UNIVERSITY OF KWAZULU-NATAL

FAECES AND SOLIDS PROCESSING

Design objectives

- Recovery of energy from faeces – solids stream
- Recovery of water from faeces
- Production of a sterile, nutrient-rich product in a form suitable for agricultural applications
- Disposal of waste streams from other unit processes within the toilet

Concept

The faeces and solids processing operation consists of three stages: (i) extruder-separator unit; (ii) dryer and (iii) combustor.

The extruder-separator converts the mixed solids stream into an optimal form for efficient drying, whilst removing solids that cannot be readily combusted. The dryer stage reduces water content in the solids to a level where efficient combustion can occur. The water is recovered via a condenser and sent for further treatment before being recycled back to the ablution block water supply. The combustor performs the energy recovery function, supplying energy back to the dryer and potentially to an electricity generation process. Waste streams from other unit processes within the toilet – waste solids from the urine processing and odourous air from the toilet pedestal - are also disposed of via the combustor.

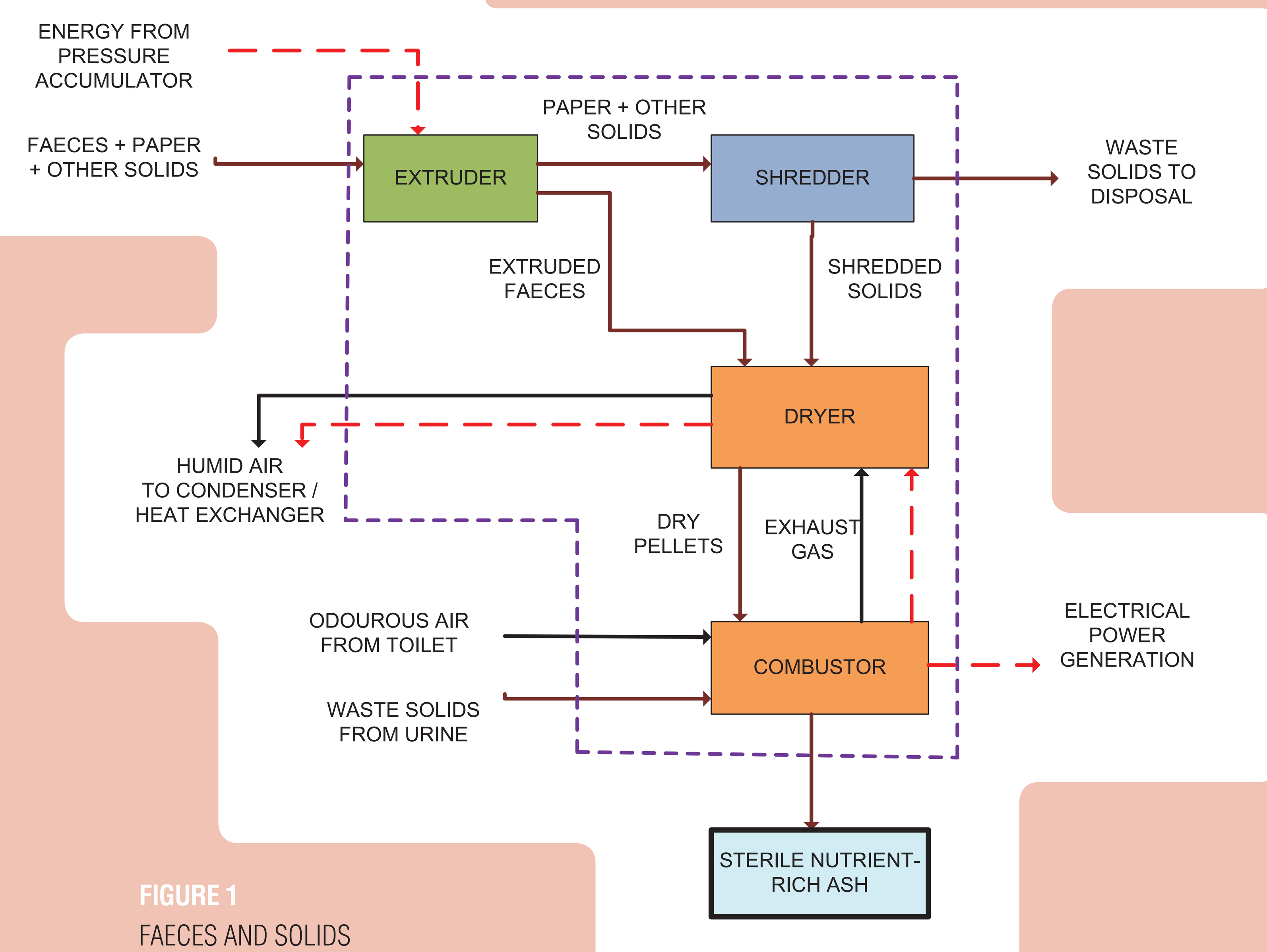


FIGURE 1
FAECES AND SOLIDS PROCESS FLOW DIAGRAM

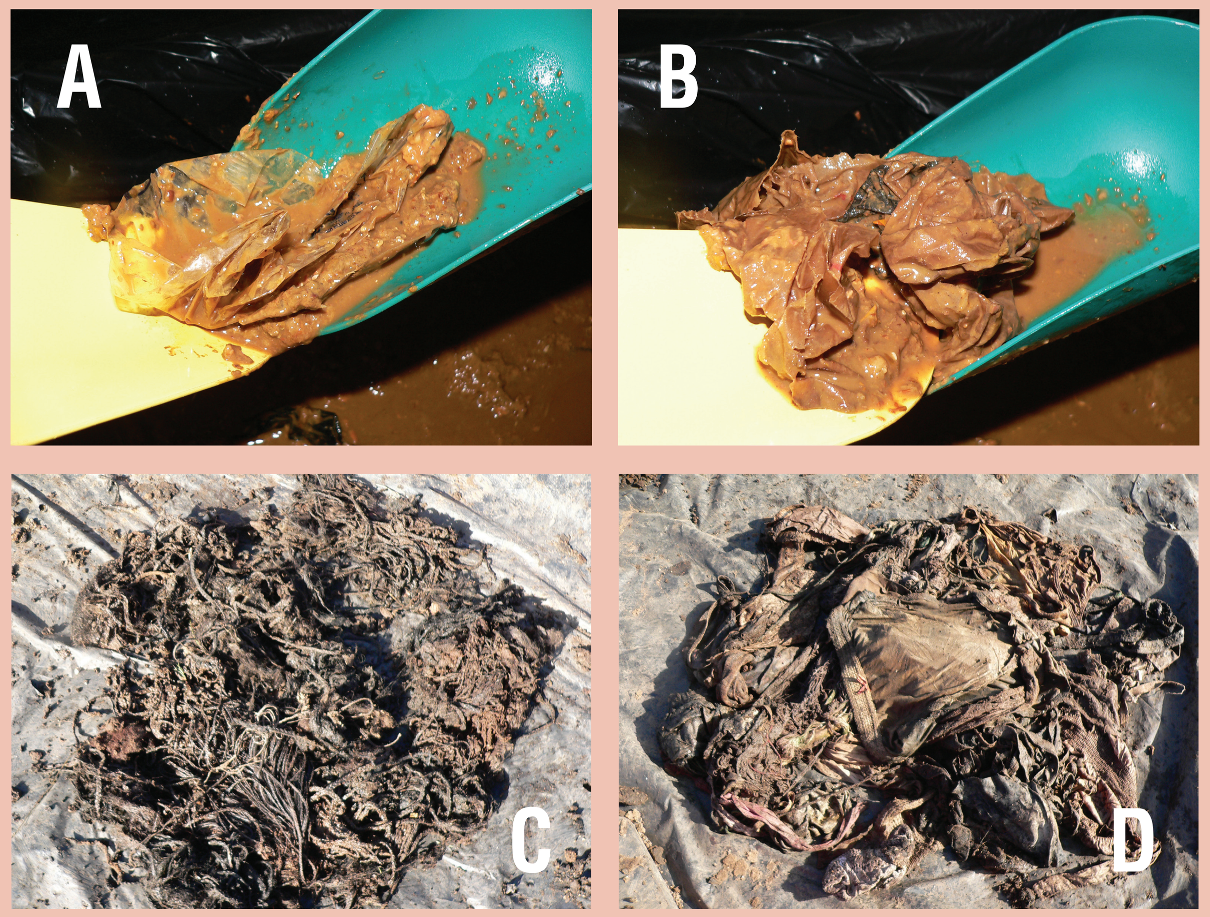


FIGURE 2
Examples of non-faecal material found in community ablution block and household latrine samples: (a) plastic packaging; (b) newspaper; (c) hair extensions; (d) clothing.

EXTRUDER

Separation of faeces and non-faecal solids: a variety of solid materials may enter the toilet in the community ablution block context (toilet paper, newspaper, plastics, rubber, clothing) (see Figure 2), some of which may require pre-treatment (shredding) or complete removal from the feed stream to the dryer.

Extruder separates faeces from other solids by using a ram to pressurise the mixed solids stream, causing faeces to be extruded through holes in the external casing and tramp material to accumulate against the endplate (see Figures 3 and 4).

Extruder forms faeces into a geometry which allows for more energy-efficient drying and combustion (see Figure 4c). The pellets formed must have sufficient structural integrity to remain intact through the downstream processes.

Segregated faeces has more predictable rheological and thermal properties than the mixed solids stream – allows for better design of downstream operations.

FIGURE 3
EXTRUDER CONCEPT

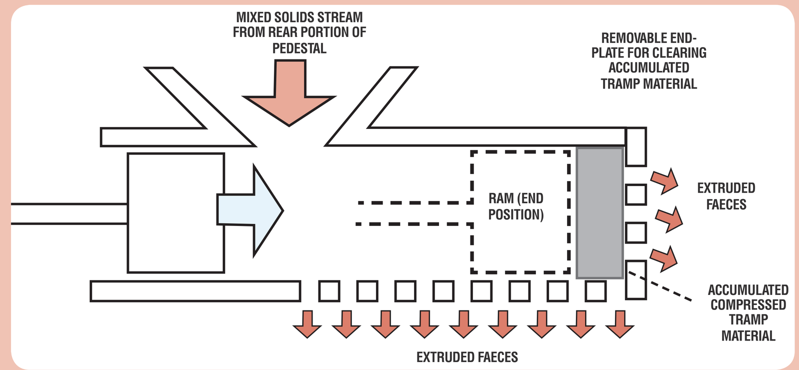
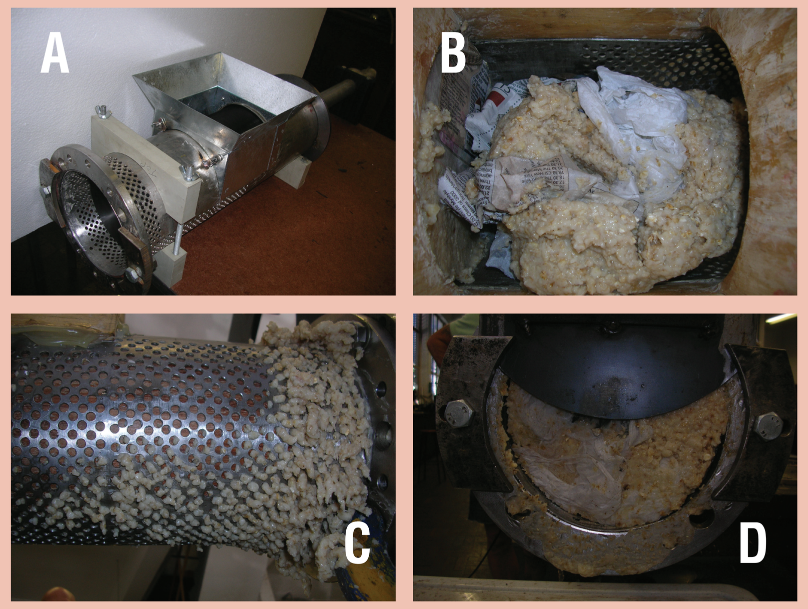


FIGURE 4
PROTOTYPE EXTRUDER:
A Extruder;
B Mixed solids stream In hopper;
C Extruded simulant faecal material;
D Accumulated non-faecal material at end of extruder



Design data requirements:

The extruder must be designed to achieve (i) efficient separation of faeces and non-faeces components and (ii) consistent production of pellets suitable for drying and combustion. The following data is required to support the design:

- Composition of the mixed solids stream – types and quantity of non-faecal material;
- Flow behaviour (rheology) of the faeces stream and dependency on environmental factors;
- Physical properties of the faecal and non-faecal material.

(1) Sample characterisation

Faeces samples from (i) individual donors and (ii) mixed batch samples from a community ablution block have been collected and analysed.

Figure 2 indicates the variety of non-faecal solids that may enter a toilet in a community ablution block. Table 1 describes the Bristol Stool classification system for faecal material, and links its categories to the water content measured in the samples we collected. Considerable variation has been observed in the physical consistency and water content of the samples analysed (Figure 6).

TABLE 1
Bristol stool classification system for faeces. Water content range for each category based on our analysis of human faeces samples.

Bristol Stool Class	Image (Brettle 2011)	Description (Lewis 1997)	Water content range
Type 1		Separate, hard lumps, like nuts	Up to 53%
Type 2		Sausage shaped, with deep cracks and lumps	53% - 60%
Type 3		Sausage shaped, with light cracks	60% - 67%
Type 4		Sausage shaped, smooth and soft	67%-77%
Type 5		Soft blobs with clear edges	77%-85%
Type 6		Soft, fluffy blobs with ragged edges	85% - 95%
Type 7		Entirely liquid with no solids	Over 95%

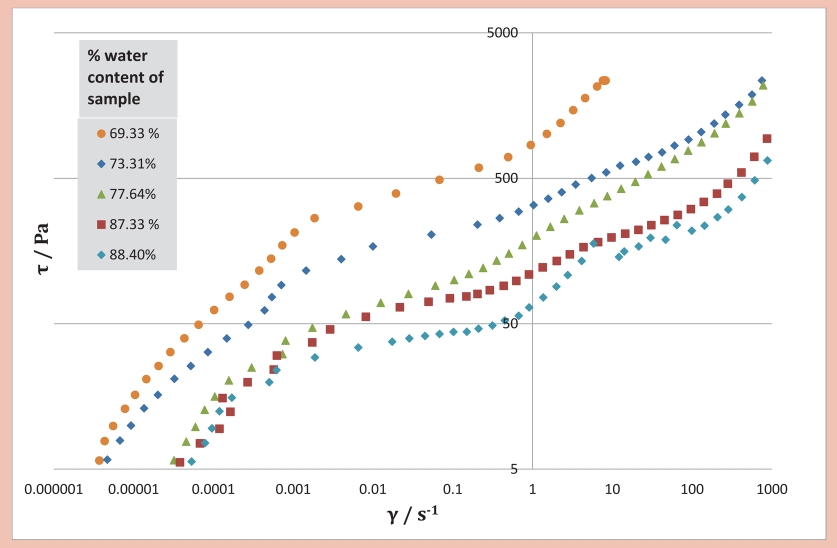
(2) Rheology study

The viscosity of faeces directly affects the applied pressure required to achieve extrusion, the dimensions of extruder required and the quality of pellets produced. Viscosity itself may be dependent on the following factors: (Franck 2004 and Gabas et al. 2012)

- The composition of the fluid, particularly moisture content and presence of long-chain molecules;
- The magnitude of shear rate applied;
- Temperature;
- The length of time for which a shearing force is applied.

Rheological tests to analyse the expected behaviour of faeces within the extruder have been performed on human faeces samples, across a range of water content (59.2 to 88.7%). Selected results are presented in Figures 5 to 8.

FIGURE 5
Variation of shear stress with shear rate for fresh human faeces samples of varying water contents (measured at 25 °C)



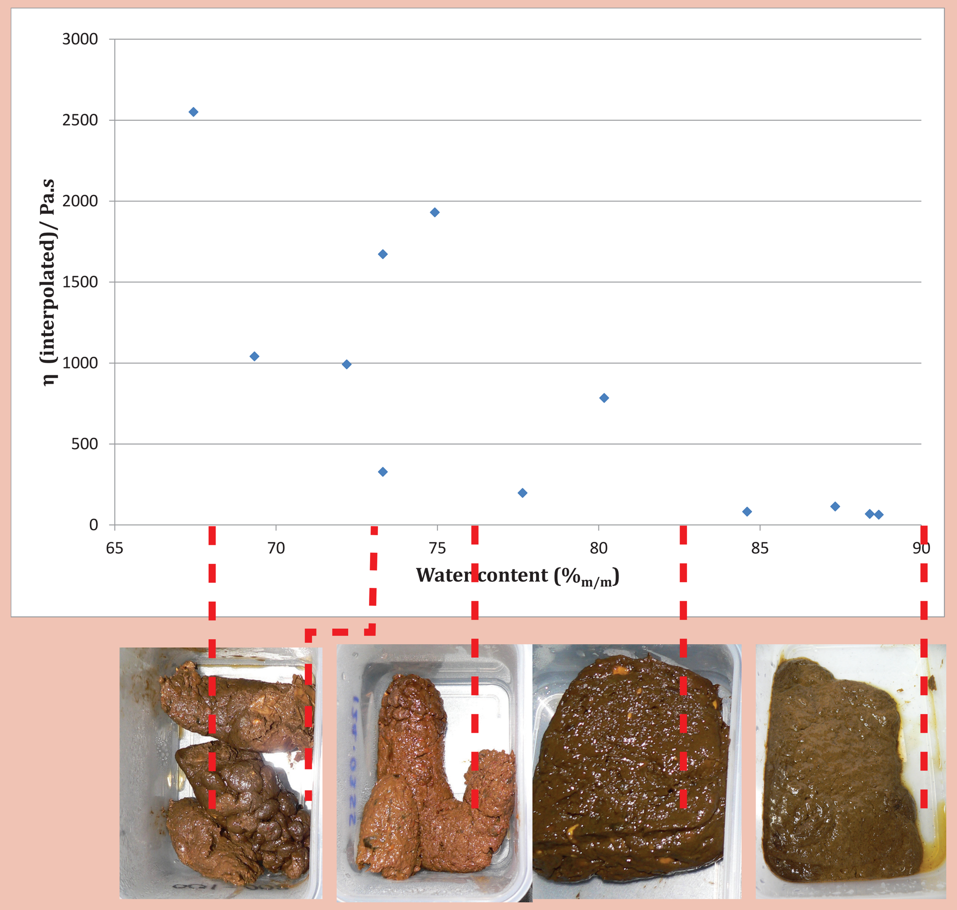


FIGURE 6
Variation in dynamic viscosity of fresh human faeces with water content of sample (applied shear rate of 1 s-1 at 25 °C) and visual appearance of samples corresponding to different water contents.

FIGURE 7
Variation in dynamic viscosity with time for fresh human faeces (applied constant shear rate of 100 s-1 at 25 °C). Pre-shear of the solids stream may be beneficial if lower viscosities desired for downstream processing functions

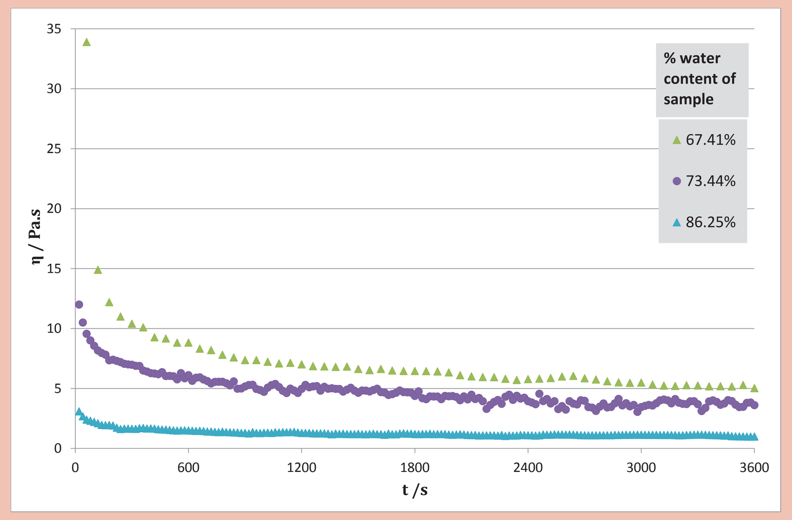
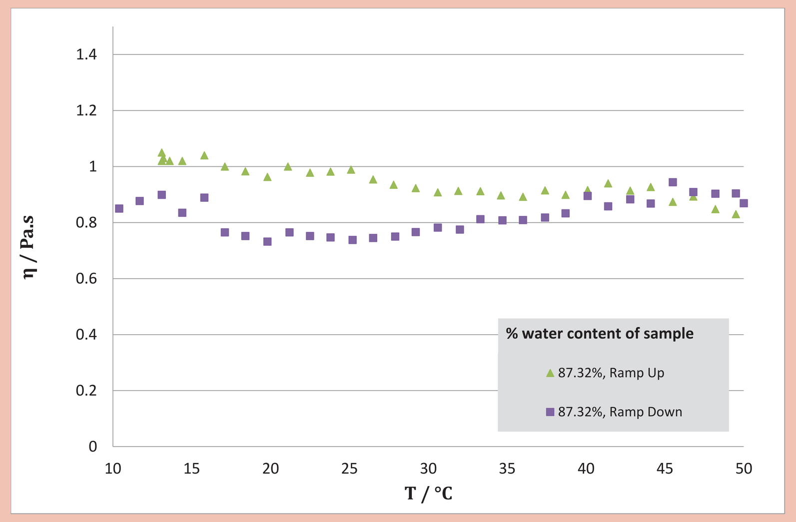


FIGURE 8
Variation in dynamic viscosity with temperature for fresh human faeces (applied constant shear rate of 100 s-1, sample water content 87%)



(3) Physical properties of faecal matter

Other characterisation work supporting the rheology study:

Samples have been analysed for volatile solids content and will be analysed for volatile fatty acid (VFA) content. High levels of these may indicate a higher concentration of longer chain molecules which could impact upon the viscosity of samples. The significance of this factor relative to water content is yet to be determined.

Particle size distribution analysis of faeces samples may provide further explanations for particular rheological behaviours.

An approximate density measurement is made for each sample, to check for any correlation with rheological data.

DRYER

Removal of water from faeces pellets to produce a product suitable for efficient combustion

Diversion of humid air to a condenser for water and energy recovery

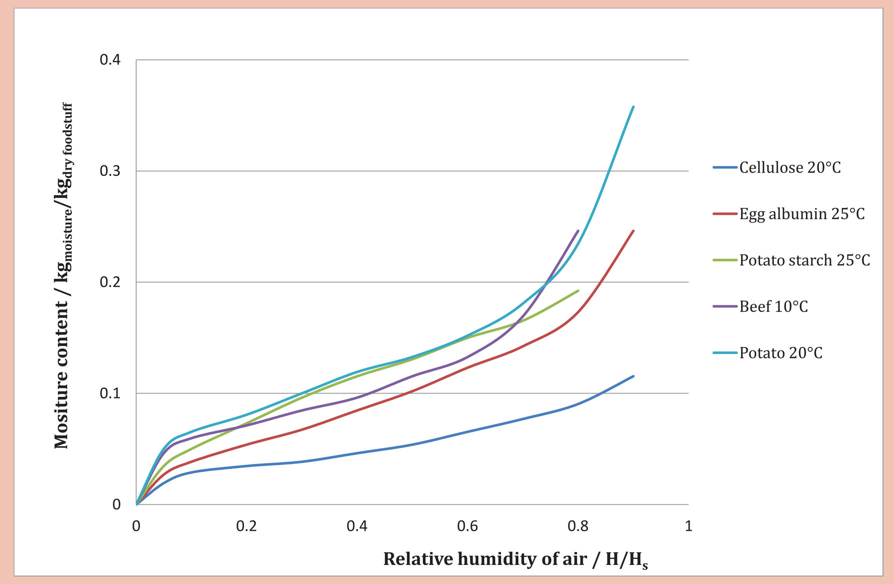
Efficient energy exchange between heated exhaust gases from combustor and wet feed material

Design data requirements

The dryer must be designed to (i) dry the feed material to a water content where it can be combusted efficiently; (ii) use the minimal quantity of energy to do this; (iii) recover energy from the combustor with the highest efficiency possible. Work here is focused specifically on (i) and (ii) - production of data to design for efficient drying.

Rates of drying are generally limited by heat transfer rates, although in some instances mass transfer of water may be the limiting factor. The aim of the drying experiments being carried out is to produce drying curves for a variety of faeces samples under a range of different, well-defined environmental conditions (temperature, humidity and and flow velocity of the air used for drying). For a given set of environmental conditions, a particular sample will dry up to a moisture content that is in equilibrium with the relative humidity of the air surrounding it. The equilibrium moisture content of a sample at a specified air relative humidity is extremely substance-specific (Figure 9).

FIGURE 9
Variation in equilibrium moisture content of different foodstuffs with air relative humidity



Foodstuffs exhibit significant differences in the shape of their equilibrium moisture content curves. Variation therefore may be expected between faeces samples from subjects with different diets. The equilibrium vapour pressure above a sample is determined by temperature, the water content of the sample, the way that the water is bound within the material and by the presence of dissolved solutes in the water (Earle 1983).

COMBUSTOR

DESIGN PRINCIPLES

Efficient combustion of dry pellets in a fluidised bed incinerator. Exhaust gases to dryer for energy recovery. Energy recovery should be sufficient to supply requirements of the other toilet unit processes.

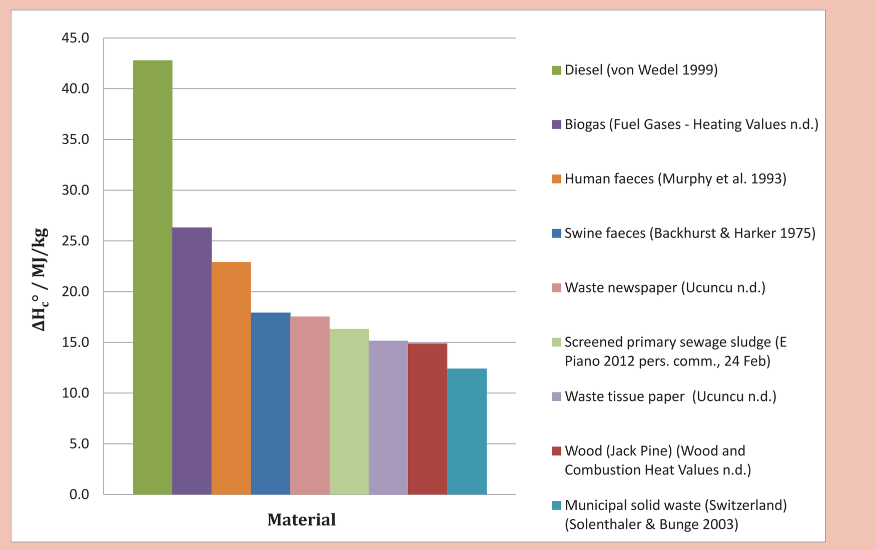
Sterile, nutrient-rich ash product produced for use in agricultural applications.

Design data requirements

The combustor should be designed to produce (i) the maximum amount of thermal energy possible and (ii) maximum recovery of useful nutrient components in the ash product. This will be dependent on the composition of the feed and the efficiency of the combustion process. The design data required includes:

- Chemical composition of the feed stream – concentrations of nitrogen, phosphorus, potassium and micro-nutrients present;
- Calorific value (energy content), specific heat and thermal conductivity of the feed stream;
- Determination of reactor conditions required for most efficient combustion (combustion temperature, feed moisture content, feed density)

FIGURE 10
Gross heat of combustion (dry solids basis) for different fuels



Little data has been found in the literature on the calorific value of human faeces. Figure 10 provides a comparison of the gross heat of combustion of different faeces-related fuels and 'conventional' fuels. The comparison indicates:

- Significant variation exists in calorific value between 'similar' fuels – e.g. wastewater sludge and animal faeces;
- The calorific value of a mixed solids stream (including toilet paper and newspaper) could be significantly different to a feaces-only stream.

Because of the reliance of the toilet processes on energy recovery from the faeces stream, it is critical to understand how much energy is available for recovery, and whether this will cover the energy requirements of the overall toilet system.

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