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FOR ALL IN A FAST CHANGING WORLD

Hydrothermal treatment of human biowastes as an alternative sanitation strategy

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One of the evolving approaches to mitigating the challenges of poor sanitation involves the exploration of new, sustainable and affordable technologies. These need to be capable of effectively treating faecal and other related wastes without any health, or environmental damage and competitive with existing strategies. This paper presents results from hydrothermal carbonization (HTC) of human biowastes; treated at >130^{0}C under pressure. Analysis shows the process is autothermic and could generate valuable end-products. These were, a carbonaceous solid material i.e. char with a high calorific value which can be used as fuel or soil conditioner, and liquid ammonia concentrate for fertilizer. The results of this study provide useful information essential for the design and operation of an HTC system (for faecal sludge treatment) which will be integrated into a self-sustainable sanitation facility planned for prototype development.

Background

The challenges of poor sanitation in the developing and remote regions of developed countries are well documented. There are long standing international programmes and strategies aimed at ameliorating poor sanitation but there is a need for novel, cost-effective, sustainable and efficient technologies for faecal waste management. These also need to be able to meet the needs of increasing population and rapid urbanization. This was the basis of the 'Reinvent the Toilet Challenge' (RTTC); an initiative funded by the Bill and Melinda Gates Foundation. The project is "about prototyping, conceptualising, and designing of highly innovative ways and means of disposing human waste (which will primarily ensure safe disposal and protect the environment) drawing on the high-value engineered circumstances demanded by potential widespread, near-term adoption in developing world" [Gates, 2011]. Objectively, we seek to develop a safe, affordable, self-sustainable (in terms of energy requirements) and eco-friendly toilet facility targeted at decentralised households or small collections of networked households. Effectively, the toilet needs to collect human biowastes including faecal sludge, treat and convert them into safe and usable products. This is required without additional financial burden or need for piped water or sewerage systems with a budget of less than \$0.05 per cap per day.

Hydrothermal carbonisation (HTC), a novel thermochemical process; is currently being researched to treat and convert human biowastes biomass into useful end-products. The process uses water at *subcritical conditions* (<300^{0}C) to transform biowastes (contained in a closed pressure vessel) into a coal-like material, herein referred to as char by supersolvation. The technological suitability of the HTC process for faecal sludge treatment was based on the following considerations:

- HTC can utilize raw wet biomass characterized by high moisture content precluding pre-drying and its associated costs [Libra et al, 2011]. This makes it suitable for human excreta with moisture content range of 65 - 85% [Wignarajah et al, 2006].
- Lower energy consumption when compared with other thermal/thermochemical processes such as incineration, dry pyrolysis, gasification, or supercritical reactions.
- Production of sterilised end-products. The process involves high temperature (180 – 200^{0}C) which will effectively kill pathogens in human faecal biowastes.

- The process is exothermic i.e. energy released during the process can be recovered to run the HTC system. Also, the combustion or anaerobic digestion of end-products will provide additional energy which can make the toilet facility self-sustainable.
- The production of value-added products such as char from the process has immense potential both in agriculture and bioenergy [Lehman et al, 2009; Ramke et al, 2002]. This could provide a financial incentive to the overall faecal management chain.
- The process is scalable and can be developed into mobile processing units which could be used onsite where faecal waste is collected for example sanitary storage stations. This will represent a safer and healthier alternative for the current faecal sludge emptying approach common in developing countries.
- Lower carbon footprint due to diminished reactor size; modest process reliability, risks and maintenance of the process are other considerations.

Primary investigations of the HTC process on human biowastes have been conducted at bench and pilot scales. For the pilot scale, the process has also been investigated in both batch and/or continuous modes. This paper presents key results, challenges and future work from completed studies.

Methodology: test materials and HTC systems

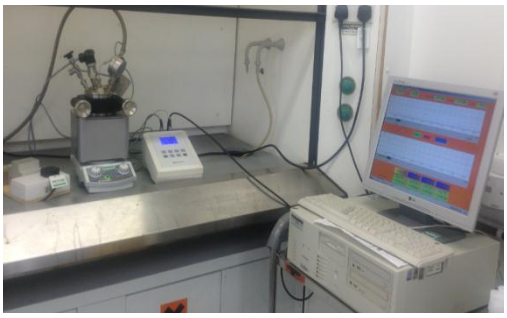
Different test materials including synthetic faecal sludge simulants (adapted recipe from Wignarajah et al, 2006), sewage sludge, raw human excreta and faecal sludge (including sanitary products) have been investigated. All test materials were sourced locally. The basic HTC process consists of three stages; balancing, heating under autogenous pressure and end-product separation. Experimental studies were conducted from different configurations of the HTC process using different heating sources; conventional heating (e.g. paar reactors - see Photograph 1) and microwave heating. The process was scaled up to a continuous flow (up to 15L of human biowastes/day) pilot plant which was operated in both batch and continuous mode (see Photograph 2). The experimental process conditions used are summarised in Table 1.

Table 1. General HTC process conditions

	Batch HTC system		Continuous HTC system
Parameters	**Microwave System**	**Paar Reactor (Conventional)**	**Pilot plant**
Sample volume (L)	**0.2 - 0.75**	**0.2**	**15**
Temperature range (^{0}C)	140 - 200		150-180
Process times* (hours)	1 - 2	6 - 20	24 – 325
Power supplied (and source of heating)	900 W (From magnetron)	825 W (Electric hot plate)	500 – 2500W (Heater ranging from immersion to band heaters)

**Average HTC process time needed for human faecal biowastes treatment. This factors warming, cooking and cooling periods of the systems. Figures for continuous system represent the total hours the rig was running continuously non-stop.*

A schematic diagram of the overall managerial options for the HTC process and recovered products within the context of our work is presented in Figure 1. This paper has focussed on the separation route to illustrate the benefits of HTC for faecal sludge treatment and management.The key parameters reported are the physical properties (smell, colour, and texture), dewaterability and calorific (heating) values of test materials before and after the HTC process. Smell and colour of end-products were observed subjectively; dewaterability test were measured using Standard Methods 2710G – Capillary Suction Time (CST) (AWWA, 2005) while heating values were estimated using a bomb calorimeter (CAL 2K, Digital Data Systems, South Africa) according to standard test procedure (ISO 1928:2009 Standard).



Photograph 1. Batch HTC system

Photograph 2. Continuous flow pilot plant

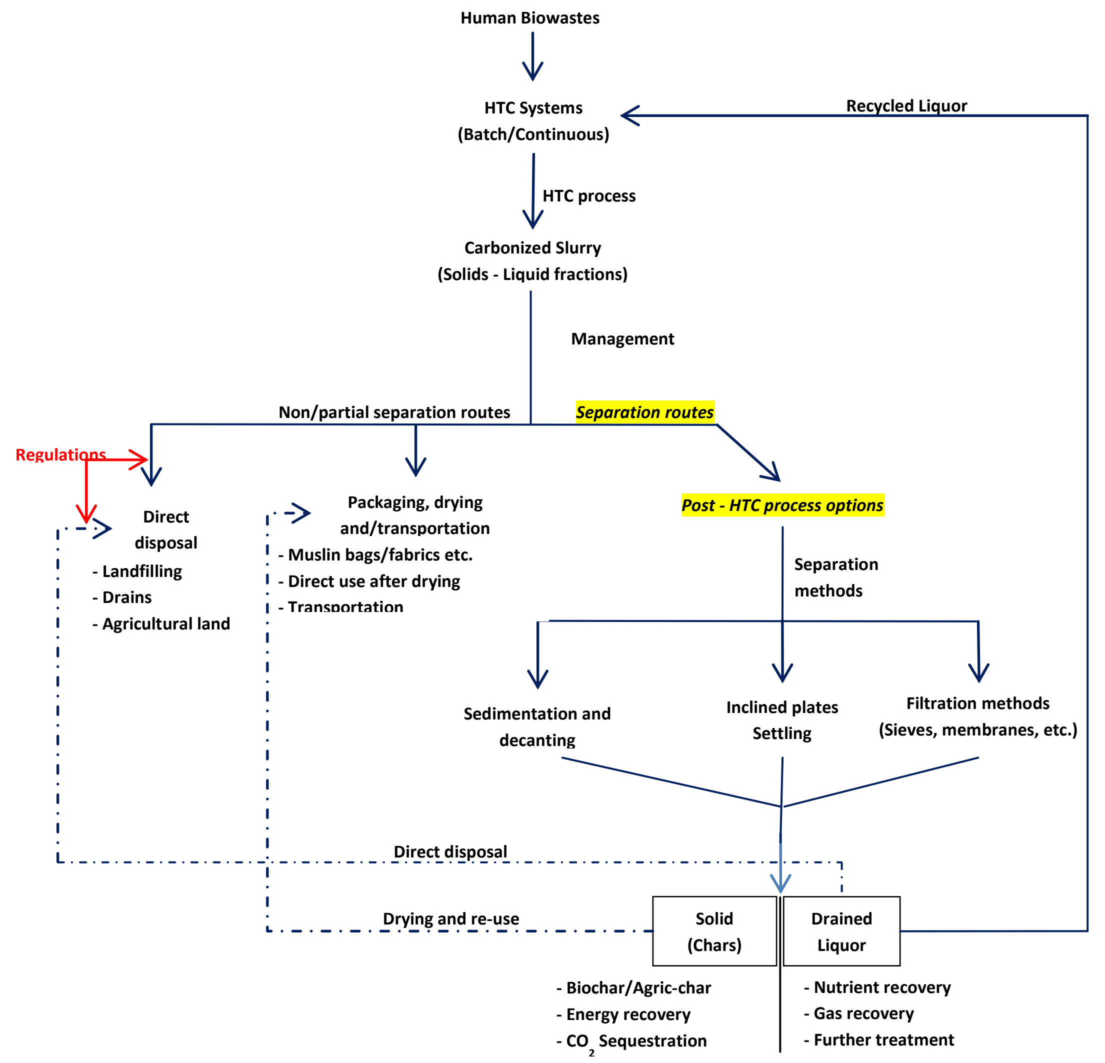
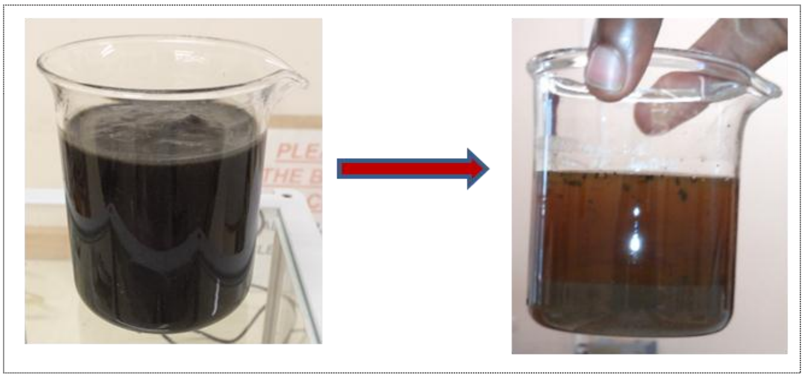


Figure 1. Schematic outline for faecal sludge treatment and management

Results

All experiments involving the different HTC configurations on all test materials indicated physico-chemical changes in end-products. The foul odours of amines, sulphides and volatile organic acids of human faecal sludge and sewage sludge were transformed into characteristic smells after the HTC process. For example, while human faecal sludge produced an almond-like odour, sewage sludge produced a typical roast coffee odour. The colour was changed from brown or yellowish brown (fresh and synthetic faecal sludges respectively) to dark coal-like coloured end-products. Particle sizes were reduced and the texture of dried solids samples allows compaction, of the easily ground, friable solids.

Photograph 3 shows a typical feedstock before and after HTC treatment. A sharp interface between solid and liquid fractions of end-product occurred and this makes separation very easy. The change in dewaterability is shown in Figure 2. While the specific resistance to filtration of raw sludgy material was 388 seconds, it took only 10 seconds for treated biowastes at 180^0C to dewater. In general, there was a drastic improvement in time required to filter and separate treated biowastes beyond the sterilization temperature (130^0C) but not above 180^0C.



Photograph 3. Test materials (sewage sludge) before and after HTC treatment

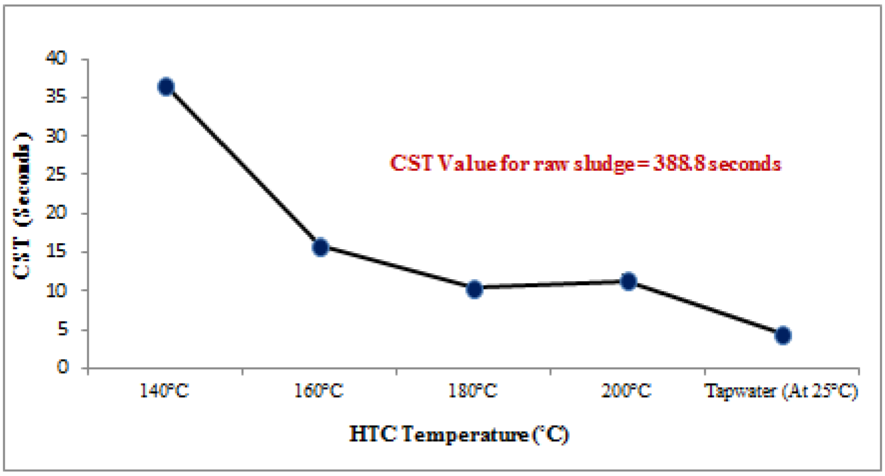


Figure 2. Changes in dewaterability of sewage sludge treated at different temperature

In terms of mass balance however, the amount of char recovered after HTC decreased as temperature increased due to further thermal decomposition of solid components of raw test materials during the process. As expected, the heating values of char correlated more with changes in temperature than heating time. When compared with raw biowastes samples, there is a significant change in heating values of char produced after HTC. For example, the calorific value of raw human excreta treated at 200^0C increased from

17-19MJ/Kg (depending on moisture content) to 25.6MJ/Kg (dried char sample) after the HTC process; representing up to 50% increase in heating value.

Table 2 compares the calorific values of some fossil fuels, agricultural biomass and treated human faecal waste.

Table 2. Comparing heating values

Fuels	Higher Heating values (HHV)* MJ/Kg
Crude oil	45.543
Range of coal	23.9 - 29.8
Corn stalk / stover	17.6 - 18.5
Sugarcane bagasse	17.3 -19.4
Softwood wood	18.6 - 21.1
Municipal solid waste	13.1 - 19.9
Refuse derived fuel	15.5 - 19.9
Treated human faecal waste	***23.5 - 25.6***[#]
Treated faecal Simulant (current study)	***22.3 - 27.9***[#]

**values varies chiefly with moisture content*

[#]*Value depends on HTC process conditions most important temperature used*

Source: Biomass Energy Data Book (2011)

Unlike coal, char derived from human biowastes using HTC process contain less sulphur, nitrogen and ash content < 20% (coal 20-40% ash). Also, their textural characteristics suggest they can be compacted into briquettes/pellets and may be co-combusted with other fuels due to similarity in calorific values. However, their combustion characteristics amongst other factors need to be fully assessed.

Conclusion

HTC, despite the use of temperature and pressure has shown to be a suitable technological approach to sanitation, reliably overcoming the heterogeneity of domestic and human biowastes. The sterilization and recovery of useful end-products, notably energy rich char (which can also be used as fertilizer) provides incentives to further develop the process. The complete transformation of foul odour associated with human biowastes by the process could improve public acceptance and hence promote its potential use as a mobile processor which will represent a safer alternative to current faecal emptying approach in developing economies. Improvements in dewaterability aids drying and the energy balance of the process compared to alternative thermal processes. Successful dewatering could improve the financial incentives for waste management in both developed and developing countries if its contingent sustainability value is assessed. Our investigations has demonstrated batch and extended continuous operation, indicating scalability and adaptability to different locations. Further work is need to optimize the energy and mass balances to achieve the best solids-liquid separation and production engineering to reduce the capital costs.

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