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The characteristics of household food waste in Hong Kong and their implications for sewage quality and energy recovery

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ABSTRACT

Food waste (FW) is a worldwide environmental issue due to its huge production amount. FW separation from municipal solid waste followed by different treatment strategies has been widely accepted. Food waste disposer (FWD) is a promising approach to separate and collect household food waste (HFW), which has been widely applied in many countries. However, the feasibility of FWD application in many countries is still being debated due to the major concerns over the impact of FWD on the wastewater treatment plants. In order to investigate the feasibility of FWD application, FW characterization is a key work to be conducted in advance. Since the FW characteristics largely vary by region, reliable and representative FW characteristics in different countries should be investigated. To provide such information for further studies on FW management for Hong Kong, HFW was collected from Hong Kong typical households over one year and analyzed systemically in this study. The FW composition varied little from place to place or season to season, and the values observed were comparable with results reported from other countries and regions. Based on the reliable HFW characteristics obtained from one-year survey coupled with statistical analysis, simulated HFW for Hong Kong consisting of 50% fruits, 20% vegetables, 20% starchy food and 10% meat was proposed for future studies. On the other hand, the FWD treatment caused more than 50% of the biodegradable organic content in HFW to dissolve. With a ratio of 1 g food waste to 1 L sewage, total solids in the wastewater stream were predicted to increase by 73%, total chemical oxygen demand by 61%, soluble chemical oxygen demand by 110%, nitrogen by 6% and phosphorus by 16%. Theoretically, 22 million m^3/year of additional methane could be generated if 50% of Hong Kong residential buildings equipped with FWD. That would certainly increase pollutant loading on the wastewater treatment plants, but also energy recovery potential.

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1. Introduction

Food waste (FW) has been attracted increasing scholarly attention due to the fact that roughly one-third of global food generated for human consumption is discarded, which results in around 1.3 billion metric tons of annual FW globally (Gustavsson et al., 2011). FW has been regarded as a significant nutritional, environmental, economic and social problem, which makes reducing and treating it a worldwide issue (Platt et al., 2014; Thyberg et al., 2015). At the same time, FW with a high organic fraction is considered as a promising resource for energy recovery via anaerobic digestion (Breunig et al., 2017; Li et al., 2016; McCarty et al., 2011; Yano and Sakai, 2016). Landfill, the conventional disposal approach of FW, can harvest biogas as energy but occupies vast land resources. Such waste disposal approach limits the possibility of recycling the valuable energy and other resources in FW back into the economy (Breunig et al., 2017; Hiç et al., 2016). Separating FW from other municipal solid waste and further energy recovery can simultaneously minimize landfill utilization, reduce the FW disposal cost and realize environmental impact abatement.

This is particularly true in Hong Kong where over 1.2 million metric tons of FW were generated in 2015, representing 33% of total discarded municipal solid waste (HKEPD, 2015). Landfill is Hong Kong's sole means of FW disposal currently, rising concerns about the depletion of the territory's landfill capacity and other environmental impacts. To ease the landfill pressure, organic waste treatment facilities were proposed to deal with the commercial and industrial FW (HKEPD, 2017). However, commercial and

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industrial FW only occupies around 29% of FW, whereas 71% of FW is from the households (HKEPD, 2015). Therefore, Hong Kong, as a densely-populated megacity, should now seek economic and environmental sustainable alternatives for FW management, especially for household food waste (HFW) treatment.

Collecting and sorting HFW is troublesome, so channeling it into the sewer system using food waste disposer (FWD) is a promising technique (Battistoni et al., 2007; Kim et al., 2015; Mattsson et al., 2015). This technology has been applied widely elsewhere, with a penetration rate of 50% in the USA (i.e., 50% of households installed the FWD) (Iacovidou et al., 2012). However, the concerns over the impact of additional FW on the sewer system and wastewater treatment plants are still being debated (Iacovidou et al., 2012; Battistoni et al., 2007). Several studies have reported that the influence of using FWDs on a sewer system is insignificant, but wastewater treatment plants may need to deal with extra chemical oxygen demand (COD) and suspended solids (SS) (Battistoni et al., 2007; Thomas, 2011). Hence, before using FWDs for FW management in a large city, like Hong Kong, an extensive investigation of the projected impacts is necessary.

Characterizing the waste stream is a key step in determining which FW management approach would be most effective (Thyberg and Tonjes, 2015). For instance, the moisture content of FW from different sources typically varies from 66% to 80%, and the biodegradable organic fraction from 80% to 94% (Fisgativa et al., 2017, 2016; Kim et al., 2015; Li et al., 2008; Thomas, 2011), which can significantly affect the treatment efficiency and residual waste for disposal (Zhang et al., 2007). COD, carbon, nitrogen and their ratios need to be determined. Kim et al. has analyzed typical USA FW and found higher COD/N ratios in the soluble phase than in the particulates (63 versus 42) when 0.45 m filter paper was used to differentiate the soluble and particulate phases, indicating potential for biological nutrient removal enhancement (Kim et al., 2015). Moreover, pH and C/N ratio are the key to successful operation of anaerobic digestion or co-digestion (Zeshan and Visvanathan, 2012; Kumar et al., 2010; Zhong et al., 2013). FW collected in San Francisco with a C/N ratio of 15 has been demonstrated to be the optimum value for anaerobic digestion with good biodegradability and a high methane yield (Zhang et al., 2007), which might be significantly affected by addition of different amount of HFW. This can be proved by a study in a small town of Italy, where FWD penetration is 67%. The results showed that FWD application led to a maximum increase in SS of 11 g per capita per day, along with a 55 g increase in COD and a 2 g increase in total nitrogen (TN). COD/N rose from 9.9 to 12 and the rate of biological denitrification was increased by 27% (Battistoni et al., 2007).

However, FW characteristics vary greatly by region, by source and even by season (Fisgativa et al., 2016; Xue et al., 2017). Comprehensive, site-specific data are thus required when planning a FW management system. No such study has been conducted in Hong Kong, so in this study HFW samples were collected from three residential communities in Hong Kong over a one-year period. The samples were systematically analyzed to highlight any significant differences within and among the sampling locations. The resulting data were then used to define the potential implications of using FWDs in terms of sewage quality and energy recovery potential (i.e., theoretical methane production).

2. Material and methods

2.1. Sampling

To cover Hong Kong residents with different living conditions, three typical residential communities located in Hong Kong's Yuen Long, Tsuen Wan and Mei Foo districts were selected for sampling (designated as A, B and C respectively hereafter). Residential housing prices correlate with income levels, and average rents and prices increased from location A to C. The price range covers the housing costs of the majority of households in Hong Kong (HKISD, 2015).

Around two kilograms of FW samples were randomly collected soon after the residents discharged the separated FW in the morning at collection points in each residential community. FW samples were then sealed and delivered to environmental lab for analysis on the same day. The sample collection in each residential community was conducted twice a week from October 2015 to September 2016. Collecting for a year in these three communities was assumed adequately to represent typical HFW in Hong Kong and its temporal variation. A 100 g subsample of each sample was ground for roughly 1 min in a FWD (Evolution 100, InSinkErator, USA) with 1 L of tap water to simulate typical FWD operation (100 g FW/1.17 L tap water) (Marashlian and El-Fadel, 2005). The FWD effluent was then well mixed for the measurement of its physical and chemical properties.

Based on the observations during one-year sampling, fruits, vegetables, meat and starchy food were determined as the major components of the simulated HFW, and the compositions were proposed and characterized. Suggested recipe was analyzed according to the COD, N, and P contents comparing with survey results.

2.2. Analytical methods

The moisture content and organic fraction of the raw FW were first determined. The FWD effluent was subjected with pH, average particle size, total solids (TS), volatile solids (VS), total chemical oxygen demand (TCOD), and total phosphorus (TP) measurements without filtration. After filtration through a 0.45 μm filter (Millex-HV, Millipore, Germany), soluble chemical oxygen demand (SCOD), soluble nitrogen (SN), soluble Kjeldahl nitrogen (SKN), and soluble phosphorus (SP) levels were determined.

The moisture content, organic fraction, TS, VS, TN, SKN, TP and SP were determined according to the standard methods (APHA, 2005). Mean particle size was assessed using a laser diffraction particle size analyzer (LS 13 320, Beckman Coulter, USA). pH was measured with a multi-parameter portable meter (Multi 3420, WTW, Germany). Low-range COD (0–150 mg/L) vials were used for TCOD and SCOD digestion with a COD reactor (Model 45600-00, Hach, USA) at 150 °C for 2 h. The COD values of the digested samples were then determined by spectrophotometry (DR 2800, Hach, USA) at 430 nm. SN was measured using a TOC/TN analyzer (TOC-5000A, Shimadzu, Japan). Nitrite and nitrate were measured using an ion chromatograph (HIC-20A super, Shimadzu, Japan) equipped with a conductivity detector and an IC-SA2 analytical column (Shim-pack IC-SA2, Shimadzu, Japan). Ammonium was determined using a flow injection analyzer (QuikChem FIA + 8000, Lachat, USA). TP was digested with persulfate to oxidize phosphorus into SP. Then SP was analyzed using ascorbic acid method coupled with a UV/visible spectrophotometer (Lambda 250, PerkinElmer Inc., USA) (APHA, 2005). All the above tests were analyzed in the environmental lab in the Hong Kong University of Science and Technology.

2.3. Statistical analysis

At each sampling interval the characteristics of the waste from the three locations were first compared using Fisher's least significant difference (LSD) method. In addition, one-way analysis of variance (ANOVA) was used to evaluate the significance of any differences. A 95% confidence level ($\alpha = 0.05$) was adopted for deter-

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