

Nutrient recovery from airplane wastewater: composition, treatment and ecotoxicological assay

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ABSTRACT

For the 2014 World Cup and the 2016 Olympic Games, Brazil has expanded its airport infrastructure. This will lead to an increase in wastewater generation from aircrafts. This wastewater is traditionally taken from the aircrafts and disposed in the public sewage collection system. However, this residual water may have a different composition than the usual sanitary sewage. Therefore, it is important to study an alternative to treat this kind of wastewater. Thus, the objective of this study was to characterize and analyze the treatment of wastewater from airplane toilets through chemical precipitation for the removal of ammonia in the form of struvite. The airplanes' effluent showed a composition similar to human urine with pH 8.9, ammonia nitrogen $4,215 \text{ mg L}^{-1}$, phosphorus 430 mg L^{-1} and a very high acute toxicity (*Vibrio fischeri*). The best treatment for struvite formation was with pH 9.0 and molar ratio $\text{Mg:NH}_4:\text{PO}_4$ equal to 1.5:1.0:1.0. In this case, the removal of ammonia and phosphorus achieved 97.0% and 95.3%, respectively. After this procedure, the toxicity by *Vibrio fischeri* decreased.

Key words | ammonia, luminescent bacteria, magnesium ammonium phosphate (MAP), struvite precipitation, urine

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INTRODUCTION

With the 2014 World Cup and the 2016 Olympic Games, Brazil has expanded its airport infrastructure. As a result, there has been increased demand for natural resources in this activity, and expansion of wastewater generation.

The greatest demand for water in airports is for non-potable purposes such as irrigation of green areas, flushing toilets and cleaning floors and airplanes (Carvalho *et al.* 2013). In order to reduce the demand for natural resources at airports, rainwater or water reuse can be used. Such practices are already being studied and applied in Brazil (Couto *et al.* 2013a, 2013b).

However, the effluent coming from airplane toilets is an under-studied wastewater. According to Xu *et al.* (2011) this wastewater is produced during travel, and is partially diluted and pre-treated by adding a cleaner. After arriving at the airports, it is taken from the aircraft and sent to a sewage treatment plant. Typically, the treatment is done together with the sewage produced at the airport.

Xu *et al.* (2011) observed that this type of waste has low presence of pathogenic microorganisms. However, the ammonia

nitrogen (AN) concentrations ($1,634 \text{ mg L}^{-1}$), chemical oxygen demand (COD) ($5,335 \text{ mg O}_2 \text{ L}^{-1}$), biochemical oxygen demand (BOD) ($4,255 \text{ mg O}_2 \text{ L}^{-1}$), anionic surfactants, copper (4.8 mg L^{-1}) and phenolics are high.

Managing this effluent individually, without mixing with other wastewater produced in airports, should be carefully evaluated if, due to the presence of disinfectant agents, air fresheners and the high concentration of ammonia, biological treatment is not recommended.

The main component of this wastewater is human urine, which is rich in nutrients: nitrogen (N) and phosphorus (P). Kirchmann & Petersson (1995) observed a nitrogen concentration in urine from 1.79 to 2.61 g L^{-1} , predominantly the ammoniacal form. In addition to that compound, urine contains lower concentrations of chloride (Cl^-), sodium (Na), calcium (Ca) and potassium (K) (Lind *et al.* 2000).

Thus, it is important that the effluent treatment process of airplanes first removes the AN. For this, two processes can be used: air stripping and precipitation of ammonia in the form of struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$). Both processes

have a high efficiency in AN removal. Calli *et al.* (2005) reported an efficiency of 94% and 98% in removing AN by air stripping and struvite, respectively. However, a disadvantage of the use of the air stripping technique is the high aeration time, which can vary from 24 hours (Martinen *et al.* 2002) to 96 hours (Silva *et al.* 2004).

In turn, ammonia removal by chemical precipitation is simple and fast. Escudero *et al.* (2015) obtained a 95% removal of AN with a 30-second reaction time. This value is much lower than found in air stripping.

Chemical precipitation of ammonia forms a mineral known as struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) as the main compound. In experiments with human and synthetic urine, Kemacheevakul *et al.* (2015) found a percentage higher than 90% of struvite in the precipitated material. This precipitate can be used as a product in activities such as agriculture (Vogel *et al.* 2015) and cultivation of algae for bio-fuel production (Moed *et al.* 2015). In the cultivation of corn and rye, applying struvite formed from human urine showed productivity higher than conventional fertilizers (Antonini *et al.* 2012).

However, during struvite formation, precipitation of other compounds that are present in the liquid phase can occur, such as pharmaceutical compounds (Kemacheevakul *et al.* 2015), metals (Uysal *et al.* 2010; Rouff 2012) and pathogens (Decrey *et al.* 2011).

Based on this, the objective of this study was to evaluate the efficiency of ammonia removal from the effluent of airplane toilets through chemical precipitation of ammonia and struvite formation. The precipitate composition formed was evaluated by X-ray diffraction (XRD). The wastewater was analyzed by acute ecotoxicological tests with a marine bacterium (*Vibrio fischeri*).

MATERIAL AND METHODS

The effluent used originated from toilets in airplanes stationed at Guarulhos International Airport 'Governor André Franco Montoro', located in the metropolitan region of São Paulo (Brazil). This is the largest airport in Brazil (Infraero 2016).

In this airport, after disembarking passengers, the airplanes are taken to a restricted area for toilet cleaning. A truck tank with a coupled suction pump removes all the material stored in the tanks of the airplane toilets. Then, the reservoir is washed with a mixture of water and detergent; this solution is also stored in the tank truck. Finally, this material is taken to the sewage treatment plant. The

liquid effluent used in this study was collected in the tank truck.

The parameters used in the characterization of the wastewater were: concentration of volatile fatty acids (VFA), COD, AN, partial and total alkalinity, electrical conductivity (EC) and potential hydrogen (pH) according to APHA *et al.* (2012). To determine VFA, the method described by Dilallo & Albertson (1961) was used, and the partial and total alkalinity was determined according to the method described by Ripley *et al.* (1986). At this stage, the samples were performed in duplicate. Wastewater samples were not filtered in any of the experimental steps.

AN removal assay

Removal tests for ammonia by chemical precipitation were carried out with $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ (magnesium chloride hexahydrate) and $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ (disodium hydrogen phosphate dodecahydrate). Ammonia removal assays were performed in a 500 mL beaker with a 300 mL effluent volume (Camargo *et al.* 2014). For stirring, a magnetic stirrer was used.

The order of reagent addition was: first, the magnesium source, then the phosphate source and finally the pH adjustment with sodium hydroxide (NaOH 15 mol L^{-1}). The reaction time was 15 minutes, with 30 min for decantation. After the end of the decantation time the liquid phase was separated from the solid phase (the precipitate).

Experimental analysis was performed using factorial design with two levels and three factors ($2^3 = 8$) and four replications, totaling 32 assays. The factors were: pH and molar concentration of magnesium and phosphate (Table 1). The response variables were: removal of ammonia (%), phosphorus concentration in the effluent and EC.

Table 1 | Experimental design used in the AN removal assay by chemical precipitation

| Treatment | pH | Phosphorus (PO_4^{3-}) | Magnesium (Mg) | Mg:P molar ratio | Mg:NH ₄ :PO ₄ molar ratio |
|-----------|------|-----------------------------------|----------------|------------------|---|
| 1 | 9.0 | 0.5 mol | 1.0 mol | 2.0 | 1.0:1.0:0.5 |
| 2 | 10.0 | 0.5 mol | 1.0 mol | 2.0 | 1.0:1.0:0.5 |
| 3 | 9.0 | 0.5 mol | 1.5 mol | 3.0 | 1.5:1.0:0.5 |
| 4 | 10.0 | 0.5 mol | 1.5 mol | 3.0 | 1.5:1.0:0.5 |
| 5 | 9.0 | 1.0 mol | 1.5 mol | 1.5 | 1.5:1.0:1.0 |
| 6 | 10.0 | 1.0 mol | 1.5 mol | 1.5 | 1.5:1.0:1.0 |
| 7 | 9.0 | 1.0 mol | 1.0 mol | 1.0 | 1.0:1.0:1.0 |
| 8 | 10.0 | 1.0 mol | 1.0 mol | 1.0 | 1.0:1.0:1.0 |

Calculations of magnesium and phosphate factors were conducted based on the molar concentration of AN present in the sample (Table 2). The amount of reagents used is shown in Table 3. The trials were statistically assessed by analysis of variance and response surface methodology with Minitab software, version 16. The Tukey test was used to differentiate treatment means ($p < 0.05$).

The pH factor is important because it is related to the solubility of the formed material. The pH range used in several studies was between 7.8 and 10.0 (Uysal et al. 2010; Liu et al. 2013; Siciliano et al. 2013; Huang et al. 2015) depending on the material used. Thus, in this study, a pH between 9.0 and 10.0 was used.

The precipitate formed in the tests was dried in a desiccator coupled to a vacuum pump. After 48 hours, the precipitated samples were placed in an oven at 38 °C. The precipitated material samples were not washed with distilled water.

The dried precipitate was analyzed by XRD, by the powder method. An X-ray diffractometer (Bruker, D2 Phaser model) was used, equipped with vertical scanning and copper tube 400 W power goniometer (λ CuK α =

1.5406 Å). Bragg-Brentano geometry was used in continuous mode with a scanning speed of 0.25 ° min⁻¹. For detection, a fast detector (Bruker, LynxEye model) was used. Voltage and current were set to 30 kV and 10 mA, respectively. The diffractometers were obtained for an exposure interval of 8 ° to 65 ° (2 θ), with 0.02 ° steps. Crystalline phases were identified using the International Centre for Diffraction Data catalog, ICDD.

Ecotoxicological tests

In order to evaluate the effluent ecotoxicity before and after removal of ammonia, an acute toxicity test with a luminescent marine bacterium (*Vibrio fischeri*) was used. In this test, the sample pH was adjusted to a range from 6.5 to 7.0 with HCl 0.1 N and 1.0 N. Toxicity calculation was performed with the Microtox[®] Omni 4.1 software. All toxicity values were transformed into toxicity units (TU) (Equation (1)). Tests with *Vibrio fischeri* were performed according to ABNT (2012). For the toxicity rating, the model proposed by Persoone et al. (2003) was used.

$$TU = \frac{100}{EC_{50}} \quad (1)$$

Table 2 | Composition of liquid effluent from airplane bathroom

| Parameter | Unit | Value |
|------------------------|--------------------------------------|--------|
| pH | – | 8.9 |
| Phosphorus | mg P-PO ₄ L ⁻¹ | 430 |
| Partial alkalinity | mg CaCO ₃ L ⁻¹ | 9,428 |
| Total alkalinity | mg CaCO ₃ L ⁻¹ | 11,323 |
| Volatile organic acids | mg HAC L ⁻¹ | 2427.6 |
| Conductivity | mS cm ⁻¹ | 28.1 |
| COD | mg O ₂ L ⁻¹ | 3,217 |
| N-NH ₃ | mg N-NH ₃ L ⁻¹ | 4,215 |

Table 3 | Amount of reagents used in the ammonia removal assay

| Treatment | MgCl ₂ ·6H ₂ O (g) | Na ₂ HPO ₄ ·12H ₂ O (g) |
|-----------|--|--|
| 1 | 16.2 | 18.4 |
| 2 | 16.2 | 18.4 |
| 3 | 16.2 | 27.5 |
| 4 | 16.2 | 27.5 |
| 5 | 32.4 | 27.5 |
| 6 | 32.4 | 27.5 |
| 7 | 32.4 | 18.4 |
| 8 | 32.4 | 18.4 |

RESULTS AND DISCUSSION

The airplane toilet effluent had a strong and unpleasant odor, characteristic of human urine. The color was dark green, which according to Xu et al. (2011) is caused by the addition of detergent (resolvable sanitizing liquid) in the toilet cleaning.

The high pH value found (8.9) (Table 2) was very close to that obtained by Etter et al. (2011) (9.0) in stored urine and superior to that found by Xu et al. (2011) (7.5) in airplane wastewater in Changchun airport in China. One hypothesis for this high pH value would be the degradation of urea during storage. This biochemical transformation can generate ammonia and consequently increase the pH (Hug & Udert 2013). In the case of the wastewater from Changchun airport, the cleaner used may have inhibited the development of bacteria active in this biochemical ammonification process.

In parallel to the high pH, a high partial and total alkalinity was also observed. The obtained values were, respectively, 9,428 and 11,323 mg CaCO₃ L⁻¹ (Table 2). This high alkalinity present in the wastewater helped

balance the H⁺ ions added to the phosphate source (Na₂HPO₄) in the chemical precipitation assay of ammonia. Thus, pH adjustment did not require a large volume of base (NaOH). However, carbonate can react with magnesium (MgCO₃) or calcium (CaCO₃) (Acelas *et al.* 2014), so carbonate can remove magnesium of the liquid phase.

A high concentration of phosphorus in the effluent analyzed (430 mg P-PO₄ L⁻¹) was found. This value was very close to that reported by Etter *et al.* (2011) in fresh urine (388 mg L⁻¹). In stored urine, Hug & Udert (2013) found a phosphorus concentration of 197 mg L⁻¹. In fresh urine, a higher concentration of phosphorus has been found, higher than the concentration obtained in stored urine. Possibly, during storage of urine natural struvite precipitation may occur, thereby removing phosphorus and ammonia (Antonini *et al.* 2012).

Another factor that may explain the high concentration of phosphorus in the effluent used in this study was the use of detergents in products to clean the toilets.

The AN concentration was 4215.0 mg NH₃-N L⁻¹ (Table 2) in the airplane wastewater. This high concentration of AN can inhibit microorganisms in effluent treatment by biological processes. Li & Zhao (2001) observed that the concentration of AN in landfill leachate must be less than 100 mg L⁻¹, otherwise the biological treatment is compromised. Thus, the high concentration found in this study (Table 2) highlights the need for a pre-treatment for removing ammonia from the airplane effluent.

The conductivity of the sample was high (28.1 mS cm⁻¹). This value is higher than that found in fresh urine (22.6 mS cm⁻¹) and stored urine (25.9 mS cm⁻¹) (Etter *et al.* 2011). Xu *et al.* (2011) observed that the detergent (resoluble sanitizing liquid) used as primary treatment for disinfection contains ammonium salts and other compounds. These ammonium salts in detergent may contain

cations that contribute to the increase of EC in the analyzed wastewater.

The organic matter (COD) also presented the highest values in airplane wastewater (3,217 mg O₂ L⁻¹) (Table 2). However, it was less than that observed in urine. As a comparison Etter *et al.* (2011) found an average COD in fresh urine of 7,660 mg O₂ L⁻¹. In stored urine, Hug & Udert (2013) found an average COD of 4,500 mg O₂ L⁻¹. Possibly, this lower of COD value found in airplane wastewater (Table 2) may be due to dilution caused by the water used for flushing the toilet and by the toilet cleaning.

Ammonia removal efficiency as struvite

The ammonia precipitation assay provided high removal of AN (Table 4). The lowest removal was found in treatments 1 and 3 (60%) and the highest in treatment 6 (98%). From treatment 1 to 4, low efficiency occurred due to the use of a phosphorus concentration lower than required for precipitation (1.0:1.0:0.5 and 1.5:1.0:0.5). In this case, the ideal theoretical ratio would be 1.0:1.0:1.0 for Mg:NH₄:PO₄.

Li *et al.* (1999) also found a reduction in AN removal efficiency in an experiment with landfill leachate when the same molar ratio of reactants (1.0:1.0:0.5) was used. This design was used due to the airplane effluent having a phosphorus concentration of 430 mg P-PO₄ L⁻¹ (Table 2).

The formation of struvite can be used both for removing AN and for removing phosphorus. Thus, the addition of only 0.5 mol phosphate obtained a maximum phosphorus removal (99.5%) in treatment 1 (Table 4).

In any treatment, the AN concentration was lower than permitted by Brazilian law (20.0 mg N-NH₃ L⁻¹) (Brazil 2011). The lowest concentration of AN was 83.0 N-NH₃ mg L⁻¹ in treatment 6. This nitrogen concentration after removal of ammonia is close to that observed in

Table 4 | Nitrogen removal efficiency, EC and phosphorus in the ammonia removal assay (Mean ± Std Dev)

| Treatment | Removal N-NH ₃ (%) | N-NH ₃ (mg L ⁻¹) | Conductivity (mS cm ⁻¹) | Removal P-PO ₄ (%) | Phosphorus (mg P-PO ₄ L ⁻¹) |
|-----------|-------------------------------|---|-------------------------------------|-------------------------------|--|
| 1 | 60.0 ± 1.5 | 1,704 ± 65 | 70.70 ± 2 | 99.5 | 2.03 ± 0.81 |
| 2 | 62.0 ± 4.0 | 1,618 ± 170 | 75.60 ± 1 | 97.1 | 12.37 ± 1.00 |
| 3 | 60.0 ± 0.8 | 1,708 ± 36 | 87.98 ± 2 | 98.5 | 6.37 ± 3.32 |
| 4 | 67.0 ± 1.5 | 1,382 ± 65 | 86.10 ± 2 | 95.6 | 18.80 ± 10.56 |
| 5 | 97.0 ± 0.6 | 119 ± 27 | 90.34 ± 2 | 95.3 | 20.20 ± 12.13 |
| 6 | 98.0 ± 0.2 | 83 ± 8 | 88.64 ± 1 | 89.3 | 45.98 ± 13.01 |
| 7 | 95.0 ± 3.3 | 209 ± 82 | 79.65 ± 1 | – | 1460.58 ± 521.85 |
| 8 | 94.8 ± 2.6 | 218 ± 14 | 80.28 ± 4 | – | 1515.15 ± 534.12 |

sanitary sewage 20 to 70 mg L⁻¹ (Metcalf & Eddy 2003) and 98.5 ± 19.5 mg L⁻¹ (Silva *et al.* 2015) in the form of ammonia and organic nitrogen. In the treatment of landfill leachate, Li & Zhao (2001) noted that aerobic biological treatment is possible with an AN concentration less than 100 mg L⁻¹. In anaerobic treatment, an AN concentration between 50 and 200 mg L⁻¹ is beneficial to the anaerobic treatment (McCarty 1964). However, in addition to chemical analysis of airplane wastewater, evaluating the toxicity of this material prior to application of the biological treatment is important.

The present study also found that the molar ratio Mg/P and pH are important factors for precipitation of ammonia. The Mg/P ratio used in treatments 5 to 8, varying between 1.0 and 1.5, resulted in efficiency greater than 90% in the removal of AN (Figure 1).

The increase in pH from 9.0 to 10.0 showed a small increase in the removal of AN in treatments 1 to 4. This increase of AN removal with pH change may be linked to the volatilization of ammonia, as the increase in pH shifts chemical equilibrium for the formation of NH₃. The pH parameter in addition to controlling the solubility of the struvite also interferes in the removal of the ammonia, since a high pH can cause volatilization of the ammonia instead of precipitation. The volatilization of the ammonia leads to a reduction of the ideal Mg:NH₄:PO₄ ratio (1:1:1) (Le Corre *et al.* 2009), which consequently reduces precipitation.

The use of higher values of pH, molar concentration of magnesium and phosphorus, produces a higher average efficiency in the removal of ammoniacal nitrogen. The lowest

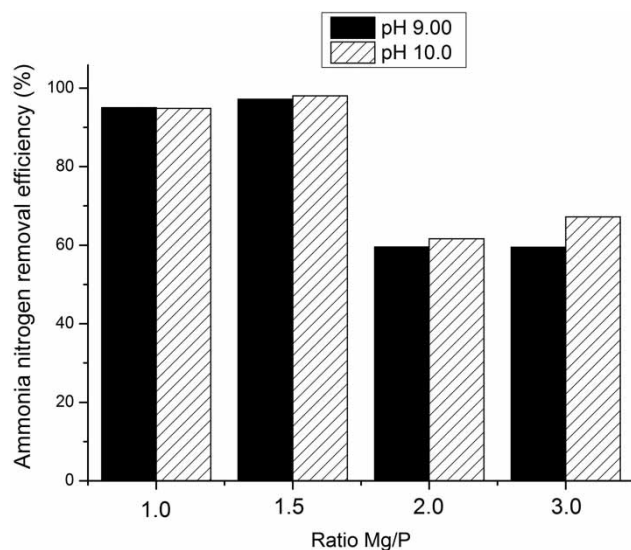


Figure 1 | AN removal efficiency in different molar ratios.

concentration of ammoniacal nitrogen was in treatment 6, however this treatment is not significantly different from treatments 5, 7 and 8 when the Tukey test is applied. Thus, the choice of the best treatment should be based on the removal of phosphorus and toxicity.

In contrast to that observed for AN, the best phosphorus removal was observed in treatments 1 to 4. In these cases, the Mg/P ratios used ranged from 2.0 to 3.0 (Figure 2). The greatest efficiency for phosphorus removal (99.5%) was found in treatment 1 (1.0:1.0:0.5). Liu *et al.* (2013) observed an increase in P removal efficiency with the increase in the Mg/P ratio in phosphorus precipitation assays in urine. Uysal *et al.* (2010) also observed that a high concentration of magnesium reduces the phosphorus concentration in assays performed with effluents in anaerobic sludge digesters.

The highest efficiency for phosphorus removal was obtained in treatment 1, when the highest concentration of magnesium and the lowest concentration of phosphorus were used. The pH was insignificant. Nonetheless, this treatment was not statistically significant when compared to treatment 2, 3, 4, 5, and 6.

The best molar ratio Mg/P for phosphorus removal was between 1.5 and 3.0. A possible explanation for this behavior would be that the phosphorus has been removed by precipitation in the form of other compounds containing Mg²⁺ and PO₄³⁻ as newberyite (Mg(PO₄OH)·3H₂O), bobierite (Mg₃(PO₄)·8H₂O) or amorphous magnesium phosphate.

Various cations (Fe, Ca, Al and Mg) may be used for phosphate precipitation. However, according to De-Bashan & Bashan (2004) magnesium is the least of these

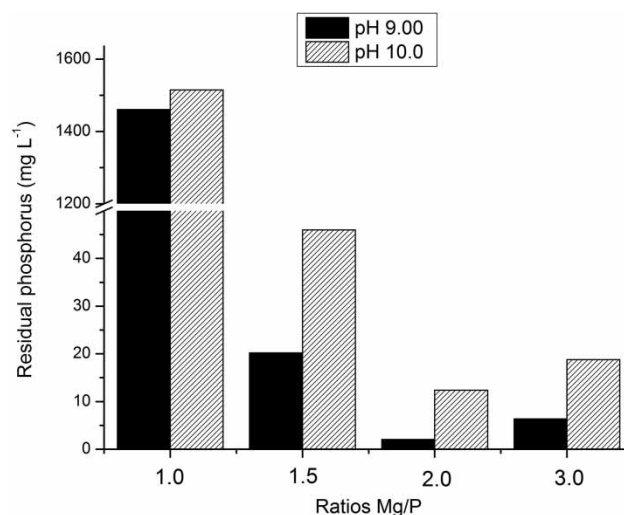


Figure 2 | Phosphorus concentration in the effluent after precipitation assays.

metals used, except for struvite formation. Korchef *et al.* (2011) studied the precipitation of struvite in synthetic water with a Mg:P ratio ranging from 1:1 to 5:1, and observed less residual phosphate concentration in the largest ratio (5:1).

A hypothesis for high phosphorus removal in treatments 1 to 4 would be that at first precipitation of struvite occurred, and then, due to the reduction in nitrogen concentration, precipitation of secondary compounds made up of phosphorus and magnesium occurred. In the study by Korchef *et al.* (2011), the use of excess of magnesium in relation to phosphorus (5:1) resulted in the formation of struvite, newberyite and cattite ($\text{Mg}_3(\text{PO}_4)_2 \cdot 22\text{H}_2\text{O}$).

Another important factor in determining the precipitate composition is the ratio N:P (Crutchik & Garrido 2011). The study of struvite crystallization reactors from an industrial effluent of fish processing showed that at a molar ratio N:P of 4.7 the formed precipitate was composed of struvite. However, an N:P ratio equal to 1.0 formed compounds of magnesium and calcium phosphate (Crutchik & Garrido 2011). In the study by Lu *et al.* (2016) it was observed that a low N:P ratio can produce other phosphorus compounds such as newberyite, and in a high N:P ratio struvite was formed.

Increasing the N:P ratio reduced the formation time for struvite and provided higher efficiency in phosphate removal (Korchef *et al.* 2011). With an N:P ratio equal to 1/4, the induction time and removal of phosphate was respectively 40 min and 21%; however, with an N:P ratio equal to 2.0 the induction time was 12 min and the removal of phosphate was 76% (Korchef *et al.* 2011). The results obtained by Korchef *et al.* (2011) corroborate the results found in this study. With a ratio of N:P equal to 2 (treatments 1 to 4, Table 1) higher efficiency in removing phosphorus occurred. However, at an N:P ratio equal to 1 (treatments 5 to 8) a reduction in efficiency occurred.

To evaluate the best treatment for ammonia and phosphorus removal, the surface of responses for these two variables were analyzed (Figures 3 and 4). Based on this analysis it was verified that the best treatment was number 5, with a nitrogen removal efficiency of 96.6% and residual phosphorus of $27.7 \text{ mg L}^{-1} \text{ P-PO}_4^{3-}$.

In all treatments, an increase in EC was noticed. This increase was caused by the reagents used ($\text{MgCl}_2 + \text{Na}_2\text{HPO}_4$). Zhang *et al.* (2009) consider that in order to remove 1 mole of N-NH_3 , 2 moles of NaCl are produced when $\text{MgCl}_2 + \text{Na}_2\text{HPO}_4$ is used. Thus, this increase of EC in all treatments (Table 2) is associated with compounds cited by Zhang *et al.* (2009).

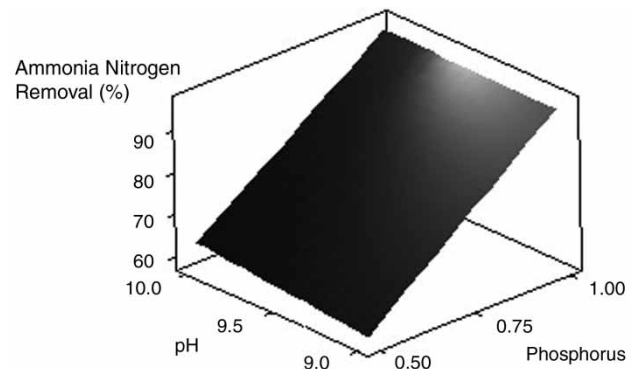


Figure 3 | Surface plot for AN removal.

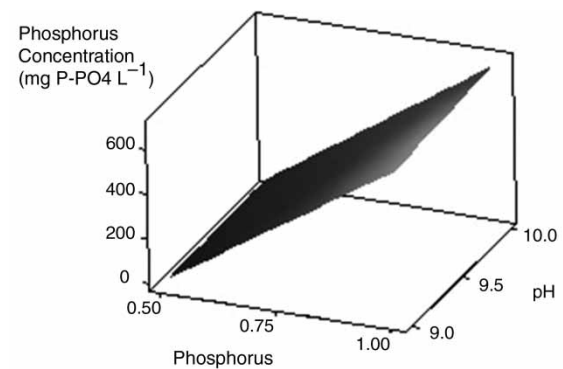


Figure 4 | Surface plot for phosphorus concentration.

When assessing the results using XRD by the powder method, it was observed that in all treatments the formation of struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) occurred (Figure 5). Comparatively, when studying chemical precipitation with synthetic urine and human urine, Lind *et al.* (2000) found struvite to be the main precipitate with other minerals such as k-struvite, montgomeryite, newberyite, brucite and eponite. As human urine contains various ions, the formation of other compounds may occur. However, in these trials, the XRD patterns showed only struvite because it has a very high formation rate. According to Le Corre *et al.* (2007) a high concentration of magnesium favours the formation of struvite in a short period of time. In all treatments a high concentration of magnesium was used (Table 1), consequently the struvite may precipitate first. Nevertheless, the precipitation of other amorphous compounds such as magnesium phosphate may have occurred.

The struvite precipitation from airplane effluent may be used in green areas of airports after microbiological and chemical characterization. As the aircraft wastewater consists of feces and urine, it may contain pathogenic organisms. Gell *et al.* (2011) observed that struvite obtained

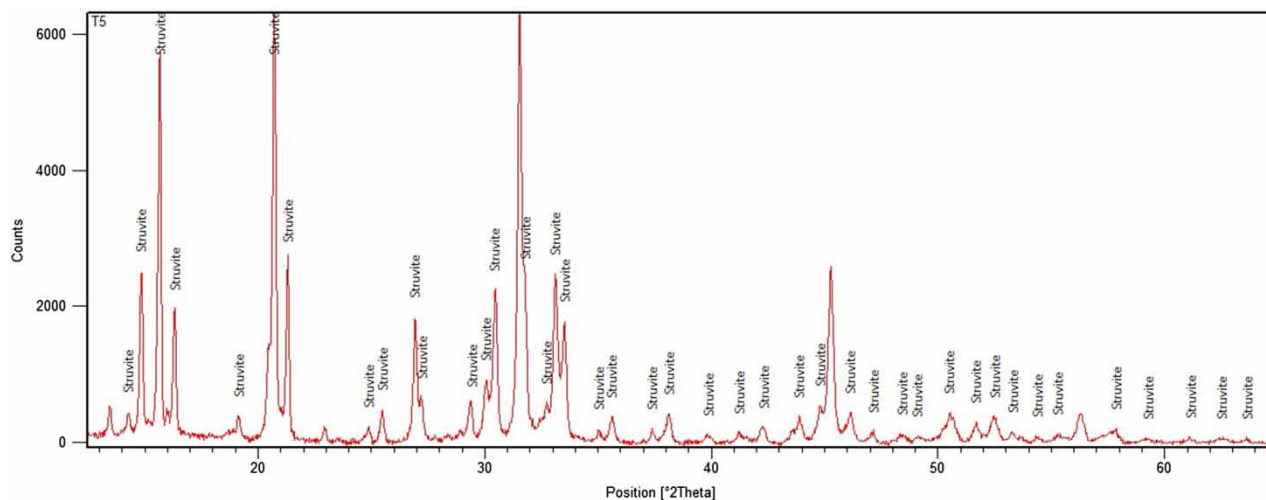


Figure 5 | XRD patterns obtained in treatment 5.

from black water and urine showed a concentration of heavy metals and microorganisms below the limits allowed by Dutch legislation. However, further research should evaluate the composition of struvite formed from aircraft waste, and what species of plants in the airport gardens could receive this struvite.

Toxicity test

The effluent of airplane toilets *in natura* showed a very high acute toxicity (279 TU), according to the classification of Persoone *et al.* (2003). In toxicity analysis of *in natura* urine with *Vibrio fischeri*, Escher *et al.* (2005) found an acute toxicity of 323 TU, and this value is very close to that found in airplane wastewater. Thus, the water used for toilet flushing and the detergent used for cleaning contributed little to the effluent toxicity.

Determining the relationship between the chemical parameters of the sample and its toxic effect is extremely complex due to the sample heterogeneity of the airplane wastewater. Possibly, the toxicity of this wastewater may be related to the high concentration of AN and alkalinity (Pablos *et al.* 2011; Emenike *et al.* 2012).

To evaluate the toxicity of the effluent after removal of ammonia, a preliminary screening was carried out with all treatments. After the precipitation of struvite, a high percentage of inhibition of the marine bacterium *Vibrio fischeri* was observed (Figure 6). The test that showed the best performance in reducing the inhibition was treatment 5, with a 97.8% inhibition. Thus, the full test was performed only for this treatment.

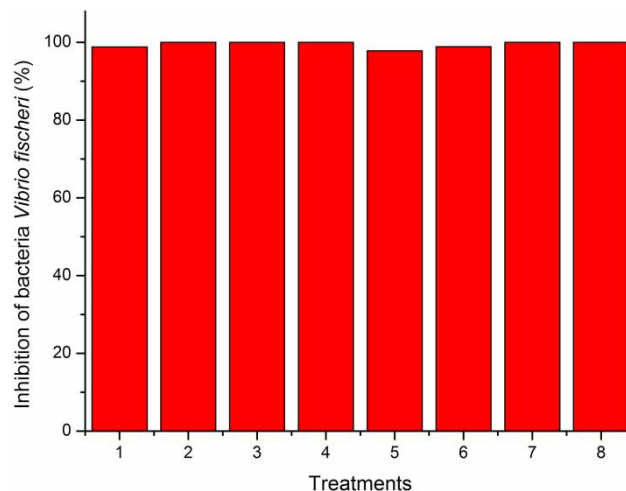


Figure 6 | Inhibition of bacteria *Vibrio fischeri* after nitrogen removal by chemical precipitation and formation of struvite.

Treatment 5 showed a reduction in toxicity of approximately 95%; however, this effluent still showed a high acute toxicity (16 TU). As this treated effluent did not reach the parameters for discharge to a water body, applying a post-treatment is important.

CONCLUSION

We concluded that the composition of airplane effluent is similar to human urine. The best treatment for struvite formation was at pH 9.0 and molar ratio Mg:NH₄:PO₄ equal to 1.5:1.0:1.0 (treatment 5). In this case, the removal efficiency of ammonia and phosphorus achieved 97.0% and

95.3%, respectively. After ammonia removal, the toxicity for *Vibrio fischeri* decreased.

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