Hygiene considerations during the collection, storage and processing of source-separated urine into a marketable fertilizer

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Abstract
Source-separated urine can be used directly in agriculture or processed into marketable fertilizers such as struvite ($MgNH_4PO_4•6H_2O$). However, source-separated urine contains bacterial pathogens originating from faecal contamination. The present study evaluates the fate of *in situ* bacteria in urine as well as pathogen surrogate organisms during the production of a fertilizer (struvite) in laboratory reactors as well as in a pilot-scale reactor operated in eThekwini, South Africa. Laboratory and field studies along with inactivation data from the literature are used to model bacteria inactivation during urine storage and struvite production. The model is used to evaluate urine storage and struvite drying under the fluctuating temperature and relative humidity. Recommendations are made to enhance microbial inactivation during urine storage and struvite production in low-resource field settings and to promote the safety of using urine-derived fertilizers.

Keywords
Urine diverting toilets; struvite fertilizers; heterotrophs; microbial inactivation; safety

INTRODUCTION

Human urine is a main source of phosphorus (P) in wastewater. Urine can be collected and stored separately from solids through urine-diverting toilets, from which point it can be used directly as a fertilizer or processed into more manageable, market-attractive products (e.g., with less foul odor) like struvite ($MgNH_4PO_4•6H_2O$) (Larsen et al., 2013). The high pH and high P levels in stored urine require only the addition of magnesium for spontaneous precipitation of struvite. The potential for urine collection and struvite recovery from a urine-diversion system was evaluated in a pilot-scale project in eThekwini, South Africa (Rhoton et al., 2014).

Source-separated urine collected in eThekwini contains a diversity of pathogens (Bischel et al., 2015) warranting thorough consideration of the fate of *in situ* microbes during the collection, storage and treatment of urine and subsequent fertilizer products derived from the urine. Naturally high concentrations of the biocide ammonia in stored urine (pH ~ 9) lead to inactivation of bacteria during storage; microbial inactivation rates depend on the storage temperature, ammonia concentrations and organism. In eThekwini, struvite is precipitated from stored urine by adding magnesium sulfate (MgSO4•7H2O), gravity-filtered, and dried outside.

The present study evaluates the fate of *in situ* bacteria in urine as well as pathogen surrogate organisms during the production and drying of struvite produced from laboratory reactors as well as a pilot-scale reactor operated in eThekwini. Laboratory and field studies are used along with inactivation data from the literature to model bacteria inactivation in a multi-step urine treatment process. The analysis is used to make recommendations for enhanced microbial inactivation during urine storage and struvite production in low-resource field settings.

METHODS

Inactivation of bacteria during urine storage and struvite production was monitored in urine samples from storage tanks maintained at the Swiss Federal Institute of Aquatic Science and Technology (Eawag, Switzerland) and eThekwini Water and Sanitation (EWS, South Africa). Inactivation in struvite dried under a range of controlled and uncontrolled climate conditions was quantified for total bacteria via flow cytometry and for total heterotrophic bacteria (THB), the gram negative *Salmonella typhimurium*, and gram positive *Enterococcus* spp. via plate counts. Test conditions (5 to 35˚C, 40 to 80 % relative humidity) were selected to reflect low-resource and low-technology field settings. Results from isothermal drying conditions conducted in the laboratory are compared to drying struvite under fluctuating relative humidity and temperature in the

field (e.g., Figure 1). Inactivation models from urine storage and struvite drying are combined to represent the total inactivation potential of these treatment processes.

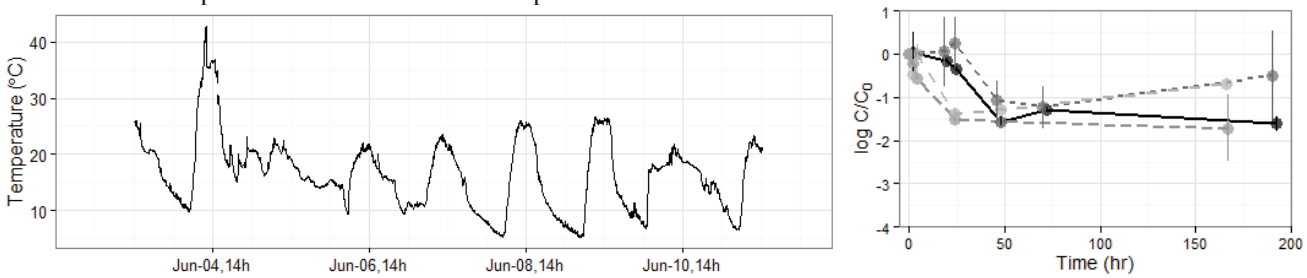

Figure 1. Example temperature fluctuations during urine storage and struvite (left). Total heterotrophic bacteria (THB) was monitored in replicate struvite cakes and dried in environmental conditions (right).

RESULTS AND DISCUSSION

Urine storage.

A review of published inactivation rates indicates that first-order inactivation of gram negative pathogen surrogates is typical, and the inactivation rate constant increases exponentially with temperature, following Arrhenius-type behavior. However, culturable THB were detected in all stored urine samples collected. THB concentrations declined during storage of fresh urine, but stabilized after a period of storage, indicating persistence of some bacteria during urine storage in environmental conditions.

Struvite production.

When struvite is precipitated from urine, bacteria accumulate in the struvite. The inactivation of bacteria during struvite drying depends on the drying temperature and relative humidity. A Weibull model was used to fit non-linear inactivation curves during struvite drying under a range of drying conditions. The concentration of surviving organisms (C, CFU/g struvite or counts/g struvite) is modeled as a function of time (t, hr) by the equation:

$$\log10(\mathrm{C}) = \log10(C_0) - (\frac{t}{\delta})^p$$

where C_0 is the initial concentration, δ is the time for first decimal reduction, and p is a shape parameter. For controlled drying conditions, the average p was less than one for *Enterococcus* spp., *S. typhimurium*, and THB in struvite dried at low humidity, and p was greater than one for the high relative humidity drying conditions. This indicates a tailing of inactivation curves at low humidity drying conditions.

CONCLUSIONS

In the production of struvite as a marketable fertilizer, urine collection is followed by a multi-step treatment process. Storage of urine, especially in the shortened time frames and field conditions anticipated for large-scale urine collection, is not expected to yield sufficient inactivation to produce a high quality fertilizer. Struvite drying provides additional treatment benefit. The combined models are compared to inactivation observed in field conditions. THB concentrations in struvite dried in environmental conditions with fluctuating temperature and relative humidity (Figure 1) declined more slowly than for any of the controlled drying tests.

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