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Characterisation of chemical composition and energy content of green waste and municipal solid waste from Greater Brisbane, Australia

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ABSTRACT

The development and deployment of thermochemical waste-to-energy systems requires an understanding of the fundamental characteristics of waste streams. Despite Australia's growing interest in gasification of waste streams, no data are available on their thermochemical properties. This work presents, for the first time, a characterisation of green waste and municipal solid waste in terms of chemistry and energy content. The study took place in Brisbane, the capital city of Queensland. The municipal solid waste was hand-sorted and classified into ten groups, including non-combustibles. The chemical properties of the combustible portion of municipal solid waste were measured directly and compared with calculations made based on their weight ratios in the overall municipal solid waste. The results obtained from both methods were in good agreement.

The moisture content of green waste ranged from 29% to 46%. This variability – and the tendency for soil material to contaminate the samples – was the main contributor to the variation of samples' energy content, which ranged between 7.8 and 10.7 MJ/kg. The total moisture content of food wastes and garden wastes was as high as 70% and 60%, respectively, while the total moisture content of non-packaging plastics was as low as 2.2%. The overall energy content (lower heating value on a wet basis, LHV_{wb}) of the municipal solid waste was 7.9 MJ/kg, which is well above the World Bank-recommended value for utilisation in thermochemical conversion processes.

1. Introduction

Australia's urban waste streams are an untapped renewable energy resource. The space available for landfill is decreasing in our major cities, and the methane produced by landfilled municipal solid waste (MSW), green waste and biosolids is now recognised as a significant, long-term source of greenhouse gas emissions. Local authorities, state and federal governments, and the waste management industry now recognise opportunities in converting the energy in urban waste streams to renewable power or other energy products. There is a clear international precedent that modern waste-to-energy (WtE) plants are clean and efficient. With appropriate technology choice, it is technically feasible for a similar industry to be developed in Australia. This is evident by plans for two major projects in Western Australia to convert more than 200,000 tonnes of MSW into electricity annually (Pugh, 2014). Despite this encouraging activity, knowledge of the thermochemical properties of Australian waste streams is considerably lacking. Such knowledge is critical for effective planning and development of WtE projects.

Solid waste generated in Australia is usually classified into three main categories: municipal, commercial and industrial, and construction and demolition waste. An estimated 53 million tonnes of solid waste was generated from all sources in Australia during 2010–11 (Australian Bureau of Statistics, 2014). Of this, 27% was municipal (household) waste, equivalent to 14.3 million tonnes (with a per capita MSW generation rate of 660 kg/year). This is a significant increase compared with the per capita rate of 447 kg/year from just eight years earlier, in 2002–03 (Australian Bureau of Statistics, 2006).

Globally, MSW is usually managed in four major ways: recycling, composting, landfilling, and WtE. Despite the significant amount of energy that could be recovered from urban waste streams as renewable energy, Australia uses only the first three methods to manage MSW. The country has no large-scale thermal treatment facilities for the disposal of non-hazardous MSW; the last MSW incineration plant shut down in 1997 (NSW Environment & Heritage, 2014), and an attempt to develop a solid waste energy recycling facility in Wollongong, New South Wales, failed, with the plant shut down in 2004 (URS Australia, 2010).

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Nomenclature

C	carbon content (wt.%)
Cl	chlorine content (wt.%)
FW	food waste
Gdn W	garden waste
GW	green waste
H	hydrogen content (wt.%)
HHV	higher heating value (MJ/kg)
LHV	lower heating value (MJ/kg)
MC	moisture content (wt.%)
MSW	municipal solid waste
N	nitrogen content (wt.%)
n	number of waste components used in Eq. (6) (9 for combustibles of MSW)
NC	non-combustibles
O	oxygen content (wt.%)
O Plst	other plastic
OC	other combustibles
Pkg Plst	packaging plastic
Pkg Ppr	packaging paper
Pnt Ppr	printing paper
S	sulphur content (wt.%)
Tex	Textiles
W	weight of sample (g, kg)
WtE	waste-to-energy
WW	wood waste
X_i	weight fraction of respective component (dry basic fractions are used for dry-based values, wet basic fractions are used for wet-based values)
Y_i	property of each component of MSW
Y_{mixture}	property of mixed MSW

Subscript

Af	air-dried sample (final)
Ai	air-dried sample (initial)
c	container
db	dry basis
f	final (including weight of container)
i	initial (including weight of container)
Of	oven-dried sample (final)
Oi	oven-dried sample (initial)
wb	wet basis

Information about feedstock chemical properties and energy content is essential to the design and operation of any type of thermochemical conversion system, whether combustion or gasification-based. The energy content of MSW can be estimated based on average physical compositions using empirical models (Chang et al., 2007; Choi et al., 2008; Kathiravale et al., 2003; Lin et al., 2013; Liu et al., 1996). While this approach is quick and inexpensive, the downside is that the energy content of the type of organic waste in the country where the empirical model was developed is likely to differ significantly from that in the country where the model is applied. This variation is directly related to sociocultural properties; for example, differences in the amount and type of food wastes. Geographical and seasonal considerations also influence the quantity and type of waste generated in different countries. To avoid this uncertainty, waste samples should be systematically collected and prepared, and the energy content should be directly measured using standard laboratory apparatus such as a bomb calorimeter. Energy content can also be calculated from a sample's ultimate analysis, which usually lists the carbon, hydrogen, oxygen, nitrogen, sulphur and ash content of the dry fuel on a weight percentage basis.

Regular surveys have been conducted in Australia's major cities to understand the physical composition of MSW, which is routinely managed by local councils. For example, Swales (2013) reported that an average MSW stream (samples collected from Brisbane City Council's transfer stations in 2013) contained 53.3% of organic matter, 14.7% of plastic, 13% of paper, 4.2% of glass, 2.7% of metal, 11.6% of others and 0.5% of household hazardous. As MSW waste streams are landfilled according to the current waste management system, the surveys focus only on the quantity and distribution of wastes; determination of thermochemical characteristics is out of their scope. If WtE is to feature in strategic thinking and future planning, then the chemical characteristics of waste – in particular, the calorific value – become important.

Researchers from developing and developed countries have reported their findings of chemical characteristics, including calorific values of MSW samples, via direct measurement; [e.g. Algeria (Guermoud et al., 2009), China (Zhou et al., 2014), Greece (Komilis et al., 2012), Greenland (Eisted and Christensen, 2011), India (Kumar and Goel, 2009), Jordan (Abu-Qudais and Abu-Qdais, 2000), Korea (Choi et al., 2008), Spain (Montejo et al., 2011), Taiwan (Lin et al., 2013), Turkey (Yildiz et al., 2013), UK (Parfitt and Bridgwater, 2008) and USA (Chin and Franconeri, 1980)]. However, Australian data for this research area are scarce.

One of the challenges in analysing the chemical characteristics of MSW is the lack of a standard method for sample collection and preparation. While most researchers categorised and analysed the different physical components of MSW (e.g. food, paper, plastics, textiles, wood, glass, metals, etc.), Agrawal (1988) analysed only two fractions of MSW: combustible and non-combustible. Most researchers collected MSW samples directly from transfer stations, community bins and final disposal sites, sorting it into different categories later on (Brunner and Ernst, 1986; Chang et al., 2007; Gidarakos et al., 2006; Kumar and Goel, 2009; Yildiz et al., 2013), while some collected each category separately from different locations (Hanc et al., 2011; Katiyar et al., 2013; Komilis et al., 2012).

The work presented here begins to address the lack of data for Australian waste streams by developing a method to characterise waste in terms of chemical composition and energy content, and applying the method to MSW and green waste from Brisbane, Australia.[1] According to a Queensland Government's report, in 2012 the city of Brisbane generated 780 thousands tons of MSW which was directed to landfill sites via transfer stations (Department of Environment and Heritage Protection, 2013). The green waste stream consists primarily of garden waste (e.g. prunings, grass clippings, trees, shrubs), and is particularly important given the large size of Brisbane's catchment area and the region's subtropical climate. Our work represents the first step towards understanding the relationship between the energy content and composition of MSW in Australia, as part of a wider characterisation of the WtE potential of priority urban waste streams.

2. Methods

2.1. Sampling of green waste

Three samples of shredded green waste were collected from three Brisbane waste transfer stations over a 3-week period in February, which is towards the end of the warmer and wetter of

[1] Brisbane is the capital city of Queensland, on Australia's East Coast. Brisbane City Council is Australia's largest local authority.