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Rheological characterisation of biologically treated and non-treated putrescible food waste

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ABSTRACT

Food waste is gaining increasing attention worldwide due to growing concerns over its environmental and economic costs. Understanding the rheological behaviour of food waste is critical for effective processing so rheological measurements were carried out for different food waste compositions at 25, 35 and 45 °C. Food waste samples of various origins (carbohydrates, vegetables & fruits, and meat), anaerobically digested and diluted samples were used in this study. The results showed that food waste exhibits shear-thinning flow behaviour and viscosity of food waste is a function of temperature and composition. The composition of food waste affected the flow properties. Viscosity decreased at a given temperature as the proportion of carbohydrate increased. This may be due to the high water content of vegetable & fruits as the total solids fraction is likely to be a key controlling factor of the rheology. The Herschel–Bulkley model was used successfully to model food waste flow behaviour. Also, a higher strain was needed to break down the structure of the food waste as digestion time increased.

1. Introduction

Food waste is gaining increasing attention worldwide due to growing concerns over its environmental and economic (Hall, 2011). Food waste is commonly defined as "the waste produced towards the end of the food chain" and is sometimes reciprocally used with the term 'food loss' (Parfitt et al., 2010). An approximate estimate of food waste globally suggests that 30–50% of the total food produced is wasted (Lipinski et al., 2013; Matharu et al., 2016). Globally food waste generated per person is 160–295 kg/year or 1.2–2 billion tonnes per year in total (Fox and Fimeche, 2013). For instance, New Zealand generated approximately 330,000 tonnes per year of food waste in 2008 (Statistics NZ, 2008; Ministry for the Environment, 2010) valued at around $750–870 million (Edmunds, 2015; Johnston and Davison, 2015).

The carbon-containing (i.e. organic) components of food waste include waste from various food industries e.g. the dairy industry, waste associated with food processing, products past their use-by date and rotten foods such as fruits & vegetables. Food waste generally contains carbohydrates, vegetables & fruits, and meat/proteins in different fractions. Coffee and tea residues are also commonly found in food waste. A significant portion of food waste is currently disposed of in landfills (Yates, 2013), but this needs to be reduced because landfill space is limited. Furthermore, the expansion of the food industry is expected to generate more food waste (Parfitt et al., 2010) and attention is required to developing alternative methods of disposal.

Processes such as hydrothermal and biological treatment can offer sustainable and economically viable solutions for disposing of food waste because these methods are capable of breaking down food waste to simpler, and easily treatable materials (Bhargava et al., 2006). Hydrothermal treatment occurs in a liquid phase at elevated temperatures (423–593 K) and pressures (2–15 MPa) in the presence of oxygen and a residence time of 15–120 min (Debellefontaine and Foussard, 2000; Baroutian et al., 2013b). The biological process of anaerobic digestion is another technique to deal with growing amount of organic food waste because biodegradation of organic materials during anaerobic digestion generates some chemicals that can be used as fertilisers. Aerobic digestion of organic materials is generally considered more eco-friendly and environmentally sustainable than chemical treatments (Bernstad and la Cour Jansen, 2012; Uçkun Kiran et al., 2014; Liu et al., 2015).

The rheological properties of food waste need to be studied prior to using any treatment process in order to ensure that suitable equipment is used. Hydrothermal and biological treatment processes involve equipment such as pumps, heat exchangers,

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and mixing systems that require accurate flow behaviour and hydrodynamics information for the optimal and efficient design of processes (Mbaye et al., 2014).

Few studies have been published about food-waste rheology or flow properties. However, there are numerous studies that deal with the rheology of the individual food waste components: carbohydrates (Thebaudin et al., 1998; Rao, 2014), vegetables & fruits (Diamante and Umemoto, 2015), and meat (Tahergorabi et al., 2012). There are also several studies that examined the rheology of wastes or sludge. For example, Baroutian et al. (2013a) and Markis et al. (2014) studied the rheology of primary & secondary sludge mixtures and their relationships with solid contents and temperature. Both studies concluded that an increase in sludge solid content and decrease in temperature increased the yield stress of sludge.

The objective of this study is to examine the rheology of biologically treated and non-treated putrescible food wastes. A standard food waste mixture was developed and comparison groups with different compositions were made to investigate the effect of different food waste components on the flow and viscoelastic properties of food waste. Anaerobic digestion was used to treat food waste. The treated samples were tested in a standard anaerobic degradation batch assay, not in bioreactor. The study was further extended by monitoring the effect of dilution and digestion on the rheological properties of the food waste.

2. Methodology

2.1. Sample preparation

Common sources of carbohydrates, vegetables & fruits, meat and also coffee & tea waste are shown in Table 1. These sources or raw materials in different weight (wet weight basis) fractions (also presented in Table 1) were blended together using a hand mixer to represent carbohydrates, vegetables & fruits, meat and coffee & tea in a standard food-waste mixture. As a result, food waste slurries were obtained.

Due to the large variability in putrescible food waste composition, it is often useful to simulate food waste using a standard recipe (Campuzano and González-Martínez, 2016). Three distinct groups of food waste: carbohydrate mixtures (Group 1), vegetables & fruits mixtures (Group 2), and meat mixtures (Group 3) were produced as shown in Table 2. Each distinct group had three types (Type 1, 2 and 3) with three different compositions within that group. Three types of compositions of each group were selected based on minimum, middle, and maximum values of the specific content (e. g. carbohydrates) composition range within that group. Composition ranges used in this study are carbohydrates (2–15 wt %), vegetables & fruits (72–85 wt%), and meat (animal proteins e.g. pork mince) (1–8 wt%).

The standard food recipe used here (Table 2) was developed previously by various authors such as Izawa et al. (2001), Nakasaki et al. (2004), Komemoto et al. (2009), and Izumi et al. (2010). This standard food recipe is similar to the composition of food waste across the world in general, and across New Zealand in particular (Marshall and Yates, 2015; Reynolds et al., 2016). The composition of the standard food waste recipe used in this study is also shown in Table 2. The standard recipe contains 8.2% carbohydrates, 24.8% fruits, 53.6% vegetables, 4.9% meat, 8% coffee & tea, and 0.5% minerals (NaCl and egg shells).

2.2. Anaerobic digestion

Samples of the standard food-waste recipe were digested anaerobically with two replicates using sludge from an anaerobic digestion plant (the Rotorua Lakes Council wastewater treatment plant, Rotorua, New Zealand) to provide necessary microbes. The samples were tested using a standard anaerobic degradation batch assay (ASTM E2170-01, 2008). Briefly, a mixture of food waste, water, inoculum, and medium were added to a 160-mL serum bottle. The medium consists of many constituents in water such as KH_2PO_4, $NaHPO_4 \cdot 12H_2O$, NH_4Cl, $CaCl_2 \cdot 2H_2O$, Na_2S, $NiCl_2 \cdot 6H_2O$, and $FeCl_2 \cdot 4H_2O$. Reagent-grade chemicals were used in these experiments. More details about regent concentrations, preparation of

Table 1
Raw materials used to generate various food-waste components.

Carbohydrates		Vegetables		Fruits		Proteins		Coffee & tea waste	
Materials	Wt.%	Materials	Wt.%	Materials	Wt.%	Materials	Wt.%	Materials	Wt.%
Noodles	40	Cabbage	15	Orange	40	Basa fish	55	Ground coffee beans	50
Toast	21	Onion	12	Apple	30	Pork mince	45	Used tea leaves	50
Cooked rice	9	Potato	34	Kiwi fruit	15	–	–	–	–
Cooked bread	30	Lettuce	20	Banana	15	–	–	–	–
–	–	Tomato	9	–	–	–	–	–	–
–	–	Carrots	10	–	–	–	–	–	–
Total	100	Total	100	Total	100	Total	100	Total	100

Table 2
Quantitative food waste composition (% by weight) of various types.

Component	Group 1 (Carbohydrates content variant mixtures)			Group 2 (Vegetables & fruits content variant mixtures)			Group 3 (Meat content variant mixtures)		
	Type 1	Type 2 (Standard recipe)	Type 3	Type 1	Type 2 (Standard recipe)	Type 3	Type 1	Type 2 (Standard recipe)	Type 3
Carbohydrate	2.00	8.20	14.40	10.48	8.20	5.92	8.46	8.20	7.94
Coffee & tea waste	8.54	8.00	7.46	10.22	8.00	5.78	8.25	8.00	7.75
Fruits	26.47	24.80	23.13	22.90	24.80	26.70	25.58	24.80	24.02
Meat	5.23	4.90	4.57	6.26	4.90	3.54	1.90	4.90	7.90
Minerals[*]	0.53	0.50	0.47	0.64	0.50	0.36	0.52	0.50	0.48
Vegetables	57.23	53.60	49.97	49.50	53.60	57.70	55.29	53.60	51.91
Total	100	100	100	100	100	100	100	100	100

[*] Minerals include 60 wt% NaCl and 40 wt% egg shells.

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