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Analyzing Irbid's Food Waste as Feedstock for Anaerobic Digestion

Assal E. Haddad

***Abstract*—**Food waste samples from Irbid were collected from 5 different sources for 12 weeks to characterize their composition in terms of four food categories; rice, meat, fruits and vegetables, and bread. Average food type compositions were 39% rice, 6% meat, 34% fruits and vegetables, and 23% bread. Methane yield was also measured for all food types and was found to be 362, 499, 352, and 375 mL/g VS for rice, meat, fruits and vegetables, and bread, respectively. A representative food waste sample was created to test the actual methane yield and compare it to calculated one. Actual methane yield (414 mL/g VS) was greater than the calculated value (377 mL/g VS) based on food type proportions and their specific methane yield. This study emphasizes the effect of the types of food and their proportions in food waste on the final biogas production. Findings in this study provide representative methane emission factors for Irbid's food waste, which represent as high as 68% of total Municipal Solid Waste (MSW) in Irbid, and also indicate the energy and economic value within the solid waste stream in Irbid.

***Keywords*—**Food waste, solid waste management, anaerobic digestion, methane yield.

I. INTRODUCTION

IRBID is a rapidly growing city that doubled its population in the last 20 years, making it the most dense city in Jordan; with a population density as high as 1,126 person per kilometer square [1]. This is mainly due to surges of refugees that fluxed into Jordan at numerous occasions because of the volatile political conditions of neighboring countries. Recently, 657,000 Syrian refugees entered the Northern Jordanian border; 140,000 of which are located in Irbid at the moment [2]. This sudden increase in population not only affected the quality of waste management municipal services, but it is actually draining the landfills' capacities reducing their expected lifespan.

The solid waste annual generation rate in Irbid is approximately 487,000 ton, 85% of which is currently being landfilled [3]. The landfill accepting this flow is not lined nor has any installed gas collection system. The current situation is not only releasing increasing amounts of methane, but it is also increasing the risk of ground water pollution. At the moment, applicable waste management options diverting waste away from the landfill include incineration, composting, or anaerobic digestion.

The National Energy Strategy is anticipating a 10% contribution from renewable energy sources to the national energy supply by 2020 [4]. Currently, Jordan spends nearly 20% of its Gross Domestic Product (GDP) on energy imports that accounts for 97% of its energy needs. Renewable energy sources account only for 2% of the total electrical generation; 60.4% hydropower, 21.1% biomass, 9.7% PV and 8.8% wind. Irbid's MSW has distinctively high biodegradable content, which is typical of developing countries' solid waste. Food waste was found to represent, on average, 68% of the MSW in Irbid "unpublished" (Fig. 1), [5]. With such a high biodegradable content, Irbid's solid waste is perceived as a valuable source of energy.

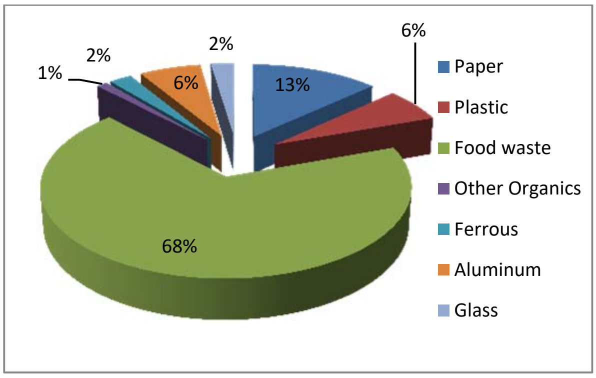

Fig. 1 Solid Waste characterization for Irbid

The high moisture content, however, presents a considerable challenge when thermochemical conversion technologies are the choice for energy extraction, thus, methane generation appears to be the more appropriate choice at this stage. Biogas production from organic wastes depends on chemical properties of waste; such as carbon, hydrogen, and nutrient content, physical properties; such as moisture content and particle size, and other operational factors; such as pH, temperature, and mixing.

A. Cases of Energy Recovery from Anaerobic Digestion of Food Waste

Singapore was able to divert 10-15% of its food waste to anaerobic digesters in 2010 while sending the remaining flow of food waste to incineration [18]. A Singapore-based company IUT Global Pte. Ltd. conducts the recycling of food waste combining both anaerobic digestion method and composting [19]. The produced bio-gas from the anaerobic digestion process is utilized by gas engines that generate energy, which is then sold to the national grid. Residues from the anaerobic digester are converted into bio-compost. Methane emissions are avoided in the composting process since microorganisms responsible of breaking down the residues function under aerobic conditions. There are two

A.E. Haddad is the Chair of the Civil Engineering Department at the American University of Madaba, P.O.Box 2882 Amman 11821 Jordan. (phone:962-77-2412424; fax: 962-5-3294440; e-mail: a.haddad@aum.edu.jo).

phases during the waste food recycling process; both depend on similar anaerobic digestion processes but differ in capacity. Phase I had an installed capacity of 3.5 MW power and treated 300 tons of food waste per day. The digestate material is then sent to composting plant I to produce bio-compost. Phase II has an installed capacity of 6 MW power and treats 500 tons of food waste per day; digestate from Phase II is sent to composting plant II [20]. The total capacity of both phases I and II is able to achieve the goal of 800 tpd (tons per day) food waste recycling for all of Singapore [6].

In UK a food waste anaerobic digester plant was established in March 2006 operating on mixed kitchen and garden waste collected from domestic properties for the first 9 months of operation. In less than a year, the feedstock was gradually switched to food waste only. The plant processes a total of 9.2 tons each day. The biodegraded waste consisted of domestic food waste (95.5%), commercial food waste from restaurants and local businesses (2.9%), and small amount of whey, and grass cuttings (1.6%). The food waste received at the plant is initially shredded in a rotary counter-shear shredder to reduce the particle size. Afterwards, the waste is passed to a feed preparation vessel where it is mixed with recirculated whole digestate and macerated to give a particle size less than 12 mm. The waste was fed into the digester through a buffer storage tank that provides three days of storage, which allows continuous feeding over weekends and public holidays. The digester itself is a 900 m3 tank that is completely mixed by continuous gas recirculation. The digestate is maintained at 42 °C by external heat exchangers. The temperature was empirically chosen based on previous experience and preference of the plant operator. The digestate was passed batch-wise to a pasteurisation tank that is 60 m^3 in volume, where it is heated to 70 °C for a minimum of one hour. Pasteurised digestate is then transferred to the digestate storage tank where it is kept for local farms to be used as separated fibre, liquor or whole digestate on agricultural land. The biogas generated, on the other hand, is used to produce electricity using a 195 kW MAN Combined Heat and Power (CHP) unit with an electrical conversion efficiency of 32% at full load and a potential for 53% recovery of heat via the jacket and exhaust cooling water streams. Electricity produced and exported to the grid is metered. A portion of the produced heat is returned into the process. [7]

In California an anaerobic sludge digester uses food waste from a local food waste processing facility together with a local wastewater treatment plant's sludge. Food waste is being grinded to form slurry which is then added their anaerobic sludge digesters. Due to closing of some industries that were previously supplying material for anaerobic treatment, the district has excess capacity in their digesters. The process of codigestion of the source separated organics and the biosolids is performed in two mesophilic and two thermophilic reactors without any noticeable difference in their performances. Odor is not an issue in this particular case since the facility is located in an industrial zone. Also, the relatively great size of the waste water treatment plant and the manner in which the source separated organics are received requires no odor control [8]. In 2008, approximately 22,000 tons of food waste was processed [9]. Despite the restrictions of the environmental regulations to use the full capacity of the energy facility; electricity generated covered 90% of the onsite electricity usage. The excess amount of the biogas is flared and the solid residuals are used as landfill daily cover [8].

In Canada there are two anaerobic digestion plants located in Ontario that serve the city of Toronto and the surrounding communities. The two plants use the biotechnische abfallverwertung GmbH (BTA) patented technology. The plant in Dufferin has the single-stage BTA configuration while the plant in Newmarket uses the two-stage process configuration [10], [11] Source separated organics are the main feedstock for both plants collected from the Toronto's residential Green Bin and the commercial Yellow bag collection program. The city of Toronto now collected over 110,000 metric tons of food waste and had plans for expanding the program to include "multi-family" apartment buildings [10].

B. Literature Review

Baky et al. collected only the rice portion of food waste and used an existing wet digestion biogas plant to measure the methane potential for rice and compared that to simulated values from the PRO II software [12]. Opatokun et al. examined samples of raw food waste and digested food waste through analyzing the product of both pyrolysis and anaerobic digestion to finally evaluate the treatment effect, product yield, and their physiochemical properties [13]. Wang et al. characterized the product of food waste samples' anaerobic biodegradation in terms of methane potential and anaerobic toxicity of leachate produced from food waste biodegradation [14]. Zhang et al. collected numerous samples of food waste in the city of San Francisco to assess their potential use as feedstock for anaerobic digestion, accounting for variations in food waste characteristics during different days and weeks [15].

Previous studies have focused on the biodegradable portion of food waste, as means to describe the methane potential, overlooking the actual proportions of food types found in the analyzed waste. This study aims at measuring methane potential for seven food types found in Irbid's food waste after thorough characterization of the food waste's major contents and chemical composition, and to also investigate the temporal qualitative variability in the food waste stream. The methane potential measured results will be compared to calculated values that were based on volatile solids content. The findings of this study will help in replacing default values used in Life Cycle Inventories for integrated waste management assessment studies carried out in Jordan, as well as assigning methane potential values for different food types.

II. METHODOLOGY

A 1 kg food waste sample was collected twice a week from 3 houses in rich neighborhood (RH), 3 houses in poor neighborhoods (PH), 3 houses in middle class neighborhoods (MH), 3 restaurants (Rst), and 3 malls (M). Samples were collected on a weekday and a weekend to address the variation during the week. Samples were sorted into four main food categories; rice (R), meat (M), fruit and vegetable (FV), and bread (B) following ASTM D-5231 [16]. To account for the sizes of each population from which a sample was taken, weights have been assigned to every tested sample; allowing the design of a food waste sample that represents the entire city. Hence, measured weights for each food type were multiplied with the weighting factor assigned previously using (1):

$$ADW_C = 0.1DW_{CRH} + 0.4DW_{CMH} + 0.1DW_{CPH} + 0.2DW_{CM} + 0.2DW_{CR} \quad (1)$$

where ADW_C: Adjusted Daily Weight of waste component, DW_{CRH}: Daily Weight of waste component from houses in rich neighborhood waste sample, DW_{CMH}: Daily Weight of waste component from houses in middle class neighborhoods waste sample, DW_{CPH}: Daily Weight of waste component from houses in poor neighborhoods waste sample, DW_{CM}: Daily Weight of waste component from Malls waste sample, DW_{CR}: Daily Weight of waste component from Restaurants waste sample.

A weighted average value for the weekly percentage of each food waste component was calculated using (2):

$$\text{WWc\%} = \frac{\left(\frac{5}{7}\right)\text{ADWcwd}+\left(\frac{2}{7}\right)\text{ADWcwe}}{\left(\frac{5}{7}\right)\text{ADWtwd}+\left(\frac{2}{7}\right)\text{ADWtwe}} \quad (2)$$

where WWc%: weekly percentage weighted average of food waste component, ADWcwd: weight of food waste component sampled on a weekday, ADWcwe: weight of food waste component sampled on the weekend, ADWtwd: total weight of food waste sampled on a weekday, ADWtwe: total weight of food waste sampled on a weekend.

Every week, three average values of food type composition were generated. To test the weekly variation over the 12-week period of the study; one way ANOVA was used with alpha = 0.05. Each type of food was measured for total and volatile solids, following the standard methods of American Public Health Association [17], and methane yield. Two identical representative food waste (RFW) samples were created (based on all 25 samples and their proportionality factor). Volatile Solid fraction of the RFW was measured on wet weight basis (g VS/g RFW) to normalize methane production. Samples were tested in a batch anaerobic digester to measure their methane yield. Two 1-L digestion bottles were prepared with 10 g VS, and 100 mL bacteria (from local wastewater treatment plant digester).

A blank sample containing only bacteria was also prepared to account for the methane produced solely by the bacteria. All digesters were then filled up to 500 ml, and they were mixed using a magnetic stirrer for 1 minute/day. Biogas was measured using the water displacement technique. After 30 days (when biogas production is negligible), biogas was collected and sampled to analyze the CH_4:CO_2 ratio using a gas chromatography. A control biogas sample with a CH_4:CO_2 ratio of 60:40 was used for calibration. Measured values of methane yield for RFW samples were compared with calculated methane yield based on the representative sample's food type composition and each food type's methane yield.

III. Results and Discussion

Average food type composition over the entire study period for rice (R), meat (M), fruits and vegetables (FV), and bread (B), were found to be 39%, 6%, 34%, and 23% [Figs. 2-5]. The ANOVA tests showed no significant difference within the weekly values of waste composition for rice, vegetables, and bread. P-Values from the ANOVA analysis were 0.236, 0.276, and 0.067 for rice, vegetables, and bread respectively. However, meat had a P-value of 0.041 indicating a significant difference in meat composition within the 12 week period of the study, probably because of the higher variety of meats as compared to other types of food analyzed.

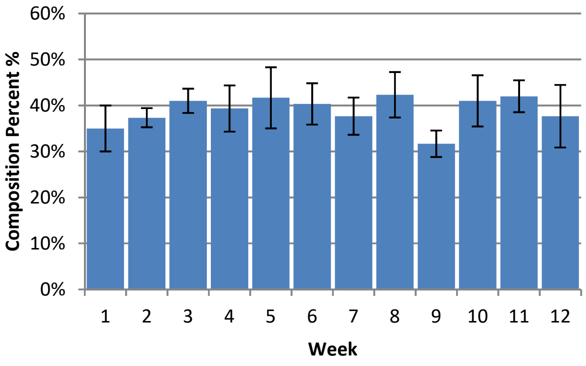

Fig. 2 Weekly average Rice percent composition of food waste and y error bars indicating standard deviation

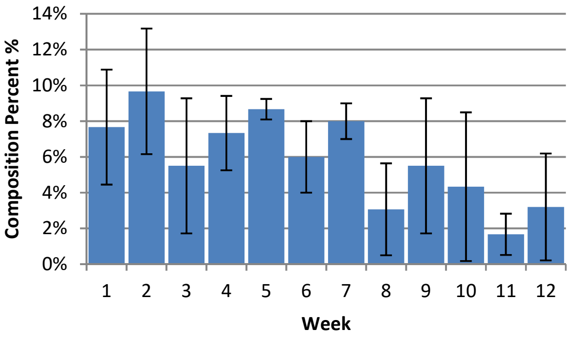

Fig. 3 Weekly average Meat percent composition of food waste and y error bars indicating standard deviation

Methane yield for rice, meat, fruits and vegetables, and bread were 362, 499, 352, and 375 mL/g VS, respectively. The average methane production for the RFW was 414 mL/g VS which was greater than the methane yield calculated (377 mL/g VS) using the representative food proportions multiplied by their measured methane yield. This was probably because missing nutrients in one food type can be found in another food type providing a comprehensive diet for bacteria to anaerobically digest mixed foods.

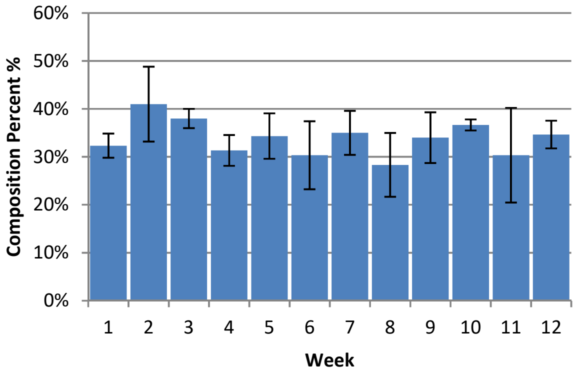

Fig. 4 Weekly average Fruits and Vegetables percent composition of food waste and y error bars indicating standard deviation

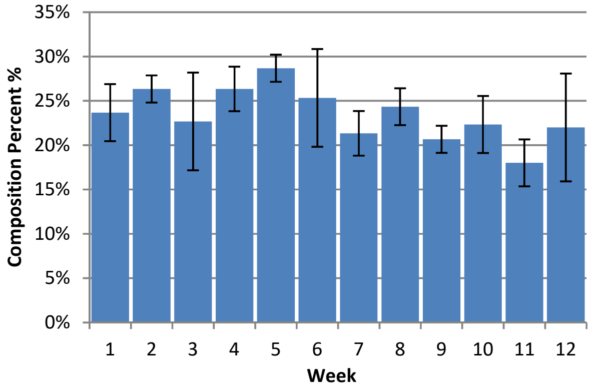

Fig. 5 Weekly average Bread percent composition of food waste and y error bars indicating standard deviation

IV. CONCLUSION

Meat was found to have the greatest methane potential, and also represented only 6% of Irbid's food waste. However, Irbid's food waste continues to have a great value as a source of renewable energy because of its extremely large volume production rate, and also because of its high bread content which was the second highest methane producer. Weekly variation in meat content was significant because of the wide range of food that was categorized as "meat (M)". Methane yield can be affected by many properties such as bone density, fat, and moisture content. Also, meat can be processed in several ways that can affect the digestion process or the quantity of VS available. Rice, bread, and fruits and vegetables, on the other hand, are relatively more homogeneous in structure and chemical composition. Difference between actual measured methane and calculated values that were based on methane potential of Volatile Solids of each food type reassures the established scientific and engineering fact that the anaerobic digestion process is affected by a combination of substrate's chemical properties and bacteria's specific reaction to such environment. Future research should investigate the thermal energy content of each food type (in the same separate manner done in this study) to be able to conduct a full and accurate Life Cycle Assessment on food waste management planning in Irbid.

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