Modern Environmental Science and Engineering (ISSN 2333-2581)
April 2015, Volume 1, No. 1, pp. 39-48
Doi: 10.15341/mese(2333-2581)/01.01.2015/006
Academic Star Publishing Company, 2015
www.academicstar.us

Using Solid Wastes of Tikrit City to Produce Electric Energy

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Abstract: In the present work, the feasibility of production electric power from solid waste of Tikrit city by incineration and anaerobic digestion is investigated. The work is divided into two stages. In the first stage, 1167 samples of solid waste taken from four different sectors of Tikrit are collected and analyzed. Depending on the results of the first stage, it is found that 112865750.5 kWh can be produced by incineration (supply 84000 capita). In the second stage six anaerobic digester are designed and constructed in order to produce biogas. The results show that 194.286 ml of methane can be produced per each 1 kg of solid waste daily. This mean that 1653160 m^3 of methane can be produced from 233120.085 ton of solid waste produced from Tikrit city each year. This quantity of methane can produce 378892.6 KWh (supply 2200 capita).

Key words: solid waste, biogas, anaerobic digester

1. Introduction

As a result of the acceleration of traditional energy sources depletion and continuous increase of the human need for energy, it is necessary to search for other sources of energy. Solid waste is considered as a renewable energy source. Tikrit city suffer so much like other Iraqi cities from the growing problem of solid waste. The present work is a trial to access the feasibility of producing electric power from solid waste of Tikrit. Cheremisinoff et al. (1976) showed that the potential energy in solid waste can be released as thermal energy and that burning waste reduces 90% of the volume of the original waste [1]. Yousif (1988) stated that 6155 Kj/Kg is obtained when the solid waste of Mosul is incinerated [2]. Salem and Abdel-Moneim (1989), stated that the electric power obtained from the garbage of Hamburg when incinerated is sufficient to cover the need of 35000 inhabitants [3]. Ajil (1991) pointed out that 64 MW can be produced if the solid waste of Baghdad city is incinerated in addition, reducing the problems of landfill [4]. Tchobanoglous et al. (1993) illustrated that the knowledge of the chemical composition of solid waste is very necessary to calculate the amount of oxygen required for the oxidation of organic components to turn it into a more stable material and less influential in the environment [5]. Faraj (2005) showed that extraction of energy from solid waste is an encouraged option due to the lack of space for landfill and the high cost of transporting garbage [6]. Qaraghouli (2011) found in her study that the content of thermal energy which can be generated from the burning of solid waste of Tikrit city is 9400.165 Kj/Kg [7]. Fadel et al. (2012) explained in their study about the possibility of benefiting from solid waste of Al-Anbar province that 275 million KWh per year can be produced from the incineration of solid waste [8].

Wilkie (2005) stated that biogas resulting from the anaerobic digestion of plants and animal organic waste will benefit the community as being a clean energy sources that contribute in reducing the problem of global warming and acid rain [9]. Younis (2007)

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found that 0.27 litter of biogas per Kg of solid waste per day can be produced by anaerobic digestion of solid waste [10]. Al Afif et al. (2007) asserted the possibility of producing methane from anaerobic digestion of olive pomace samples [11]. Ahmadi and Rahmani (2009) explained that anaerobic biological system have several advantages compared with traditional aerobic systems which are; simple, saving energy, production of a small amount of sludge, and it is easy to operate [12]. Ahmadi and Younis (2012) conducted many experiments using four anaerobic biological systems work in varying temperatures (35, 45, 55, and 60°C) to treat domestic solid waste. The results show that 2.7 litter of biogas can be produced per Kg of solid waste [13].

2. Scheme of the Work

The scheme of this work has been divided into two main stages:

First Stage: In this stage, four residential sectors representing different economic and social level of the population is employed namely: AL Arbaeen, Industrial district, Al-Shuhada, and Al-Qadisiyah. Herbert Larkin equation is used to select 1167 sample of solid waste [14, 15].

$$n = P(1-P)/(SE \div t) + [P(1-P) \div N] \qquad (1)$$

Where:

n = sample size required

N = population size (the size of the studied sector)

t = standard class corresponding to the level of significance 0.95 equal to 1.96

P = the proportion of providing the property and a neutral, equal to 0.50

SE = error rate equal to 0.05

Table 1 includes some information of the studied sectors. Two plastic bags are given to each family. One for food waste and the other is dedicated to the rest components of the solid household waste. Samples collection begins at November 2012 until June 2013 in order to cover all climatic changes throughout the year. Samples are taken daily to cover the daily variation.

Solid waste production rate is calculated using Eq. (2).

$$\text{Production rate (kg/capita/day)} = B/(A*7) \qquad (2)$$

Where;

A is the number of individuals within families studied in each sector (person)

B is the amount of household solid waste produced every week in every sector (kg/week)

Table 1 Some Information of the Studied Sectors

Studied sector	Al-Arbaeen	Industrial district	Al- Shuhada	Al- Qadisiyah	Total
Number of families	19	12	27	20	78
Number of individuals within studied families	117	58	109	131	415
Mahalla No.	*414	*201	*204	*214	-
Number of population	*845	*655	*2183	*2547	6230
Number of samples specified by Herbert Arkin Equation	264	242	327	334	1167

*Source: Central Bureau of Statistics/Statistical Directorate Salah al-Din (2012).

The components of solid waste are sorted manually, which includes various types of materials namely, (food waste, paper, cardboard, plastic and leather, rubber and fabric, glass, metals, wood, gardens residues, ash, and dust and other materials. The weight of each component is recorded in order to find the weighted percentages for each component. Heat value (Kj/Kg) of the solid waste can be calculated using Eq. (3).

$$HE = \Sigma\ Wt\%*\text{Heat value}/\text{Total weight} \qquad (3)$$

Where:

HE = total thermal energy of solid waste, Kj

Wt% = weight percent for each component of solid waste.

Heat value = average heat value of each component (Kj/Kg)

Knowing that: 1 Kj = $2.777*10^{-4}$ KWh [8], It is easy to convert thermal energy to electric energy.

Second stage: Six anaerobic digestion units (batch units) are designed and constructed in order to perform the experiments of this stage. These units are constructed according to Ryckeboer et al. (2002) and Costi et al. (2004) [16, 17]. Food waste is isolated from other components of solid waste and digested anaerobically since other components are nonbiodegradable [18]. Fig. 1 represents the anaerobic biological digester. Water displacement method is used to find the volume of the released biogas [19].

Samples of solid waste taken from the studied sectors are cut so that its size is 40-50 mm [20-22] and put into the reactor.

Two treatment systems are used, each system is composed of three anaerobic digester unit. In the first system, solid waste (14 kg) is mixed with different weight percent of waste sludge taken from Al-Dibaie wastewater treatment plant while the inlet wastewater of this plant is used to mix solid waste (14 Kg) in the second system [23]. Table 2 includes the mixing ratios of the two systems. The first system is operated at 35°C while the second is operated at 25°C. In order to minimize the heat loss, glass wool of 5 mm thickness is used. The pH is controlled between 7-8 for all reactors [13, 24, 25]. The liberated gas is measured continuously. In order to measure methane mole percent in the biogas, gas chromatography of Oil Training and Development Institute in Baiji is used.

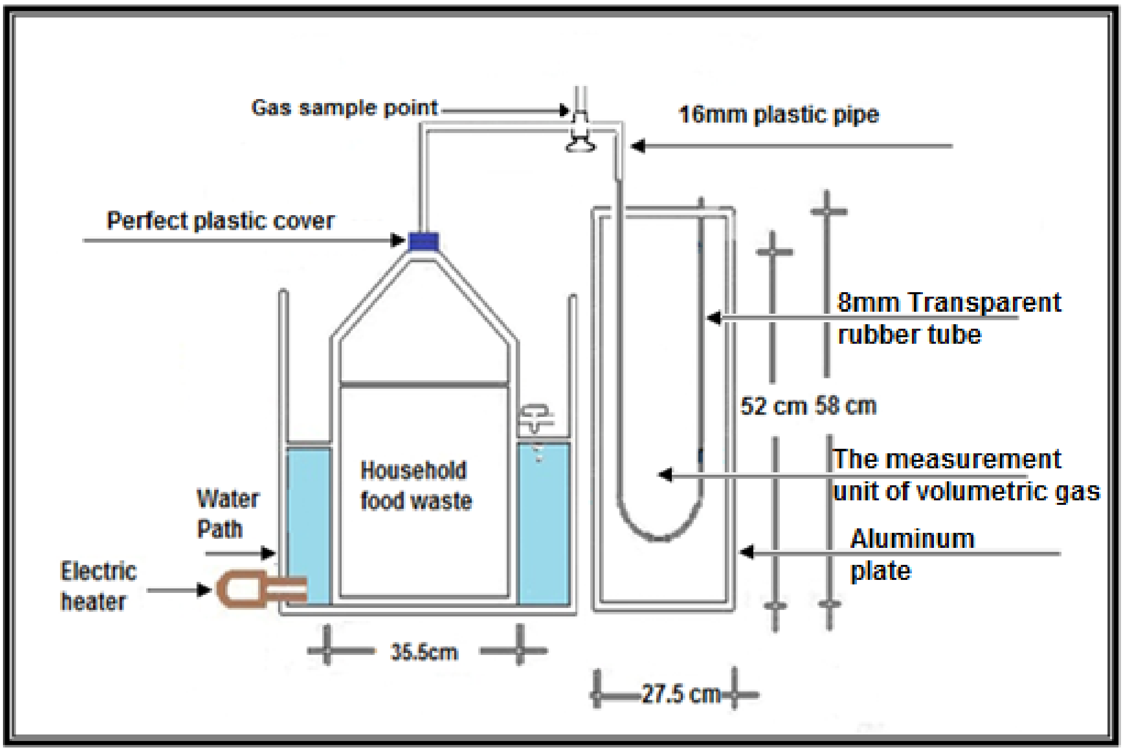

Fig. 1 Anaerobic Digestion

Table 2 Mixing Ratios of Solid Waste with Sludge and Wastewater

System	Reactor No.	mixing ratios%		
		Solid waste	Sludge	Wastewater
First System	First Second Third	85 75 65	15 25 35	- - -
Second System	Fourth Fifth Sixth	85 75 65	- - -	15 25 35

3. Results and Discussion

3.1 Results of the First Stage

3.1.1 Components of Domestic Solid Waste

Fig. 2 shows the distribution of the percentages of the components of domestic solid waste for the studied sectors of Tikrit. It was found that food waste constitutes the largest percentage among the other components (56.894%) which is compatible with the results of Al Najjar (1998) (63.6%) [26].

3.1.2 Production Rate of Solid Waste

Fig. 3 shows the variation of solid waste production rate through the seasons of the year while Fig. 4 shows the variation of production rate of the studied sectors. The overall rate of per capita production of domestic solid waste is 0.498 Kg/capita/day. This result is in good agreement with that obtained by Qaraghouli (2011), 0.46 Kg/person/day [7]. The increase in the production rate may be due to the increase of daily income of a family. Faraj (2005) [6], stated that the production rate of the middle income countries range is 0.35-0.65 Kg/capita/day [27]. Fig. 4 shows that the highest rate is 0.612 Kg/capita/day for Al-Shuhada district while the lowest rate is 0.366 Kg/capita/day in industrial district. This is due to the economic level difference of families. Al-Rawi and Tayyar (2012) [28], in their study in Mosul, concluded that the big difference in the levels of Iraqi families does not affect the components of solid waste only, but affect also the production rate. Fig. 4 also indicates that the highest production rate is in summer 0.568 Kg/capita/day, while the lowest value is in winter 0.395 Kg/capita/day. This is compatible with the results of Qaraghouli (2011) [7]. This due to the increase in the consumption of fruits and vegetables, drinking water, ice cream, and juices.

Fig. 5 shows that the production rate during Friday and Saturday in all seasons are the highest as compared with other days of the week. These two days are a holidays.

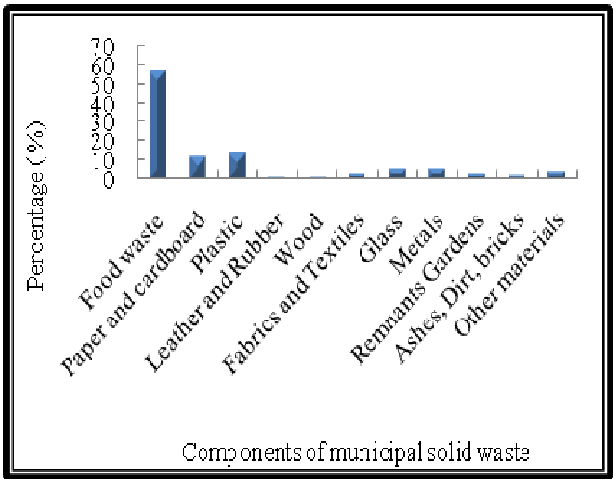

Fig. 2 Solid Waste Components Distribution of the Studied Sectorsin Tikrit During the Four Seasons

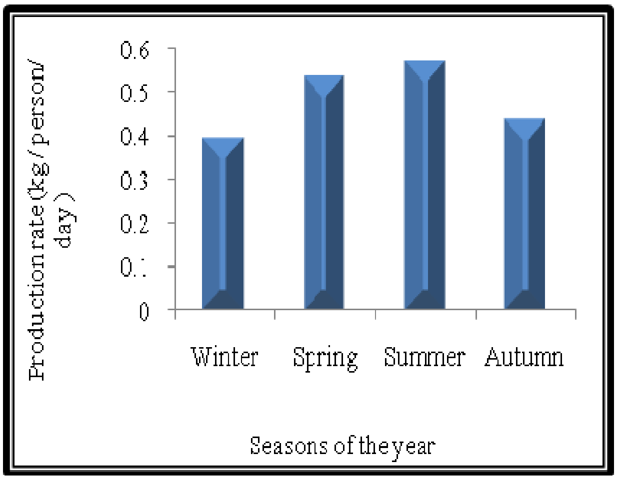

Fig. 3 Production Rate of Solid Waste of Four Sectors of Tikrit During All Seasons

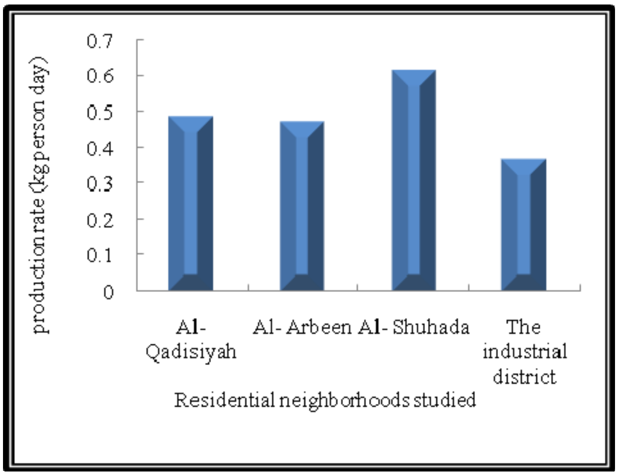

Fig. 4 Variation of Solid Waste Production Rate through All Seasons

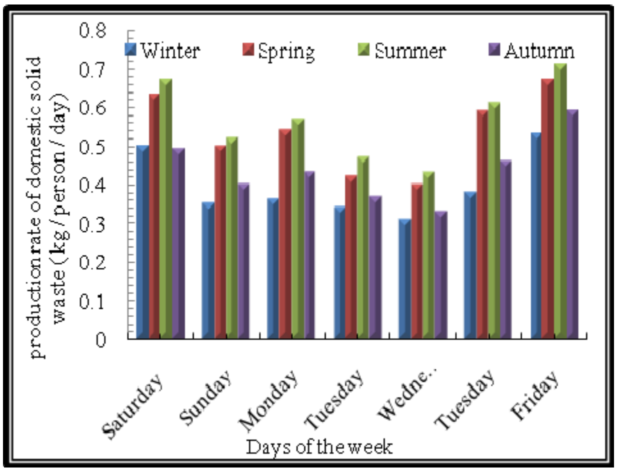

Fig. 5 Daily Variation of Solid Waste Production Rate

3.1.3 Energy Content of Solid Waste

Table 4 represents the calculation of total thermal energy content of solid waste for the duration November 2012 to June 2013 of Tikrit. Total heat value is 9916 Kj/Kg (equivalent to 112865750.5 KWh) which is higher than that obtained by Qaraghouli (2011) [7], 9400 Kj/Kg, equivalent to 91,723,963.74 KWh. This increase is due to the increase of the rates of paper and plastic, textiles and other materials resulting from the increase of economic level. The percent of paper and plastic are 0.11277 and 0.13272 and the corresponding percent of Qaraghouli (2011) are 0.10179 and 0.11546 respectively [7]. Tchobanoglous et al. (1993) stated that it is possible to get thermal energy content in the industrialized nations as much as 12000 Kj/Kg due to high percent of plastic, paper, cardboard, wood, and garden waste [5].

Calculation of total thermal energy and electric power generated from solid waste of Tikrit city is performed as follows:

Total waste per year (kg/year)

= production rate (kg/capita/day)*population (capita)*365(day/year)

= 0.498*225420*365 = 40974593.4kg/year

Total thermal energy (Kj/yr)

= thermal energy [(kj/Kg)* waste generated (Kg /year)]

= (9916.229* 40974593.4) = 406313451336 (Kj/year

Kj = 2.7778 * 10^{-4} KWh

Total electric power (KWh/year)

= total thermal energy (Kj/year)*2.7778*10^{-4} KWh/Kj)

Total electric power

= (406313451336*2.7778*10^{-4})

= 112,865,750.5(KWh/year)

Table 4 Thermal Energy Content (kJ/Kg) of Solid Waste [5]

Components	Weight percent, (%)	Thermal energy, (Kj/Kg)	The resulting thermal energy, (Kj/Kg)
Food waste	0.56894	4652	2646.708
Paper	0.11277	16747.2	0.11277
Plastic	0.13272	32564	4321.894
Wood	0.00491	18608	91.365
Textile	0.01887	17445	329.187
Leather	0.0086	17445	150.027
Glass	0.04350	139.56	6.0708
Metal	0.04356	697.8	30.396
Remnants of Gardens	0.02107	6512.8	137.224
Ash, Dust, etc.	0.04511	6978	314.777
Total			9916.229

3.2 Results of the Second Stage

3.2.1 Production of Biogas from the Anaerobic Biological Reactors

Figs. 6 & 7 illustrate the relation between the volume of the produced biogas (ml) with the operating time. The production of biogas is increased with time for both systems. The highest volume of biogas reached 3170 ml for the third reactor of the first system. The corresponding volumes of the first and second reactors of the first system are 2365 ml and

2930 ml respectively. The corresponding volumes of the fourth, fifth, and sixth reactors of the second system are 1840, 2385, and 2820 ml respectively (Fig. 8). This is due to the mixing ratio with sludge and wastewater of the third and sixth reactors (35%) is higher than that of the other reactors. Sherris et al. (2004), Kim et al. (2005), Min et al. (2005), Aelterman et al. (2006), Chang et al. (2006), Logan and Regan (2006), Reddy et al. (2006); Clauwaert et al. (2007), and Hassoun (2008) stated that biogas production can be enhanced by increasing the blending ratio of the material added to solid waste and the type of material used [29-36]. The produced biogas of the reactors of the first system are higher than the corresponding of the second system. This is due to two reasons: the first reason is the sludge contains higher proportion of the necessary organic nutrients to complete the anaerobic biological treatment as well as it contains more microorganisms while the second reason is the temperature of the first system 35°C is higher than that of the second system 25°C resulting in more activity of microorganism. This is consistent with the interpretation of Rabaey et al. (2005), Younis (2007); Rodrigo et al. (2007) and Patil et al. (2009) who stated that 35°C is ideal for the microorganisms that are responsible for the production of biogas [37-39].

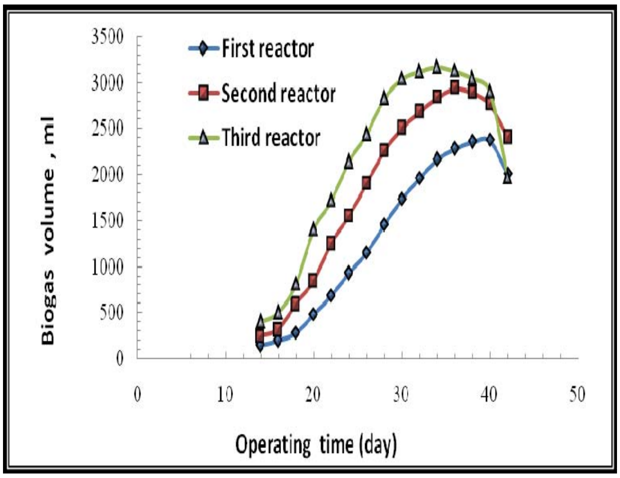

Fig. 6 Relation of Biogas Production with Operating Time for the First System

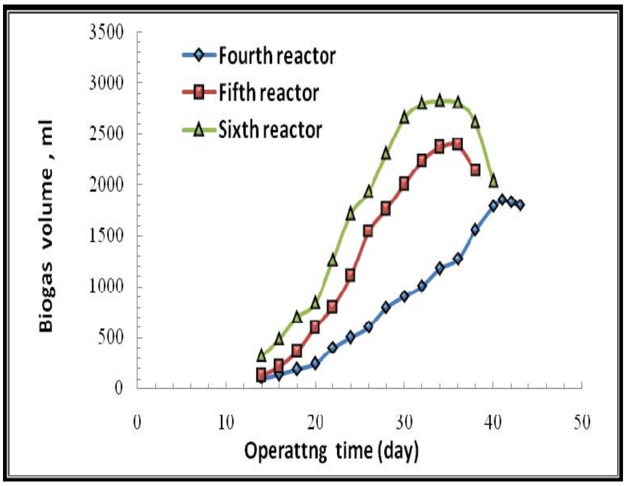

Fig. 7 Relation of Biogas Production with Operating Time for the Second System

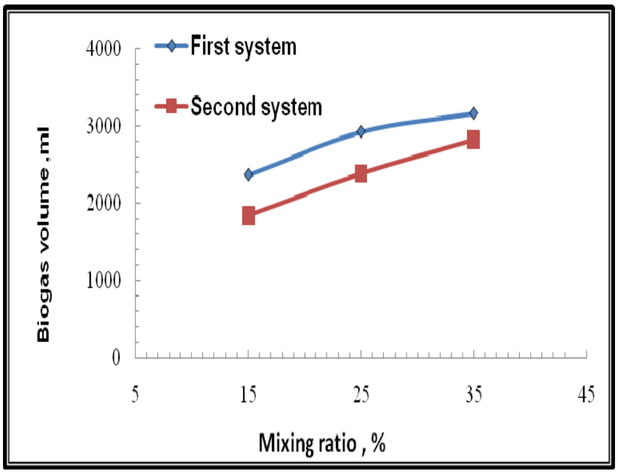

Fig. 8 Relation between Biogas Production with Mixing Ratio

3.2.2 Methane Content of Biogas

Samples of biogas were analyzed for all six reactors using gas chromatography at the Institute of Oil Training and Development in Baiji and the results are shown on Figs. 9 and 10. It is clear that methane content of the biogas of the reactors of the first system are higher than the corresponding of the second system. The reason for that is the sludge is used to mix the solid waste in the first system while wastewater is used to mix the solid waste in the second system. Sludge contains larger numbers of microorganisms, especially methane former bacteria that is relevant in the middle thermal field (Mesophilic) and it has optimal necessary food such as Nitrogen, Phosphorus, and Potassium. It is clear that methane begins to appear at 14th day of operation and continuously increased till 34th day of operation then it is decreased. This is because all organic compounds decompose first to acetic acid by acid former bacteria before methane is formed due to direct decomposition of acetic acid to methane and CO_2. After 34th day of operation, it seems that the available food begins to be depleted resulting in a decrease in methane production.

3.2.3 COD Removal Efficiency

Figs. 11 and 12 illustrate the results of the COD removal efficiency as a function of biogas production for the first and second system respectively. It is clear that the removal efficiency is increased with the increase of biogas production for all reactors. This is due to the decomposition of organic matter to acetic acid and then to methane resulting in reducing COD. Therefore, as the production of biogas increased, the remaining COD is decreased. The highest removal efficiency for the first system is 93.2% and the corresponding removal for the second system is 90%. This is due to the availability of more food and microorganisms in the first system as compared with that of the second system. Moreover, the microorganism activity in the first system is greater due to higher temperature. This is in good agreement with the interpretation of Kishore (1998) [40].

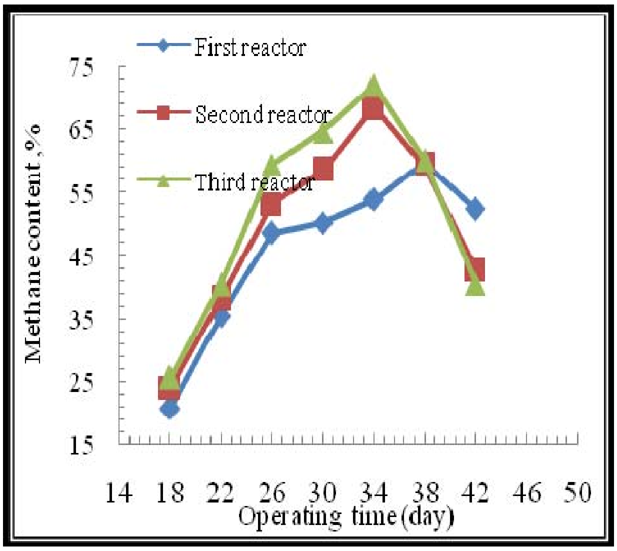

Fig. 9 Relation between Methane Content with Operating Time for the First System

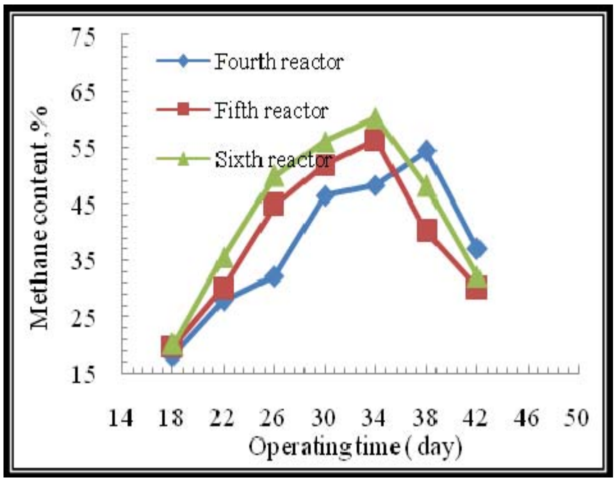

Fig. 10 Relation between Methane Content with Operating Time for the Second System

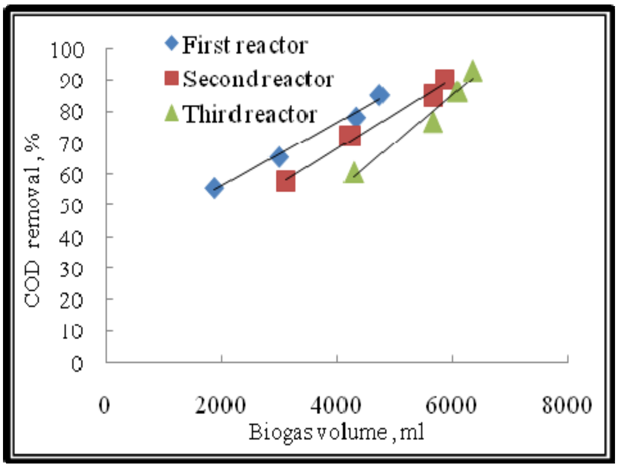

Fig. 11 Relation between COD Removal and Biogas Production (First System)

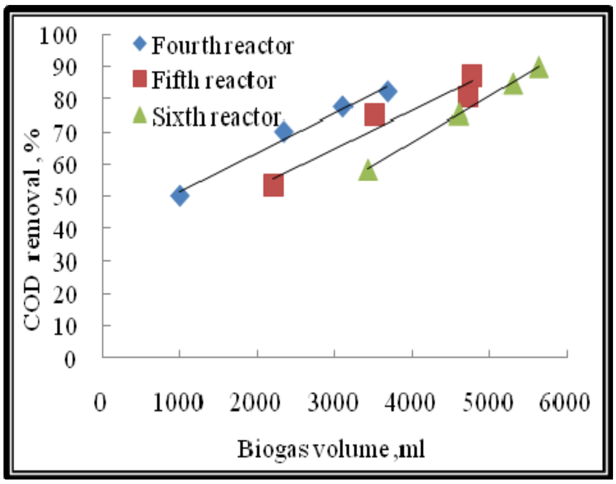

Fig. 12 Relation between COD Removal and Biogas Production (Second System)

3.2.4 Calculation of Electrical Energy

Since the third reactor of the first system gives the best results, thus it is used as a basis for calculation of electric power. Table 6 include data of methane volume produced through the operating days. It is clear that the total sum of the volume of methane through 54 days is equal to 18702.145 ml. This volume is get from the treatment of 14 kg of food waste. However, the present system is batch, and since in the field it is continuous, i.e., the produced gas is kept at maximum or near maximum, thus the maximum gas production is used to perform the calculations. From Table 6 it is clear that the reactor works near maximum from day 30 till day 38. The average daily produced methane of these days is 2720 ml. This volume comes from the treatment of 14 Kg solid waste, thus the daily production of methane is 194.29 ml/Kg. The produced methane per year is 70914 ml/Kg. Thus, the volume of methane resulting from treatment of 23312085 Kg of food waste obtained from Tikrit city is equal to 1653160 m^3. Knowing that the standard of electric power generation per 1 m^3 of methane is equal to 1.8 KWh [28], it can be concluded that total electric power generated using anaerobic treatment is equal to 378892.6 KWh/year.

Table 6 Daily Production of Methane

Day	Methane, volume %	Biogas volume (ml)	Metane volume (ml)	Day	Methane, volume %	Biogas volume (ml)	Methane Volume (ml)
14	8.3	400	33.2	36	65	3125	2031.25
16	15.5	500	77.5	38	60.1	3045	1830.045
18	25.6	810	207.36	40	49.4	2900	1432.6
20	32.1	1400	449.4	42	38.3	1975	756.425
22	40.3	1715	691.145	44	29.8	1000	298
24	48.7	2140	1042.18	46	20.7	635	131.445
26	59.4	2440	1449.36	48	18	410	37.8
28	62.2	2825	1757.15	50	16.1	280	45.08
30	64.6	3037.5	1962.225	52	11.5	220	25.3
32	67.7	3120	2112.24	54	7.8	180	14.04
34	72	3170	2282.4		Total	35327.5	18702.145

3.2.5 Comparison between Incineration and Biological Treatment Method for the Production of Electric Power in Tikrit

From the above results it can be concluded that the amount of electrical energy which can be generated by incineration of solid waste of Tikrit is equal to 112,865,750.5 KWh/year, while 378892.6 KWh/year can be produced by anaerobic treatment method. This power is capable to supply 84000 and 2200 capita respectively. It is clear that the amount of electricity generated by incineration is greater than that generated by anaerobic biological treatment. The reason is due to the amount of waste dealt by incineration is greater than that of anaerobic treatment. Although incineration method give more electric energy, anaerobic bioremediation remain more safe and preserve the environment. Due to the current circumstances faced by the country (Iraq) and specially the problem of electricity, we prefer incineration to produce electric power, provided that address the resulting toxic combustion gases to keep the environment. Incineration method can get rid of the largest amount of solid waste at hand, Faraj (2005), Mandalawi (2005), and Hamadani (2007) stated that incineration method can reduce 80-95% of the total weight of the solid waste. Other reasons to choose incineration, it does not need pre-treatment [6, 41, 42].

4. Conclusions

(1) The production rate of solid waste of Tikrit is 0.499 Kg/capita/day.

(2) Incineration method can produce 112,865,750.5 KWh/year while it is possible to produce 378892.6 KWh/year by anaerobic biological treatment method.

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