Development And Field-testing Of An Onsite, Self-contained And Sun-powered Human And Toilet Wastewater Treatment System

Clément A. Cid¹, Kangwoo Cho¹,², Yan Qu¹, Cody Finke¹, Penvipha Satsanarukkit¹, Asghar Aryanfar¹, Michael R. Hoffmann¹

¹ Linde-Robinson Laboratories, California Institute of Technology, 1200 E California Boulevard, Pasadena CA 91125, USA
² Korea Institute of Science and Technology (KIST), Cheongryang, Seoul, Korea

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Novel technologies are needed to address 2.5 billion people in the world that don’t have access to safe sanitation facilities [1]. One of the main barriers is expensive wastewater infrastructure and the scarcity of water in many regions.

An off-the-grid electrochemical system that decontaminates wastewater and produce hydrogen is under development to provide a solution for on-site wastewater treatment in rural and peri-urban communities [2]. The system has at its core photovoltaic-powered electrochemical reactors (Fig. 1). Each reactor is composed of a series of anodes and cathodes: the anodes are bismuth oxide/titanium dioxide semiconductors coated on a titanium plates (BiOₓ/TiO₂/Ti) [2]; the cathodes are stainless steel plates. Cathodes and anodes are assembled together with 2 mm separation (Fig. 1).

In a slightly saline solution of sodium chloride (concentration equals or higher than 20 mM) and when a voltage higher than 2.5 V is applied between the electrodes, the chloride can be oxidized at the anode to form reactive chlorine species (Cl•) that will undergo reduction/oxidation reactions to finally oxidize the organic matter present in the solution, if any (Fig. 2). In parallel the main reduction reaction at the cathode is the production of hydrogen [3].

The fundamental concept has been tested on bench-scale (1 anode, 2 cathodes, 40 mL process volume) and prototype-scale (20 L process volumes) with primary and secondary effluents from wastewater treatment plants in a totally integrated, off-the-grid “proof of concept” prototype with photovoltaic panels, charge controller and lead-acid batteries (Fig. 3). The specific design elements and the treatment approach have been proven to be viable for the treatment of raw domestic wastewater on a prototype-scale reactors and human urine, human feces and synthetic human waste analogues on lab-scale reactors [4, 5].

Even though the system was tested with various wastewater effluents, efforts are on the way to use this technology directly with toilet effluents in developing countrie. These effluents are more concentrated in organics (high COD), dissolved solids and bacteria. This field study is performed in two locations in India: Ahmedabad (Gujarat) and Kottayam (Kerala).
Figure 1 — A block flow diagram of the various components of the treatment system included in the Caltech prototype toilet system. The process scheme includes a separate treatment path for combined human waste, for urine that has been collected in a waterless urinal, and for grey water treatment.

Figure 2 — Schematic diagram of a photovoltaic (PV)-powered wastewater electrolysis cell for on-site wastes treatment for reuse with simultaneous solar energy storage by hydrogen production.

Figure 3 — Treatment of actual human wastewater collected in unit on campus after primary sedimentation. Treatment time was four hours. The appearance of the wastewater at t = 0 minutes is on the left and the treated water on the far right at t = 240 minutes.

References:


*Atl-Hydro, PO Box 22354, Fish Hoek, Cape Town, South Africa

**Department of Chemical Engineering, Cape Peninsula University of Technology, PO Box 652, Cape Town, 8000, South Africa

***Centre for Water Sanitation and Research, Cape Peninsula University of Technology, PO Box 1906, Bellville, 7535, South Africa

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Contact: wade.edwards@atl-hydro.co.za

Summary
UbuntuSAN is a point-of-use decentralised dry sanitation model that matches human-centred design with a community-centric micro-entrepreneurship model by combining a low-volume, aerosol-free toilet and sludge cartridge design with decentralised mobile parabolic solar pyrolysis for sludge sanitisation and biochar production which can be utilised for community stove fuel, agricultural compost and low-voltage electricity generation.

Contextualisation & Background
Given the well documented health risks associated with manual pit emptying, a recent evaluation study of pit emptying technologies (PET) confirmed that current PET hardware is fraught with problems and concluded that alternative solutions such as smaller, more frequently emptied toilet cartridges may be a better long-term solution. In this project we have designed a low-volume, self-contained, non-aerosol sludge collection cartridge which serves as the principle sludge removal mechanism thereby minimising the health risks associated with sludge removal, transport, and processing. The integration of these easy-to-handle sludge cartridges with a mobile concentrated solar power (CSP) parabolic trough bicycle trailer facilitates processing of the sludge providing an end-to-end sanitation solution no more complex than a simple bicycle. Unlike other solar-based solutions, simplicity addresses several hurdles experienced by micro-entrepreneurs faced with using complex technology; namely, low education levels, long and complicated training requirements, and frequent maintenance coupled with expensive, inaccessible replacement parts when needed.

Results
Here we present results that demonstrate that an integrated sludge extrusion process combined with mobile CSP can achieve torrefaction-range temperatures (figure 1) which serves to sanitise sludge by exceeding thermal pathogen kill rates and increases the energy density.
of the extruded sludge for beneficiation purposes. This process therefore has the potential to be implemented as a resource recovery and sludge beneficiation strategy with the products of the process potential being used for heat and electricity generation or agricultural compost depending on community cultural uptake barriers.

Figure 1: Thermal profiling in pyrolysis applications indicating relationships between temperature and energy density of pyrolysis end-products

Pyrolysis and torrefaction is therefore an attractive solution for developing countries where energy costs are high and there is a demand for development of cost effective treatment methods for treating excreta or faecal sludge. Here we demonstrate that sludge treatment using mobile parabolic trough CSP is a sustainable option for sludge sanitisation and beneficiation.

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References

Applications of Concentrated Solar-Energy in Innovative Sanitation Solutions


Department of Civil, Environmental, and Architectural Engineering; and Department of Chemical and Biological Engineering, University of Colorado, Boulder, CO 80309 USA. *Karl.linden@colorado.edu; Ph: +1 303-492-4798

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Sanitation solutions for the 40% of the world’s population currently lacking access to basic sanitation require consideration of new technologies and approaches to demand. On-site sanitation systems that promote health, dignity, and a cleaner environment offer promise, but existing designs have proven to have shortcomings. Furthermore, most on-site systems provide no incentives to the user to either purchase, use, or maintain the system. Therefore, it is an important though challenging endeavor to develop a self-contained onsite sanitation solution that renders fecal waste harmless within a short time-span without the need for flush water or electricity, and that produces valuable human waste-derived products for income generation.

In response to the Bill & Melinda Gates Foundation Reinvent the Toilet Challenge, a solution utilizing concentrated solar energy to reduce the treatment process land footprint and time needed to render the waste safe and potentially usable as a soil amendment or solid fuel is under development. A prototype was constructed which uses parabolic solar concentrators that focus sunlight into fiber optic bundles. This high intensity solar energy is transmitted through the bundles which are distributed to a reactor where the various individual cables indirectly heat the fecal waste via radiation. The system comprises various containers that are switched between collection, treatment, and removal modes with provisions for gas collection and sensors to track operation. Urine is diverted at the source and treated thermally for potential use as a fertilizer.

Results related to the prototype which was developed and applied to human fecal matter will be presented. The concentrated solar energy capture and transmission through fiber optics was analyzed and found to be an efficient treatment methodology for a compact land footprint application such as on-site sanitation treatment. Heat transfer modeling of the reactor was conducted and validated through experimentation with the prototype, verifying that the waste is sterilized in a short time span and significantly reduced in volume. Exhaust gas characterization was undertaken for potential energetic value as well as to ensure safety. Treatment methods for addressing odor issues and other problematic gases were also analyzed to ensure a safe and pleasant user experience.

In order to enhance a sanitation market driven approach, potential products were characterized. Biochar derived from urine diverted human waste and synthetic human waste was generated in a laboratory furnace at temperatures varying from 300°C to 850°C. Results showed a product with agronomic enhancement potential (high cation exchange capacity and pH), however with less water retention relative to typical wood-based biochars. Biochar generated from synthetic human waste was found to be significantly different from chars generated from real human waste with respect to pH, CEC, and char handling properties. Nutrient sorption from urine was comparable to activated carbons and wood-based biochars. Promising results are
demonstrated for adsorption of odors such as hydrogen sulfide and for trace organic contaminants in stormwater and wastewater. The product was found to sequester carbon when generated at the higher temperature conditions. As a solid fuel, the biochar could be made into briquettes using lime and molasses binders and had a high energy content, comparable to that of typical commercially available charcoals.