SOLAR-DRIVEN THERMAL TOILET WITH BIOCHAR PRODUCTION

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ABSTRACT

The Solar-Biochar Toilet is a state-of-the-art project incorporating the latest scientific advances in the areas of solar thermal processes, thermal driven disinfection, and hydrothermal biochar production and utilization. The University of Colorado Boulder is working to explore fundamental research questions regarding applications of solar-driven hydrothermal pyrolysis to mixed human waste, without need for intensive pre-drying, to produce a char that has advantages in soil applications for agriculture. Research will provide the scientific basis for the Solar-Biochar Toilet system to safely generate valuable end products that could increase the toilet's use and offer households and/or entrepreneurs a valuable human waste-derived product for income generation.

Keywords: BIOCHAR, FIBER OPTIC, HYDROTHERMAL CARBONIZATION, PYROLYSIS, SOLAR THERMAL

PROJECT PLAN

The project started in September 2012. This Faecal Sludge Management Conference contribution reviews the approach and theoretical basis for the Solar-Biochar Toilet concept. Specifically, the technological components of the solar collector, the transmission of solar energy via a fiber optic cable, and the design of the reaction chamber will be presented. This presentation is summarized below.

Solar Concentrator

Based on physical properties of the waste stream we calculate the energy input required for a family of 4 to be from 4,000 to 14,000kJ. Energy inputs for families of 10 and shared toilets for 50 individuals were also calculated. If we assume 3 hours per day of solar operation the power requirement becomes about 1300W of net input to the reactor (using energy estimates for hydrothermal carbonization at 180°C and accounting for conduction loss to the surrounding ground). For readily achievable values for concentrator reflectivity, secondary reflectivity, intercept factor, fiber bundle fill factor, fiber Fresnel reflections and fiber transmission we calculate the solar efficiency as roughly 0.46. This efficiency with an average direct irradiance of 800W/m^2 over the operation period requires a mirror diameter of approximately 1.9m (1000W) for mixed waste pyrolysis and HTC or 1.1 – 1.3m (400W) for solid waste pyrolysis (refer to Figure 1). A larger scale system supporting 50 people would require a concentrator area of about 46m^2.

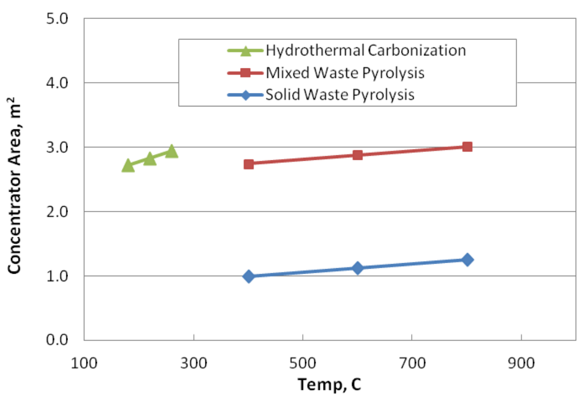

Figure 1: Theoretical Concentrator Area Required for a Family of Four

Fiber Optics

A small-scale, fiber optic-based system is proposed. Concentrated sunlight is delivered to a fiber optic bundle located at the focus of a small parabolic concentrator. The fiber optic cable is fed to the reactor of the Solar-Biochar Toilet where the various individual cables are terminated at the outside of the reactor or lid. The waste container is illuminated via radiation heat transfer. The Solar-Biochar Toilet reactor can achieve high temperatures with low solar input by limiting heat losses to conduction in the surrounding ground.

Reaction Chamber

The Solar-Biochar Toilet reactor/solar receiving container can be designed for virtually any number of users with solar power input scaled accordingly. The proposed baseline system comprises two containers that are switched between “collecting” and “pyrolysis” mode. The pyrolysis zone will have a gas discharge hole above the waste-filled collection container for product gases, roughly 14.2 m^3 of steam and 0.66 m^3 of methane per day per family of four. For hydrothermal carbonization (HTC), the pyrolysis zone gas discharge will be fitted with a 20psig pressure-relief valve to allow the reactor to maintain suitable reaction conditions of 180-220°C and 18 psig.

End Products

It is expected that the solid product, biochar, from the thermal decomposition of human waste will consist largely of condensed aromatic (graphitic) zones that when applied as a soil amendment will (1) impart agronomic benefits and (2) is recalcitrant over a long timescale. Ultimate and proximate analysis of the char will be conducted, including: surface area/microporosity, cation exchange capacity, pH, longevity in soils, nutrient content, pathogen inactivation, and heavy metals. HTC and dry pyrolysis will be compared in order to evaluate the quality of each biochar product which may inform the final design of the reaction vessel.

Dry pyrolysis will also be evaluated with urine diversion in order to compare the biochar that is not in contact with the added nutrients in the urine, and to evaluate if these nutrients can be better utilized by a separate purified urine system. Adsorption studies will be conducted in the liquid and gas phase which can enrich the biochar with the abundance of nitrogen, phosphorus, and potassium in human waste. The heating characteristics have been studied in preliminary experiments and the heat capacity of wet faeces is approximately 5.6 J g^{-1} K^{-1}. Thermal drying of the faeces appears to be no more energy intensive than that required to evaporate the liquid.

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