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Development of a novel nutrient recovery urinal for on-site fertilizer production

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ABSTRACT

Waterless urinals can save significant amounts of water but they can also be used to separate concentrated urine at source. Urine collection in established buildings is often costly because the plumbing system must be retrofitted for separate urine pipes. In addition, waterless urinals often have issues with blockages because of solids building up in the piping system.

To solve these challenges, we have developed a fertilizer-producing urinal that uses no water and does not have to be connected to a conventional sewage line to operate. We designed and constructed the urinal using a plastic funnel and collection tank. The urinal recovered 11.23 ± 1.3 g of solid fertilizer per kg of urine and we found that 1000 nutrient recovery urinals could produce an income of $85/day. This novel approach offers a new and easy method for collecting urine within office blocks or other commercial buildings. In addition, the recycling of nutrients at source offers a more sustainable and environmentally method for fertilizer production since minimal energy is required and “waste” streams are converted into useful products.

1. Introduction

Much like other parts of the world, the City of Cape Town in South Africa is currently experiencing a severe drought with the average volume of water in dams being at 24.4% in February 2018 [1]. The water shortage has been a driver for the city to consider waterless sanitation systems, both by the City of Cape Town and citizens. Sanitation systems such as waterless urinals would therefore help cities prepare for a water sensitive future.

In addition, waterless urinals offer an excellent method for separating urine and are well suited for office blocks because they (1) use no water for flushing, (2) can reduce operating costs for buildings, (3) water utilities can offer building owners fee discounts and [2] (4) provide novel nutrient recovery opportunities such as using ion exchange to remove nutrients [3]. Urine is rich in three key ingredients required for fertilizer production: nitrogen, phosphorus and potassium, contributing about 80% of the nitrogen, 56% of the phosphorus and 63% of the potassium typically found in domestic wastewater streams [4]. In addition to being rich in nutrients, the urine stream only makes up 1% of the volume of domestic wastewater streams [5]. There is no doubt that urine is valuable. In fact, a recent review paper refers to urine as “liquid gold” because of its value. The paper also describes how we should re-examine our current sanitation systems to gain maximum benefit from urine [6].

However, waterless urinals are not widely used because of maintenance issues as a result of pipe clogging [7], odour concerns [2] and the need to retrofit the plumbing system of buildings [8]. The removal of key minerals responsible for pipe clogging could potentially solve some of these challenges. For example, Boyer and co-workers showed that ion exchange could be used to remove calcium and magnesium from urine thus minimising mineral precipitation [3]. Odour concerns can be remediated by installing sealant liquid traps, membrane traps or biological blocks [9].

Since the clogging of pipes is a major concern with waterless urinals, it is important to understand how this happens by understanding the chemistry of urine [3]. Fresh urine hydrolyzes in the presence of microbial urease [10] and produces ammonium carbonate and an increase in pH [3]. This leads to the precipitation of struvite and other minerals. This is the reason for the clogging of waterless urinals which can be avoided by preventing urea hydrolysis or forcing mineral precipitation to occur [3,11]. Thus, if the precipitation process can occur in a removable container attached to a waterless urinal, these issues could be avoided.

The use of calcium hydroxide has been shown to be an effective method for stabilizing urine (preventing enzymatic urea hydrolysis) [12]. This is because an increased pH results in the precipitation of

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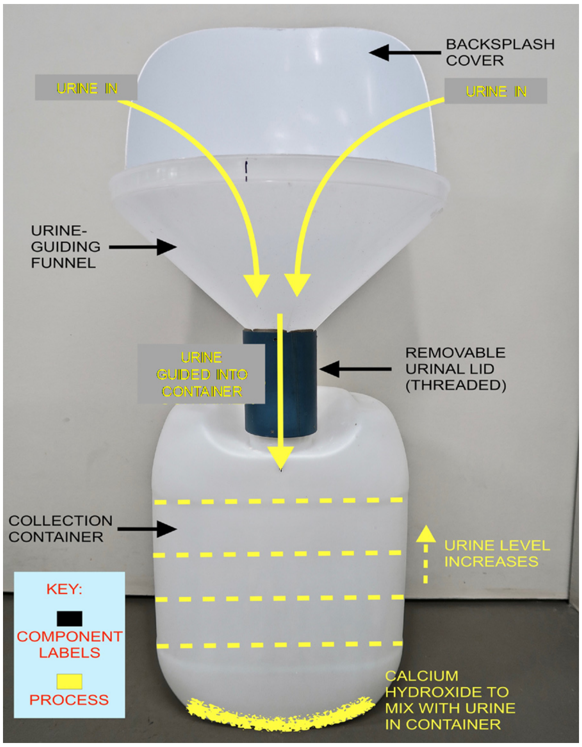

Fig. 1. Fertilizer-producing urinal showing different design characteristics.

calcium phosphate and magnesium hydroxide while also inhibiting the activity of urease, the enzyme responsible for enzymatic urea hydrolysis [12]. In addition, the use of calcium hydroxide can be used as a passive dosing system in the urinals, dissolving as needed provided enough calcium hydroxide is added to the container. Randall et al. [12] suggested a dosage of 10 g $Ca(OH)_2$ per litre of urine, thus if the collection tank is 25 L, only 250 g of $Ca(OH)_2$ would be needed per urinal. This method also means the urine could be collected and stored indefinitely, provided the container is sealed and the pH remains above 12. The fundamental study by Randall et al. in 2016 laid the groundwork for the applied research work presented here where we report on the development and testing of a standalone and waterless fertilizer-producing urinal that does not need to be connected to a conventional sewage line.

2. Material and methods

2.1. Urinal design

The makeshift fertilizer-producing urinal used for the experimental process consisted of plastic components (see Fig. 1). The design was found to be sturdy and successfully completed the task of collecting urine in a public bathroom such that calcium phosphate formed in the removable collection container.

The urinal itself consisted firstly of a urine collection funnel, which guided urine gradually downwards into the tank below. Secondly, the urinal had a 25 L collection tank below the funnel. This was used to capture the donated urine and house it in such a way as to mix with the pre-dosed calcium hydroxide powder. Lastly, the urinal featured a backsplash board to prevent urine from spraying back out of the funnel. The funnel was connected to the collection tank via a threaded PVC pipe which deposited urine below the actual thread. The current urinal was open to the atmosphere but future designs will include a one-way valve. In addition, the contents of the urinal were mixed manually for 30 s each day. We found that daily mixing was adequate to keep the solution pH above 12.

Table 1
Properties of stabilized urine obtained from each 25 L urinal. There were four collections in total. A dosage of 250 g $Ca(OH)_2$ was added to each urinal. The mass collected included the urine, undissolved calcium hydroxide and solid precipitate (fertilizer) while the dried mass was obtained after filtering the solids from the liquid fraction. *This concentration was not included as it was an outlier because of an analysis error.

Parameters	Container Number				Mean	Std. Dev.
	1	2	3	4		
pH	12.34	12.17	12.4	12.35	12.32	0.10
Temperature (°C)	20.1	19.3	19.3	19.2	19.5	0.42
Urea (mg/L)	13 900	12 100	12 300	*	12 800	987
NH_4-N (mg/L)	350	310	380	385	356	34.5
PO_4-P (mg/L)	6.25	5.98	6.21	6.22	6.17	0.124
Total Ca (mg/L)	923	943	1045	1068	995	72.3
Total Mg (mg/L)	14	14	14	19	15.3	2.50
Total K (mg/L)	588	550	755	589	621	91.5
$Ca(OH)_2$ added (g)	250.0	250.4	250.0	250.0	250.1	0.180
Mass collected (kg)	25.7	24.0	24.4	24.1	24.5	0.783
Dried mass (g)	263	249	272	318	276	29.9

2.2. Urine collection

The urinal was installed in a male bathroom in the New Engineering building at the University of Cape Town (UCT), South Africa. Signage indicating the aims and scope of the project were placed above each urinal, as well as a consent form, the completion of which was stated as a mandatory step before donating urine. This consent form was in accordance with the UCT ethic's approval policy on the use of human subjects for research purposes.

The urinal was pre-dosed with 10 g $Ca(OH)_2$ per litre of urine thus resulting in a total mass of 250 g $Ca(OH)_2$ per 25 L urinal [12]. Urine was then donated into the collection tanks by male donors and the level of urine within each collection tank was monitored daily to avoid overfilling of the tanks. Donors could donate as often as they would like. An empty urinal, except for the addition of $Ca(OH)_2$, was then installed to allow for the subsequent collection of urine. In total, there were 4 collections of urinal containers thus the experiment was repeated 4 times (see Table 1).

The urinal was used for a period of three weeks and the donors were anonymous. The urinals were in operation Monday to Friday from 8am to 17:00 each day. When not in use, the urinal collection tank was removed, sealed with a lid and stored in a refrigerator overnight at 4°C. The temperature of the urine is given in Table 1. The temperature was not monitored continuously but it was measured after a urinal container collection.

2.3. Urine processing

All donated urine was then carefully removed from the collection tank whenever the tank was full. This was performed within the confines of the Civil Engineering Water Quality laboratory at UCT. The contents of the tank were initially allowed to settle completely so that the solid precipitate could settle to the bottom of the tank. The liquid supernatant was then slowly and carefully removed by pumping. The liquid supernatant was sent for analysis. The remaining liquid and solid precipitate in the collection tanks were then re-mixed to form a sludge. This sludge was filtered to separate the remaining liquid and solids using a vacuum filter and Buchner funnel. The diameter of the filter paper was 150 mm with a pore size of 1.2 μm (595 Schleicher & Schuell, Dassel Germany). The solids were kept in aluminium drying trays (32 × 26 x 6 cm) and dried at ambient room temperature (~22°C) until all the liquid had evaporated. The amount of solid remaining was then determined by measuring the net mass of solids in the trays. The process produced a solid fertilizer as well as a liquid fertilizer.