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**Site Study of Amonia Containing Fly Ash Concrete**

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**Abstract**

Site tests of amonia containing fly ash concrete were carried out in parallel with especially designed lab column test. It was hypothesized that the conditions in the lab test would be harsher than the ones occurring on site, and thus the lab test could provide a quality control method for assessing the influence of ammonia in fly ash containing concretes with respect to emission of amonia to the surrounding air and the occupational hazards involved. The present study was intended to confirm whether this hypothesis is indeed correct by comparing the amonia gas concentration monitored in harsh field conditions and in the lab column test. The results confirm this hypothesis and the relations obtained could be used as a basis for setting limits for amonia content in the fly ash to assure its safe utilization on site in concrete to meet occupational safety limits.

## 1. Introduction

The introduction of Selective Catalytic Reduction (SCR) technologies for environmental control in the burning of coal in electricity producing plants has resulted in fly ash which contains ammonium. The source of the ammonium is ammonia in excess of the amount needed for the reduction of $NO_x$ (called ammonium slip), which is deposited as ammonium sulfate on the fly ash particles.

In the alkaline environment which is developed in Portland cement concrete, the ammonium sulfate reacts with calcium hydroxide and ammonia gas is released. Studies have shown that the presence of the ammonium sulfate in the fly ash does not affect the properties of the concrete if the ammonia content in the ash is not greater than 300 mg/kg (ppm by weight) [1], which is a value much higher than that obtained in fly ash produced using SCR installations.

Thus, the main concern which should be addressed is the effect of the ammonia gas evolved on the occupational health hazards of labors involved in the production and placing of the concrete. This issue has been dealt with in several references [1-6] which address the permissible exposure limits (PEL) concentration of the ammonia in air in terms of volume concentrations using ppm (by vol.) units. The limits set in the US by OSHA (Occupational and Safety Health Administration) are 25 ppm for the 8 hours TWA (Time Weighted Average), with the recommendation not to exceed half of it. Values of occupational safety limits of 14 and 31 ppm have been reported in Denmark [4] and Germany [2], respectively. A major concern is also the comfort level with respect to odor and eye irritation, where the threshold values are lower. Odor limits of 3 ppm and 3.8 ppm have been reported in Denmark [4] and Germany [2], respectively. Threshold value for eye irritation of 15 ppm was reported in Germany [2].

In practice, the control of the ammonia emission is not through direct measurement of the emitted amonia into the air, but rather through the ammonia content in the ash in units of mg/kg (ppm by weight), which can be more readily quantified and can thus serve much better for quality control purposes. In view of that it is of significance to determine the maximum amonia content in the ash that would not lead to conditions which may cause occupational hazards on site. The values set by various agencies and reported in several publications are in the range of 50 to 100 mg/kg [2-6]. These limits imply that the ammonia gas emitted during placement of concrete containing fly ash with amonia to the surrounding environment will be within the safety and comfort limits. This limit is usually obtained when the ammonia slip in the SCR installation is less than 2 ppm [5].

Recently SCR technologies were incorporated in electric power plants in Israel and in view of that the current study was set in order to develop limits for the ammonia content in fly ash produced using SCR technologies and evaluate whether the limits in other countries are adequate in Israel, considering the higher temperature characteristic to it. The need for that came up since there are very few available and accessible published studies relating the amonia content in the fly ash to the emitted levels from the concrete to account for the 50 to 100 mg/kg limiting values for the ammonia in the ash set by various bodies.

In a previous paper [7] a lab study was reported, in which simulation of the ammonia emission was carried out in a specially designed system, consisting of a column of a 2 meter height in which concrete was cast at the bottom, having 200 mm thickness, immediately after mixing. The air above the concrete in the column was monitored for ammonia using a colorimetric method and a standard NIOSH method [7]. The air velocity above the concrete in the column could be adjusted and it was set to be at a very low velocity of 0.15 meter/minute which is considered as "near stationary air". The intention was to use this lab test as a quality control method to provide indication whether there might be occupational health hazards involved and develop guidelines for the limiting values on the ammonium content in the fly ash which would assure safe utilization in the concrete. It was shown that the lab test could provide effective characterization of ammonia containing fly ash with respect to emission of amonia from concretes with the tested fly ash. The effect of ammonia content in the fly ash, the fly ash content in the concrete and various parameters such as mixing time and temperature could be resolved.

Since the lab test was run at a very low air velocity and the restriction whereby the ammonia could not dissipate out of the column, it was assumed that these conditions would be harsher than the ones occurring on site, and thus the column test could provide a quality control method for assessing the influence of ammonia in fly ash containing concretes. The present study was intended to confirm whether this hypothesis is indeed correct by running in parallel site and lab tests and comparing between the results obtained for ammonia release.

## 2. Scope of site tests

The site tests consisted of three monitored modules:

<u>Concrete slab</u>: A slab of approximately 100m$^2$ in size with the required formwork to cast ready mixed concrete at a thickness of about 200mm. The concrete was prepared in a ready mix plant and transported to the casting site, with a transport duration of about 1 hour. Special cable assembly were placed over the slab, enabling hanging of ammonia monitoring instruments (colorimetric and NIOSH methods) at a height of about 1 meter above the

concrete, to enable continuous monitoring. These monitoring equipment could simulate workers operating over the slab during casting and compacting. Photos of this assembly are presented in Figure 1. Three such measurement points were set and the results reported are the average of the three.

Figure 1: Photos of the site slab before and after casting showing the installation for the amonia monitoring equipment above the slab

Sealed cabinet concrete: 1 $m^2$ by 2 meter high cabinets which were covered with plastic sheets, labeled "sealed cabinets", whereby concrete was cast at the bottom to a height of 200mm (Figure 2). The cabinet was place outside, near the site slab, and it essentially performed as a greenhouse where the temperature build-up was much higher than that in the surrounding and the air movement (i.e. air velocity) in it was expected to be nil. These conditions magnify harsh aspects of the environment, in terms of temperature and air movement, and thus are expected to represent extreme conditions for build-up of ammonia concentration in the air. In essence these are "natural amonia magnifying conditions". The covered cabinet was equipped with a special installation to serve as a holder for the amonia monitoring equipment, about 1 meter above the concrete surface (Figure 2b).

(a) (b)

Figure 2: Photos of the sealed cabinet (a) showing the amonia monitoring equipment set above the concrete in the cabinet (b)

Human monitoring: The crew involved in the site study was monitored all along the test using the standard NIOSH test whereby the set-up of a pump and ammonia adsorbing material in a glass vial are attached to the worker. This monitoring included the crew in the ready mixed concrete plant, the truck drivers (from the moment of entering the concrete plant station until

the completion of discharge on site), and the crew in the site itself where the concrete was cast into the slab and the sealed cabinet.

Environmental monitoring was carried out through the test, including temperature, humidity and air velocity.

The fly ash evaluated was produced in an SCR installation of an Israeli power plant. Two samples were tested, with 4 and 12 mg/kg of ammonia. These are considered as low values and therefore the concrete composition were designed to have high fly ash contents of 160 and 320 kg/m$^3$. The concretes were designed to represent normal strength concrete in the range of 30 to 40 MPa grade. In order to facilitate easy casting on site they were near SCC or SCC type.

The volume of concrete required for the slab testing ranged from 30 to 45 m$^3$ and it was produced in a ready mixed concrete plant at about one hour drive from the slab site, and was transported by about 6 truck batches, each with about 7 m$^3$ of concrete. Concrete production started at 06:30, with the first truck arriving at about 07:30 to the site, and the whole transport and casting operation was completed in less than 2 hours. The concrete trucks arrived on site at about 15 minutes intervals.

## 3. Results

### 3.1 First site slab test

The first slab site test was carried out with the 4 mg/kg fly ash at a content of 160 kg/m$^3$. The time period was winter when the weather is mild with temperature ranging between 25°C at midday and 15°C at night, Figure 3.

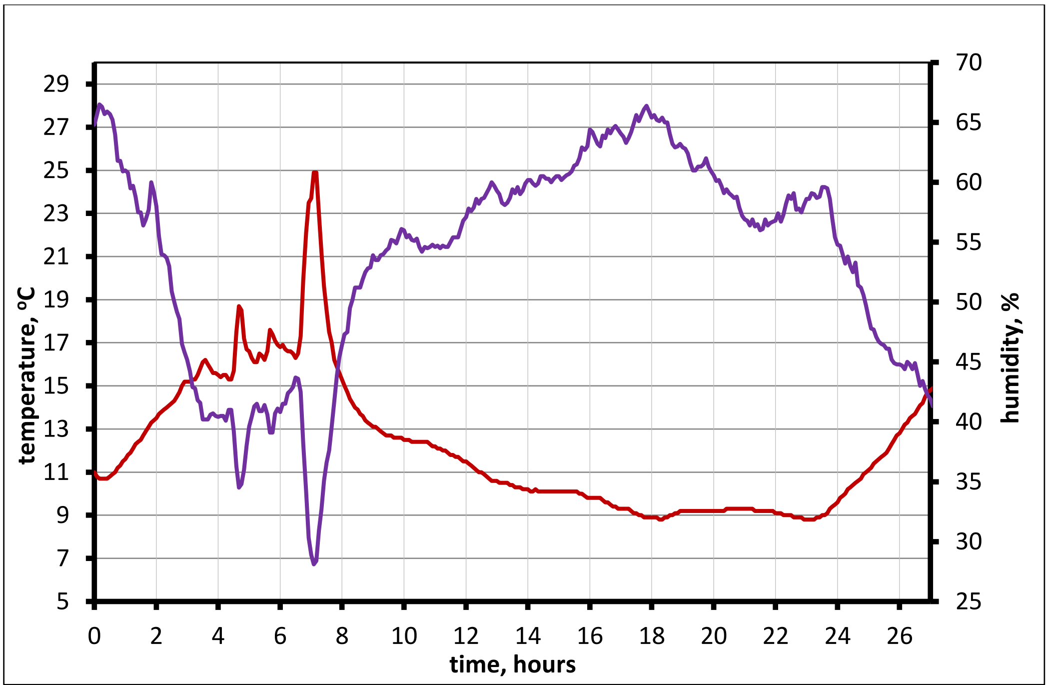



Figure 3: Temperature and humidity of the surrounding environment during the first slab test; monitoring started at about 06:00 and the peak temperature occurred at about 13:00 (midday)

The air velocity during that time was on the low side, less than 0.5 m/sec.

The composition and properties of the concrete are presented in Table 1.

Table 1: Composition and properties of the ready mixed concrete used in the first slab test

| Ingredient, kg/m$^3$ | | | | Unit weight, kg/m$^3$ | Slump, mm | Air content, % wt. | Strength, MPa, at age, days | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cement | Fly ash | water | aggregates | | | | 1 | 7 | 14 | 28 | 60 | 90 |
| 290 | 160 | 191 | 1659 | 2300 | 230 | 1.5 | 9.1 | 24.8 | 33.9 | 39.4 | 38.8 | 41.4 |

Slab monitoring: Monitoring of the slab by the colorimetric and NIOSH devices positioned over it during the period of 24 hours (at 1.5 hours intervals during the first 6 hours after casting) resulted in both tests in nil values, namely below the sensitivity of the instrumentations, which were in the range of 0.05 to 0.1 ppm.

Crew monitoring: the ready mixed crew monitoring using the NIOSH tests method over their whole period of activity (60 minutes for the ready mixed concrete plant crew and about 120 minutes for the drivers) resulted in nil values, i.e. below the measurement sensitivity, Table 2. Some of the drivers were also monitored on site while they were discharging the concrete and were therefore at closer proximity to it. Here too the values were below the measurement sensitivity. Monitoring of the crew in charge of casting the concrete on site slab also indicated very low values, one below the sensitivity limit and the other 0.2 ppm, Table 2.

Table 2: Amonia concentration exposure of the crew, using the NIOSH test method, during the first site test with 160 kg/m$^3$ of fly ash having 4 mg/kg amonia

| Crew description | | Amonia concentration exposure, ppm | Duration of exposure, minutes |
|---|---|---|---|
| Ready mix plant operators | Operator 1 | < 0.1 | 60 |
| | Operator 2 | < 0.1 | 60 |
| | Concrete sampler | < 0.2 | 43 |
| Drivers | Driver Truck #1 | < 0.05 | 112 |
| | Driver Truck # 1 – concrete discharge period | < 0.2 | 15 |
| | Driver Truck #3 | < 0.1 | 123 |
| | Driver Truck # 3 – concrete discharge period | < 0.5 | 15 |
| Concreting crew on site | # 1 | < 0.1 | 67 |
| | # 2 | 0.2 | 67 |

Lab column test: The ready mixed concrete was also cast into the lab testing column, in an environment of 20ºC controlled temperature and low air velocity, near stationary. The ammonia concentration was monitored by the colorimetric and NIOSH test methods. The results are presented in Figure 3, showing similar trends for both tests, with peak values of about 0.9 ppm, much higher than the nil values observed in the slab and crew monitoring. The peak in the lab test occurs is in the range of 6 to 8 hours.

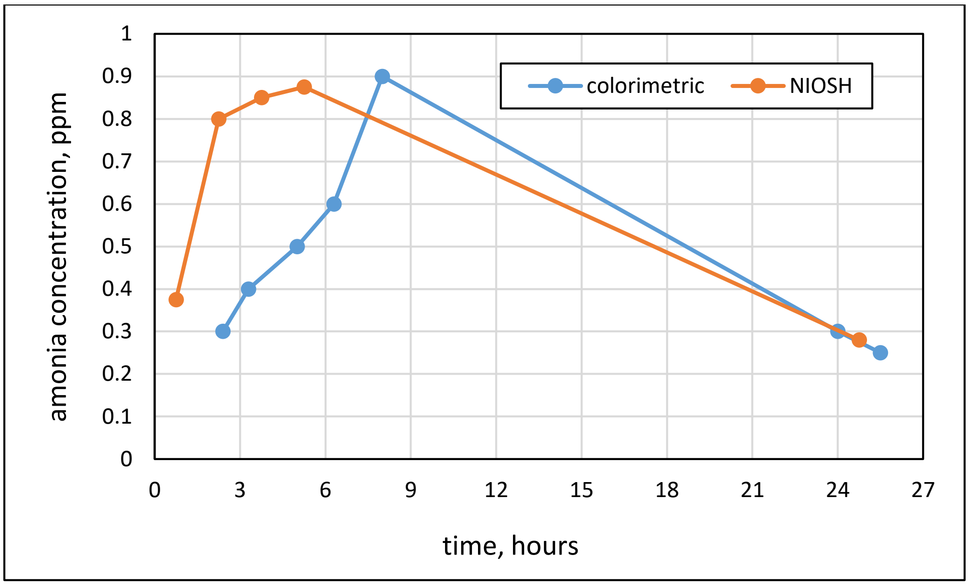



Figure 3: Amonia concentration in the lab column test of the ready mixed truck concrete with 160 kg/m$^3$ of fly ash of 4 mg/kg of amonia

It is of interest to compare the amonia emission in the lab column test of the ready mixed truck concrete with a concrete of similar composition prepared in the lab and placed in the column after 20 minutes of mixing in the lab mixer, Figure 4.

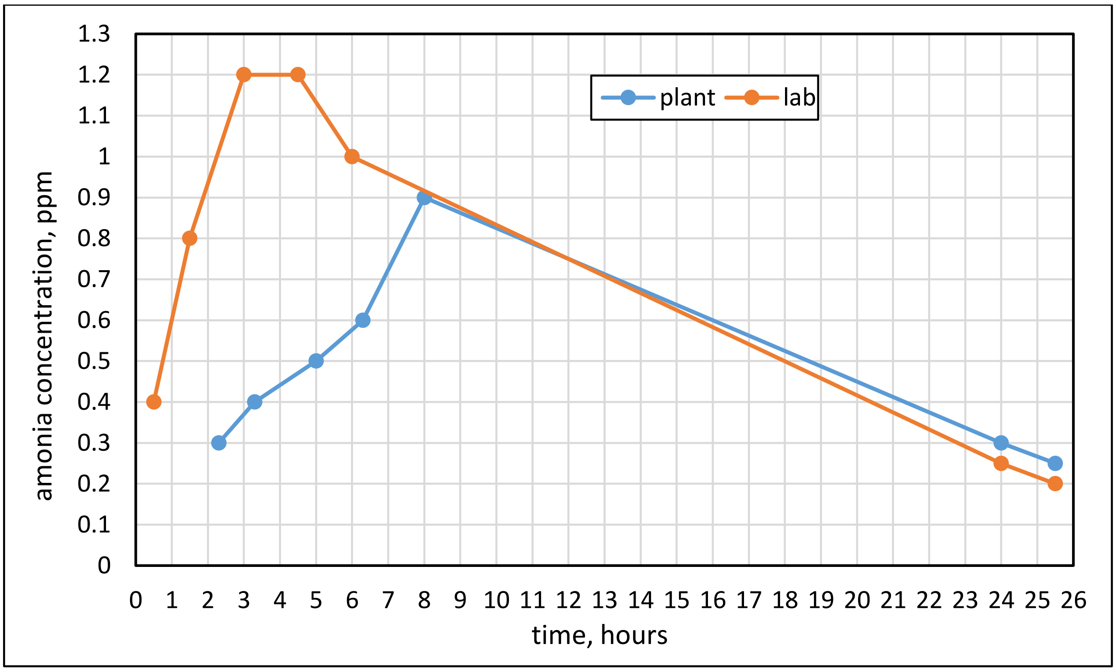



Figure 4: Comparison of the amonia concentration curves in the lab column test of the ready mixed truck concrete and a concrete of similar composition prepared in the lab, 160 kg/m$^3$ of fly ash with 4 mg/kg amonia

The lower amonia release of the truck concrete is associated with the extended mixing, which was shown in the previous paper [7] to lead to lower amonia discharge, due to initial emission which takes place during the extended mixing. The delayed time of the occurrence of the peak in the ready mix truck concrete could be the result of greater retardation as observed from the temperature-time curves, Figure 5.

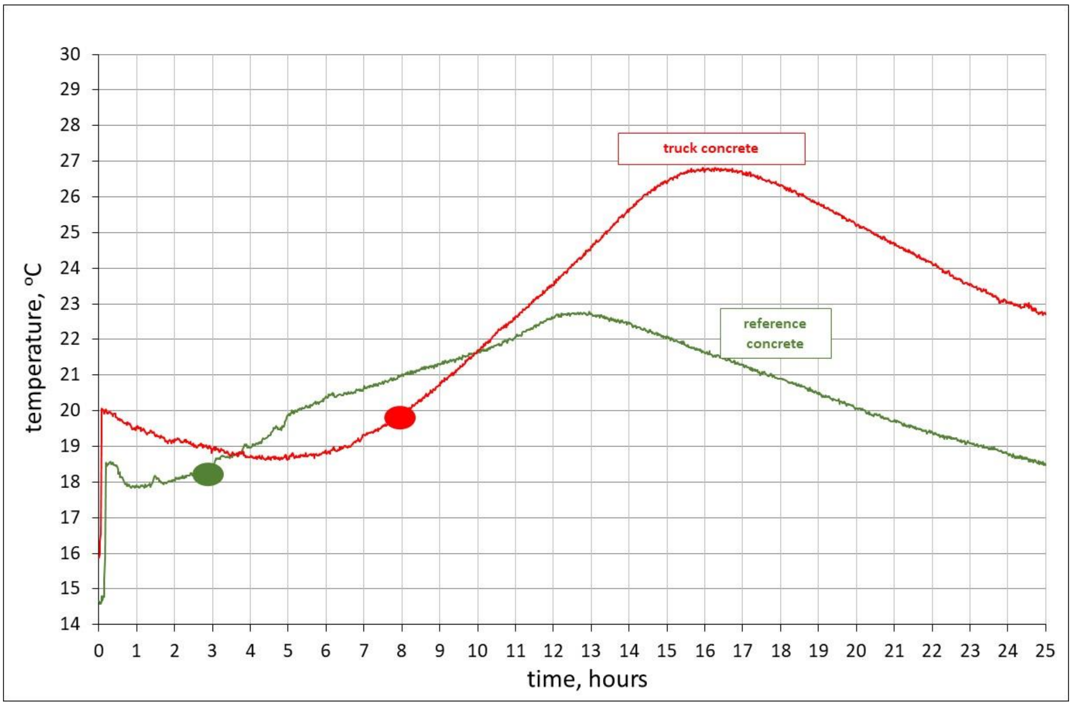



Figure 5: Temperature-time curves in the lab column tests of ready mix truck concrete and lab prepared concrete of similar composition, 160 kg/m$^3$ of fly ash having 4 mg/kg of amonia; the points on the curve mark the time of the peak amonia-time curve

### 3.2 Second slab site test

The second slab site test was carried out with the 12 mg/kg fly ash at a content of 160 kg/m$^3$. The time period was already summer with temperature ranging between 35°C during midday to 25°C at night, Figure 6. Air velocity was at the low side ranging from 0.74 to 1.14 m/sec.

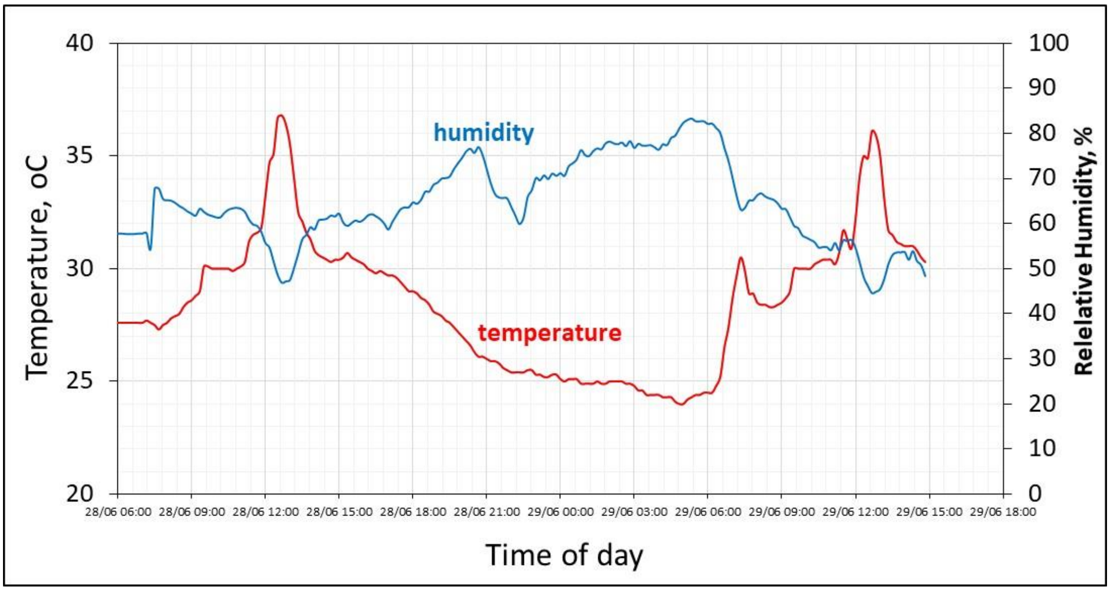



Figure 6: Temperature and humidity during the casting of the second slab; monitoring started at about 06:00 and the peak temperature occurred at about 13:00 (midday)

The properties of the concrete were similar to the one in Table 1, but the mix was adjusted with the admixtures to obtain an SCC concrete, compared to the near SCC in the first slab concrete.

Slab monitoring: Monitoring of the slab by the colorimetric and NIOSH devices positioned over the concrete during the period of 24 hours (at 1.5 hours intervals during the first 6 hours after casting) resulted in nil values for the colorimetric test (below sensitivity range of 0.1 ppm) and nil or very small values for the NIOSH tests, Table 3.

Table 3: Amonia concentration over the slab in the second site test, 160 kg/m$^3$ of ash with 12 mg/kg amonia, determined by the NIOSH method

| Time period, hours | Amonia concentration, ppm |
|---|---|
| 0.0 – 1.5 | 0.1 |
| 1.5 – 3.0 | 0.1 |
| 3.0 – 4.5 | 0.08 |
| 4.5 – 6.0 | < 0.1 |
| 24.0 – 25.5 | < 0.1 |

Crew monitoring: The ready mix crew monitoring using the NIOSH tests method, over their whole period of activity (60 minutes for the ready mixed concrete plant crew and about 120 minutes for the drivers), resulted in nil values, i.e. below the measurement sensitivity, Table 4.

Monitoring of the crew in charge of casting the concrete on site also indicated very low values, 0.1 and 0.4 ppm, Table 4.

Table 4: Amonia concentration exposure of the crew using the NIOSH test method during the first site test with 160 kg/m$^3$ of fly ash having 12 mg/kg amonia

| Crew description | | Amonia concentration exposure, ppm | Duration of exposure, minutes |
|---|---|---|---|
| Ready mix plant operators | Operator 1 | 0.1 | 90 |
| | Concrete sampler | < 0.1 | 30 |
| Drivers | Driver Truck #1 | < 0.1 | 70 |
| | Driver Truck # 3 | < 0.1 | 65 |
| | Driver Truck #6 | < 0.1 | 70 |
| Concreting crew on site | # 1 | 0.1 | 154 |
| | # 2 | 0.4 | 136 |

Lab column test: The results of amonia monitoring in the lab column of the ready mixed truck concrete are presented in Figure 7, showing similar trends for the colorimetric and NIOSH tests, with peak values in the range of 2.5 and 3.0, much higher than the small values observed in the slab and crew monitoring.

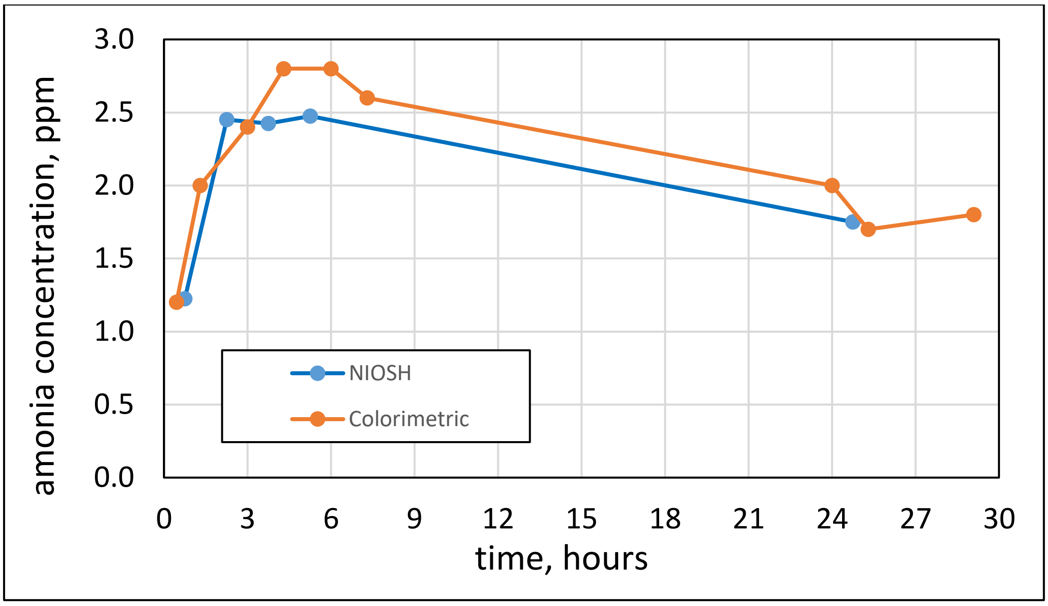
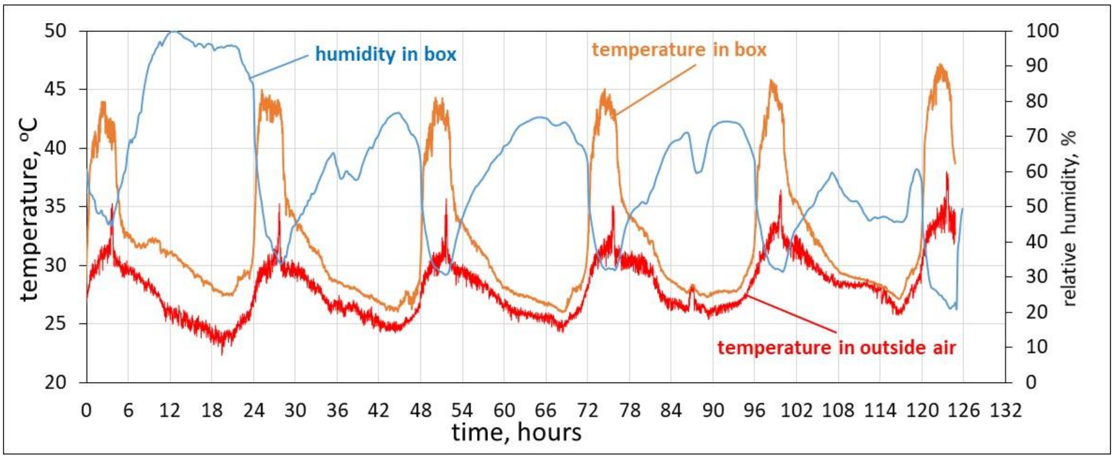



Figure 7: Amonia concentration-time curves in the lab column test of ready mixed truck concrete with 160 kg/m$^3$ of fly ash with 12 mg/kg of amonia

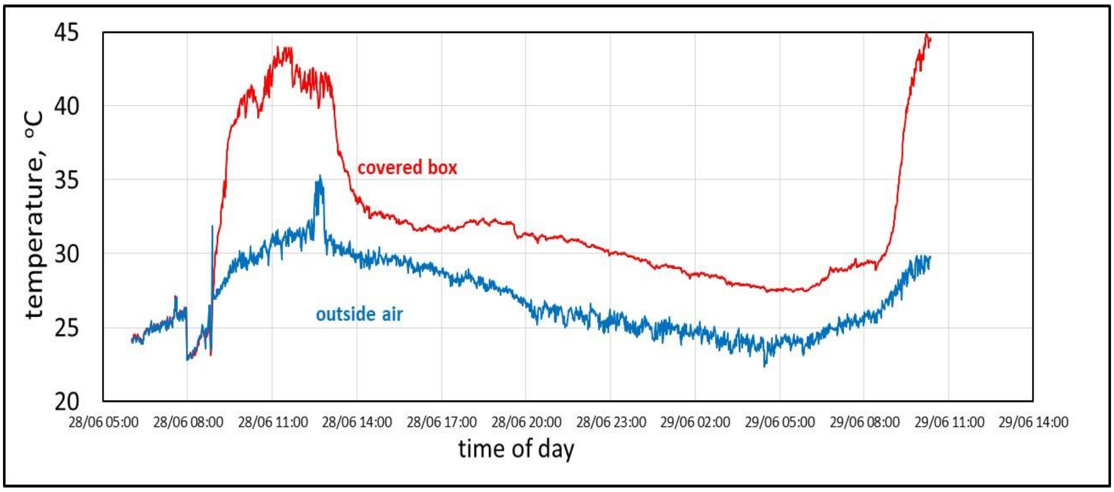
### 3.3 Sealed cabinet tests

The sealed cabinet tests were carried out with the 12 mg/kg ammonia fly ash, using the mix produced in the ready mixed plant for the second site slab tests (160 kg/m$^3$ of fly ash in the concrete) as well as another mix which was prepared in a free fall mixer with 320 kg/m$^3$ of the same ash. The mix design of this latter concrete was based on the first one by making adjustment in which the additional 160 kg/m$^3$ of ash replaced cement and sand in equal portions, namely the cement and sand content were reduced each by 80 kg. The 28 days strength of the 320 kg/m$^3$ ash was similar to that of the 160 kg/m$^3$ of ash, 39 MPa, suggesting that the efficiency coefficient of the ash is 0.50.

Monitoring of the temperatures inside the cabinet and in the surrounding outside of it indicated that indeed a significant greenhouse effect is obtained, Figures 8 and 9.

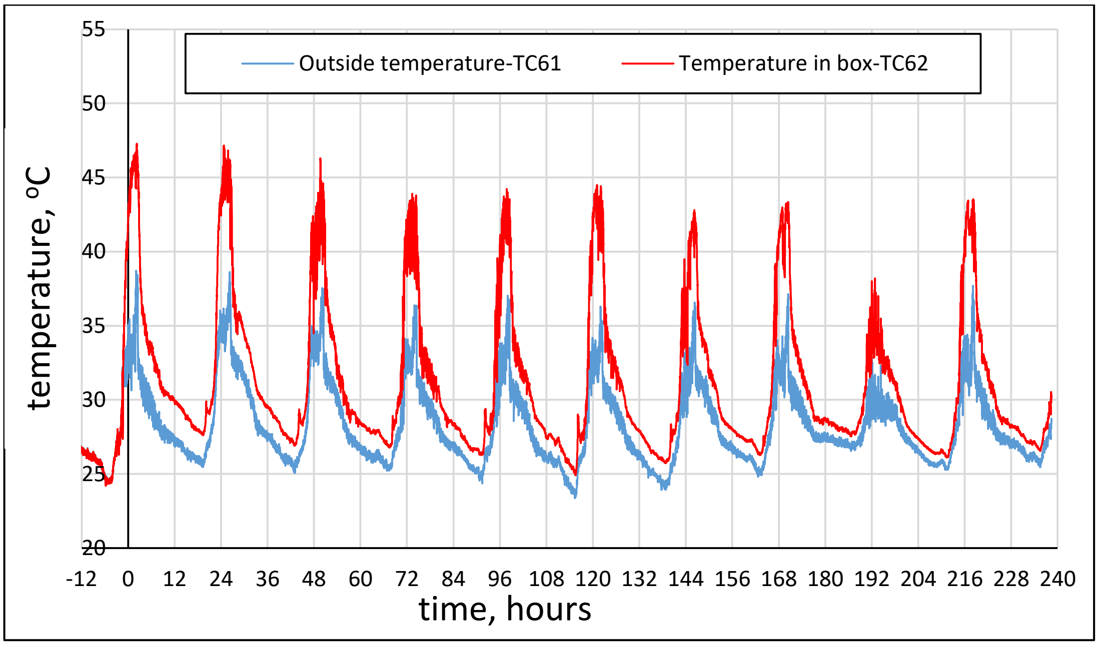



(b)




(a)

Figure 8: Temperature and humidity inside and in the open environment outside of the sealed cabinet for the 160 kg/m$^3$ fly ash concrete with 12 mg/kg amonia, (a) first day, (b) the whole period of monitoring

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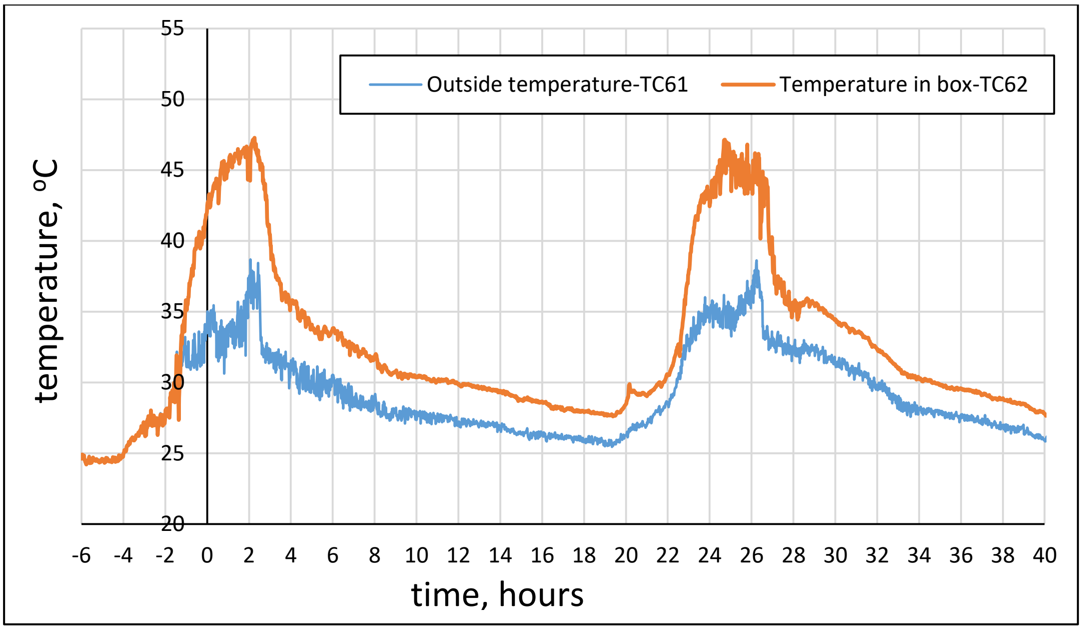



(a)

Figure 9: Temperature inside and in the open environment outside of the sealed cabinet for the 320 kg/m$^3$ fly ash with 12 mg/kg amonia (a) the first two days, (b) the whole period of monitoring

Both tests were carried out during hot summer season and it can be seen that the outside temperature peaked at about 35°C (midday), and at that time the temperature in the box was 10°C higher, about 45°C. During night the outside temperature dropped to about 25°C and the inside temperature was few degrees higher, slightly less than 30°C.

The high temperature regime inside the sealed cabinet was also reflected in the concrete temperature, Figures 10 and 11.

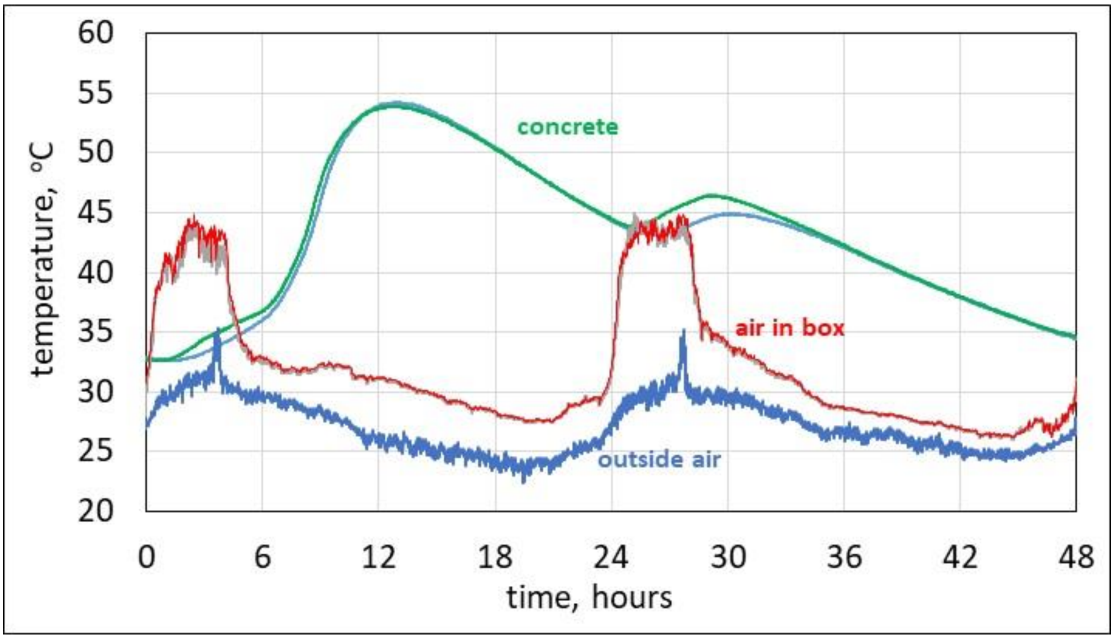
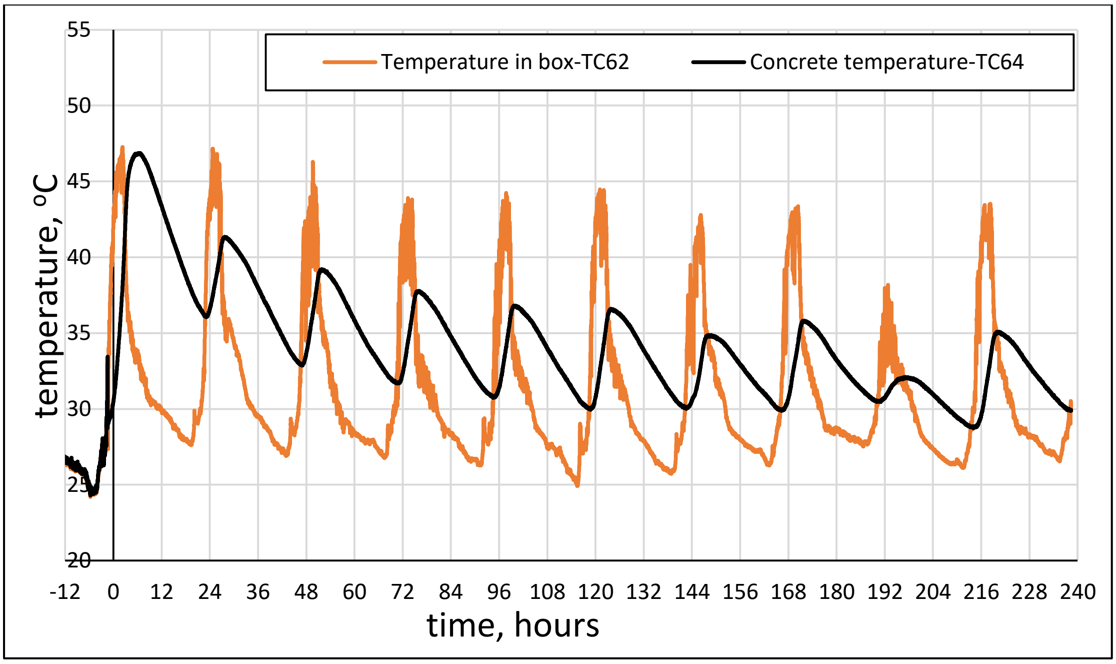
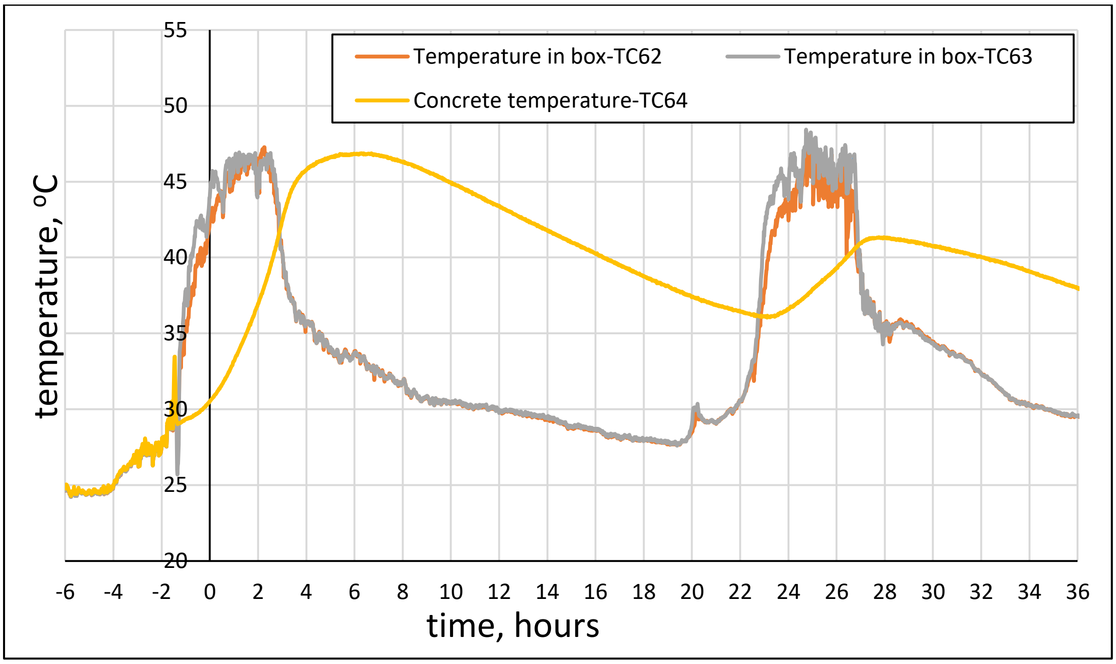



Figure 10: Concrete temperature inside the sealed cabinet compared with the inside and outside temperatures for the 160 kg/m$^3$ mix




(b)




(a)

Figure 11: Concrete temperature inside the sealed cabinet compared with the inside temperature for the 320 kg/m$^3$ fly ash mix having 12 mg/kg amonia (a) during the first 1.5 day, (b) during the whole test period

In both cases the temperature inside the concrete was quite high and did not drop drastically within the first two days: in the 160 kg/m$^3$ fly ash mix (ready mixed concrete) it peaked at about 55°C after 12 hours and maintained about 45°C during most of the second day (Figure

8). The 320 kg/m$^3$ fly ash mix exhibited similar trends (Figure 9), but lower temperatures, between 45ºC and 35ºC. This may be due to the lower cement content in this mix.

In both cases the temperature was much higher in the concrete in the sealed cabinet compared to the one in the lab column test, as shown for the 320 kg/m$^3$ ash concrete in Figure 12.

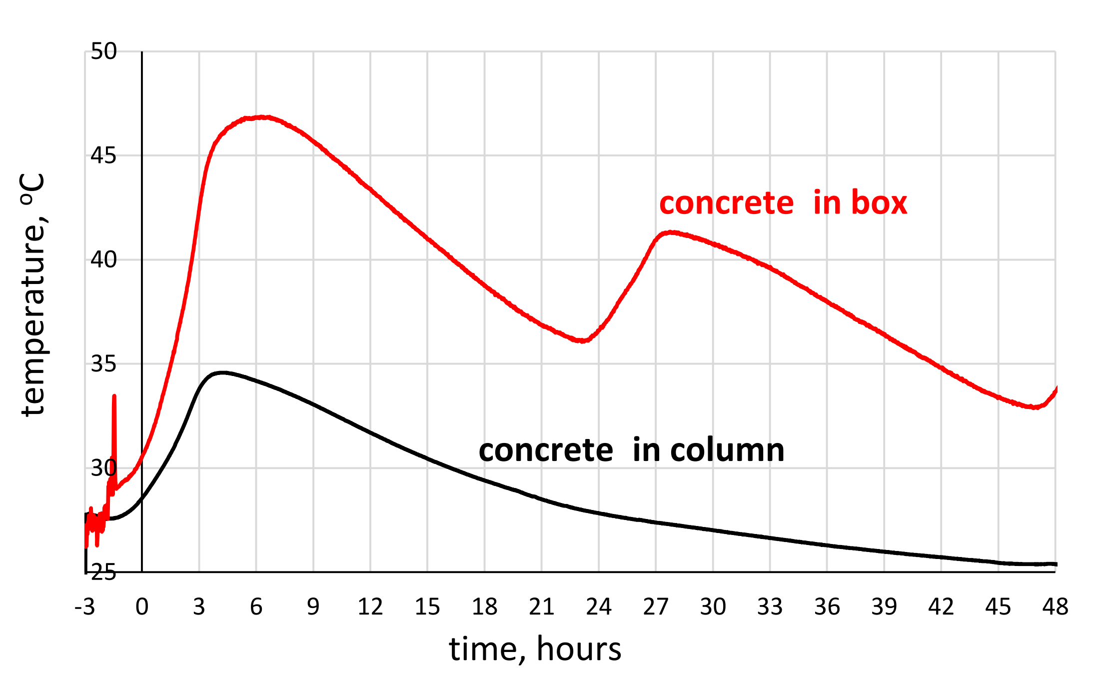


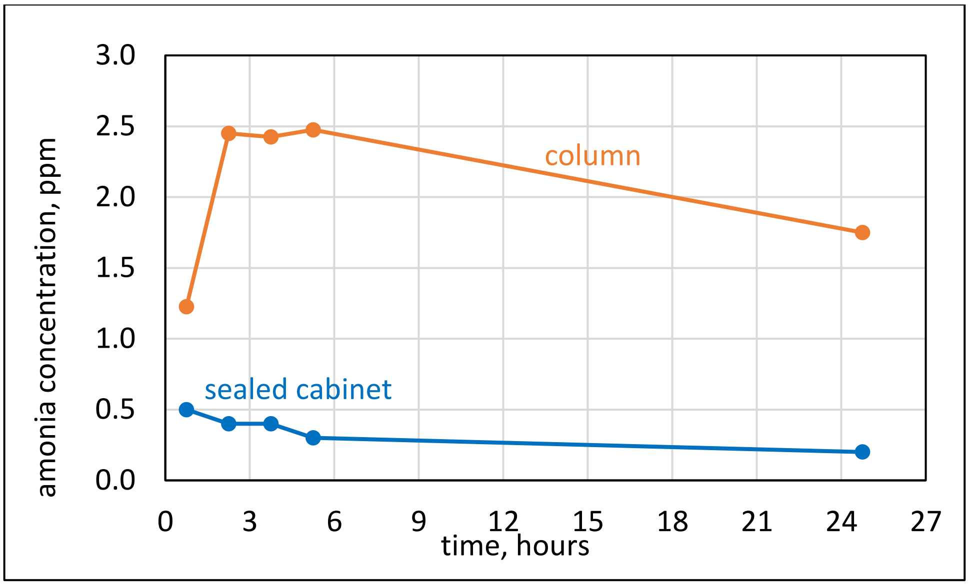

Figure 12: The temperature-time profiles of the concretes in the sealed cabinet placed outside and in the lab column test for the 320 kg/m$^3$ ash with 12 mg/kg amonia

The difference in the peak temperature is 10ºC, but there is also another noted difference, where the decline in temperature in the concrete in the box is much milder than that in the lab column, due to the surge induced during the temperature build-up in the second day, toward midday.

These results clearly indicate that the conditions are much harsher in the sealed cabinet, both with respect to the higher temperature compared to the external environment and the lab conditions, as well as the stationary air compared to the external conditions, effective for the slab concrete. These observations support the statement that the sealed box conditions represent "natural magnifying conditions".

<u>Amonia concentrations</u>

Amonia concentration-time curves are presented in Figures 13 and 14 where comparison is made between the levels obtained in the sealed cabinet and the lab column tests.

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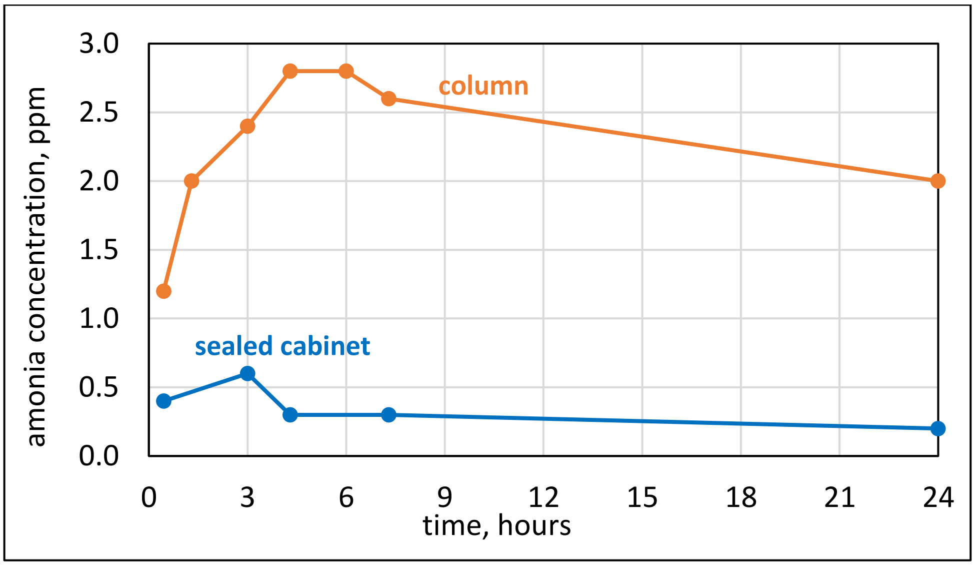
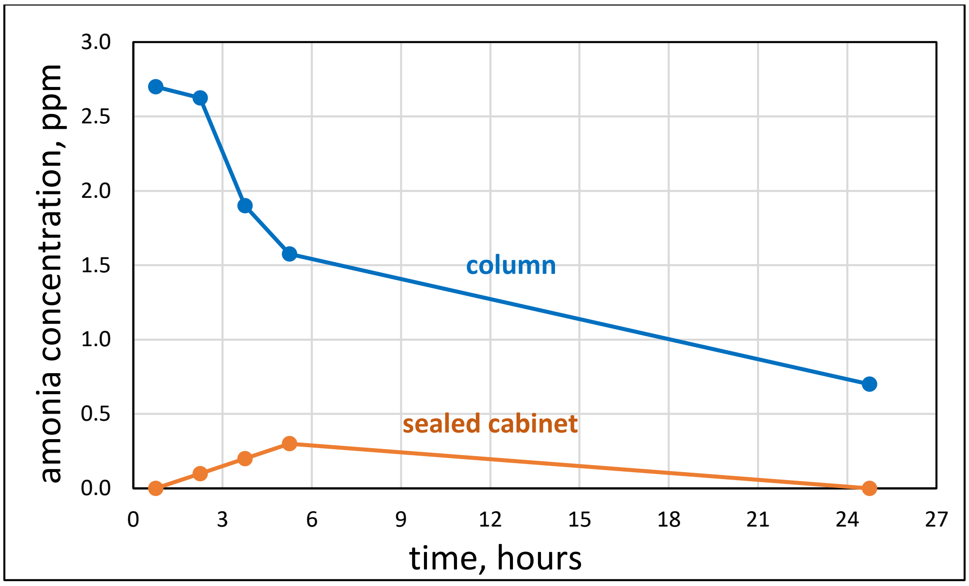
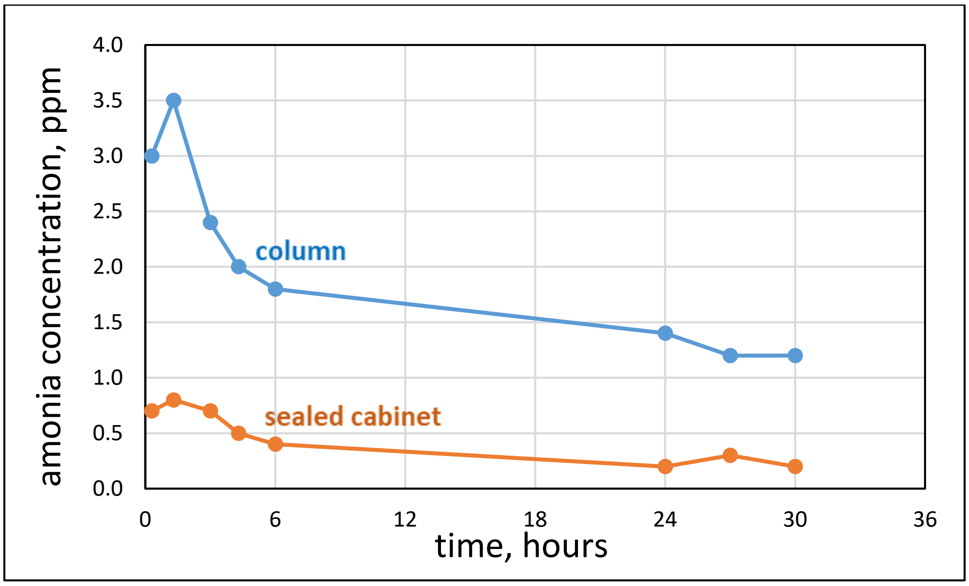



(a)

Figure 13: Ammonia concentration-time curves during the first day of exposure in the sealed cabinet and lab column tests for the 160 kg/m$^3$ fly ash concrete with 12 mg/kg amonia, (a) Colorimetric method, (b) NIOSH method




(b)




(a)

Figure 14: Ammonia concentration-time curves during the first day of exposure in the sealed cabinet and lab column tests for the 320 kg/m$^3$ fly ash with 12 mg/kg amonia, (a) Colorimetric method, (b) NIOSH method

It can be seen that the values in the sealed cabinet are much smaller than in the lab column test in all the cases studied here and in the two type of measurements (colorimetric and NIOSH). Both methods resulted in a similar trend of a peak within the first 6 hours and decay later on, which is characteristic to both testing conditions, the sealed cabinet and lab column. The values obtained by the colorimetric method are somewhat higher than the NIOSH method, which is consisted with the data reported in the previous study [7].

The monitoring equipment were placed one meter above the concrete surface in the sealed cabinet. In order to determine the uniformity of the amonia concentration over the cabinet height, to resolve whether some is escaping out of the box when emitted from the concrete,

measurements at 0.1 and 1.0 meter were compared, Figure 15. It can be seen that the amonia-time curves are practically identical at the 0.1 and 1.0 meter tests.

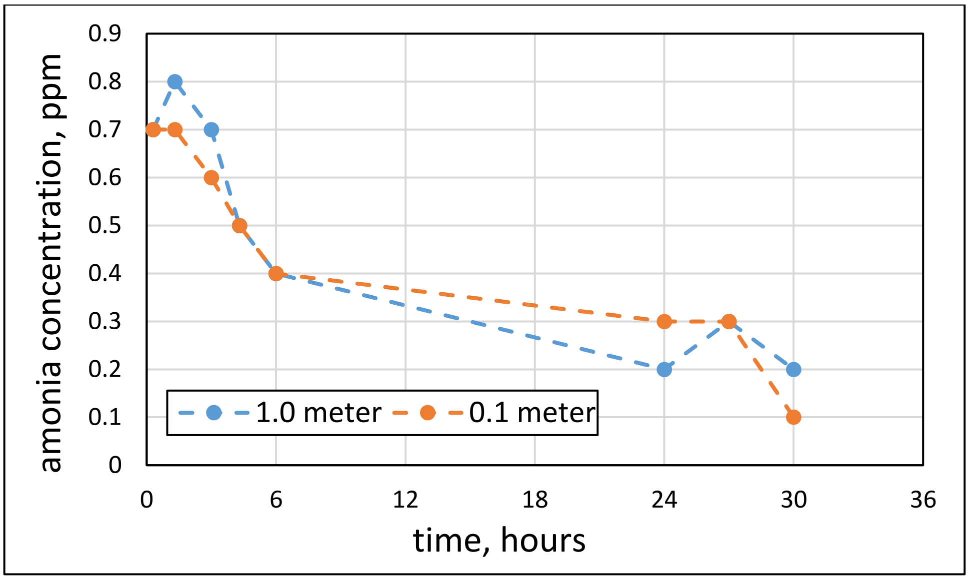



Figure 15: The effect of the height of monitoring amonia on the recorded values in the sealed cabinet with the 320 kg/m$^3$ fly ash concrete, using the colorimetric method

Although the more significant influences are during the first day there was interest in doing follow up tests for about a week. The amonia concentration monitored for up to one week using the colorimetric methods, and plots of the ammonia concentration and temperature inside the cabinet, are presented in Figure 16. It can be seen that the amonia concentration is drastically decreased over this time period, but small peaks can be observed at the time of temperature maximum which occur at midday in each of the week days. These small peaks can be attributed to the temperature rise from about 25°C to 50°C which occurs at noon time. Whether this is just a result of the effect of environmental temperature in the cabinet or a surge in the reactivity of the concrete is not currently resolved, since the temperature rise is associated also with higher temperature within the concrete (Figure 12).

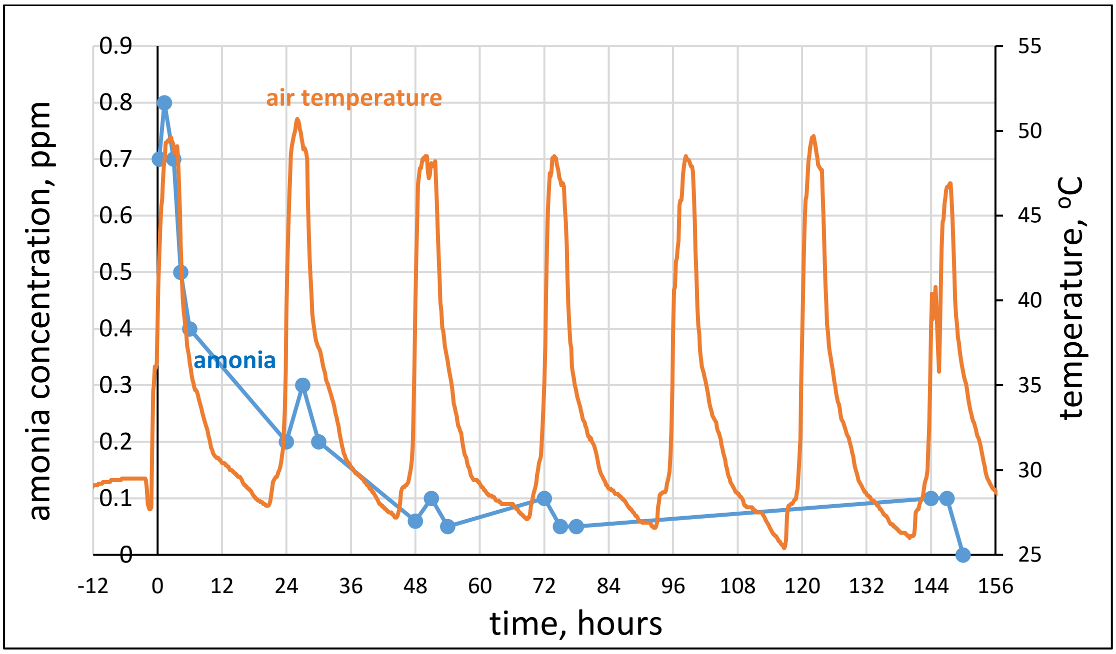



Figure 16: Amonia and air temperature-time curves beyond 24 hours for the 320 kg/m³ fly ash concrete in the sealed cabinet determined by the colorimetric method

## 4. Discussion

Comparison between the amonia concentrations determined in the various modules is presented in Figures 17 to 19.

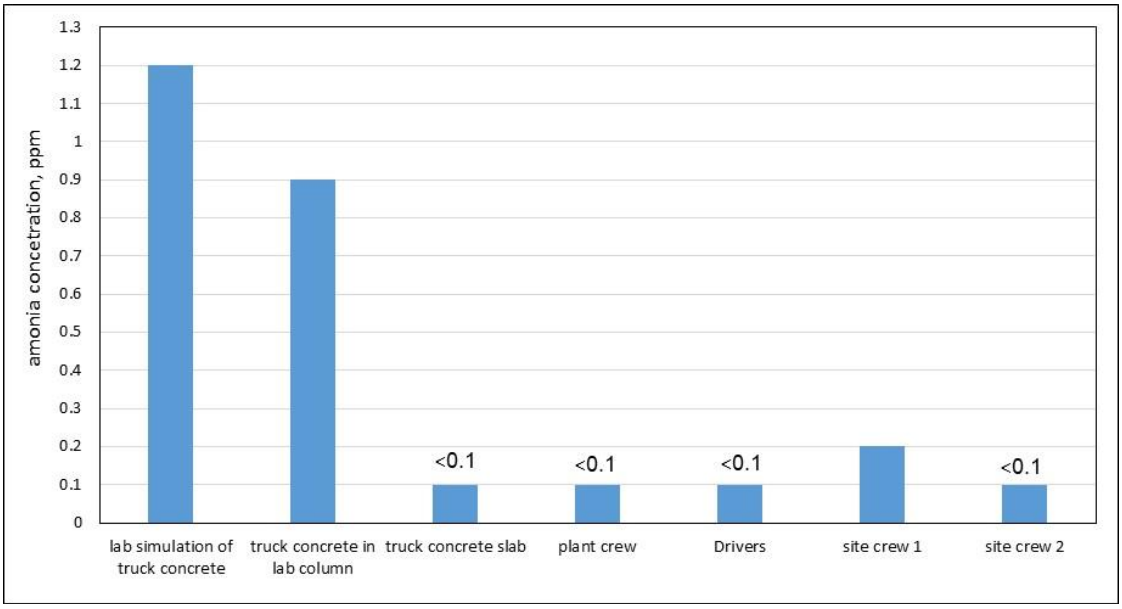



Figure 17: Maximum amonia concentrations determined in the various modules of the ready mixed concrete prepared with 160 kg/m³ of fly ash with 4 mg/kg ammonia

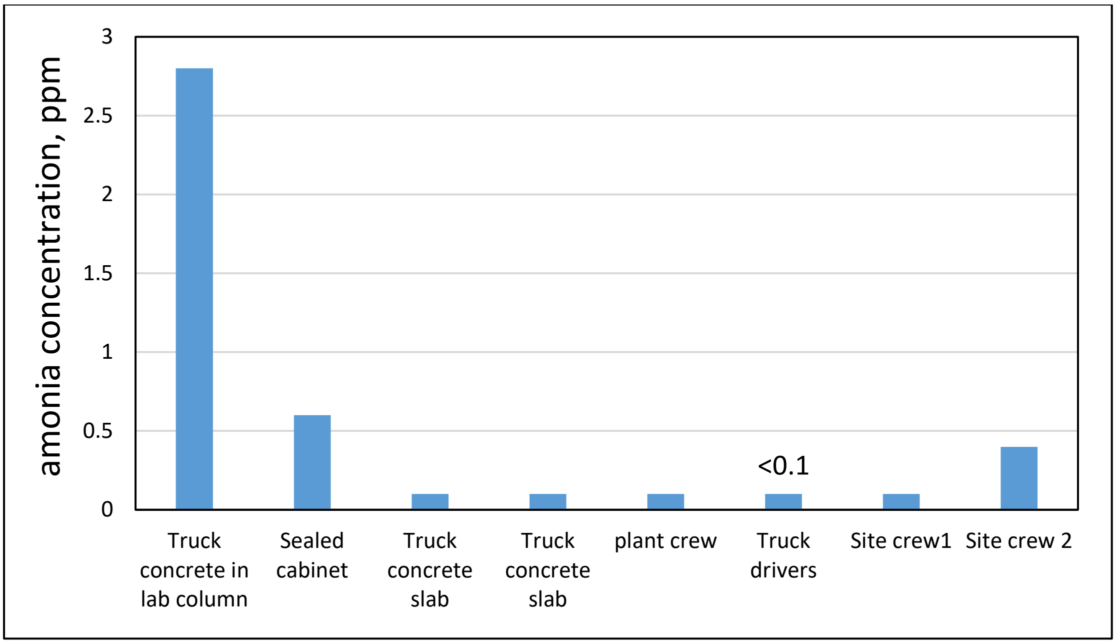



Figure 18: Maximum amonia concentrations determined in the various modules of the ready mixed concrete prepared with 160 kg/m³ of fly ash with 12 mg/kg ammonia; the lab column test was carried out at 20°C, the maximum temperature in the sealed cabinet was 45°C and on the open site 35°C at mid day (and more than 25°C at night).

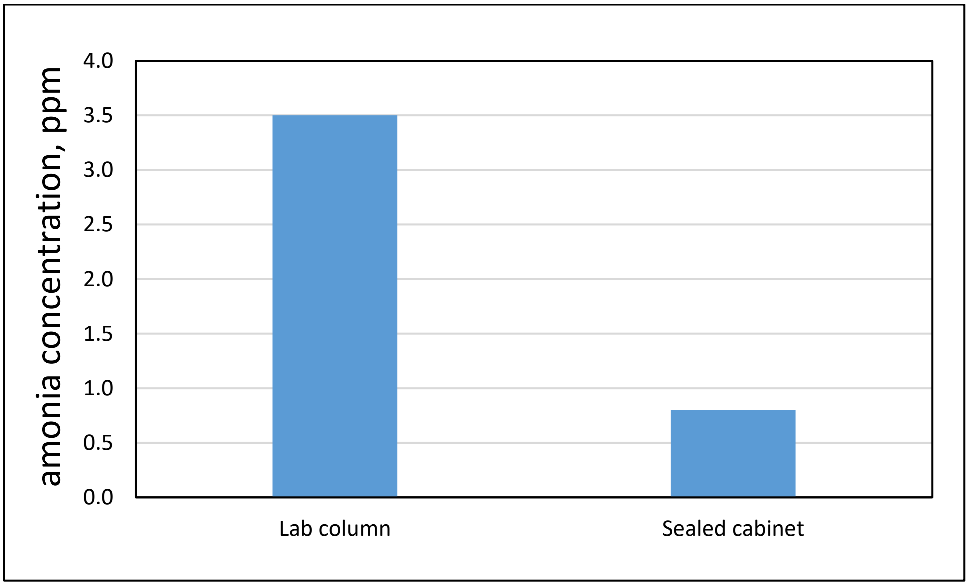



Figure 19: Maximum amonia concentrations determined in the lab column and sealed cabinet for lab mixed concrete prepared with 320 kg/m³ of fly ash with 12 mg/kg ammonia; the lab column test was carried out at 20°C, the maximum temperature in the cabinet was about 50°C and on the open site 45°C at midday (and more than 25°C at night).

These tests clearly show that the highest level of amonia concentrations were obtained in the lab column tests, in spite of the fact the temperature there was lower than the site temperature, as well as the enhanced temperature in the sealed cabinet tests, which ranged as high as 50°C at midday. The higher values in the column can be accounted by the fact that the whole test is done in a very confined space which does not let the amonia to dissipate around, as well as the setting of the lab test with very low air velocity, near stationary. The

fact that the values in the column are much higher than in the sealed cabinet, in spite of the higher temperatures in the cabinet, suggest that that the confinement and low air velocity are more crucial than the temperature. This is further confirmed when considering the difference between these results and the ones obtained over the site slab and the crew, which were considerably lower, all of them, regardless of temperature; the site and crew amonia concentrations were very close to the sensitivity of the amonia instrument detection, or even below it (nil values). This is true for the human monitoring as well as the simulation of humans and air monitoring above the slab. Although the air velocity over the site slab was very low, there was no buildup of amonia, with values much lower than in the sealed cabinet.

These results clearly indicate that the hypothesis that the column lab test represents extreme conditions, which are much harsher than those occurring on site or even in the sealed cabinet which was considered to be "natural amonia magnifying conditions". The values in the lab column were about 5 times higher than in the sealed cabinet and more than 7 to 10 time higher than the slab site test values for human and air. Thus the lab column test can be considered to be an adequate measure for assessing the amonia concentration released from concrete, as it represents extreme conditions.

In view of that, the relation between the maximum amonia content in the lab column tests and the composition of the concrete (fly ash content) and characteristic amonia content in the ash (in units of mg/kg) developed in the previous study was used to analyze all the data: the lab concretes as well as the ready mixed truck concretes which were also tested in the lab column at 20°C. In the previous study it was shown that there is a linear relation between the maximum amonia concentration obtained in the lab column tests and the amonia content in the concrete, expressed in terms of amonia content per unit weight of mix water, based on the proposal by Rathbone and Robl [3]. This relation is shown here in Figure 20 for all the data obtained in this study, clearly confirming the linear relation of Rathbone and Robl. The data in Figure 20 is shown for the amonia concentrations determined by the colorimetric tests which gave higher values than the NIOSH standard test of amonia exposure.

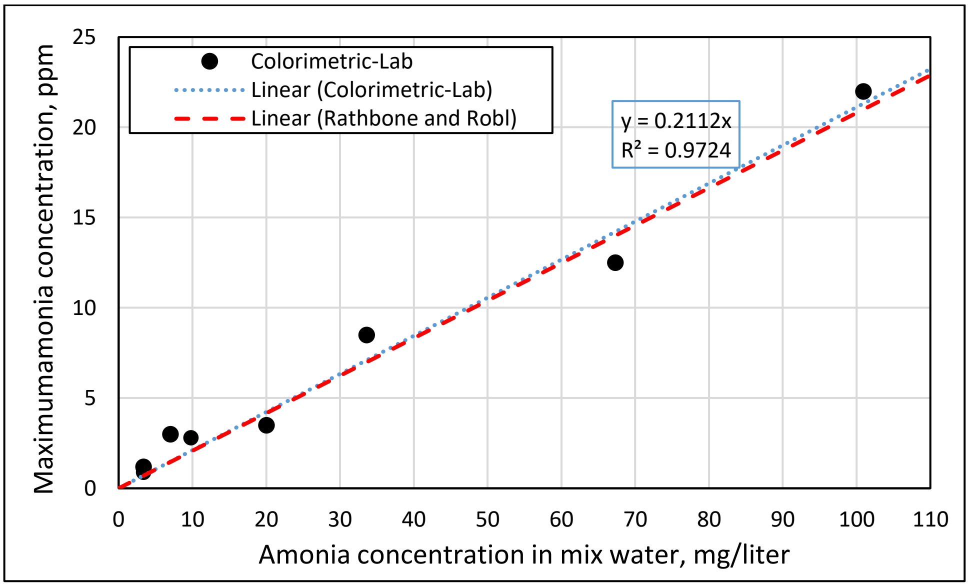



Figure 20: Relations between the ammonia concentration in the mix water and the maximum ammonia concentration into the lab test column, comparing the results of the current study (black points) with the relation reported by Rathbone and Robl [3] for "no ventilation" conditions

The linear relation in Figure 20 which extends over a wide range of amonia containing fly ash (4, 12 and 180 mg/kg) and a range of fly ash contents in the concrete (40 to 320 kg/m$^3$) can serve as a means for setting the limits of amonia concentration in the fly ash to avoid health hazards on site. Since in practice the water content in concretes varies over a small range, about 150 to 200 kg/m$^3$, it is proper to assume a representative value of 170 kg/m$^3$, to determine typical amonia concentration levels emitted from typical representative normal strength concretes. Assuming a typical concrete with 170 kg/m$^3$ of water content and 120 kg/m$^3$ typical maximum content of fly ash content in normal concretes, and setting a limit of half of the Permissible Exposure Limit (PEL) of the Threshold Average Value (TWA) of 12.5 ppm (half of 25 ppm) for the peak value in the lab column test, the maximum permitted amonia content in the fly ash can be calculated on the basis of the best fit linear relation in Figure 20:

$$12.5 = 0.211 \cdot A_{max} \cdot (120/170)$$

where $A_{max}$ is the maximum amonia content in the ash, in units of mg/kg

$A_{max}$ is calculated to be 84 mg/kg. The actual amonia concentration on site, in the air as well as the exposure of the crew, based on the observations in this study, will be much lower than the half of the TWA value set in the column test. An estimate for that can be obtained from Figures 17 to 19, where the values for the lab column tests were about 5 time higher than in the sealed column and more than 7 to 10 time higher than over the concrete slab and crew involved in the various stages of the concrete production and placing. This implies that with the limit of 84 mg/kg obtained in the calculation, the amonia concentration values in the sealed cabinet will not exceed 2.5 ppm, and will be less than 1.2 to 1.8 ppm on the site slab. These values are lower than the odor threshold limit reported in references [2,4].

## 5. Conclusions

- The peak in amonia concentration shows up usually within 6 to 8 hours after concrete preparation and casting and decays later on within the first 24 hours and decreases further during the next few days
- The amonia concentration detected in the lab column test is much higher than in the site tests: in the sealed cabinet (about 5 times higher), over the site concrete slab and the crew involved (more than 7 to 10 times higher), in spite of the much higher temperature in the site tests
- These results confirm the hypothesis that the lab column test represents extreme conditions with respect to amonia release, much higher than that occurring on site
- Monitoring with the colorimetric and NIOSH tests methods indicate values higher in the colorimetric tests and therefore conclusions based on the colorimetric test are on the safe side
- There is a linear correlation between the maximum amonia concentration in the lab column tests and the amonia content in the concrete, expressed as weight of amonia per unit weight of mix water
- Based on this linear relation an estimate for the maximum permitted amonia content in the fly ash can be calculated, setting a maximum TWA value in the column of 12.5 ppm, which is half of the PEL of 25 ppm, assuming maximum fly ash content of 120 kg/m$^3$ for normal concrete. Based on the relation of maximum amonia content in the lab column test and the site tests, it can be estimated that the maximum amonia concentration on site will be less that the odor limit of 3 to 3.8 ppm reported in literature [2,4]

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