

Development and operation of struvite reactors to recover phosphorus from source separated urine in eThekweni

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ABSTRACT

Source-separated urine as source for fertilizer production has been tested in the laboratory and in pilot installation. However, eThekweni is an ideal place for testing urine collection and fertilizer production on a large scale, as during a sanitation programme, eThekweni Water and Sanitation (EWS) installed 75 000 urine diverting dry toilets in different areas. In the first phase of a research project, collection tanks were installed at 300 households and the urine was collected regularly by EWS staff. The first reactor for removal of phosphorus from urine using magnesium chloride solution to form the mineral struvite worked well and removed up to 91 % of total phosphorus. Electrical conductivity measurements in bench-scale experiments coupled with chemical speciation modeling indicated that the change in electrical conductivity during the precipitation reaction could be used for an automated magnesium addition method. This system was used to predict different chemical addition schemes and thus optimize the process parameters.

1. INTRODUCTION

75 000 urine diverting dry toilets (UDDTs) have been installed in the rural and peri-urban areas of eThekweni to address the sanitation “backlog” (1). UDDTs allow the separation of urine from the faeces stream by a divider inside the pedestal (2). The source-separated urine is a source for fertilizer production, as it contains the majority of nutrients found in wastewater streams (3). Since October 2010 the Swiss Federal Institute of Aquatic Science and Technology (Eawag), eThekweni Water and Sanitation (EWS), the University of KwaZulu-Natal and the Swiss Federal Institute of Technology Zurich (ETHZ) work together in the VUNA project to develop a sustainable urine collection system and urine treatment processes (www.eawag.ch/vuna). In a first step, struvite reactors were developed and tested for phosphorus removal by struvite precipitation. By adding soluble magnesium to urine, struvite (magnesium ammonium phosphate hexahydrate; $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) precipitates, and can be recovered as a powder in decentralised reactors. This process has been tested extensively for the treatment of urine, for example in Nepal (4) and Vietnam (5).

2 MATERIALS AND METHODS

2.1 Urine quantities and qualities

Urine is collected at the UDDTs in 4 L containers connected to the urine pipe at the back of the toilet. A total of 300 households in the areas of Ehlanzeni, Umnini and Ntshongweni participated in the trial. The urine was collected and transported by staff of EWS regularly and brought to a central storage site located at the agricultural research hub in Newlands-Mashu. At 30 households, the 4 L tanks had sight glass installed in order to measure the urine volumes. A facilitator took readings once a day for at least a month. The composition of the collected urine was analysed in a first screening of 27 households in the three different areas in September 2011. The analysis was undertaken by EWS Scientific Services in Pinetown, Durban.

2.2 Struvite reactor

The first reactor (volume 50 L) was equipped with an overhead stirrer and was based on a design developed by Etter et al. (2011) (3). Baffles and 45° twisted stirrer blades provided fluid mixing. A filter bag and filter disc was tested to separate the crystals from the liquid. Industrial grade magnesium chloride was used for struvite precipitation. The dissolved magnesium was added in a molar ratio of 1.1:1 mol Mg : mol P. Dissolved phosphate and total phosphorus (P) were measured to determine the performance of the reactor. Both parameters were measured using a Merck Nova 60 photospectrometer (Ammonium molybdate spectrometric method, Merck, Darmstadt, Germany). To determine dissolved phosphate, samples were filtrated with a pore size of 0.45 µm prior to dilution and analysis. The crystals size was determined with a Malvern Mastersizer 2000 diffractometer.

2.3 Titration experiments and modelling

Bench-scale titration experiments were undertaken to support the reactor optimization. An autotitrator (Mettler DL70 Titrator, Mettler-Toledo GmbH, Giessen, Germany) was used to add dissolved magnesium chloride at different concentrations and rates into a glass beaker containing 150 mL urine. Electrical conductivity was measured on-line with combined pH/EC meter (WTW 340i, Wissenschaftlich-Technische Werkstätten, Weilheim, Germany) and recorded during the experiment. These results were compared to predictions from a computer program simulating thermodynamic equilibria.

3 RESULTS AND DISCUSSION

3.1 Urine quantities and qualities

The volume measurements showed a urine production of 0.6 L·d⁻¹ of urine per household. On average, 6 people live in one household, which leads to a production of about 0.1 L·pers⁻¹·d⁻¹, which is significantly lower than literature values of 0.6 up to 1.5 L·pers⁻¹·d⁻¹ (4). This indicates that the household UDDTs were

not the only place where urination took place. A more sophisticated measurement campaign will be undertaken in 2012 to investigate these results further.

The average dissolved phosphate concentration (27 samples) was $215 \pm 58 \text{ mg}\cdot\text{P L}^{-1}$ (median $235 \text{ mg}\cdot\text{P L}^{-1}$), which is similar to the dissolved phosphate concentrations that Etter et al. (3) measured in Nepalese UDDTs ($195 \pm 65 \text{ mg}\cdot\text{P L}^{-1}$). Only 20 % of the samples showed lower concentration than the average, whereas one sample hardly contained any dissolved phosphate at all. It could be that this sample contains other liquids than urine, which were flushed into the urine compartment.

Based on the average dissolved phosphate concentration, about 590 L of urine would be needed to produce 1 kg of struvite, which would be produced in 3.3 days by the 300 participating households. This calculation does not take into account that some particulate phosphorus will be filtered together with the freshly precipitated phosphate.

3.2 Struvite reactor operation

Measuring the dissolved phosphate content of the influent and after addition of magnesium (prior filtration) indicated that using a molar ratio of 1.1:1 mol Mg : mol P is sufficient to remove over 95 % of dissolved phosphate. The performance of the filtration was estimated by measuring the total phosphorus content of the influent and the effluent after filtration. 82 to 91 % of the total phosphorus could be removed with the tested cotton fabric used as filter material used. However, filtration was considerably simpler by using a filter disc instead of a filtration bag.

By improving the mixing conditions with baffles and twisted stirrer blades in the reactor, it was possible to reduce the mixing time from 10 min (3) to 1 min with the same phosphorus removal efficiency.

As the precipitation reaction in this reactor configuration is uncontrolled in terms of crystal growth conditions, mostly fines are produced. Particle size analysis of the struvite crystal showed an average size of 78 μm (volume weighted mean).

3.3 Titration experiments and modelling

While monitoring the electrical conductivity during bench-scale titration experiments, the conductivity decreased due to the removal of ions (Mg^{2+} , NH_4^+ , PO_4^{3-}) as struvite. After nearly all phosphate had been precipitated, the electrical conductivity increased. The modelled data matched very well the experimental data. The conductivity behaviour will be used to automate the dosage system and will be tested in a new reactor configuration.

4 CONCLUSIONS AND FUTURE WORK

Less urine than expected was produced at the household's UD toilets. Technical aspects or sociological issues might be the reason and will be investigated further. Electrical conductivity changes during the precipitation reaction and will be tested in an automated dosing system in a new reactor. Overall phosphorus recovery could be improved by a better filtration system. Other filter materials and increasing the struvite crystal size during precipitation will be considered. The particle size remains a critical parameter for the final production of a useful product. This will be the goal of the next experimental programme.

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