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Evaluation of a microwave based reactor for the treatment of blackwater sludge

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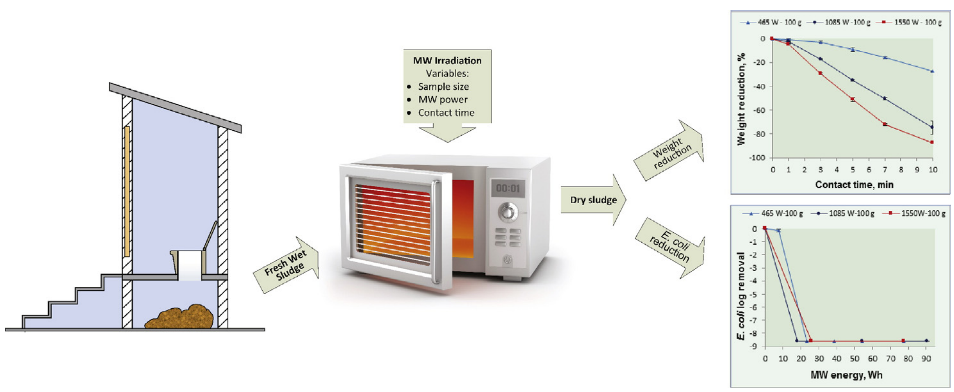
HIGHLIGHTS

- There is lack of fast and efficient fecal sludge treatment options in emergencies.
- Microwave treatment is rapid and efficient in sludge volume and pathogen reduction.
- Power and contact time can be varied to reach diverse levels of sludge treatment.

GRAPHICAL ABSTRACT



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ABSTRACT

A laboratory-scale microwave (MW) unit was applied to treat fresh blackwater sludge that represented fecal sludge (FS) produced at heavily used toilet facilities. The sludge was exposed to MW irradiation at different power levels and for various durations. Variables such as sludge volume and pathogen reduction were observed. The results demonstrated that the MW is a rapid and efficient technology that can reduce the sludge volume by over 70% in these experimental conditions. The concentration of bacterial pathogenic indicator *E. coli* also decreased to below the analytical detection levels. Furthermore, the results indicated that the MW operational conditions including radiation power and contact time can be varied to achieve the desired sludge volume and pathogen reduction. MW technology can be further explored for the potential scaling-up as an option for rapid treatment of FS from intensively used sanitation facilities such as in emergency situations.

1. Introduction

Heavy usage of onsite sanitation facilities (i.e. 50–400 users per sanitation facility as observed in emergency settings) results in the rapid accumulation of fresh fecal sludge (FS) which should be frequently and safely disposed. Rapid accumulation rates result in the generation of large volumes of FS which can create a significant challenge for FS management especially, during its transportation and disposal. The situation can be worsened by the generation of such huge amounts of FS in a locality with limited disposal possibilities. Particularly, if the availability of land is inadequate for local disposal, the FS may need to be hauled

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long distances to the final disposal site. In such situations, it might be economical to reduce the sludge volume in order to minimize the transport and ultimately the operation and maintenance costs of the sanitation system. Furthermore, FS contains various compounds of interest including high concentrations of organic and inorganic matter, and large amounts of pathogens. Pathogenic organisms found in FS include bacteria, viruses, protozoa, and helminths (WHO, 2001; Fidjeland et al., 2013). These organisms present a major concern to public health especially in the disposal and/or reuse of the sludge. The pathogenic organisms should thus be reduced to safe levels (e.g. *E. coli* ≤ 1000 CFU/g TS (WHO, 2006)) in order to minimize public health risk posed by the possible outbreaks of excreta related epidemics. The presence of organic matter in the FS is yet another important aspect in the FS management as it can lead to offensive odors and attract vector organisms (such as houseflies and mosquitoes) that can spread diseases. Therefore, organic stabilization of the FS is desirable to ensure safe waste disposal practice. The aspects highlighted above form a major challenge in FS management but can be addressed by the use of appropriate FS treatment technologies.

A number of FS conventional treatment options are available, including the conventional drying (e.g. in sludge drying beds), composting, co-composting with organic solid waste, anaerobic co-digestion with organic solid waste (producing biogas), and co-treatment in wastewater treatment plants (WWTP) (Ingallinella et al., 2002; Ronteltap et al., 2014). These technologies have been tested and applied in regular sanitation contexts. They have associated benefits, but also limitations that make their application less suitable in some specific contexts such as the emergency situations. For instance, the composting technology produces a hygienically safe product rich in humus; however, it requires much space, long treatment duration, and may pose environmental pollution and public health risks in low-lying areas in the case of flooding (Katukiza et al., 2012). Anaerobic co-digestion with organic solid waste offers the benefit of both increasing biogas production, as well as using the final (end) product as a fertilizer. However, this option has the limitation of involving a relatively slow digestion process. In addition, a post treatment stage is required for the further removal of pathogens (Katukiza et al., 2012). Co-treatment in WWTPs is a possible option for FS treatment, but the probable heavy hydraulic, organic, and solids loads may limit the application of this alternative (Lopez-Vazquez et al., 2014), especially, if the co-treatment of sludge was not considered in the original design.

Generally, the major limitations of conventional FS treatment technologies highlighted above include their relatively slow treatment processes and large space requirements, which make them less feasible in scenarios with high FS generation rates and limited land space. Such scenarios are commonly faced when dealing with heavily used onsite facilities such as during an emergency situation. Inappropriate FS treatment in emergencies has, in some cases, resulted in the adoption of poor disposal methods, especially in less developed countries where common practice is to use pit latrines and septic tanks. These facilities fill up rapidly when intensively used, in which case the adoption of poor disposal methods is likely to occur. A recent example is the open dumping of raw FS reported in Haiti after the earthquake in 2010 (Oxfam, 2011). Such poor FS management practices pose great dangers to affected people whose public health is already jeopardized by the poor living conditions in the disaster environment. For instance, the rapid spread of a cholera epidemic after the Haiti earthquake in 2010 which claimed approximately 500,000 lives was associated with inadequate sanitation provision (Tappero and Tauxe, 2011). Similarly, sanitation related outbreaks of diarrheal diseases were reported after the earthquake in Pakistan in 2005, the tsunami in Indonesia in 2004, the floods in Bangladesh in 2004, and the floods in Mozambique in 2000 (Watson et al., 2007).

These challenges for FS treatment in areas with high generation rate and limited land space demonstrate the need to explore more options which are fast and efficient. MW technology may present an appropriate alternative for future applications in FS treatment in such areas. The MW irradiation has characteristics such as instant and accurate control of the power input as well as providing fast and uniform heating throughout the target material (Haque, 1999). With its unique nature in rapid heating, the MW technology application appears very promising for FS treatment in the situations requiring rapid treatment options. Furthermore, MW based applications can potentially provide compact and easily portable as well as fast and effective FS treatment package units with reduced footprints. The MW technology uses microwave energy which is a non-ionizing electromagnetic radiation with wavelengths between 1 mm and 1 m and frequencies between 300 MHz and 300 GHz (Haque, 1999; Tang et al., 2010; Remya and Lin, 2011). The technology has been widely used in communication, industrial, scientific, medical and instrumentation applications (Haque, 1999). Most of the above applications utilize the technology for heating where the microwaves cause molecular motion in the target material by inducing the migration of ionic species and/or the rotation of dipolar species (Haque, 1999; Thostenson and Chou, 1999). The heating by microwaves depends on the dissipation factor, which is the ratio of the dielectric loss factor to the dielectric constant of the target material. The dielectric loss factor depicts the amount of MW energy lost in the material by dissipation in form of heat while the dielectric constant depicts the ability of material to delay or retard microwave energy as it passes through. Therefore, materials that are easily heated by MW energy have a high dielectric loss factor (Haque, 1999; Thostenson and Chou, 1999).

The MW technology was applied in the treatment of some common wastes such as sewage sludge which contains dipolar molecules (e.g. water and organic complexes) with high loss dielectric properties that enable selective and concentrated heating by microwaves (Yu et al., 2010). A number of studies that were conducted using the various types of sewage sludge demonstrated the success of MW treatment in many aspects including pathogen reduction (Tyagi and Lo, 2013). For instance, complete pathogen destruction was reported when primary, anaerobic digester and waste activated sludges were heated by MW to temperatures above 65 °C (Hong et al., 2004, 2006; Tyagi and Lo, 2013). In addition, over 80% volume reduction was reported when anaerobic sewage sludge was exposed to MW irradiation (Menéndez et al., 2002). The pathogen destruction by MW was associated with both the non-thermal (electromagnetic radiation) and thermal (temperature) effects of the electromagnetic energy. Electromagnetic radiation causes the molecules of the irradiated material to orient themselves in the direction of the electric field. This may result in hydrogen bonds breaking leading to the denaturation and death of microbial cells (Banik et al., 2003; Tyagi and Lo, 2013). On the other hand, the destruction by thermal effect is caused by the rotation of dipole molecules under an oscillating electromagnetic field which results in rapid heating of water to boiling point. The cells of microorganisms are then ruptured and the bound water is released (Hong et al., 2004; Wojciechowska, 2005; Tang et al., 2010; Tyagi and Lo, 2013).

Such successful applications in sewage sludge treatment demonstrate the potential of the MW technology in treating FS. Although different in aspects such as concentration of organics, pathogen, TS, and others, the fresh FS has relatively similar dielectric properties to that of sewage sludge. For instance, FS contains dipolar (e.g. water and organic complexes) molecules which are important in the MW heating. The dipolar characteristic of the fresh FS thus provides an opportunity for its treatment by the MW technology.

Despite the successful evaluations of the MW treatment using various kinds of sewage sludge, no studies have yet been reported with respect to FS context. It is thus desired to evaluate MW application on FS, since FS is more concentrated, and comparatively has more pathogens, and organics, among others. Therefore, the objective of this study is to investigate the potential of a microwave (MW) based technology for treating fresh blackwater FS extracted from a highly concentrated domestic blackwater stream. The study focused on three aspects of