% , volume) <sup>2</sup>	5.5	6

<sup>1</sup> Low W:C mix = 3.25 ml X20/kg cement + fly ash, 3.25 ml Air 40/kg cement + fly ash  
High W:C mix = 0.65 ml Air 40/kg cement + fly ash

<sup>2</sup> Air content determined only for concrete mix containing the admixtures

**Table 3. Chemical Composition of Fly Ash Samples**

<b>Sample</b>	<b>C (%)</b>	<b>SiO<sub>2</sub> (%)</b>	<b>Al<sub>2</sub>O<sub>3</sub> (%)</b>	<b>Fe<sub>2</sub>O<sub>3</sub> (%)</b>	<b>CaO (%)</b>	<b>MgO (%)</b>	<b>Na<sub>2</sub>O (%)</b>	<b>LOI (%)</b>	<b>NH<sub>3</sub> (mg/kg)</b>
Bowen	1.5	54.5	28.3	6.6	2.4	1.2	0.4	2.1	0
Mill Crk	1.5	49.5	20.7	17.8	4.3	1.0	0.5	1.7	0
Rockport	0.7	42.3	22.7	5.3	16.0	4.0	1.4	0.9	0
Conesville	0.7	45.8	24.3	19.2	2.4	0.8	0.4	1.2	230
Belew Crk	4.0	55.2	31.9	5.8	0.8	0.8	0.4	4.3	74
Yates	6.8	53.7	27.0	11.3	1.9	1.3	0.5	8.1	245

**Table 4. Ammonia in Air Above Fresh Mortar:  
100 mg N/kg ash, no ventilation**

<b>Time (hrs)</b>	<b>Ammonia Concentration in the Air (ppm)</b>		
	<b>Bottom</b>	<b>Middle</b>	<b>Top</b>
<b>0</b>	0	0	0
<b>0.5</b>	11	10	7
<b>1</b>	16	14	12
<b>2</b>	16	16	16
<b>6</b>	17	17	17
<b>22</b>	12	12	13
<b>52</b>	9	9	9

**Table 5. Maximum Ammonia Concentration in Air Above Fresh Mortar: Varying Ammonia Concentration and Ventilation Rate**

Ventilation Rate	Ammonia Concentration in Ash (mg/kg)				
	74 <sup>1</sup>	100	200	245 <sup>1</sup>	400
0 L/min	10 ppm	16 ppm	35 ppm	35 ppm	--
0.5 L/min	--	--	20 ppm	--	--
1 L/min	--	--	--	--	37 ppm
2 L/min	--	--	--	--	20 ppm

<sup>1</sup>Ammoniated fly ash samples used in the mortar mix

**Table 6. Maximum Ammonia Level in Air Above Fresh Mortar**

Ammonia Concentration	Low W:C Mix	High W:C Mix	Low W:C Mix w/ Plasticizer
100 mg N/kg ash <sup>1</sup>	16 ppm	20 ppm	--
245 mg N/kg ash <sup>2</sup>	38 ppm	54 ppm	55 ppm

<sup>1</sup>Low flow = low W:C ratio mix, high flow = high W:C ratio mix

<sup>2</sup>Low flow = low W:C ratio mix, high flow = low W:C ratio mix with plasticizer

**Table 7. Ammonia Recovery from Sonotube Apparatus**

Vessel (Volume)	Initial N Conc. (mg/L)	Final N Conc. (mg/L)
Source <sup>1</sup> (3.46 L)	118	2
Trap <sup>2</sup> (3.50 L)	0	112
<b>Ammonia Recovery = 96%</b>		

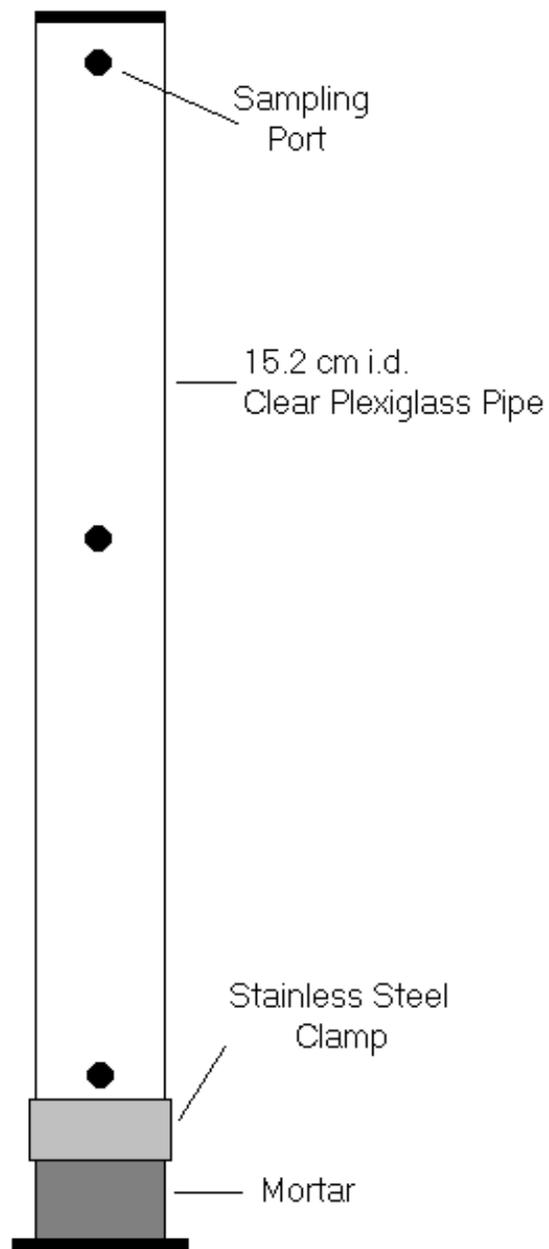


Figure 1. Assembly used for the measurement of ammonia concentration in the air above freshly placed mortar.

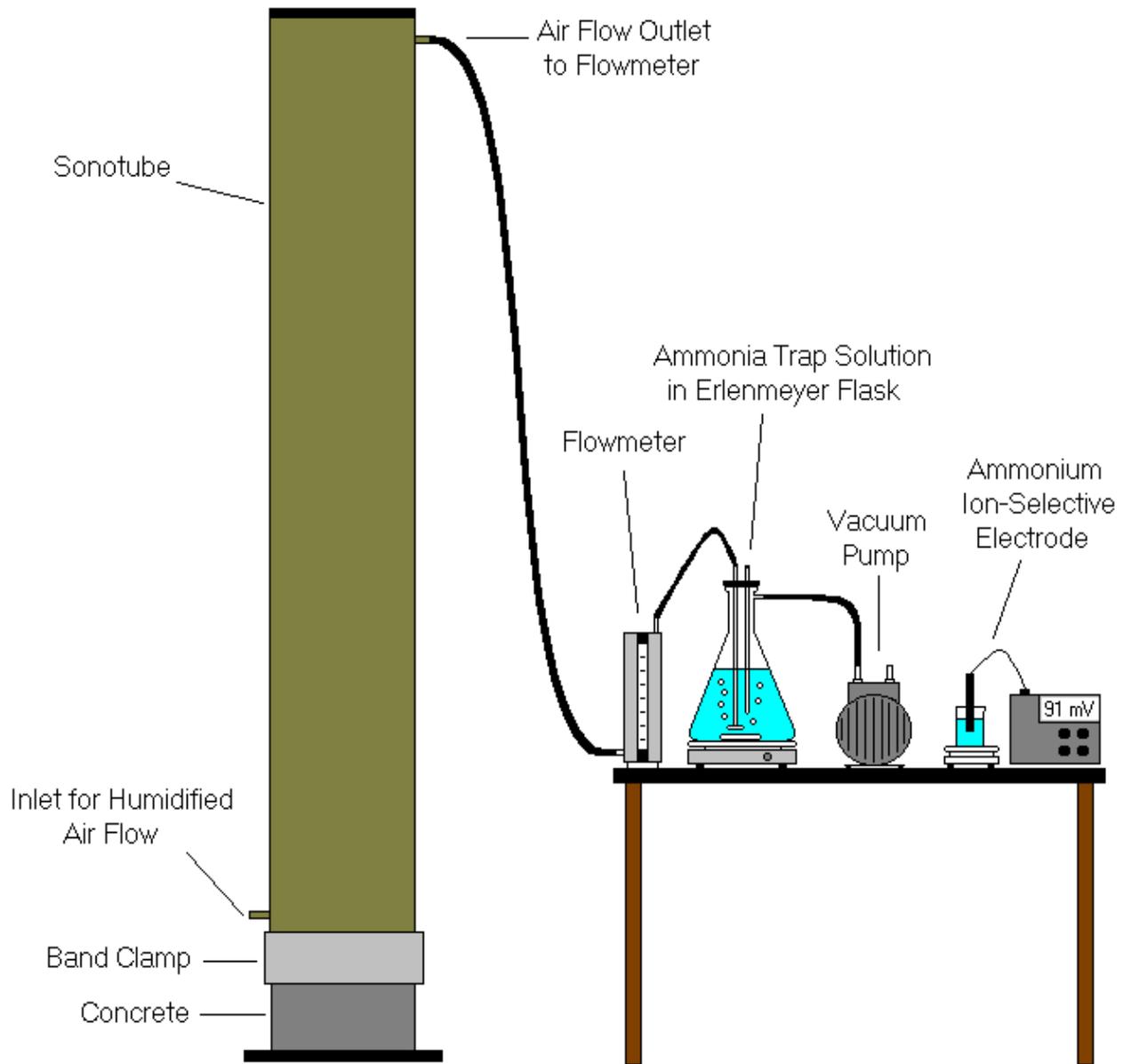


Figure 2. Assembly used to measure the rate of ammonia loss from concrete.

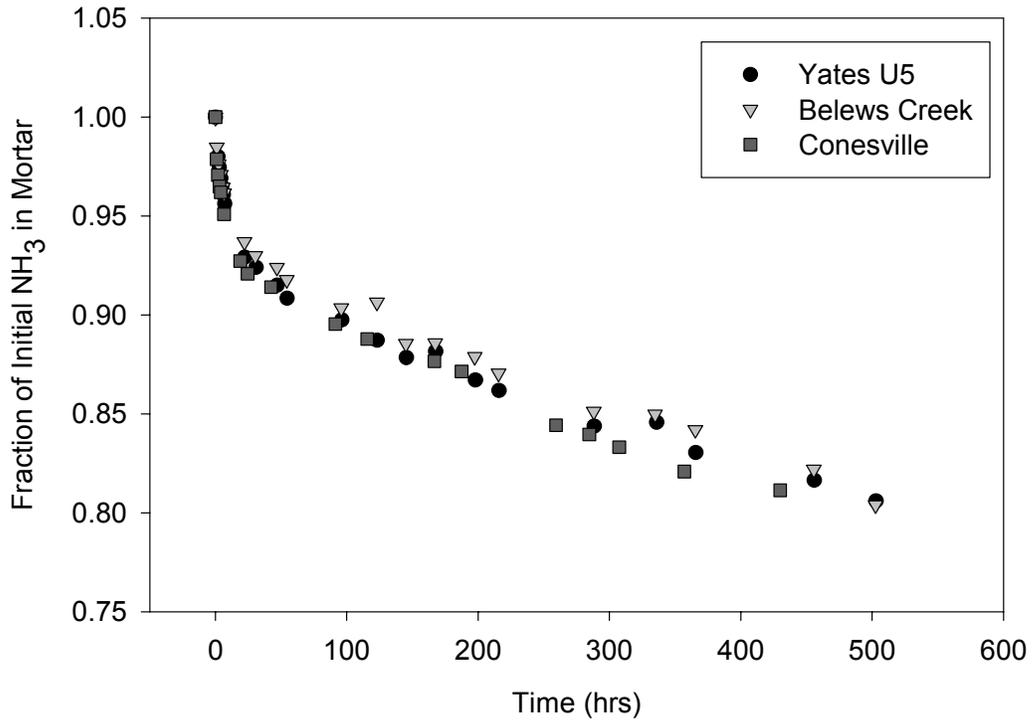
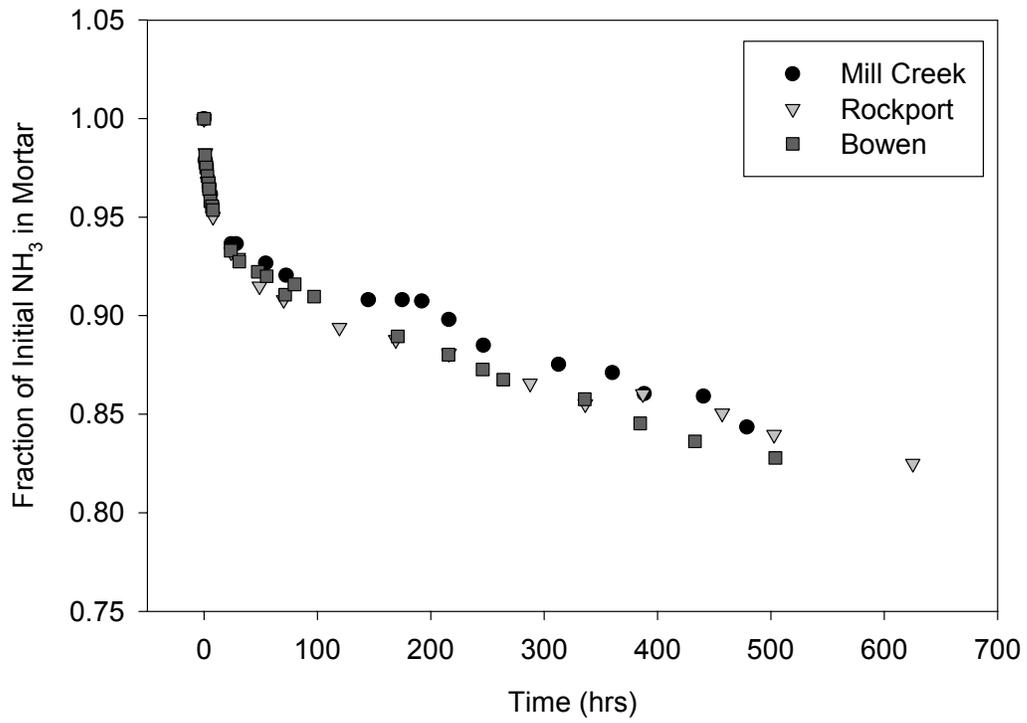


Figure 3. Fraction of initial ammonia concentration remaining in mortars, prepared using non-ammoniated (top) and ammoniated (bottom) fly ash, as a function of time.

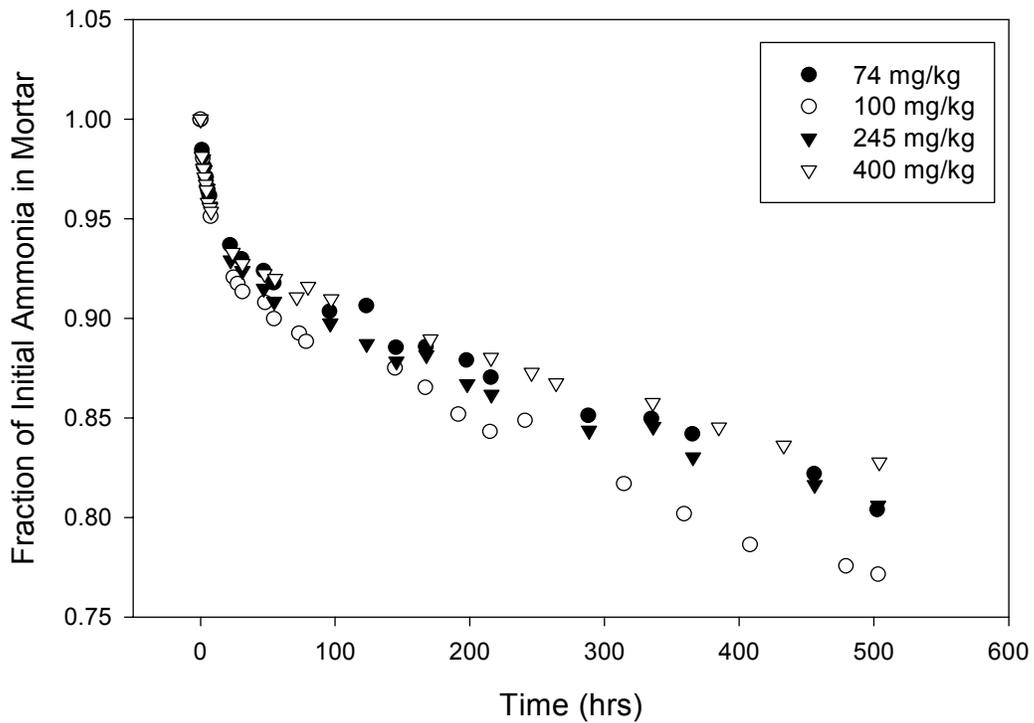
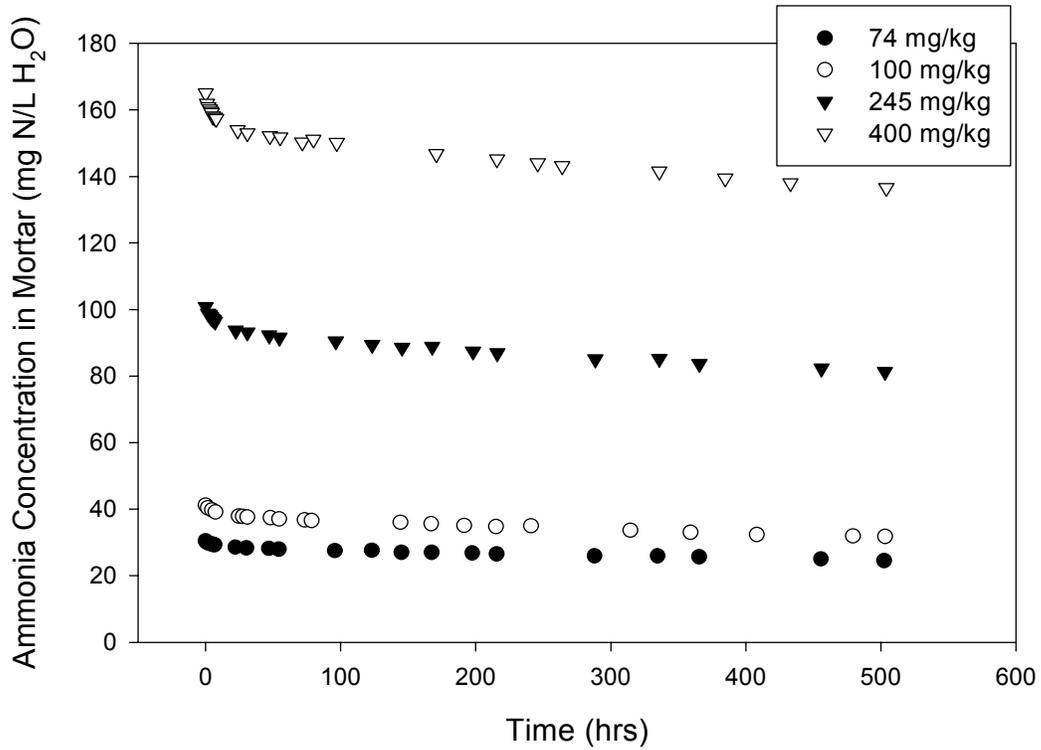


Figure 4. Ammonia loss from mortars containing different ammonia concentrations. Solid symbols represent mortar prepared using ammoniated fly ash, open symbols represent non-ammoniated ash.

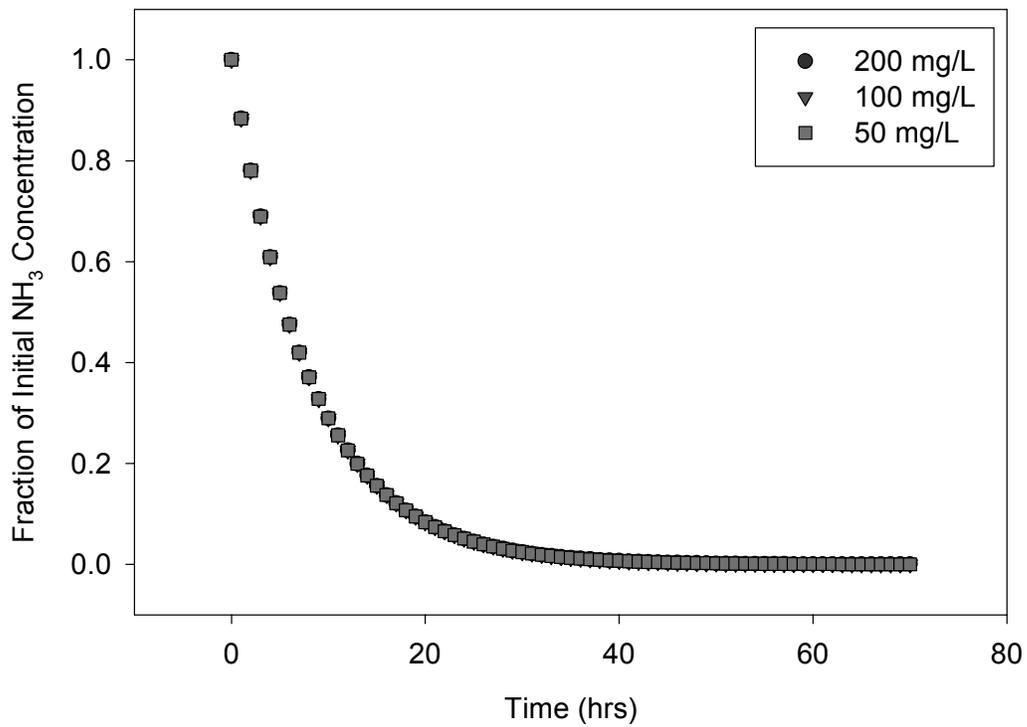
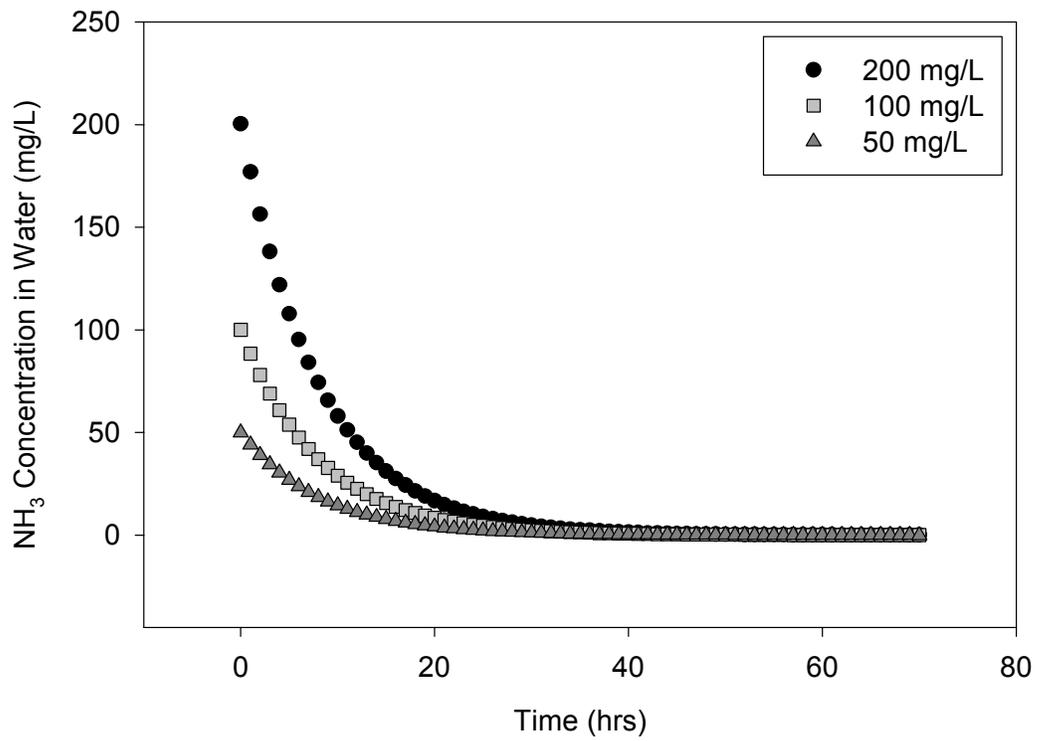


Figure 5. Ammonia loss from water containing three different ammonia concentrations (calculated from Weiler, 1979).

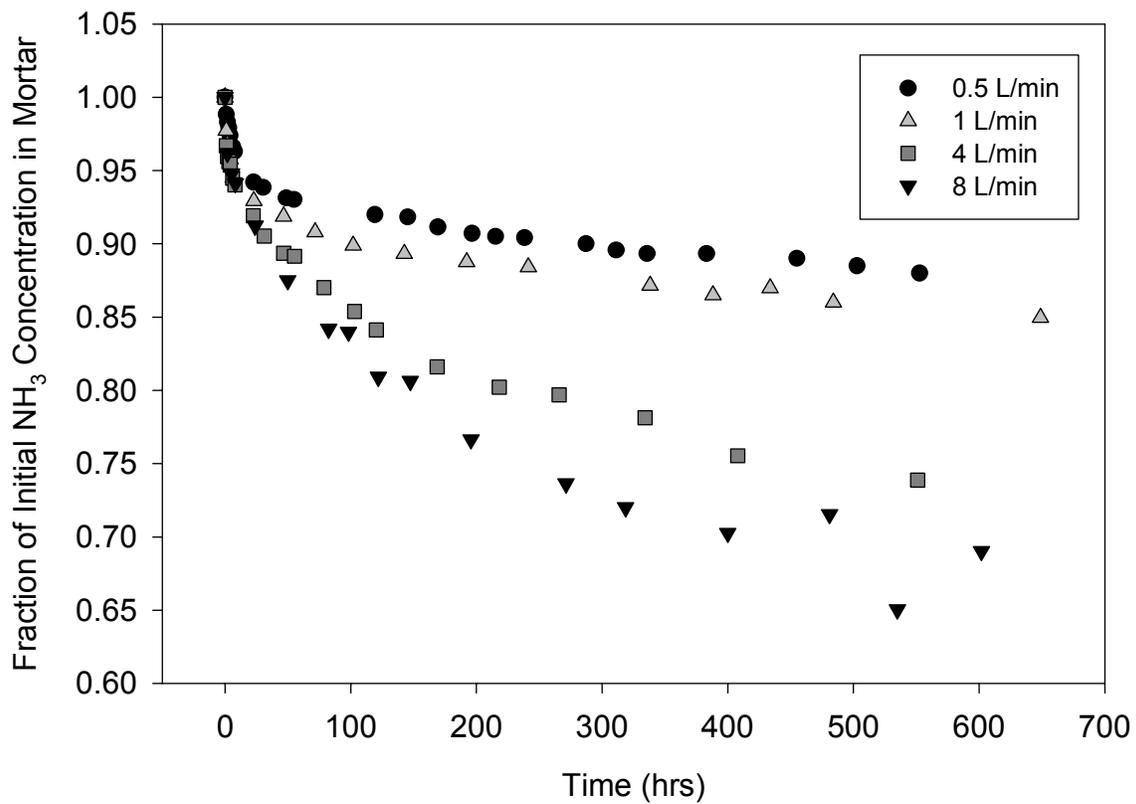


Figure 6. Ammonia loss from mortar as a function of ventilation rate (Low W:C ratio mix, Bowen fly ash, 18°C, 400 mg N/kg fly ash).

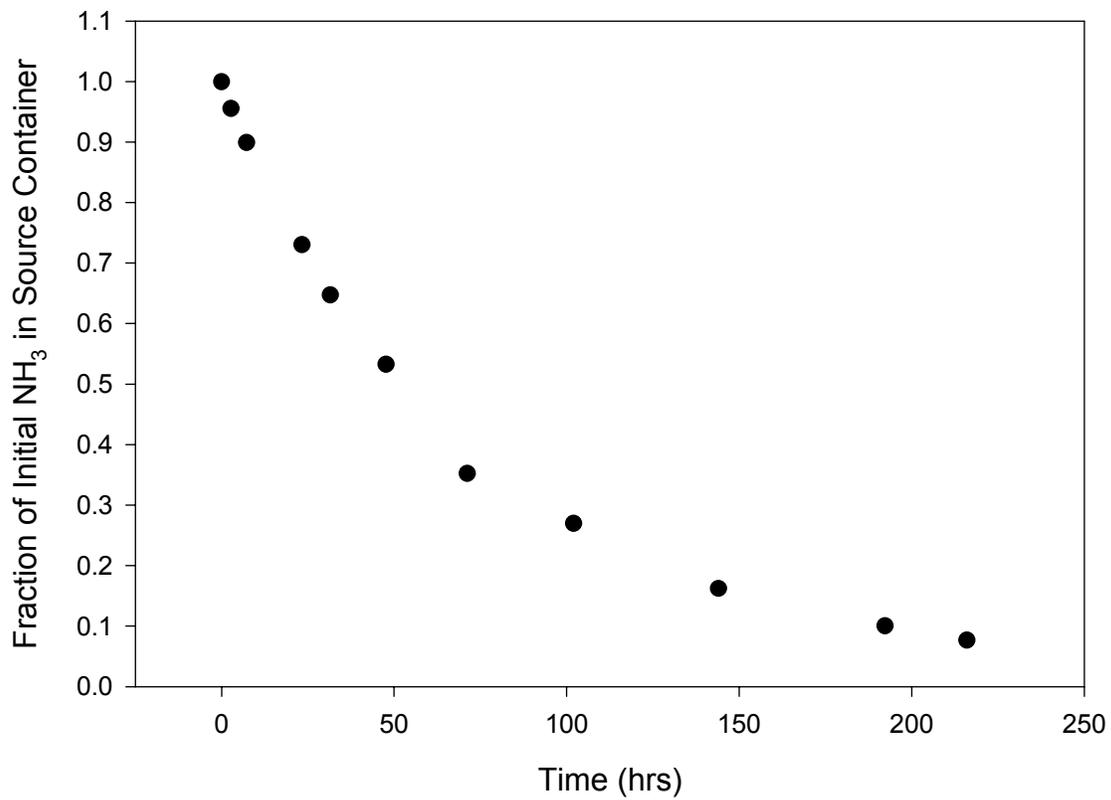


Figure 7. Ammonia loss from water within Sonotube apparatus.

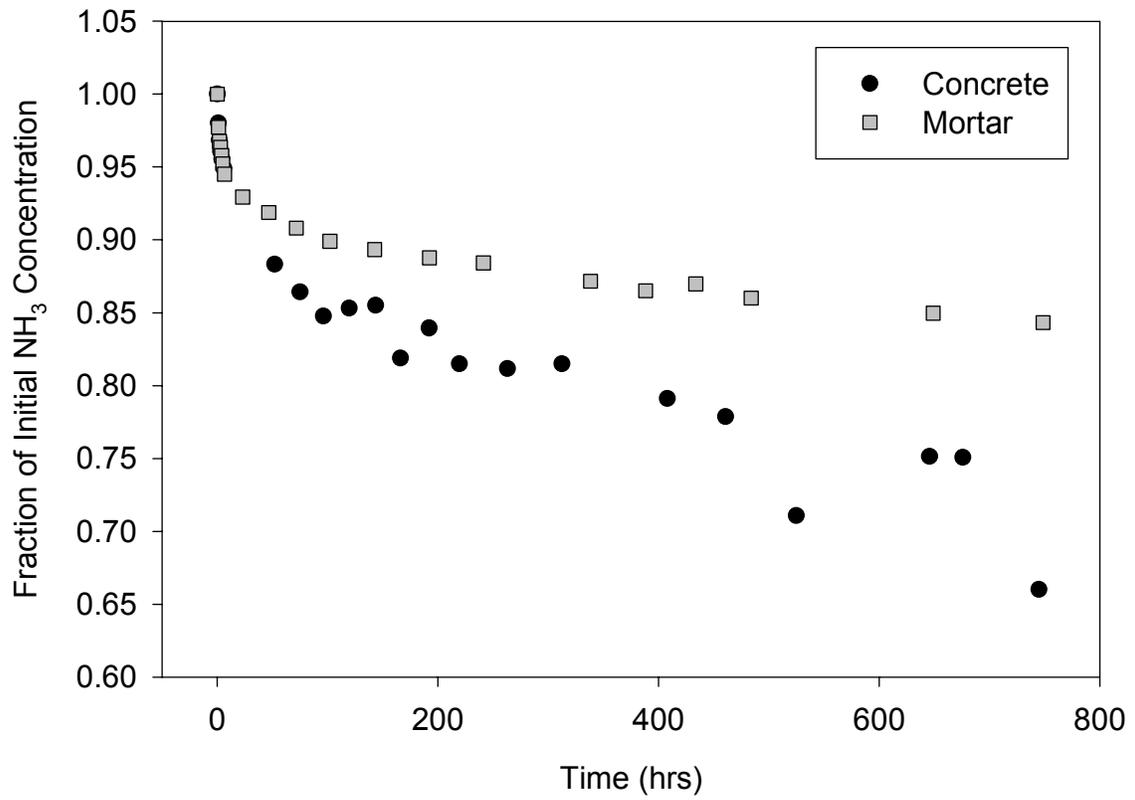


Figure 8. The loss of ammonia over time for concrete vs. mortar.

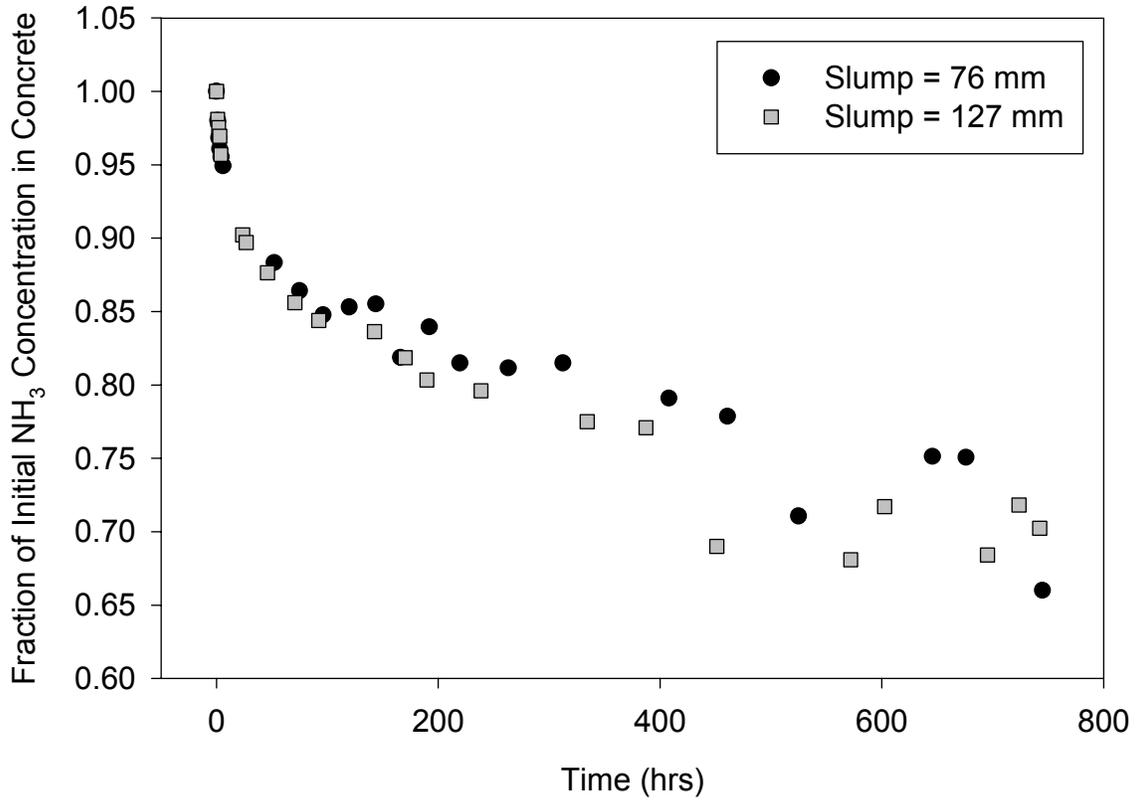


Figure 9. The effect of slump, that was increased using water reducing and air entraining admixtures, on ammonia diffusion from concrete.