Characterization of energy content in food waste by using thermogravimetric analyser (TGA) and elemental analyser (CHNS-O)

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Abstract. Food waste samples from various categories were examined for their energy content. In this work, the objective was to characterize the energy contents in food waste to assess their potential for renewable energy resources. The food waste samples that were analysed included tofu, carrot, corn, chicken, biscuit, rice and beef. The food wastes were characterized by proximate analysis using Thermogravimetric Analyser (TGA) and by ultimate analysis using Elemental Analyser (CHNS-O). The energy content in food waste was then evaluated using various higher heating value (HHV) correlations that were researched and established by many researchers. The results from both analyses demonstrated that the energy content from the higher heating value (HHV) calculated by using different equations indicated the food waste usage as an energy source. The highest HHV was found in the beef. Among the samples prepared, it can be observed that the most efficient ‘waste-to-energy’ sample is the protein-based food because this food has the highest amount of volatile matter with the lowest amount of ash content and fixed carbon content. Plus, protein food gives the highest percentages of carbon and hydrogen elements in order to help the combustion process going perfectly in order to convert it into an energy source.

1. Introduction

Alternatives for renewable energy have been sought and researched by many researchers. Their aims were mainly to address the energy crisis faced globally. As reported by the United States of America Energy Information Administration in 2016, energy demand will continue to expand almost 48% from 2012 to 2040[1]. This suggests that there is an urgency for substituting the fossil fuel energy with other alternatives, hence projecting the future of renewable energy feedstock from various sources. In addition, the emission from the combustion of fossil fuel to produce energy has adverse effects towards the environment. In recent years, researchers have focused on obtaining renewable energy from a wide variety of sources for instance, solar, wind, hydro, tidal wave, geothermal, and biomass particularly agricultural wastes. Also, research interest in anaerobic digestion of agricultural waste especially palm oil mill effluent has grown in the production of biogas as the renewable energy source. The merits of applying renewable energy are they are cleaner, simple to construct and assemble and emits less hazardous pollutants such as noxious and toxic compounds from the combustion of biofuels.

While many researches have reported the use of low moisture content of biomass, not many have focused on the use of food waste (FW) as renewable energy. FW is another type of biomass with high
moisture content. FW constitutes about 64% of municipal solid waste (MSW) in many parts of the world[2]. It is an organic waste discharged from various sources including food processing plants, and domestic/commercial kitchens, cafeterias and restaurants [3]. FW has been predicted to escalate in the next 25 years due to economic and population growth mainly in Asian countries [4]. Most of the time, FW ends up at landfill site, emits hazardous greenhouse gases. Most local authorities employ landfilling practice as disposal method without any further treatment to mitigate the problems associated with FW.

As FW poses environmental threats, research on FW has posed a serious economic along with environmental concern that sparked an awareness of FW[3]. In fact, research interest in FW has been growing rapidly in recent years. Increasing focus on FW has been given to the collection, minimization, treatment and energy recovery[5][6].

Research on FW for energy recovery has gained much interests from most scientists nowadays. FW can be converted into energy via two common technologies: biological (e.g. anaerobic digestion and fermentation) thermal and thermochemical technologies (e.g. incineration, pyrolysis, gasification and hydrothermal oxidation (Fig. 1)[7].

![Figure 1. Summary of food-waste-to-energy technologies](image-url)

Most often, the research on FW are focusing on the mixtures of edible and non-edible food such as fruits and vegetables peels; flesh and bones from poultry, fishes and meats; mixed cereals; oils and fats; and food packaging. FW separation has not been extensively implemented in many Asian countries particularly Malaysia due to various constraints which include low awareness among waste generators and low demand of products from food waste such as compost[8][9], animal feed, single-cell protein and other fermented edible products, baker’s yeast, organic acids, amino acids, enzymes (e.g. lipases, amylases, and cellulases), flavors and pigments, the biopreservative bacteriocin (from the culture of Lactococcus lactis on cheese whey), and microbial gums and polysaccharides[10].

FW by nature is an inherently complex component which makes it a very attractive source of value-added products. Due to its complexity, FW has not been thoroughly investigated as a potential energy source. Furthermore, the varied composition of FW mixture can influence the overall energy content, making it essential to individually characterize common FW constituents.

In the light of technological advances and motivational drive to utilize food waste as a raw material to both reduce the environmental burden of its disposal and address the concerns about future resources for energy, this study proposed a comprehensive understanding of the properties of FW individually through ultimate and proximate analyses. Through proximate analysis, the use of Thermogravimetric Analyser (TGA) provide a quantitative makeup of moisture, volatile matter, fixed carbon and ash. Meanwhile through ultimate analysis, the use of Elemental Analyser (CHNS-O) supplemented the
energy content evaluation by determining the contents of carbon, hydrogen, nitrogen, sulphur and oxygen. The heating value of a biomass can be determined experimentally by using a bomb calorimeter.

The use of bomb calorimeter, though relatively simple and accurate, may not always be accessible to all researchers. Therefore, to circumvent this problem, both TGA and CHNS-O can be used to estimate the energy content of a biomass[11]. The determination of energy content in specific FW can be obtained by employing established correlation in terms of high heating value (HHV). Therefore, this study sought out a better understanding of the characteristics of individual FW; and the relationship between energy content and proximate analysis factors using TGA; and the relationship between energy content between ultimate analysis factors using CHNS-O.

2. Materials and Methods

2.1. Food Waste Samples

The materials to be used for this experiment were a wide variety of food waste; sweet corn, carrot, white rice, biscuit, cooked tofu, cooked chicken and beef burgers. The FW samples were collected and prepared in two forms; wet and dried sample before the analyses. In order to prepare the dry feedstock material, it was dried by using conventional oven in a porcelain crucible at 50°C. After the analyses, the HHV for each sample can be calculated by using the equations provided in Table 1.

| No. | Equation | Based on | Unit | References |
|-----|----------|----------|------|------------|
| Eqn. (1) | \( \text{HHV} = 354.68C + 1376.29H - 15.92\text{Ash} - 124.69(\text{O+N}) + 71.26 \) | Proximate & Ultimate analyses | kJ/kg | [12] |
| Eqn. (2) | \( \text{HHV} = 0.1846 \text{VM} + 0.3525 \text{FC} \) | Proximate analysis | MJ/kg | [13] |
| Eqn. (3) | \( \text{HHV} = -1.675 + 0.3137C + 0.7009H + 0.0318O \) | Ultimate analysis | MJ/kg | [14] |
| Eqn. (4) | \( \text{HHV} = 0.3491C + 1.1783H + 0.1005S - 0.1034O - 0.0151N - 0.0211\text{Ash} \) | Proximate & Ultimate analyses | MJ/kg | [15] |
| Eqn. (5) | \( \text{HHV} = 0.1905\text{VM} + 0.2521\text{FC} \) | Proximate analysis | MJ/kg | [11] |

Note: The amount of element (C, H, N, O), ash, volatile matter (VM), fixed carbon (FC) are expressed in mass percentage.

2.2. Proximate analysis

TGA determined the moisture, volatile matter (VM) and ash content according to D1762-84 (ASTM, 2007). The analysis was run until the temperature reaches 1100°C, where the first step ran from 25°C to 950°C with heating rate of 20°C/min in 100 mL/min of nitrogen gas flow and second step ran from 950°C to 1100°C with heating rate of 20°C/min in 100 mL/min of air flow. For moisture content analysis, FW samples were dried at 105°C for 2 h (i.e. oven dry); for volatile matter samples were heated to 950°C for 11 min (covered crucible) and for ash content 750°C for a minimum of 2 h (uncovered crucible). The weight of the original sample, subtracted by its moisture content, ash content and volatile matter content (as determined by the aforementioned proximate analysis) corresponds to the stable carbon fraction of that sample and hence, this fraction is termed ‘fixed carbon or fixed-C fraction’.
2.3 Ultimate analysis
The ultimate analysis was performed using a Thermo Finnigan Flash EA 1112 Series Elementa
l Analyser CHNS-O. The elements that were analyzed are carbon, hydrogen, nitrogen and sulfur.
Oxygen content was not measured or calculated because of the interference of inorganic oxides in the
ash[16]. Prior to the analysis, all FW samples must be dried overnight in the oven at 50°C to reduce
its moisture content.

3. Results and Discussion
3.1. Proximate analysis.
Table 2 concluded the summary of the contents in each of the food sample. Overall, it can be seen that
wet FW samples exhibited high moisture content. For volatile matter, the results vary from one sample
to another because of the differences in their categories and contents. However, similar trends were
also being observed for which high VM present in all dry samples. The highest VM exhibited from
tofu could be contributed by the presence of fats. Both cooked chicken and beef also exhibited high
VM in which fat is believed to be the contributing factor [17]. Meanwhile, the presence of VM in
white rice and sweet corn indicate the presence of cellulose in the form of dietary fibre. The least
amount of VM was exhibited by carrot and this is due to the absence of fat and considerably high
amount of minerals exhibited by the ash content[18]. In addition, it is also noted that the low amount
of total carbohydrate and calories in carrot suggested the low fixed carbon content[18].

Table 2. The summary of the proximate analysis resulted from the thermogravimetry analyzer
(TGA).

| Food waste samples | Food categories | Type of sample | Moisture content (%) | Volatile matter (%) | Ash content (%) | Fixed carbon (%) |
|--------------------|----------------|----------------|----------------------|---------------------|----------------|-----------------|
| Sweet Corn         | Carbohydrate, Fat, Protein, Dietary Fiber | Wet           | 56.4                 | 21.0                | 20.7           | 1.9             |
|                    |                | Dry           | 0.3                  | 54.7                | 33.5           | 11.5            |
| Carrot             | Carbohydrate, Sugar, Fiber                | Wet           | 66.4                 | 5.0                 | 26.2           | 2.4             |
|                    |                | Dry           | 45.0                 | 8.3                 | 46.2           | 0.5             |
| White Rice         | Carbohydrate, Protein, Fat, Dietary Fiber, Sugar, Calcium | Wet | 53.9 | 25.0 | 12.6 | 8.5 |
| Biscuit            | Carbohydrate, Fats, Protein, Cholesterol, Sodium | Dry | 11.6 | 60.1 | 17.0 | 11.3 |
| Tofu               | Protein, Fat, Calcium, Iron, Carbohydrate, Fiber | Wet | 32.7 | 29.9 | 32.3 | 5.1 |
| Cooked             | Protein, Fat (include saturated fat), Cholesterol, Sodium | Dry | 14.0 | 73.4 | 3.7 | 8.9 |
| Chicken Burger     | Protein, Fat, Vitamin B12, Zinc, Iron, Cholesterol | Wet | 13.8 | 21.5 | 62.7 | 2.0 |
| Beef burger        | Iron, Cholesterol | Dry | 3.1 | 67.3 | 19.7 | 9.9 |

Proximate analysis of both dry and wet for all FW samples, are shown in Fig. 2 and Fig. 3
respectively. The first weight loss are shown at the temperature range from 30 to 100°C where
dehydration of the starting material took place. As can be seen, for wet samples in Fig. 3, there is a steep
drop of weight loss for all samples. Dehydration of wet FW samples are greater than that of dry samples.
Single stage decomposition is shown the TG plots (Fig. 2 & Fig. 3). The rapid decline in weight of wet
samples indicate that less volatile matter than in the dry samples. The dry sample contains more volatile
matter due to the easy-to-combust characteristics which is formed by changing its states from solid to
vapour.
Figure 2. The TG plot of dry FW samples.

Figure 3. The TG plot of wet FW samples

3.2 Ultimate Analysis
Ultimate analysis for all dry FW samples are presented in Table 3. The elemental content of C, H, N, S, O vary between all samples. All FW samples shows no presence of sulphur implies the benefits of utilizing FW as renewable energy source. The highest elemental percentage distribution recorded is carbon with 53% found in beef. The low carbon content in carrot indicates its low potential as an energy feedstock. Nevertheless, with the high content of ash in carrot, this suggest its potential additive in organic waste composting [19]. Meanwhile, the high amount of oxygen in corn and tofu have acceptable
heating value with high content of VM, carbon, hydrogen and oxygen[20].

Table 3. The summary of the ultimate analysis resulted from the elemental analyzer (CHNS-O).

| Food waste samples | Carbon, C (%) | Hydrogen, H (%) | Nitrogen, N (%) | Sulfur, S (%) | Oxygen, O (%) |
|--------------------|---------------|-----------------|----------------|--------------|---------------|
| Sweet Corn         | 43.1          | 6.8             | 2.3            | 0            | 47.8          |
| Carrot             | 13.1          | 21.4            | 3.5            | 0            | 62            |
| White Rice         | 40.1          | 6.7             | 0.1            | 0            | 53.1          |
| Biscuit            | 50.5          | 8.3             | 0.1            | 0            | 41.1          |
| Tofu               | 23.0          | 17.4            | 5.1            | 0            | 54.5          |
| Cooked Chicken     | 53.6          | 5.97            | 17.26          | 0            | 23.2          |
| Burger             |               |                 |                |              |               |
| Cooked Beef Burger | 53.0          | 8.8             | 4.0            | 0            | 34.2          |

3.3 Estimation of Higher Heating Values

The calorific data for all FW samples are shown in Table 4. The calculated values of HHV from Eqns (1), (3) and (4) do not vary very much from each other. The values were derived from elemental content in ultimate analysis. On the other hand, the calculated values of HHV from Eqn (2) and (5) were derived from the proximate analysis data. Similarly, the HHV calculated from these two equations do not differ much.

Beef constitutes the highest calorific value under ultimate analysis category. Meanwhile, tofu constitutes the highest under proximate analysis category. This can be attributed to only the values of VM and fixed carbon used in determining the HHV. The ash content and moisture content were neither counted nor considered in the calculation.

Table 4 The summary of the estimation of HHV for FW samples.

| Food waste samples | Eqn 1 (MJ/kg) | Eqn 2 (MJ/kg) | Eqn 3 (MJ/kg) | Eqn 4 (MJ/kg) | Eqn 5 (MJ/kg) |
|--------------------|---------------|---------------|---------------|---------------|---------------|
| Sweet Corn         | 17.936        | 14.151        | 18.132        | 17.375        | 13.320        |
| Carrot             | 25.267        | 1.708         | 19.405        | 22.350        | 1.707         |
| White Rice         | 16.610        | 15.078        | 17.289        | 16.043        | 14.298        |
| Biscuit            | 23.555        | 10.731        | 21.291        | 22.213        | 10.370        |
| Tofu               | 24.686        | 16.687        | 19.469        | 22.741        | 16.226        |
| Cooked Chicken     | 21.939        | 15.913        | 20.061        | 22.671        | 15.316        |
| Burger             |               |               |               |              |               |
| Cooked Beef Burger | 25.881        | 13.840        | 22.207        | 24.829        | 13.758        |

The variation of calculated HHV using different correlations is as expected. However, the values presented in Table 4 provide a good indication to estimate the calorific value. The calculated HHV for sweet corn derived from ultimate analysis is in agreement with HHV reported by C-Y. Yin et al [11] and [21]. Similar findings have been observed in the HHV for carrot in its own category as vegetable[22]. Processed and baked food such as tofu, chicken and beef burger and biscuits respectively represent food that may contain additives such as preservative, colourings, stabilizers and coagulants. The mixtures may have some influence on the HHV as compared to their raw materials; soy bean, raw
chicken and beef, and wheat flour. Tanai [22] reported that baked food product of the same category with biscuit, the HHV of white bread and whole grain bread are 13.03 MJ/kg and 12.65 MJ/kg respectively. The HHV of biscuits is higher than that of the two breads might be due to the higher fat content in biscuits, another source of carbon that affects the calorific value of biscuits. The HHV calculated for tofu also lies in the same range between 20 – 25 MJ/kg, similar to what has been reported by Uzun et. al [23].

Beef sample exhibited the highest HHV in its own category from protein group. The HHV calculated for beef from proximate analysis data is almost similar to what has been reported by Tanai [22]. In view of the results obtained, the HHV calculated for all FW samples do not differ much from that of HHV for empty fruit bunch from palm oil[24], raw saw-dust[25], coconut fibre, sugarcane basses, rice husk and eucalyptus leaves[26]. It is also important to note that it is comparable with that of coal[26]. Nevertheless, the values obtained are very much less than that of fossil fuels. The calorific value for fossil fuels are more than 40 MJ/kg, for instance, HHV for gasoline is 46.4 MJ/kg and natural gas 52.2 MJ/kg.

4. Conclusion
This work was devoted to characterize the energy content of various types of food waste. This was performed by analysing the elemental content and combustion and thermal behavior of food waste. It can be concluded that biomass from food waste can be used as substitute for energy source. Beef sample contained the highest amount of energy, indicating its potential for energy production. Overall, the calculated values of HHV shows a strong correlation with experimental HHV obtained from literature. Hence, the presented results show that both TGA and CHNS-O can be used to estimate and predict the calorific value using appropriate correlations.

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