Source-separation of human excreta as a driver for optimised resource recovery via pyrolysis

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Currently, 3.1 billion people, mostly in low- and middle-income countries, rely on improved on-site sanitation facilities, such as pit latrines and septic tanks, to access sanitation services (WHO/UNICEF, 2019). The material that accumulates in such facilities is known as faecal sludge (FS) and consists of human excreta (faeces and urine) with or without the addition of flush water, toilet paper, greywater or other waste discarded in sanitation systems (Velkushanova et al., 2021). Resource recovery from FS has been gaining interest within the scientific community, particularly nutrient and energy recovery (Diener et al., 2014). However, the composition of FS is very variable, depending on on-site conditions, sanitation technology type and types of input (Krueger et al., 2021). Therefore, reaching a uniform treatment output quality and ensuring that recovered products are appropriate for their intended use is challenging. Similar issues have been faced with other types of waste, such as municipal solid waste, and source-control has been crucial in achieving consistent resource recovery rates and quality of end-products (World Bank, 2012). In that context, there is a need to understand how FS composition impacts resource recovery and identify ways to improve recovery rates through source-control.

Source-separation of faeces and urine has been reported as being beneficial for resource recovery from FS (Chipako and Randall, 2020; Larsen, 2020). However, its effects on specific FS and end-product characteristics cannot easily be quantified based on existing studies, as there are many varying influencing parameters of FS composition that are challenging to monitor for on-site sanitation systems. This study aims to quantify the effects of source-separation of faeces and urine on resource recovery via pyrolysis by: 1) characterising the two components (separately and combined) for their thermal properties and 2) using thermogravimetric analysis to evaluate the effects on thermal decomposition. This work will be supplemented by the elemental characterisation of human excreta and its components and by deploying pyrolysis treatment to assess the resource recovery value of end-products (ongoing work).

Samples of source-separated faeces and urine were collected from 12 volunteers over a period of 4 months (September-December 2021), in the UK. The samples were categorised as: 1) source-separated faeces and urine (SSF, SSU); and 2) mixed faeces and urine (MUF). All other sampling parameters were kept constant to allow for the investigation of source-separation effects. The MUF samples were prepared by blending raw faeces and urine at a ratio of 1gr:10mL. This ratio is considered representative of the ratio of daily excretion (Rose et al., 2015) and that reported for on-site sanitation systems (Krounbi et al., 2019). Samples were analysed via proximate analysis (using standard method ASTM D7582-15 as adapted by Krueger et al. (2021) for implementation on an STA 449 F5 Jupiter simultaneous thermal analyser) and for their calorific value by bomb calorimetry (using standard method ASTM D5865M-19 (ASTM, 2019)). Thermal analysis was conducted to obtain the thermogravimetric analysis (TGA) and derivative thermogravimetry (DTG) curves (under N_2 flow, 50ml/min).

Table 1: Proximate analysis and calorific value results for mixed faeces and urine (MUF) and source-separated faeces (SSF) samples (on a dry basis). HHV = Highest Heating Value

	Volatile matter (%)	**Fixed carbon (%)**	**Ash content (%)**	**Calorific value [HHV] (MJ/kg)**
MUF	70.0 (± 0.2)	11.2 (± 0.3)	18.9 (± 0.5)	17.8 (± 0.0)
SSF	72.5 (± 0.6)	15.1 (± 0.3)	12.5 (± 0.4)	21.8 (± 0.1)

Proximate analysis and calorific value results (Table 1) show a significant increase in ash content and decrease in fixed carbon and calorific value when urine is present, compared to source-separated faeces only. This effect can be explained by the high presence of inorganic salts in urine (Rose et al., 2015) and suggests that source-separated faeces are more suitable for pyrolysis treatment and energy recovery applications compared to mixed excreta sources. TG and DTG curves (Figure 1) confirm the different thermal decomposition behaviour between MUF and SSF samples. These novel data begin to quantify the benefits of urine separation for energy recovery.

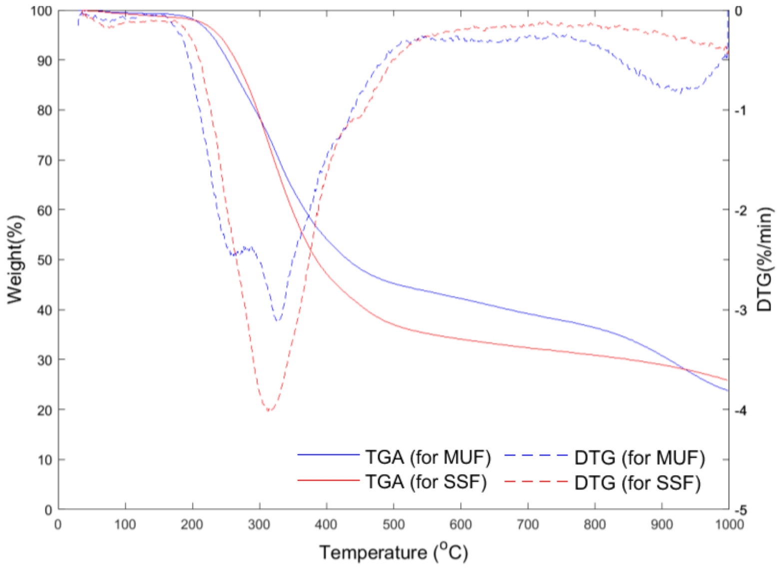

Figure 1: TGA and DTG results for mixed faeces and urine (MUF) and source-separated faeces (SSF)

Common agricultural practices also suggest that the urine fraction is more suitable for non-thermal treatment methods, with the objective of nutrient recycling. Ongoing analysis, including on the nutrient and heavy metal content of human excreta (via ICP-OES), will investigate these nutrient recovery effects, which will be presented at the conference.

Overall, this work shows that source-separation of human excreta, followed by separate treatment of urine and faeces based on their individual properties, is a promising way to increase the value of recovered products. Quantifying this added value can inform the design of new circular sanitation systems and treatment technologies, and create financial incentives for increased sanitation coverage through human waste valorisation.

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