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Biogas Production by Anaerobic Fermentation of Hotel Food Wastes

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HOTELS face many issues related to managing and reducing food waste, as there is an estimation that one-third of the worldwide whole food production is wasted per annum. The disadvantages of failing to safely dispose of food waste appear through the rotting of organic materials and their transformation into greenhouse gases, which harm the surrounding environment. According to UK statistics, about 289,700 tons/year of waste are produced; where 79,000 tons of such wastes are food wastes. Where, Only 43% of these amounts were recycled each year. Therefore, it becomes evident that some effective technologies should be used to convert this amount of food waste into a form of renewable and environmentally friendly energy. Anaerobic digestion is a promising source for clean energy, where such food wastes are digested in the absence of oxygen by methanogenic bacteria to produce a mixture of carbon dioxide and methane. This mixture is called a biogas. It is employed to generate electricity and heat to run hotel equipment, and in addition, biogas fertilizer is produced as a by-product. The importance of recycling food waste is to produce environmentally friendly alternative energy, reduce energy consumption, reduce gas emissions and, reduce organic solid wastes by converting those to fertilizers with high nutritious value.

Keywords: Anaerobic digestion, Biogas production, Hotel food wastes, Recycling.

Introduction

Food waste problem

Food waste (FW) is a serious environmental issue in the 21 century worldwide (Li et al., 2018; Thompson & Haigh, 2017) after the increased global interests in the depletion of fossil fuels and the global warming resulted from the higher emission of greenhouse gases and other pollutants (De Clercq et al., 2016). The global production of municipal solid wastes was estimated to be 2.01 billion tons of solid wastes in 2016. 32-50% of those wastes are considered to be organic wastes. By 2050, the production of such wastes is predicted to reach 3.4 billion tons (de Jonge et al., 2020).

FW can be produced from hotels, companies, restaurants, canteens, and families. The total solids (TS) account for 18.1-30.9%, whereas the 17.1-26.35% could be volatile solids (VS) (Chen et al., 2017). Therefore, significant environmental pollution and pathogen proliferation are associated with FW because of the increased moisture percentage and hence increased degradation rate. The food banks estimated an annual food loss of 1.3 billion tons worldwide. It accounts for about 1/3 of the global food production (but even more than 40% in Canada and USA) and this quantity will increase as the population and economy increase (Wang et al., 2019). In Europe, it is 100 million tons with the an average value of the loss of 179kg/year per capita (but in the

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Netherlands up to 579kg) and consumers are the main responsible for this state of affairs. According to FAO (2019), a high amount (34%) of food is wasted across the Near East and North Africa (NENA) region which leads to many serious problems that include the insecurity of food supply, elevation of food imports, water shortage and consequently severe environmental impacts. This region of the world accounts for 68% of the food chain supply early stages that start from the production sites to the retails (Abiad & Meho, 2018; Baig et al., 2019). The VS, proteins and carbohydrates contents are relatively high in FW that is also characterized by a high C:N ratio. This ratio is considered to be a suitable candidate to undergo anaerobic digestion. Yet, one should note that FW contains heterogeneous components that affect the balance of the nutrients and substrate properties (Fisgativa et al., 2017; de Jonge et al., 2020). Berjan et al. (2018) showed that, FW ranged from 265 to 790 m^3/capita/year in Yemen and UAE, respectively. In particular, elevated living standards and urbanization in Gulf Cooperation Council (GCC) countries led to an enormous production of municipal solid wastes (MSW)which were estimated to reach 8 million tons annually (Nizami et al., 2017).

In KSA, different types of wastes are produced in large quantities mainly in the form of organic wastes from the industrial section, MSW, and sewage. 3.0 Million Tons of Oil Equivalent (mtoe) in KSA are assessed to be the overall biomass energy potential (Khan & Kaneesamkandi, 2013). This makes KSA to come after Egypt, Sudan and Morocco and to be in the 4th place. Furthermore, the generation of solid wastes in the kingdom of Saudi has increased significantly to be 15 million tons (with an average rate of 1.4-1.75kg/capita/day) exceeding most of the countries in the gulf area (Ouda et al., 2016). There are many other factors that worsen the situation like the generation of high volumes of vegetable and fruit wastes in multiple sites of the KSA because of the heavy touristic activities to the holy sites, urbanization and increased population. According to Waqas et al. (2018a), only 10-15% of MSW was recycled in KSA, while the rest was disposed in landfill. FW is surely a very complicated problem that requires different approaches to be solved. In response, KSA and FAO are working together to put action laws and to have suitable strategic schemes to achieve the main goal of reducing and recycling FW (Baig et al., 2019).

Food waste of hotel industry

FW generated by hotels has the most visible impact on the environment (Mensah, 2020). According to the World Bank report, 3.4 billion tons/year of waste will be generated worldwide by 2050, compared to the present value of 2.01 billion tons/year (de Jonge et al., 2020). Hotels are considered as the leader of tourism development contributing to the waste problem in tourist destinations by producing huge amounts of wastes. This is due to the nature of their characteristics, functions and services. Moreover, hotels tend to consume extensive amounts of water, energy and non-durable products (Zorpas et al., 2015). Typically, a hotel guest can produce 1 kg/day of waste that accumulates to thousands of tons of waste annually according to the International Hotels Environment Initiative (IHEI, 2002) (Ghadban et al., 2016). Therefore, the increase in food waste is a key concern of the hospitality industry. However, the rate of waste production is depends on the type, size, and the waste management facilities of the hotel (Abdulredha et al., 2018).

Accordingly, the harmful impact of hotels on the environment has attracted customers' attention. Additionally, in the past few decades, guests' demands for environmentally responsible lodging have rapidly increased. Therefore, the hospitality and tourism sector has become increasingly concerned about its impact on the environment (Goncalves et al., 2016). Despite this, the landfill is considered as primary waste management in small hotels. Furthermore, the lack of attention to environmental responsibilities, FW management by small hotels resulted in lack of funds, knowledge and poor decision-making (Ghadban, et al., 2016). Accordingly, the award-winning hotels of the future will offer the most amenities and those with sufficient waste management facilities. Therefore, every hotel should have a wide variety of energy saving options, which can be decided after a serious energy audit and a cost-benefit study (Parpairi, 2017).

According to the study of Sandaruwani et al. (2016), the hotel industry sector is considered as the most energy consumers and food waste producers. Consequently, the rapid growth of the hotel industries can make an additional problem for the sustainability of the destination. The production of solid wastes by hotel are categorized under food and non-recyclables [46.2%], cardboard [11.7%], paper [25.3%], glass [5.6 %], plastic [6.7%], and metal [4.5%]. Accordingly, a large amount of food waste is produced by the hospitality sector compared to the other types of solid waste. This will create more challenges in the efficient use of this foodstuff and the disposal of their own waste. Hence, more efficient waste management can bring significant savings depending on the waste management regulations in that sector. Other benefits of eco-friendly waste management include an improved hotel industry image, reduced GHG emissions from the decreased transportation of waste, reduced costs due to smaller order requirements from suppliers, improved relations with stakeholders, reduced risks and liabilities, and health and safety benefits (Ball & Taleb, 2010).

Huang et al. (2012) confirmed that hotels are considered the most energy-intensive buildings due to their multi-usage functions and continuous operations. As a result, decreasing energy consumption across the hotel often leads to less operational cost and less environmental impacts. Al-Aomar & Hussain (2017) showed that hotel supply chains are increasingly recognizing their ability to make an environmental contribution by reducing their consumption of water and energy in addition to less solid waste production. Moreover, coastal hotels were particularly interested in waste management (recycling and regenerating through food production and fertilizing hotel grounds) and alternative energy sources (solar, wind and biogas energy sources).

Food waste management in hotels

Proper treatment is needed for different wastes based on their composition and properties. Afterward, wastes are sorted to select the biodegradable ones that could be a potential substrate in a biogas plant. The wastes and the land volumes play an important role in determining the waste treatment option where the biogas option is the best choice when the available land is limited. Hotels are found to handle and manage wastes very efficiently and in an environmentally friendly approach. The recycling and the consequent elimination of wastes significantly reduce the emission of GHG and avoid further ozone depletion. Hence, it can reduce the rate of global warming and the pollution percentage. Anaerobic digestion for food wastes is sought to be a very effective tool for energy production in addition to its positive environmental impacts (Chen et al., 2017).

Reid et al. (2017) investigated the desalination of reticulated water using "retrofitting diesel fired boiler with biomass gasifier" and heating systems based on biogas plants. Such innovative approaches have numerous economic advantages as well as their sustainable outputs strengthening the work of Chen (2015). Such efforts are very inspiring to the hotel industry since the tourism industry is committed to being a green and sustainable industry, like many other sectors that anticipated their responsibilities toward the environment (Huang et al., 2014). The term "green" means the arrangements that could decrease the hazards on the environment by recycling for instance (Banytne et al., 2010). Similarly, and according to Green Hotel Association, "green hotel" can be described as an eco-friendly facility that operates with comprehensive environmental practices to create positive contributions as showen in Fig. 1. Such practices include saving energy, water, employing eco-friendly policies and decreasing wastes emission/disposals with increasing approaches for recycling projects to keep the earth we live in and reduce operational costs (Rahman & Reynolds, 2016). Recently, several hotel brands have been seen to be proactive towards their environmental performance and to be actively green functioning (Chang et al., 2014). Kuminoff et al. (2010) discussed the differences between operating as a green facility to reduce the costs of water and energy consumptions and the high costs that are initially needed in the adaptation process. The high cost of the adaptation process is considered a big obstacle for small hotel businesses (Chang et al., 2014).

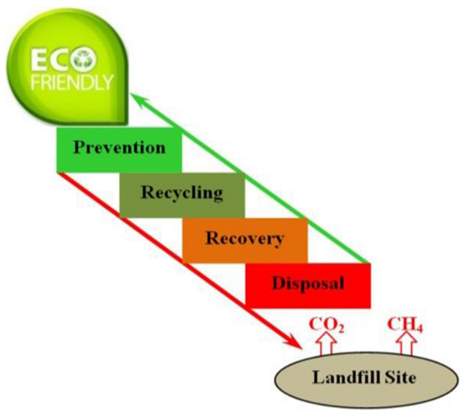

Fig. 1. Eco-Friendly management of food wastes.

Food Waste-to-Renewable Energy

Renewable energy is now attracting most of the research interests and research funding for a sustainable energy source. The expansion and dependence on renewable energy sources still need more financial mechanistic support. The most convenient mechanisms nowadays are energy auctions and feed in tariffs (Atalay et al., 2017). Several techniques are implements for processing wastes into added value products like the production of biogas, organic fertilizers and chemical (Jara-Samaniego et al., 2017; Waqas et al., 2018b; Khan & Kaneesamkandi, 2013). The evaluation of the KSA wastes as well as the available feedstocks, revealed that AD will be the most proper waste treatment strategy since most of the wastes consist of organic matter. Another key factor that favors over any other energy treatment strategy is the tropical nature of KSA and hence its high temperature throughout the whole year (Baig et al., 2019). That's why the new vision for Saudi Arabia (SV2030) has set several renewable and sustainable energy (RnSE) projects with the ultimate goal of producing 9.5 GW (Khan, 2017; Amran et al., 2020) in response to the predicted high energy demand of the kingdom by 2032 (120 GW) (Salam & Khan, 2018).

Anaerobic digestion has many more advantages over gasification, land filling and incineration. Methane (CH_4) and nitrogen as ammonia (NH_3) are generated by AD and aerobic digestion of organic wastes. AD produces digestates that are rich nutrient sources for soils and plants (Waqas et al., 2018a) and hence it is considered nowadays as a major technology for energy production from organic wastes and KW treatment (Ali et al., 2019; Wang et al., 2019). AD based on its environmental impact is a clean and green technology for generating energy (Chen et al., 2017). The digestion is mainly done by microbial action in an anaerobic condition to breakdown organic material into CH_4 and CO_2. The process is affected by many factors like, temperature, pH, solid waste content, C:N ratio and ratio of feed: inoculum (Li et al., 2018; Ali et al., 2019). The biogas slurry amount can significantly increase the biogas generation by AD which in consequence can be utilized to produce heat energy and/or electrical energy. Moreover, the digestate, which is the process residual, could be utilized as a biological fertilizer instead of the synthetic one (Wang et al., 2019). Pauer et al. (2019) showed how the pre-treatment of FW with microwave exposure, bead mill, can significantly enhance the biogas yield.

Anaerobic high-solid treatment (HST) is a potential way in the treatment of organic wastes (Abdelsalam et al., 2020). The HSTs have a convenient yield of biogas upon the processing of such wastes (0.4–0.6 Nm^3 CH_4/kg volatile solids) according to Westerholm et al. (2020). Some reports demonstrated that it could produce twice methane more than that the biological treatment of manure and wastewater sludge (Fisgativa et al., 2017). Such yield stresses the importance of FW as an important energy source via AD process either by complete digestion or co-digestion with mixed organic wastes. (Sembera et al., 2019). Equation 1. summarizes the conversion of food wastes to biogas (Mirmohamadsadeghi et al., 2019):

$$C_cH_hO_oN_n S_s + wH_2O \rightarrow mCH_4 + nNH_3 + sH_2S + (c - m)\ CO_2 \quad (1)$$

where, *m* and *w* are the reaction variables depending on the elemental components of carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulfur (S); $m= 1/8(4c + h - 2o - 3n - 2s)$ and $w= 1/4(4c - h - 2o + 3n + 3s)$.

The degradable fraction of food wastes mainly includes carbohydrates ($C_6H_{12}O_6$), proteins ($C_{13}H_{25}O_7N_3S$), and lipids ($C_{12}H_{24}O_6$).

The main gas produced by the bio digestion of FW in biogas plants is methane that can be purified to generate electric power. Two biogas generators with a capacity of 30-50kVA (kilo volt ampere) can be used to power a whole hotel or lighten a road with 1000 volt-amps. Biogas production would help in the consumption of high sewage volumes and FW that are produced by various city buildings (Zamanzadeh et al., 2017; Srivastava et al., 2020). Lou et al. (2013) demonstrated in their study that AD processing of FW could lessen the energy problem by producing sufficient heat and/or electricity. Since one ton of FW could be converted to 247m^3 methane that is equivalent to 89.78GJ heating potential or electrical generation amounting to 847kWh (Thi et al., 2015).

Despite the huge capacity of biogas plants, their establishments are not spread out as one should assume. This could be attributed to the high initial funding investments for constructing such plants which can't be afforded by many hotel facilities especially the small ones (Mensah, 2020)

The Microbiology of AD of Food Waste

There is an increasing interest in the microbial AD of FW. High throughput sequencing schemes that utilized 454 and Illumina platforms were employed to describe different microbiomes involved in AD (Shi et al., 2018).

Bacterial phyla *Firmicutes, Acteroidetes, Chloroflexi* and *Proteobacteria*are are the general microbial candidates of the diverse involved microbiome in the AD of FW. They are not exclusive to AD of FW as they could be seen in other AD treatments of different substrates and systems as shown in Fig. 2 (Zamanzadeh et al., 2016).

Different microbial organisms account for specific individual treatment stages and have syntrophic relationships with each other. Hydrolyzing bacteria produce exoenzymes like xylanase, lipase and amylase where they are adsorbed on the surface of the substrate and initiating the hydrolytic process (Mirmohamadsadeghi et al., 2019). The hydrolytic process breaks down the polymers into monomers and water soluble oligomers (e.g. amino acids, glucose, glycerol and fatty acids). This stage is considered to be the rate limiting step of the production of biogas from high weight wastes. Afterwards, the resulted water soluble oligomers are further degraded into alcohols, gaseous by-products (CO_2, H_2S, NH_3 and H_2) and short fatty acid chains (acetate, lactate, propionate and butyrate) via acidogenesis stage. Facultative anaerobic bacteria can consume the unfavorable generated oxygen in the first stages to keep the anaerobic condition needed by the obligatory anaerobic microorganisms. In the latter stage, the produced organic matter is turned into hydrogen, CO_2 and acetic acid. Eventually, methane is generated by methanogens from methyl, acetate and CO_2. Methanogenesis is considered the rate limiting step of biogas production from low buffering capacity wastes (de Jonge et al., 2020). Many bacterial strains could be the key methanogen microbe such as *Methanothermobacter, Methanoculleus, Methanosaeta, Methanothermobacter* and *Methanobacterium*. They are determined via the operating temperature and reactor configuration (Koo et al., 2019). Moreover, there is low methanogenic species diversity as *Methanoculleus bourgensis* accounts for 88.7±3.5% in FW digester. This bacterial species can coexist with other methanogenic species in the process of FW and/or recycling wastewater (Lee et al., 2018; Koo et al., 2019).

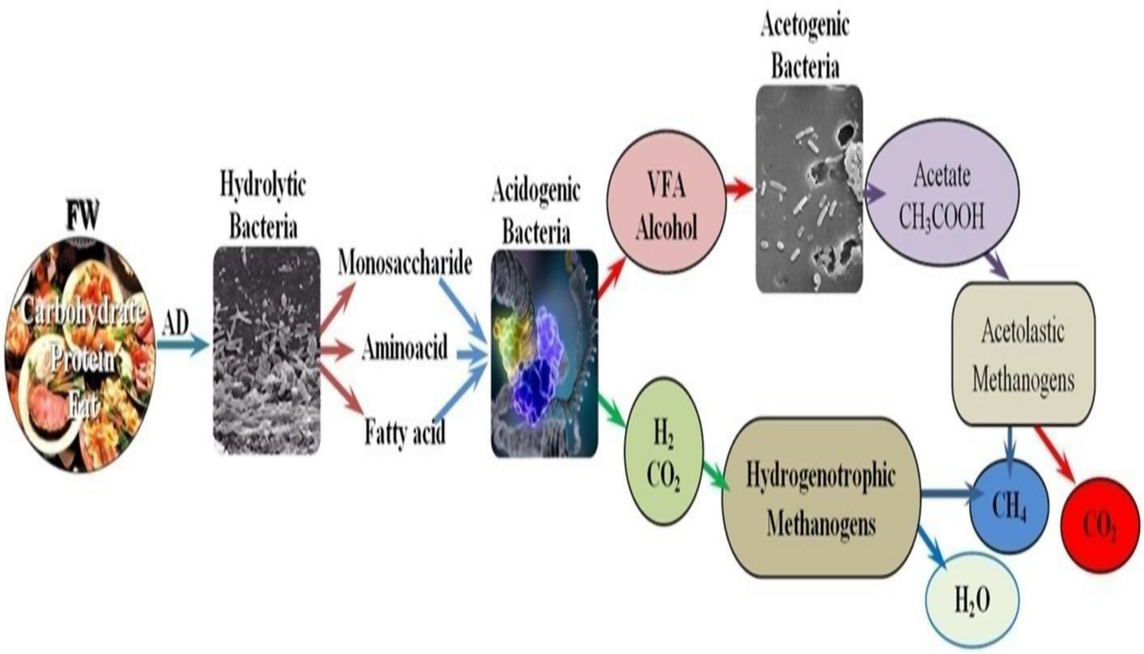

Fig. 2. Stages of anaerobic digestion of food wastes (Srisowmeya et al., 2020).

Conclusion

Wasted food is a serious environmental problem worldwide. There are different sources of Food Waste such as restaurants, canteens, families, companies and hotels. Hotels industry contributes to food waste problem due to their functions, characteristics and services. Therefore, eco-friendly hotel operations that implement comprehensive environmental practices to create positive contributions to protect the earth we live in have increasing attention to hoteliers. Accordingly, anaerobic digestion of food wastes to produce biogas is considered a suitable technology for food waste management for hotel industries. Hence, biogas is a clean and potential source for the production of heat and electrical energy that are needed to operate hotel facilities and in addition; biogas fertilizer is produced as a by-product. One of the most challenges to waste management of food wastes via anaerobic digestion is the awareness of hotels guests. As the awareness increases of such management the growth of green hotels will be increase. Therefore, the impact of hotel guests' trends toward recycling of food waste should be taken in consideration to determine the intentions of customers to visit such green hotel.

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إنتاج الغاز الحيوي عن طريق التخمير اللاهوائي لمخلفات طعام الفنادق

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تواجه الفنادق العديد من المشكلات المتعلقة بإدارة وتقليل نفايات الطعام، حيث تشير التقديرات إلى أن ثلث الإنتاج الغذائي العالمي يتم هدره سنويًا. وتظهر مساوئ عدم التخلص الآمن من نفايات الطعام من خلال تحلل المواد العضوية وتحويلها إلى غازات دفيئة، مما يضر بالبيئة المحيطة. ووفقًا لإحصاءات المملكة المتحدة، يتم إنتاج حوالي 289700 طن/ سنة من النفايات؛ حيث وجد ان 79 ألف طن من هذه النفايات عبارة عن نفايات غذائية. ويتم إعادة تدوير 43% فقط من هذه الكميات كل عام. لذلك، يصبح من الضروري استخدام بعض التقنيات الفعالة لتحويل هذه الكمية من نفايات الطعام إلى شكل من أشكال الطاقة المتجددة والصديقة للبيئة. ويعتبر التحلل اللاهوائي مصدرًا واعدًا للطاقة النظيفة، حيث يتم تحلل مثل هذه المخلفات الغذائية في غياب الأكسجين عن طريق بكتيريا تخليق الميثان لإنتاج خليط من ثاني أكسيد الكربون والميثان ويعرف هذا الخليط بالغاز الحيوي. حيث يتم استخدامه لتوليد الكهرباء والحرارة لتشغيل معدات الفنادق، وبالإضافة إلى ذلك، يتم إنتاج سماد الغاز الحيوي كمنتج ثانوي. لذلك تكمن أهمية إعادة تدوير مخلفات الطعام في؛ إنتاج طاقة بديلة صديقة للبيئة، تقليل استهلاك الطاقة، تقليل انبعاثات الغازات، وتقليل النفايات الصلبة العضوية عن طريق تحويلها إلى أسمدة ذات قيمة تسميدية عالية.