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Environmental Advantage Assessment of Recycling Food Waste in Riyadh, Saudi Arabia

Ibrahim M. Alruqaie and Badr H. Alharbi

National Center for Agriculture Technology (NCET), King Abdulaziz City for Science and Technology, P.O. Box 6086 Riyadh 11442, Kingdom of Saudi Arabia

Corresponding Author: Ibrahim M. Alruqaie, National Center for Agriculture Technology (NCET), King Abdulaziz City for Science and Technology, P.O. Box 6086 Riyadh 11442, Kingdom of Saudi Arabia

ABSTRACT

Increased food waste production in major cities of Saudi Arabia is a challenge to environmental pollution. The main objective of this study was to investigate the environmental assessment of recycling food waste in Riyadh, Saudi Arabia. The study was carried on food waste samples collected from restaurants in a governmental organization. Among the various pollutants methane gas production was significantly higher than other gaseous pollutants. Food waste sample contained mostly rice, bakery products, meat and fat contents. On relative basis, the CH₄ emission was 99% (0.33 g) of the total gaseous emission in the experimental system. The other 1% of emission was due to some other gases in descending order as NH₃ (4×10^{-4} g) > CO (2.1×10^{-4} g) > H₂S (2×10^{-4} g) > SO₂ (5.6×10^{-5} g). The average methane production was highest after 98 days of digestion at a temperature less than 50°C. The study showed the potential for safe disposal of food waste in Riyadh, Saudi Arabia in order to mitigate the environmental pollution resulting from land disposal of food waste in and around the capital study. The study also earmarked the areas for future study of safe disposal and recycling of food waste in Saudi Arabia.

Key words: Food waste, methane emission, different biogases, environmental pollutants, mitigation

INTRODUCTION

It is well known that biological breakdown of organic matter produces a complex containing a variety of gases (Farquhar and Rovers, 1973; DeWalle *et al.*, 1978). Some of these emitted gases are known to be odorous while others are known to be greenhouse gases or toxic pollutants. These gases include, among others, sulfur dioxide (SO₂), hydrogen sulfide (H₂S), carbon dioxide (CO₂), methane (CH₄) and volatile organic compounds (VOCs) with the main proportions being for CH₄ and CO₂ forming approximately 50 and 40%, respectively (Al-Omar *et al.*, 1987; Tchobanoglous *et al.*, 1993; El-Fadel *et al.*, 1996). Both the methane (CH₄) which accounts for twenty one times more greenhouse effect than CO₂, but CO₂ has important implications on climate since these absorb infrared radiation and affect tropospheric and stratospheric ozone (O₃), respectively (Seinfeld and Pandis, 2006). Bouallagui *et al.* (2004) compared the performance of anaerobic digestion of Fruit and Vegetable Waste (FVW) in the thermophilic (55°C) process with those under psychrophilic (20°C) and mesophilic (35°C) conditions in a tubular anaerobic digesters on a laboratory scale. They further stated that the production of biogas was 144 and 41% less by psychrophilic and mesophylic digesters, respectively when compared to the production of same gas by the thermophilic digester used in this study. Similar trend was observed for the production of

net energy which was lower in the thermophilic digester than psychrophilic and mesophilic digesters.

Therefore, recycling food waste will certainly contribute to greenhouse gases mitigation efforts. Furthermore, the technology for utilization and recycling food waste is vital for clean, friendly and sustainable environment, because otherwise the harmful pollutants and greenhouse gases will be emitted into the atmosphere which produces odors and pathogens that can cause diseases as a result of food waste decomposition.

Up to now, little is known about the quality and quantity of different types of gases produced and emitted into the atmosphere during the decomposition processes of conventional Saudi food wastes. In this study, emissions of SO₂, H₂S, CO, CH₄ and NH₃ produced during decomposition process of conventional Saudi food wastes (a mixture of meat, chicken, rice, bread and vegetables) were studied quantitatively in a laboratory scale set-up.

MATERIALS AND METHODS

The experiment was carried at Food Technology Laboratory, National Center for Agricultural Technology (NCAT), King Abdulaziz City for Science and Technology (KACST), Riyadh Kingdom of Saudi Arabia during 2011.

Collection of food waste samples: Representative samples of conventional Saudi food wastes were collected from different restaurants of the capital city Riyadh, Saudi Arabia. Food waste was placed in a pilot scale close system in the laboratory. As the biological breakdown of organic matter in the food waste started in the experimental set-up, the concentration of six gases (SO₂, H₂S, CO, CH₄, O₂ and NH₃), temperature and humidity were monitored in the system by two instruments called RKI EAGLE and Testo, respectively. The experiment was run for a period of about three months. The experiment consisted of seven time periods. Each period was of 14 days. So the time of different periods was first period [14 days], second period [28 days], third period [42 days], fourth period [56 days], sixth period [70 days] and the seventh period [84 days]. This was followed by quantitative calculations of pollutants that would be emitted into the atmosphere if the food waste recycling was not fully utilized, were carried based on the results from the laboratory scale system and the food waste disposal statistics in Riyadh city.

Experimental setup: The experimental setup consisted of a 14 L plastic container, a representative sample of conventional Saudi food waste (a mixture of meat, chicken, rice, bread and vegetables) and the two monitoring instruments. The food waste sample was collected from the restaurant of KACST (King Abdul Aziz City for Science and Technology) in Riyadh city. The sample was ground to fine pieces. Then, 1 kg of the ground sample was placed into 2 L glass container and sealed into the large 14 L plastic container which was connected to two instruments designated for monitoring the emitted gases, temperature and humidity in the sealed container. It is an admitted fact that the biodegradation process of food waste is accelerated with an increase in temperature of the system until an optimum temperature is reached above which the degradation rates decline. This optimum temperature has been reported within the range of 50-62°C in small scale systems (Haug, 1993). Therefore, the system was placed in temperature controlled environment to maintain temperature below 60°C (~20°C) that is suitable for biodegradation process of food waste in the system. Many researchers reported that maintaining sufficient moisture content in the system is vital for active biodegradation process (De Bertoldi *et al.*, 1983; Westlake, 1995; Christensen *et al.*, 1996). Optimum moisture content was reported within the range of 50-70% while the moisture content less than 20% can severely inhibit the biodegradation

Table 1: Proportion of different types of constituents in food waste sample

	Rice		Bakery products		Meat		Fat		Bones		Fruit and vegetables	
Total food waste (kg)	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
29.62	11.47	38.72	5.55	18.74	7.45	25.15	3.86	13.03	0.65	2.19	0.64	2.16

process (Polprasert, 2007). Therefore, approximately 1 L of water was added to the system for maintaining sufficient moisture content in the system during the experimental time.

Physical constituents of food waste sample: Food waste samples were collected from the left over of Restaurant of King Abdulaziz City for Science and Technology (KACST), Riyadh Kingdom of Saudi Arabia. The food waste sample contains a variety of different types of food items such as rice, bakery products, fat, bones and, fruit and vegetables. On relative basis, the percentage of different types of items in a representative food waste sample was 38.72 (rice), 18.74 (bakery products), 25.15 (meat), 13.03 (fat), 2.19 (bones) and 2.16 (fruits and vegetables) as given in Table 1 according to KACST (2009).

Data analysis: Data were analyzed by ANOVA and regression techniques for treatment evaluation at 5% level of significance according to SAS Inst. (2001).

RESULTS AND DISCUSSION

Chemical composition of food waste sample: The representative food sample was analyzed for chemical composition. Different parameters (expressed as %) were moisture (38.4), carbohydrates (25.56), crude protein (17.26), crude fat (15.27), fiber (0.3) and ash (3.21). The results showed that food waste samples is rich in carbohydrates, crude protein and fat contents while fiber and ash were in small amounts (Table 2).

Evaluation of different types of gases: The relative percentage of pollutant emissions in the system during the study period is shown in Fig. 1. The CH₄ emission was 99% (0.33 g) of the total gaseous emission in the experimental system. The other 1% of emission gases included NH₃, CO, H₂S and SO₂. The sequence of these gases in descending order of production was NH₃ (4×10⁻⁴ g)>CO (2.1×10⁻⁴ g)>H₂S (2×10⁻⁴ g)>SO₂ (5.6×10⁻⁵ g). Data in Fig. 1 indicated that the production of methane (CH₄) was significantly higher than all other gases emitted from the food waste. The results agree with the findings of Lee *et al.* (2009) who reported the methane yield of Food Waste Leachate (FWL) to be 358 and 478 mL g⁻¹ VS after 10 and 20 days of digestion, respectively, with an average methane contents of 70%. Also they obtained the highest methane yield of 403 mL g⁻¹ VS at 35°C due to the adaptation of seed microorganisms to mesophilic atmosphere while methane yields at 25, 45 and 55°C were 370, 351 and 275 mL g⁻¹ VS, respectively. Similarly, Zhang *et al.* (2007) reported the methane yield of 348 and 435 mL g⁻¹ VS, respectively after 10 and 20 days digestion. The average methane contents of biogas was 73% while the average VS destruction was 81% at the end of the 28-days digestion test. The present study results coincide well with the results of Cho *et al.* (1995) who reported the methane yields of food waste at 37°C and 28 days digestion time. The results were 482, 294, 277 and 472 mL g⁻¹ VS for cooked meat, boiled rice, fresh cabbage and mixed food wastes, respectively. The methane yield was higher in the present study than the findings of Heo *et al.* (2004) who evaluated the biodegradability of a traditional Korean food consisted of boiled rive (10-15%), vegetables (65-70%) and meat and eggs (15-20%) and reported that after 40 days methane yield of 489 mL g⁻¹ VS could be obtained at 35°C.

Table 2: Proximate chemical composition of experimental food waste sample

Ash (%)	Fiber (%)	Crud fat (%)	Crud protein (%)	Carbohydrates (%)	Moisture(%)
3.21	0.3	15.27	17.26	25.56	38.4

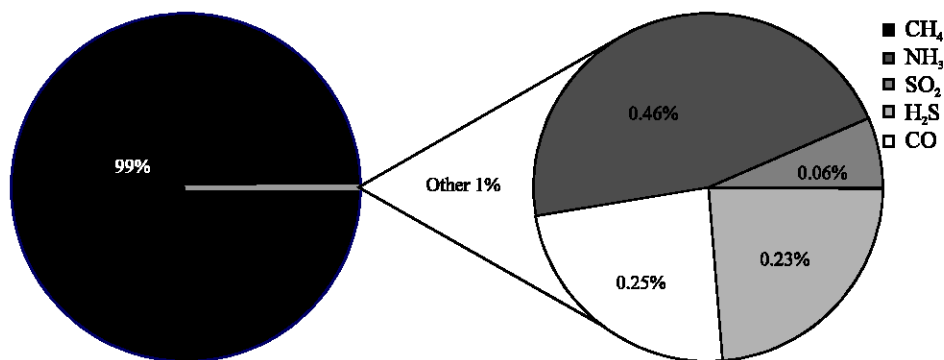


Fig. 1: Relative proportion of pollutant emissions in the experimental system

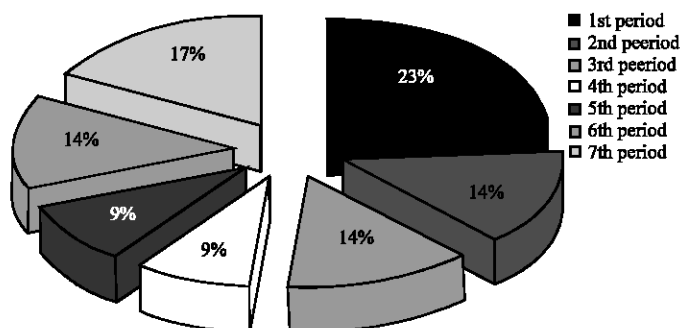


Fig. 2: Emission of CH₄ during different time periods

Furthermore, the study period was divided into seven (nearly) equal periods for comparison. Each period was approximately of 14 days. On relative basis, the rate of production of CH₄ from food waste was 23, 14, 14, 9, 9, 14 and 17% during 1st, 2nd, 3rd, 4th, 5th, 6th and 7th study period, respectively. This variability in production could be due to the decomposition of different types of organic matter from food waste at different time periods and conversion of organic material to inorganic form by producing various gases in the system (Fig. 2). In the case of NH₃, the production was 7, 13, 13, 9, 14, 21 and 23% during 1st, 2nd, 3rd, 4th, 5th, 6th and 7th study period, respectively. The NH₃ production showed substantial increase towards the end of study. This might be due to delay in the conversion of organic nitrogen (NH₄) to gaseous form (NH₃) due to bacterial activity and low oxygen concentration under aerobic conditions with higher biological activity consuming more oxygen (Fig. 3). The production of CO was 27, 3, 21, 19, 16, 6 and 8% during 1st, 2nd, 3rd, 4th, 5th, 6th and 7th study period, respectively. The production of CO was higher during the early period of study which could be attributed to higher decomposition of organic matter as compared to other materials in the food waste (Fig. 4). The SO₂ production was 37, 5, 23, 20, 15, 0 and 0% during 1st, 2nd, 3rd, 4th, 5th, 6th and 7th study period, respectively. The significant higher SO₂ production in the initial study period could be due to higher aerobic

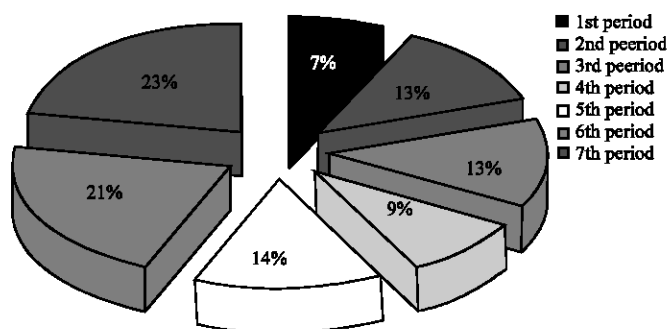


Fig. 3: Emission of NH_3 during different time period

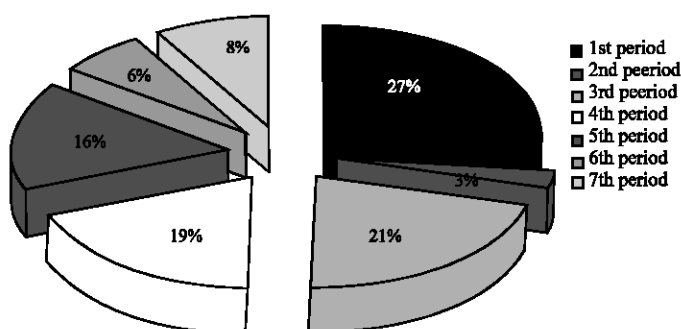


Fig. 4: Emission of CO during different time period

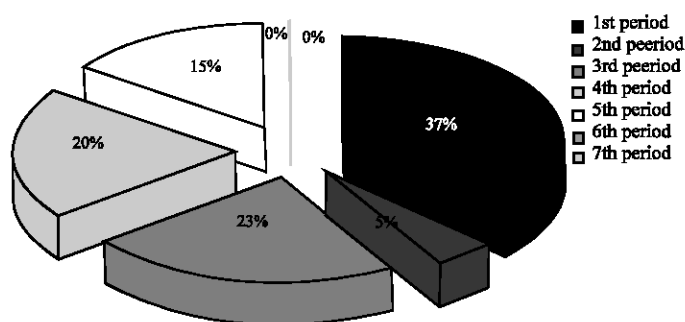


Fig. 5: Emission of SO_2 during different time period

conditions than the last period of study due to the availability of more oxygen in the system (Fig. 5). Similar to SO_2 , the production of H_2S was 36, 20, 17, 8, 7, 6 and 6% during 1st, 2nd, 3rd, 4th, 5th, 6th and 7th study period, respectively. The relative higher concentration of H_2S during early study period might be due to reduced conditions in the system due to anaerobic conditions (Fig. 6).

The statistical presentation for the concentration of measured gases in the study is presented in Table 3. Data show that the mean concentration of various gases was CH_4 (23616308.33 m^3), NH_3 (28899.20 m^3), CO (14593.45 m^3), H_2S (14363.20 m^3) and SO_2 (3933.73 m^3) during the study period. The sequence in order of increasing trend for production of various gases came as to $\text{CH}_4 > \text{NH}_3 > \text{CO} > \text{H}_2\text{S} > \text{SO}_2$.

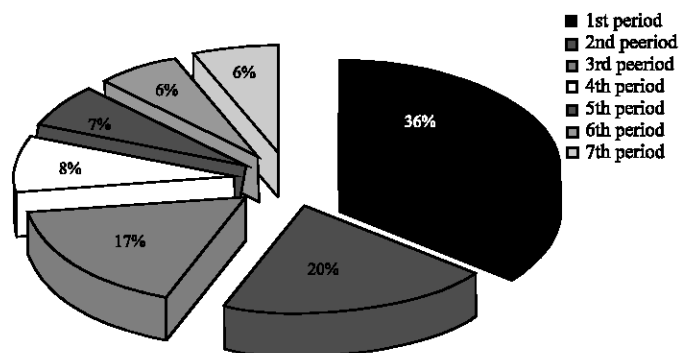


Fig. 6: Emission of H₂S during different time periods

Table 3: Estimation of different gases from food waste in the experimental system during studied periods

Period	CH ₄	NH ₃	CO	H ₂ S	SO ₂
Mean					
1	38846045.62	14477.91	27157.32	35986.83	10208.92
2	23451814.24	25443.58	2604.57	20183.57	1199.17
3	22842295.59	26765.89	21703.45	16912.38	6379.05
4	14153509.96	18745.90	19288.12	8480.50	5585.92
5	14892184.20	28548.63	16085.29	6523.93	4107.85
6	22602117.10	43117.42	6595.34	6138.04	55.22
7	28526191.63	45195.10	8720.03	6312.17	0.00
Mean	23616308.33	28899.20	14593.45	14363.20	3933.73
SD	8400014.737	11513.71	8896.33	na	3788.42
Maximum					
1	86610118.94	26353.30	58495.12	141574.23	41025.86
2	39878530.46	43813.17	3503.70	24100.56	1344.41
3	26832612.86	52909.57	69787.43	29285.86	12262.85
4	23262476.10	33356.95	45361.83	18335.74	17014.84
5	25921044.80	46355.24	34917.52	9008.43	18350.38
6	28434244.80	52486.30	9182.42	8747.72	799.48
7	31238182.19	52645.31	9191.81	6638.11	0.00
Mean	37453887.17	43988.55	32919.98	33955.81	12971.12
SD	22321204.49	10459.45	na	na	na
Minimum					
1	377046.91	0.00	0.00	0.00	0.00
2	6712771.56	9988.69	1645.76	11345.32	1063.43
3	16616054.36	14845.01	3145.80	9930.55	1331.55
4	3983779.65	7066.64	7668.78	4525.74	1063.43
5	4624126.35	19021.54	3817.49	4493.53	0.00
6	15908036.49	19047.45	3602.00	5485.79	0.00
7	24566641.19	30032.19	8824.70	6066.96	0.00
Mean	10398350.93	14285.93	4100.65	5112.51	494.06
SD	na	97299.16	3139.28	4380.55	622.65

na: Not-available

Based on the estimated annual food waste of 216.5 ton/year in Riyadh city (Alruqaie, 2003) and the results of the present study, the annual emission of the natural gas (~CH₄) and biogas (CH₄+CO₂) from food waste in Riyadh city were calculated. Also, the corresponding annual useable

Table 4: Annual emission of the natural gas and biogas from food waste in Riyadh city and the corresponding annual useable energy in biogas

Item	Total quantity
Annual potential gas utilization	
Natural gas (CH ₄) (ton)	26.90
Natural gas (CH ₄) (m ³)	37662.33
CO ₂ (ton)	10.76
CO ₂ (m ³)	5478.16
Biogas (CH ₄ +CO ₂) (ton)	37.66
Biogas (CH ₄ +CO ₂) (m ³)	43140.48
Annual useable energy in biogas	
Calorific energy (kWh)	258842.91
Useable electricity (kWh)	86280.97
Useable heat (kWh)	172561.94

energy in biogas was estimated. The values of different types of energy were 258842.91 kWh (calorific energy), 86280.97 kWh (useable energy) and 172561.94 kWh (useable heat) from the biogas produced from food waste in Riyadh, Saudi Arabia (Table 4).

CONCLUSIONS

The study showed that among the various pollutants methane gas production was significantly higher than other gaseous pollutants. The CH₄ emission was 99% (0.33 g) of the total gaseous emission in the experimental system. The other 1% of emission was other gases in descending order as NH₃ (4×10⁻⁴ g)>CO (2.1×10⁻⁴ g)>H₂S (2×10⁻⁴ g)>SO₂ (5.6×10⁻⁵ g). On time scale and concentration basis, the production of various gases was CH₄ (23% in first week), NH₃ (23% on 7th week), CO (27% in first week), SO₂ (37% in first week) and H₂S (36% in first week). The total methane production was highest after 98 days of digestion at a temperature less than 50°C than other types of gases. The study showed the potential for safe disposal of food waste in Riyadh, Saudi Arabia in order to mitigate the environmental pollution resulting from land disposal of food waste in and around the capital study. The study also identified areas of interest for future investigations on safe disposal and recycling of food waste in Saudi Arabia.

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