The Autarky toilet – a modular approach for integrated on-site treatment of wastewater, urine and faeces through stream separation at the source

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Abstract
The Blue Diversion AUTARKY toilet is a sanitation system for the household level, which does not rely on water and wastewater infrastructure. Due to a three-way diversion, water, urine and faeces can be treated in separate modules, on-site using new transformative technologies. A biological water recovery system provides water for hand washing and personal hygiene. The end-products from the urine and the faeces treatment can be processed and used as fertilizer in agriculture. Its modular logic and novel design allows for an independent application of each treatment module as a stand-alone system as for example a hand washing station or an autonomous urine treatment unit.

Keywords
Source separation, on-site wastewater treatment, resource recovery, toilet design innovation

INTRODUCTION

The Blue Diversion AUTARKY toilet (www.autarky.ch) can be implemented in densely populated slums in developing countries where the health of people and the environment severely suffer from the lack of adequate sanitation services, but also in water scarce or remote areas of every part of the world. The toilet is designed for single households up to ten people and offers water for hand washing and personal hygiene. A novel pan design enables stream separation of flushing water, urine and faeces and guarantees for hygiene and comfort during and after usage. No connection to water supply or a sewer infrastructure is required; it operates completely off the grid. The valuable nutrients from the urine and faeces treatment are recovered and can be used as fertilizer in agriculture after further processing steps. The development of Blue Diversion AUTARKY is based on the concept of the Blue Diversion Toilet (Larsen et al. 2015) and is designed by EOOS.

MATERIALS & METHODS

The toilet features a flush function, a washbasin with soap for hand washing and a shower head for personal hygiene (anal cleansing and menstrual hygiene). Water from flushing and hygiene, urine and feces are treated separately in three different modules (Figure 1).

Source separation. A source diverting pan and a valve separating urine and flushing water, guarantee for the separation of wastewater, urine and faeces into three independent operating treatment modules which address the specific risks and resource recovery potentials of the three waste streams (Figure 2).

Water recycling (water wall). Different treatment steps ensure that the recovered water is safe for reuse. The closed water cycle produces approximately 75 L/day of clean water and provides running water at any time. However, some water has to be added in the beginning of operation and filled up by the user if necessary. The used water is pumped into a biologically activated membrane bioreactor (BAMBi) in the back wall of the toilet where organic matter and ammonia are degraded

(Künzle et al. 2015). The gravity ultrafiltration membrane retains pathogenic organisms such as bacteria, viruses and helminths. After pumping the cleaned water into the clean water tank, it is polished by an electrolysis unit. Traces of organic matter and ammonia are converted, and colour removed. Residual chlorine produced by electrolysis protects the clean water against the regrowth of pathogens. Further post-treatment options with more concentrated wastewater (higher loads of urine and traces of faeces) are currently investigated in the lab, combining the gravity-driven membrane bioreactor with granular activated carbon (GAC) and UV-185 nm and GAC and an optimized electrolysis.

Urine treatment. To avoid malodour, which is produced by fermenting bacteria, and to avoid ammonia loss due biological urea hydrolysis, the fresh urine is stabilized with the addition of calcium hydroxide. The resulting high pH value of about 12.5 also helps to inactivate pathogens and to conserve the valuable nutrient urea. The stabilized urine is trickled down an evaporation pipe, which is ventilated with ambient air in order to dry the urine leaving behind a solid containing all nutrients excreted with urine.

Faeces treatment. Faeces may contain harmful compounds such as pathogens, which must be inactivated quickly. When enriched with oxygen from ambient air and heated above ca. 400°C under high pressure, the faeces sludge decomposes and organic matter is mineralized completely. This process is called hydrothermal oxidation (HTO). The final products are carbon dioxide, water, dissolved ammonia and precipitated inorganic solids including phosphate minerals. The energy contained in faeces is also recovered to support the treatment processes. Electricity is produced on-site with photovoltaic modules, wind turbines or other decentralised energy sources, if the system cannot be connected to the electricity grid.

Four modules. Each treatment module (water, urine, faeces) functions as an independent process unit and is therefore self-sustaining and operational as a stand-alone system. A fourth module, "the user interface", integrates the user features with an appealing design language that ensures a pleasant and a hygienic toilet usage. As an independent module, the water wall can be operated as a hand washing station in public toilets or schools with inadequate or inexistent hand washing facilities. The urine module is applicable for nutrient recovery from urine of UDDTs or urine-water separating urinals.

Figure 1: The AUTARKY toilet

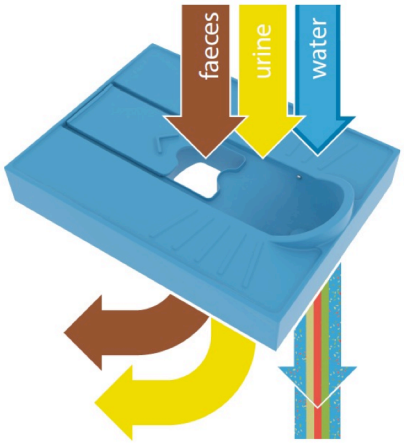

Figure 2: Separation of the three streams: wastewater, urine and feces at the source

RESULTS & DISCUSSION

Lab results proof that the addition of calcium hydroxide to fresh urine prevents urea hydrolysis form occur. It is therefore an ideal method to stabilize urine and thereby preventing nitrogen loss from source-separated urine. Also hydrothermal oxidation proofed to mineralize faeces completely to carbon dioxide, water and minerals such as phosphate salts. The remaining streams are off-gas and a mixture of water and minerals. Both, urine and faeces treatment are lab-approved. In 2014, with TRL 6[1], the water wall with the electrolysis as a post-treatment unit was field-tested for six weeks under slum conditions in Mukuru, an informal settlement in Nairobi, Kenya. Results showed that the recycled water was hygienically safe during the entire test and the electrolysis was able to provide sufficient chlorine to prevent regrowth and proved effective in reducing the colour of the water. Water for hand washing and the hand shower was available during the entire test period. Further lab experiments show that the post-treatment combination of granular activated carbon and an optimized electrolysis is a highly promising disinfection option for even more concentrated wastewater. The social acceptability of the fourth module, "the interface", was also assessed during the field test in Nairobi. Evaluation results showed high satisfaction rates regarding design, ease of use and functionality. Upcoming challenges are process simplifications of the urine and the faeces treatment modules for field application and the demand for resources, especially electricity and heat, has to be optimized.

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[1] Technology readiness level (TRL) is a method of estimating technology maturity. 1 is the lowest level of technology readiness where basic principles are observed; 9 is the most mature form when a technology is applied in its final form and under mission conditions. 6 represents a prototype demonstration in a relevant environment.