Evaluation of an automated struvite reactor to recover phosphorus from source-separated urine collected at urine diversion toilets in eThekwini

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ABSTRACT

In the present study we attempted to develop a reactor system to recover phosphorus by struvite precipitation, and which can be installed anywhere in the field without access to a laboratory. A reactor was developed that can run fully automated and recover up to 93% of total phosphorus (total P). Turbidity and conductivity signals were investigated as automation proxies for magnesium dosage, thus making laboratory phosphate measurements to determine the exact magnesium dosage unnecessary. Conductivity is highly influenced by the dosing parameters (molarity and pump speed) and turbidity is affected by particle size distribution issues. Algorithms based on both conductivity and turbidity signals were not able to detect the precipitation endpoint in real time. However it proved possible to identify the endpoint retrospectively from the conductivity signal, and thereafter to dose an algorithm-calculated volume of urine to use up the excess magnesium dosed.

Keywords: struvite precipitation, human urine, turbidity, conductivity, automation, magnesium dose, VUNA

INTRODUCTION

Worldwide, 2.5 billion people lack access to improved sanitation, leading to waterborne diseases (UNICEF and WHO, 2012). In many countries water scarcity makes a waterborne sanitation solution nearly impossible. Thus dry sanitation systems, such as urine diversion dehydration toilets (UDDT), have been implemented in many cases to overcome the sanitation backlog. One example is the eThekwini Municipality where over 75 000 UDDT have been installed in the rural and peri-urban areas (Roma et al., 2011). The advantage of a UDDT is source separation of the urine from the faeces (Tilley et al., 2008). Source-separated human urine is an ideal source for fertilizer production, as the majority of nutrients found in wastewater streams originate from urine (Larsen et al., 1996). One way to extract nutrients from stored urine is by adding soluble magnesium to recover phosphate by precipitating struvite (magnesium ammonium phosphate hexahydrate; $MgNH_4PO_4{\cdot}6H_2O$) (Tilley et al., 2008). This can be done in industrial processes such as OSTARA or Multiform Harvest. An important factor for struvite recovery in a reactor is the magnesium source itself, as it has an effect on operating costs (Etter et al., 2011). Low-cost magnesium sources have been widely studied, and include bittern, magnesite and seawater (Ye et al., 2011; Etter et al., 2011; Sakthivel et al., 2012; Dai et al., 2014). However, accurate dosage in a struvite reactor is problematic. Chemical analysis has to be undertaken to measure phosphate concentration beforehand and the right overdosage with magnesium has to be determined experimentally to reach maximum phosphate recovery. To overcome this, on the one hand, other methods, such as electrical conductivity, have been tested to estimate phosphate concentrations by correlation to measurements (Etter et al., 2011), with attempts to develop an automated feedback control system (Shepherd et al., 2009). On the other hand, turbidity has been successfully used to analyse the struvite crystallization kinetics in urine (Triger et al., 2012). However, no known method exists, to the authors' knowledge, to dose magnesium accurately in a struvite reactor without prior phosphate measurement of the urine.

In the present study, the aim was to develop a fully-automated struvite reactor that incorporates an automated feedback control system to determine the magnesium dosage rate and time, given a certain molarity of dosing solution. Electrical conductivity and turbidity were investigated for this purpose.

MATERIALS AND METHODS

Urine source

Urine was collected at UDDTs of around 700 households in the rural and peri-urban areas of eThekwini, KwaZulu-Natal, South Africa. Plastic containers (25 ℓ) were connected to the urine pipe on the back of the toilet and brought to storage tanks. Collection was done by staff of the eThekwini Municipality Water and Sanitation unit at regular intervals. The collected urine was transported to a central collection point at Newlands Research Site with a total storage capacity of around 15 000 ℓ and brought to storage tanks (2 200 ℓ) at the university, close to the laboratory used for reactor trials. Storage time was at least 1 month.

Urine analysis

Prior to analysis, urine was filtered using a glass-fibre filter with an average pore size of 0.4 µm (Machery-Nagel, Düren, Germany) and diluted with distilled water. Dissolved phosphate in the stored urine was measured using a Merck NOVA 60 spectrophotometer (Ammonium molybdate spectrometric method, Merck, Darmstadt, Germany). Total phosphate was measured using Merck test kits without filtering.

Struvite precipitation model

An ionic speciation model was developed to predict conductivity and suspended solids, which are further interpreted as turbidity, during struvite precipitation. The model describes

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