DESIGN AND DEVELOPMENT OF WATERLESS URINAL SYSTEMS AND NUTRIENT RECOVERY PROCESSES FROM STORED URINE

S RAMESH SAKTHIVEL

CENTRE FOR RURAL DEVELOPMENT & TECHNOLOGY

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S Ramesh Sakthivel

CENTRE FOR RURAL DEVELOPMENT AND TECHNOLOGY

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Dedicated to

My Parents Shri R Subbaian and Shrimati S Rajammal

CERTIFICATE

This is to certify that the thesis entitled "*Design and Development of Waterless Urinal Systems and Nutrient Recovery Processes from Stored Urine*", being submitted by S Ramesh Sakthivel, to the Indian Institute of Technology, Delhi for the award of degree of **Doctor of Philosophy,** is a record of bonafide research work carried out by him. He has worked under my supervision and guidance in conformity with the rules and regulations of the Indian Institute of Technology Delhi. He has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard. The research report and the results presented in this thesis have not been submitted, in part or in full, to any other University or institute for the award of any degree or diploma.

Dr V M Chariar
Research Supervisor
Centre for Rural Dev & Technology
Indian Institute of Technology Delhi
New Delhi-110016
India

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(S Ramesh Sakthivel)

Abstract

Waterless urinals can assist in conservation of water and reduce the volume of wastewater generated. However, existing models of waterless urinals available in the market are expensive to install and maintain. Performance and cost effectiveness of a waterless urinal system depends primarily on odour prevention traps installed in the system. Therefore, "Zerodor" - an odour trap working on the principle of a ball valve was developed in this study (Patent Protected). The design of odour trap was kept similar to a normal waste coupler installed in conventional urinal pans to reduce the costs of new installations and retrofitting existing urinals.

Hydrolysis of urea present in human urine into ammonia generates odour in urinals. Therefore, odour control efficiency of the odour trap developed was determined. In addition, a membrane based odour trap being installed in India and a normal urinal without an odour trap were also used in the study for the purpose of comparison and control measurements respectively. Over 98% reduction in the ammonia released was observed by use of "Zerodor" - the odour trap developed in the study. Performance of "Zerodor" was found to be superior to the membrane trap which was studied for purpose of comparison. Particle flow analysis and test for resistance to clogging conducted revealed comparable performance of the odour trap developed with the membrane trap used in the study. Analysis of installation and maintenance costs reveal that adoption of "Zerodor" can significantly reduce the installation and maintenance costs associated with waterless urinals.

Source separation of urine and harvesting of its nutrients can reduce the nutrient loads in wastewaters. Diminishing global phosphorus reserves call for identification of suitable alternatives to meet the future demand for phosphate based fertilisers. In this context, phosphorus recovery from urine assumes greater importance. Struvite precipitation from stored urine can be effected by addition of an external magnesium source. However, relatively little work has been done on the kinetics of struvite precipitation from urine, although the body of work is growing. In this study, dissolution of magnesium and struvite precipitation experiments with stored urine using $MgCl_2.6H_2O$, $MgSO_4.7H_2O$, MgO, $Mg(OH)_2$ and bittern were conducted. In addition, wood ash has been tested as an alternative magnesium source to reduce cost of struvite production.

Over 98% phosphate removal was observed for all the conventional magnesium sources used. The reaction time taken for 95% phosphate removal observed were in the order of; bittern > $MgSO_4.7H_2O$ > $MgCl_2.6H_2O$ >MgO > $Mg(OH)_2$ with a reaction time of 0.9, 1.8, 2.9, 5.4 and 536 minutes, respectively. Results of dissolution and precipitation experiments reveal that struvite crystallisation process is the rate limiting step for phosphate removal for bittern, $MgSO_4.7H_2O$ and $MgCl_2.6H_2O$, while dissolution of magnesium was found to be the rate limiting step for MgO and $Mg(OH)_2$. However, the rapid phosphate removal rate observed for MgO is comparable to bittern, $MgSO_4.7H_2O$ and $MgCl_2.6H_2O$. Presence of phosphate in urine hinders dissolution of $Mg(OH)_2$, and therefore it is not a suitable magnesium source.

In the experiments conducted using wood ash, 99% of the phosphate removal was observed. Depending on the wood ash used, the precipitate can contain high concentrations of heavy metals. This could be problematic if the precipitate were used as fertiliser depending on the applicable fertiliser regulations. The financial analysis of struvite precipitation revealed that wood ash and bittern are considerably cheaper than industrially produced magnesium sources. However, transportation cost of bittern to inland locations would increase the cost of struvite production. The precipitate obtained using wood ash is more like a soil conditioner enhanced with phosphorus than a phosphate fertilizer. Therefore, a direct comparison with magnesium sources that produce pure struvite is not possible.

Although the process of struvite precipitation from urine is relatively simple, transportation cost of urine renders the process unviable at a central level. The operations of fluidised bed reactors, which are often used for struvite production at a centralised level, are also relatively complicated. Based on the literature available, it was hypothesised that developing a simple flow through reactor can aid economical production of struvite from stored urine which offers optimal conditions. In this study, a continuous up-flow struvite reactor was developed for low-cost struvite precipitation from stored urine at a decentralised level. Experiments were conducted to determine precipitation and recovery efficiencies of phosphate.

Around 85% precipitation and 81% recovery efficiencies of phosphate by the continuous up-flow struvite reactor designed was observed. The experiments conducted reveal that precipitation of struvite from urine using bittern can be achieved without stirring. The morphology and particle size of struvite obtained are in agreement with previous studies. Scale formation on the components of reactor observed was minimal. A comparative analysis with a manually operated low-cost struvite reactor developed in Nepal, shows that struvite production by use of reactor developed in this study could be economically viable at community scale because of lower operating costs.

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