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Methane Biogas Production from Mixing of Algae and Municipal Solid Waste by Anaerobic Digestion

Ali, A. H.*, Abdul Razaq, Z., Tlaiaa, Y. and Khishala, A. D.

Al- Mustansiriyah University, College of Engineering, Environmental Engineering Department, Iraq – Baghdad, Bab – Al – Muthem, P.O. Box 14150

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ABSTRACT: The present study was designed to investigate the capability of algae biomass to increase methane biogas production from anaerobic digestion of municipal solid waste. Batch anaerobic digester was used for digesting the mixture of algae and organic fraction of municipal solid waste (OFMSW). A variety condition of algae to organic fraction municipal solid waste mixing ratio, pH, temperature, and total solid are studied for a period of 12 days. It was observed that maximum methane biogas production was found to be 946.0012 mL/gm v.s at optimum condition of mixing ratio of algae to OFMSW were, 1:2, temperature, total solid and pH of 32 ^{o}C, 8 % and 7.5 respectively. Multiple correlation methodology optimized the methane production with a correlation coefficient (R^2) to be 0.925. The first order kinetic model was used to assess the dynamics of the biodegradation process. The obtained negative value of (k = - 0.2543), indicates that the solid waste biodegradation was quick with a correlation coefficient (R^2) of 0.9906. The Gompertz model was used to adequately describe the experimental cumulative methane biogas production from lab scale anaerobic digesters. The theoretical methane biogas yield was found to be 1016.76 mL/gm v.s which is very close to experimental value 946.0012 mL/gm v.s. with high correlation coefficient R^2 of 0.998.

Key words: Algae biomass, Anaerobic digestion, First order kinetic, Gompertz model, Methane biogas, Multiple correlation

INTRODUCTION

Increasing production and disposal of wastewater have recently caused an accelerated eutrophication of receiving waters. Excessive enrichment, or eutrophication, of receiving waters by nutrient-rich wastes have caused a major water pollution problem. Sewage treatment plant discharges final effluent to the local water source. This effluent contains a high concentration of essential growth nutrients, Phosphorus, Nitrogen and other trace elements required by phytoplankton.

On the other hand, the generation and disposal of large quantities of organic waste without adequate treatment results in significant environmental pollution public health hazards causing diseases like malaria, cholera, typhoid. The disposal of this large quantity of waste is an urgent economic and environmental issue with growing populations and lower availabilities of land for disposal. Inadequate disposal of waste can cause serious environmental problems such as soil, groundwater and surface water contamination due to the direct waste contact or leachate; air pollution due to uncontrolled greenhouse gas (GHG) emissions from anaerobic decomposition or burning of the waste, and spreading of diseases by different vectors such as birds and insects (Visvanathan et al., 2006). A combination of a reduction in the availability of landfill areas, combined with the introduction, and steady increase of Iraqi landfill tax provides a strong incentive to investigate an innovative means of waste management. In response to this challenge, reuse of solid wastes generated from society activities will be investigated in the present study. But, biogas is distinct from other renewable energies because of its characteristics of using, controlling and collecting organic wastes and at the same time producing fertilizer and water for use in agricultural irrigation. Biogas does not have any geographical limitations nor does it require advanced technology for producing energy, also it is very simple to use and apply. Replacing fossil fuels with sustainably produced biomass or organic residues will not only be a way to cope with the

*Corresponding author E-mail: ahmedhassoon_2021@yahoo.com

depletion of fossil fuel resources, but also to reduce the CO_2 emissions into the atmosphere and therefore minimize the risk of global warming (Kale and Mehele, 2008).

In the present study, Algae biomass was used as sources of nitrogen, phosphorus for anaerobic digester to be mixed with an organic fraction of solid waste and produced methane biogas.

In batch studies of anaerobically digesting of algae waste-grown have widely varying in lipid contents, and the technologies for lipid extraction are still under development (Woertz et al. 2009). Consequently, the anaerobic digestion of algal biomass is likely to be the near-term, appropriate usage of algae biomass grown in wastewater treatment plants. Be that as it may, algae typically produced less methane biogas than wastewater sludge approximately 300 to 400 ml/gm vs. Several studies have focused on overcoming low C/N ratios as well as comparatively low methane productivities by practicing co-digestion. Samson and LeDuy, 1983, showed that the methane produced and productivity became twice when equivalent masses of algae biomass (*Spirulina*) and wastewater sludge were co-digested. Also, Yen (2004) and Brune (2007) added waste paper to aqua-cultural microalgal sludge in percent of (50% w/w) to adjust the C:N proportion to around 20-25:1 which, in this way, doubled the methane production rate from 0.6 to 1.2 L/L day at 35°C and after 10 days retention time.

The present study aims to study the effect of mixing ratio, pH, temperature and total solids (TS), on methane biogas accumulative and daily production, studying the possibility of using methane biogas production resulted in pilot system in electricity generation, and predicting of maximum accumulative methane production and rate of biodegradation by applying, Gompertz and first order kinetics models.

MATERIALS & METHOD

The solid wastes used in the present study are collected from four transfer stations located in Baghdad (New Baghdad, Al-Dora, Al-Nahrwan and Al-Baya'a). The biodegradable organic fractions (OFMSW) (Food waste + paper and boards+ wood + textile) represents about 75% of solid waste. The remaining is the inorganic fraction which is about 25%. In the present study, the inorganic fraction is disregarded; and organic fraction is used only. The substrates used for the study were putrescible waste mixed with anaerobic sludge collected from thickener of Al-Rustamiyah sewage treatment plant, the old project, Baghdad, Iraq (33°16'30.8" N, 44°31'57.4" E). Algae biomass that mixed with OFMSW were harvested from Diyala river (33°16'42.8" N, 44°31'41.7" E) from the point of Al-Rustamiyah wastewater treatment plant outfall where the eutrophication phenomena were predominant. To convert solid into slurry, the OFMSW milled using a mechanical blender minced into pieces of <0.005 m in diameter. The reason for this process is to ensure smoother running by avoiding the choking of the digester. The physical parameters of OFMSW including pH, moisture content (MC), density, total solids (TS) and volatile solids (VS) were measured and listed in Table (1). All the raw materials are mixed well before the anaerobic digestion began. The lab scale anaerobic digesters were made from glass bottles, which have a volume of 1L. The bottles are plugged with rubber plug and equipped with a valve for biogas measurement. Anaerobic digesters are operated in a batch system at different parameters. Biogas formed was measured by the liquid displacement method as also has been used by the other researchers (Budiyono et al. 2010; APHA, American Public Health Association 2003). The anaerobic digestion of experimental laboratory set up is shown in Figs 1. In this method, the gases produced from reactors (CH_4, CO_2, N_2 and H_2S) are transferred to barrier solution containers which contain 2% NaOH solution to absorb CO_2, N_2 and H_2S while CH_4 are measured from the change in heights of displaced liquid which accumulate in a graduated cylinder. In lab scale, different parameters including mixing ratio, pH, temperature and total solid were studied to select the best conditions given maximum accumulative methane biogas production. Alkalinity and volatile fatty acid were measured daily to find Acid / Total inorganic carbon ratio (A/TIC) ratio to maintain the range within the optimum (0.1- 0.4) (Sanchez et al. 2005).

Effect of mixing ratio (Algae /OFMSW): Algae biomass was used as sources of nitrogen, phosphorus for anaerobic digester to be mixed with an organic fraction of solid waste to adjust carbon to nitrogen ratio (C:N) in best ratio for maximizing methane production.

This step was performed to determine the influence of mixing ratio on methane production, using a constant amount of algae biomass and different amount of OFMSW at room temperature. The mixing ratios were (1:1, 1:2, 1:3, 1:4, 1:5, and 0:1). While pH and total solid kept constant at 7.3 and 10% respectively. The experiment continued until no methane was measured.

Effect pH:

To study the effect of pH on methane production, the mixing ratio kept at best value obtained from previous experiment and total solid 10%, while varying pH of the sample in the range (6.5, 7, 7.5, 8 and 8.5) using 0.1 H_2SO_4 and /or 0.1 NaOH to get the desired pH, were tested. The best pH will be used in further experiment.

Effect of temperature:

To study the effect of temperature on methane production, mixing ratio and pH are kept at best values while total solid is 10%. Different degrees of temperature (27, 30, 32, 36, and 40 ºC) are used to select best temperature. To keep the temperature at desired value; water bath was used for this purpose.

Effect of Total solid (TS):

The effect of TS on methane production was investigated in the range (8, 9, 10, 11 and 12%). The other parameters: mixing ratio, pH and temperature are fixed at best optimum values.

Table 1. Physical and chemical properties of OFMSW

Parameter	Value
pH	6.01
Bulk density, BD	532 kg/m^3
Total solids, TS	27.35%
Volatile solids, VS	81.15%
Moisture content, MC	72.65%
Alkalinity as ($CaCO_3$)	1183
Volatile fatty acid as ($CaCO_3$), VFA	317

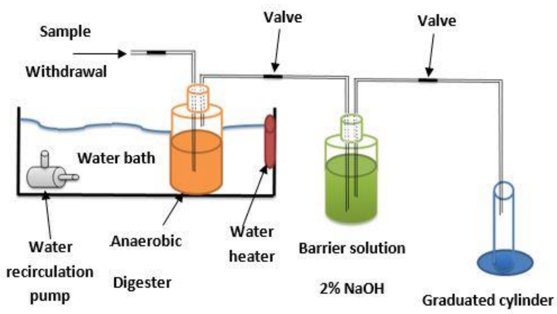

Fig. 1. Schematic diagram for the Lap Scale anaerobic digesters

RESULTS & DISCUSSION

Effect of Algae/OFMSW mixing ratio: Mixing ratio of Algae/OFMSW has an impact on methane biogas production shown in Figs 2 and 3. The outcomes of accumulative methane biogas demonstrate that, as shown in Fig.2 the maximum accumulative methane biogas production of was (543.26 mL/gm v.s) at mixing ratio of (1:2 algae/OFMSW), while for others mixing ratio of algae to OFMSW (0:1, 1:1, 1:3, 1:4 and 1:5) the maximum accumulative methane biogas productions are (344.05, 268.55, 438.11, 255.79, and 322.89 mL/gm v.s) respectively. Notwithstanding, the maximum daily production of methane was seen at (6th, 2nd, 3rd, 4th, 3rd, and 3rd) days for mixing ratio of (0:1, 1:1, 1:2, 1:3, 1:4 and 1:5), where the maximum daily productions are (191.80, 94.02, 222.21, 128.09, 74.15 and 143.72 mL/gm v.s) respectively. Hence, the best proportion which is (1:2) will be utilized as a part of further experiments. The explanation behind picking this proportion is to adjust between the Carbone to Nitrogen proportion (i.e., C\N). If C\N ratio less or more the needs ratio, the production may be decreasing. High C/N ratio may cause a rapid consumption of nitrogen by methanogens and leads to minimize the gas production. Meanwhile low C\N ratio leads to higher pH values exceeding 8.5 and ammonia accumulation, which is toxic to methanogenic bacteria (Verma, 2002).

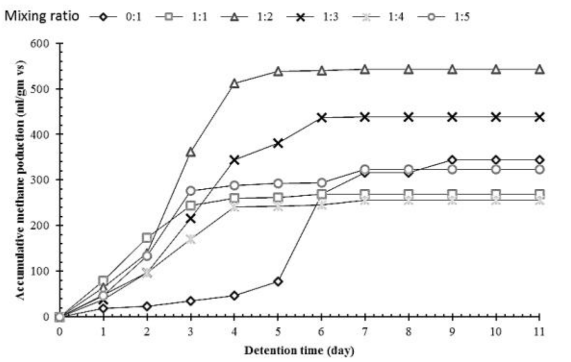

Fig. 2. Accumulative methane production from different ratio of Algae/OFMSW at pH=7.3 and TS =10%

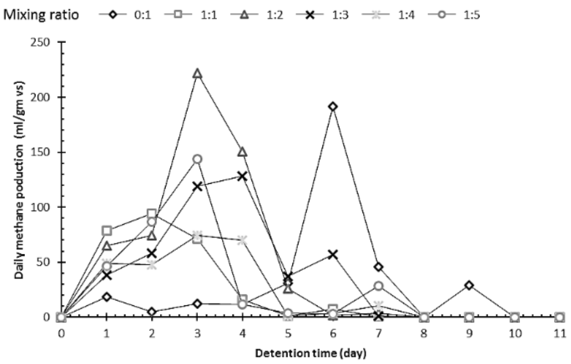

Fig. 3. Daily methane production from different ratio of Algae/OFMSW at pH=7.3 and TS =10%

Effect of pH: pH of Algae/OFMSW was a vital factor on methane biogas production because of the affect on bacteria that decompose the mixture to a simple products and methane. The pH of mixed algae and OFMSW was balanced in the ranges of (6.5, 7, 7.5, 8 and 8.5) by utilizing 0.1 H_2SO_4 and 0.1 NaOH. Temperature and total solids are fixed at 30±1 ºC and

10% respectively. While mixing ratio of Algae/OFMSW is fixed at optimum value of (1:2) obtained from above trials. The experiments operate until no or a little methane biogas production is generated which is happened after 9 days. The maximum production of accumulative methane biogas (722.34 mL/gm v.s) occurs at pH (7.5) as shown in Fig. 4. While, as shown in Fig. 5 the maximum daily production of methane biogas occurs at the 4^{th} day where the productions is (144.67 mL/gm v.s). The reason for this best pH might be credited to that, methanogenic bacteria responsible for methane production will often grow at pH ranged between 6.5 to 8.2 units (Anunputtikul, 2004). Fluctuation in pH value has an effect on the anaerobic digestion process in light of the fact that the hydrogen ion concentration has direct impact on bacteria development. The perfect pH for methanogens growth rate will be enormously decreased underneath pH 6.60. A pH less than 6.10 or more than 8.30 bring about poor performance and even the insufficiency of the digester (Lay et al., 1997). So, it is necessary to correct the unbalanced and low pH condition in the digester. The methane biogas process also becomes more sensitive towards increment of pH value because the concentration of free ammonia increases as pH value raises and this may inhibit bacterial activity (Hansen et al., 1998). Therefore, pH was maintained at 7.5 for other experiments.

Effect of Total solid (T.S): The effect of TS was studies at optimum conditions of (1:2, and 7.5) for mixing ratio, and pH respectively got from previous experiments. The T.S is varied in the range of 8% to 12%, while, the maximum accumulative production of methane biogas was happened when TS percent of 8% where the methane production is (797.43 mL/gm v.s) as clear from Fig.6. However, the maximum daily methane production as shown in Fig. 7 occur at the (4^{th}, 5^{th}, 4^{th}, 6^{th} and 1^{st}) days for TS of (8, 9, 10, 11 and 12 %) where the productions are (143.41, 152.31, 144.67, 117.25, and 142.75 mL/gm v.s) respectively.

A high content of volatile solid of substrates (i.e., 11 and 12 %) may not cause a high biogas yield because of the presence of non-disintegration volatile solids in form of lignin. It is important to note that the volatile matter content of any substrate represents the extent of solids that is changed into methane biogas (Itodo et al., 1992; Ituen et al., 2007). Consequently, for a successful digestion to happen; the anaerobic digestion process of organic wastes that mixed with thickener sludge as a bacteria source will give a harmony between carbon to nitrogen proportion (C/N) and the lignin content (Nuhu et al., 2013). In addition to that, when TS percentage increases, the percent of water declines, in like manner decreasing the activity of microorganisms, which then influences the amount of biogas, especially at higher value of the TS (Yusuf'et al., 2011).

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Effect of temperature: The impacts of various temperature values (27, 30, 32, 36 and 40 ^{o}C) on methane generation were studied at optimum conditions of (1:2, 7.5, and 8%) for mixing ratio, pH, and total solid respectively obtained from previous experiments. The maximum accumulative methane (946.00 mL/gm v.s) obtained at optimum temperature of (32 ^{o}C). For temperatures (27, 30, 36 and 40 ^{o}C) , the production of methane biogas are (757.85, 797.42, 837.25 and 463.78 mL/gm v.s) respectively as shown in Fig.8.The maximum daily methane production for a variety of temperature (27, 30, 32, 36 and 40 ^{o}C) occurs at the (2^{nd}, 6^{th}, 3^{rd}, 3^{rd}, and 1^{st}) day where the methane productions are (170.85, 143.41, 218.12, 205.64 and 111.55 mL/gm v.s) respectively as shown in Fig.9. It was found by numerous scientists that mesophilic microorganisms play a significant parts in methane generation rate. The mesophilic level ranging from (25-40 ^{o}C). The methanogenic activity was exceptionally touchy to temperature. Over certain limit (i.e., 35 ^{o}C), the methanogenic activity turns out to be low and

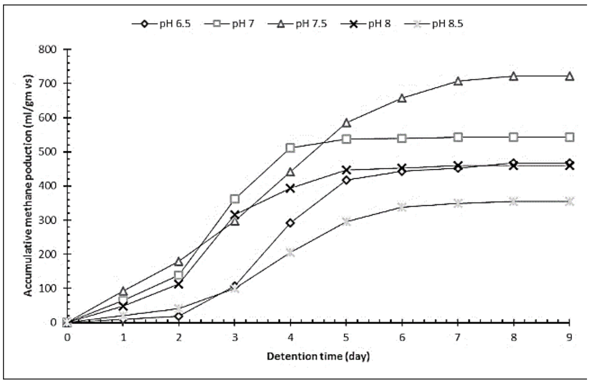

Fig. 4. Accumulative methane production at different pH, mix ratio = 1:2 and TS=10%

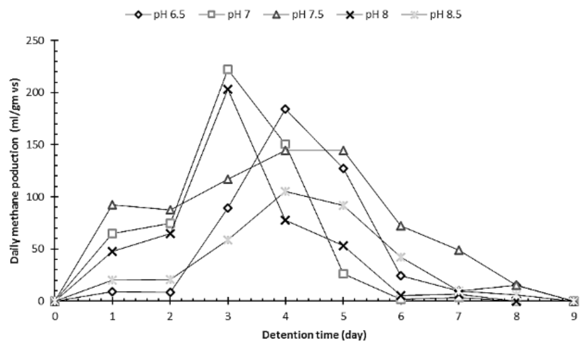

Fig.5 . Daily methane production at different pH, mix ratio = 1:2 and TS=10%

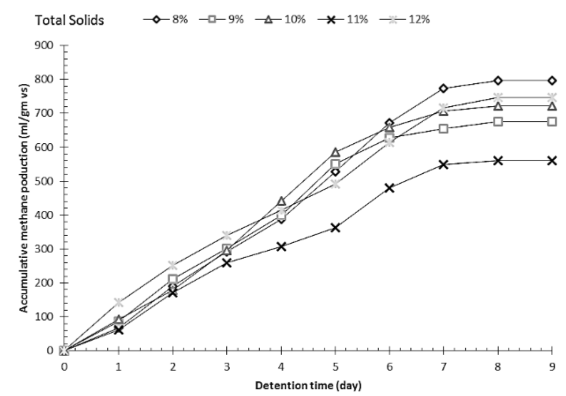

Fig. 6. Accumulative methane production at different total solid content, mixing ratio 1:2, pH=7.5

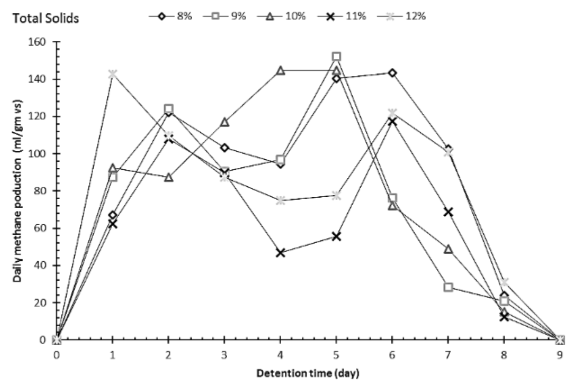

Fig. 7. Daily methane production at different total solid content, mixing ratio 1:2, pH=7.5

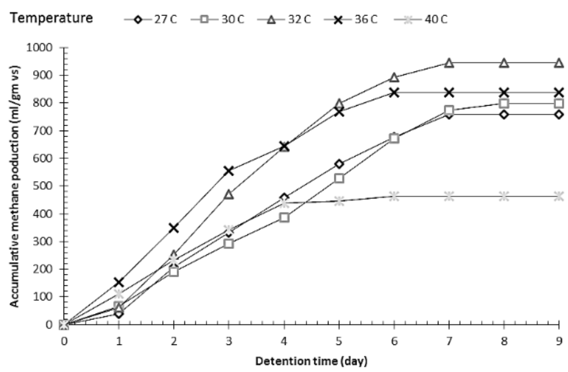

Fig. 8. Accumulative methane production at different Temperature, mix ratio = 1:2, pH = 7.5 and TS=8%.

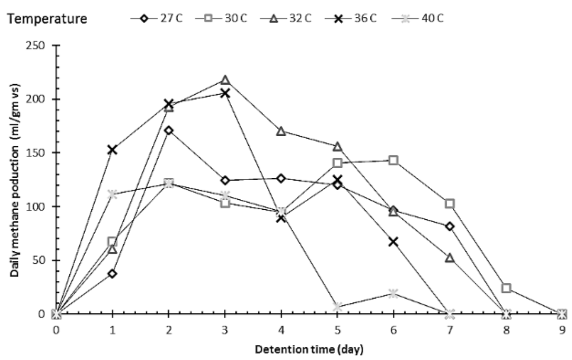

Fig. 9. Daily methane production at different Temperature, mix ratio = 1:2, pH = 7.5 and TS=8%.

abatements the action of the methane forming bacteria (Yogita et al., 2012). The TS reached to 4.0054% after 8 days of experiment operating period where the TS consumption is about 49.93% as appeared in Fig.10, this gives an indicator to the degree of reaction happen within the anaerobic digester. These results are in good agreement with those obtained by Bitton, (1994); Mackie and Bryant, (1995). Thus, the temperature was fixed at this value in further experiments.

Table (2) shows comparison between the accumulation methane production obtained in the present study and those obtained by other researchers.

Methane to biogas fraction at optimum conditions was measured by syringe method to be 76%. Daily and accumulative biogases (CH_4, CO_2, N_2, and H_2S) at optimum conditions are illustrated in figs 11 and 12 respectively, and detailed in Table (3).

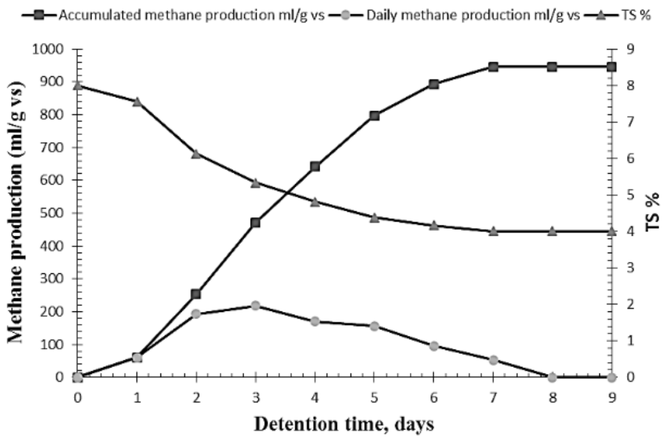

Fig. 10. TS percentage reduction with daily and accumulative methane production

Table 2. Methane yield recorded from anaerobic digestion of the solid organic waste

Type of waste	Methane yield, (mL/gm v.s)	References
OFMSW	360	Vogt et al., 2002
Fruit and vegetable wastes	420	Bouallagui et al., 2005
OFMSW	530	Forster et al., 2007
OFMSW	200	Walker et al., 2009
Rice straw	350	Lei et al., 2010
Horse and cow dung	353	Yusuf et al., 2011
Household waste	350	Ferrer et al., 2011
Food waste	396	Zhang et al., 2011
OFMSW	450	Hussein, 2014
WH/OFMSW	1039.8	Merawi, 2015
Algae/OFMSW	946	Present study, 2016

Table 3. Daily production of biogases

Time	CH_4	CO_2	N_2	H_2S
0	0	0	0	0
1	60.5	19.0	0.3	0.01
2	192.5	49.8	0.8	0.006
3	218.1	61.6	0.6	0.002
4	170.5	59.8	0.5	0.017
5	155.9	63.6	1.1	0.014
6	95.5	32.1	0.6	0.004
7	52.8	19.4	0.3	0.01

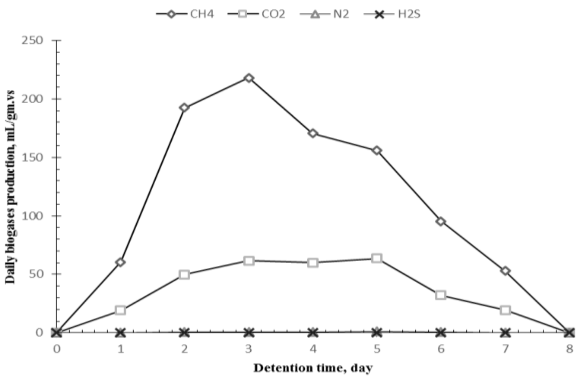

Fig. 11. Daily biogases production at, mix ratio =1:2, pH =7.5, T =32 ^{0}C and TS =8%

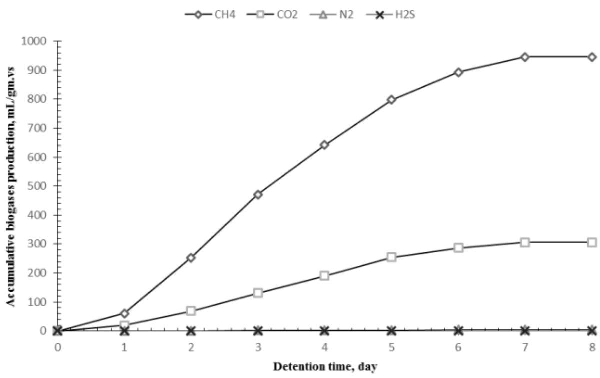

Fig. 12. Accumulative biogases production at, mix ratio =1:2, pH =7.5, T =32 ^{0}C and TS =8%

Subramani and Nallathambi, (2012) measured the methane fraction resulted from anaerobic digestion of mixing kitchen waste and sewage water to be 65%. This indicates that municipal solid waste using in the present study is better than kitchen waste. This may attribute to that the percentage of carbon source may be higher in municipal solid waste due to presence of large fraction of paper and wood.

It was found that, the most affecting parameter affected on anaerobic digestion was mixing ratio with increase the production up to 36.67%, while the overall production increasing with adjustment all the parameters i.e. (mixing ratio, pH, temperature and total solid) to optimum conditions was 63.63% as shown in Figs.13, and 14.

Total Volatile Acids and Total Alkalinity: At optimum conditions for anaerobic digestion process obtained from the laboratory scale anaerobic digester of (mixing ratio 1:2, pH 7.5, temp. 32 ^{o}C and T.S 8%), the stability of anaerobic digestion process was measured. To assess the process stability of the anaerobic reactor, both VFAs and alkalinity are the good indicator. The ratio (VFAs/Alkalinity) obtained is fluctuated between (0.2116 to 0.6835). The process appeared to be steady in light of the fact that no accumulation of VFAs. Zhao and Viraraghavan, 2004, report that if the proportion of VFAs to alkalinity surpassed 0.80, the restriction of methanogens occurred, methanogens which is responsible for methane production. Different looks into, for example, Sanchez et al. (2005) and Malpei et al. (1998) have expressed that ideal normal proportion of VFAs to alkalinity ought not be more than 0.40 and ought not be under 0.1 which is near the normal proportion got in the present study (0.4128). The variation in ratio of VFAs to alkalinity was shown in Fig.15.

Multiple correlations for methane production process:

Multiple correlations methodology was employed to find the relationship between the methane production and optimum mixing ratio, pH, temperature and total solid. **Equation ($Y=aX_1^bX_2^c X_3^d X_4^e X_5^f$)** was solved to find out these relationships by the application of Excel program.

Based on the experimental data, independent variable coefficients can be calculated. The correlation coefficient (R^2) is found to be 0.925. The desirable value of R^2 is close to 1, which means better correlation between the experimental and predicted values. The experimental maximum methane production obtained at optimum conditions which are (1:2, 7.5, 32 and 8%) for mixing ratio, pH, temperature and total solid respectively is close to that obtained from multiple correlations. The obtained equation is as follow:

$$Y = 10^{5.51253} \times (X_1^{0.49058} \times X_2^{-0.07496}$$
$$58 \times X_2^{-0.07496} \times X_3^{-0.65307} \times X_4^{-1.4113}) \quad (1)$$

Where: Y: accumulative methane production (mL/gm v.s), X_1: mixing ratio, X_2: pH, X_3: temperature (^{o}C), X_4: total solid (%), $Y_{practical}$: 946.0012 (mL/gm v.s), obtained from lab scale anaerobic digester and $Y_{theoretical}$: 902.3784 (mL/gm v.s), calculated from the equation by multiple correlation.

Application of Gompertz and first-order kinetic models: The experimental results for accumulative methane production are fitted with Gompertz and first order kinetic models. The results are listed in Table (4) and shown in Figs 16 and 17. The parameters for each model were estimated by non-liner regression using STATISTICA version-7 and EXCEL-2013 software.

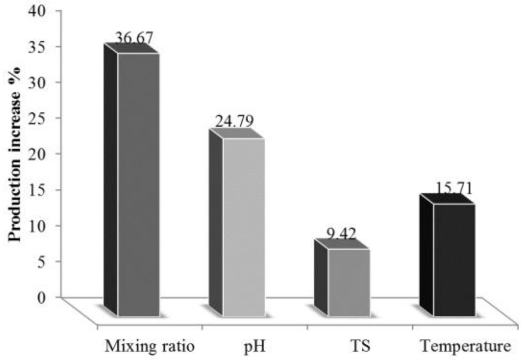

Fig. 13. Methane production increase percentage

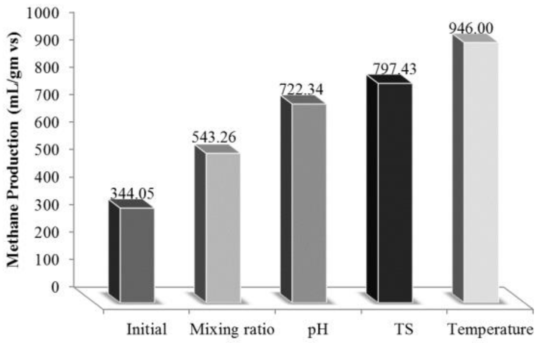

Fig. 14. Methane production increase after factors adjustment

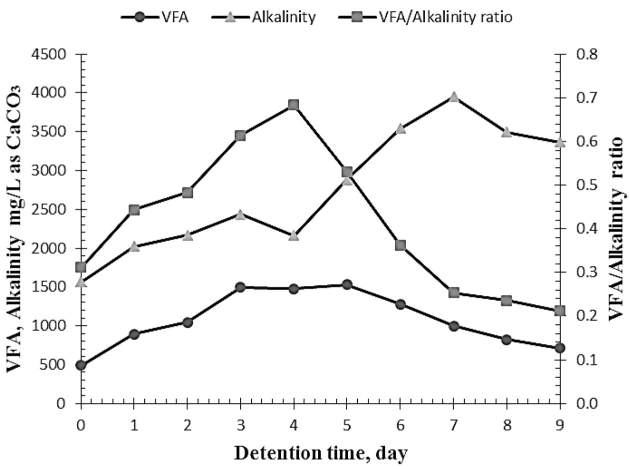

Fig. 15. Variation of VFA/ Alkalinity ratio

Table 4. Parameters of Gompertz and first order kinetic models

Gompertz model	**B, mL/gm v.s**	**Rb, mL/gm v.s day**	**λ, days**	**R^2**
	1016.76	221.7167	0.9167	0.998
Experimental	946.0012	218.1284	1	----
First order kinetic model	K, 1/day		R^2	
	- 0.2543		0.9906	

From the Figs 16, 17 and Table 3 the following conclusions can be drawn: Gompertz model is fitted exceptionally well with the experimental data of accumulative methane production obtained from lab scale anaerobic digester at optimum condition with high correlation coefficient. The experimental methane production potential (B, mL/gm v.s), maximum biogas production rate (Rb, mL/gm v.s/day) and lag phase (λ, days) are near those got by the applied model. The acquired results are fitted with the experimentally data. Table (5) demonstrates the comparison of data acquired from the present study and those got by different specialists by applying Gompertz model. Algae/OFMSW biodegradability was evaluated in this study by applying a mathematical model that based on the first order kinetics. The term (–k) is a measure of the rate of consumption of the biodegradable fractions that's changed into the biogas yield increases with time. The acquired negative value of (- 0.2543), demonstrates that the solid waste biodegradation was quick. This additionally affirms the biodegradation ideal conditions which are Algae/OFMSW mixing ratio, pH, temperature, and T.S% enhance the anaerobic digestion process. This is in steady with those outcome acquired by Yusuf et al. (2011).

Pilot scale anaerobic digester: The anaerobic process at pilot scale digester was performed at optimum conditions obtained from lab scale where the mixing ratio, pH, temperature and TS are (1:2, 7.5, 32 ^{o}C and 8%) respectively. According to the literature, the ignition efficiency depends onto purity of methane. The energy from methane can be converted to electricity with a typical efficiency of 34–40% for large turbines and with an efficiency of 25% for smaller generators (Nielsen, 2007; Tafdrup, 1995). For this analysis a range of efficiency from 25–40% was used. Equation (2) can be used with the generation efficiency to determine the amount of electricity possible from methane:

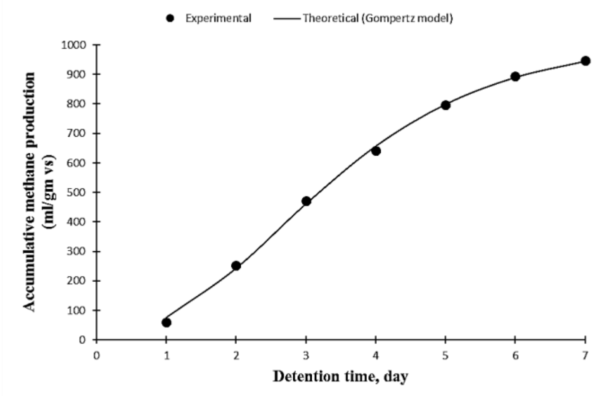

Fig. 16. Comparison of experimental data and modified Gompertz model for methane production

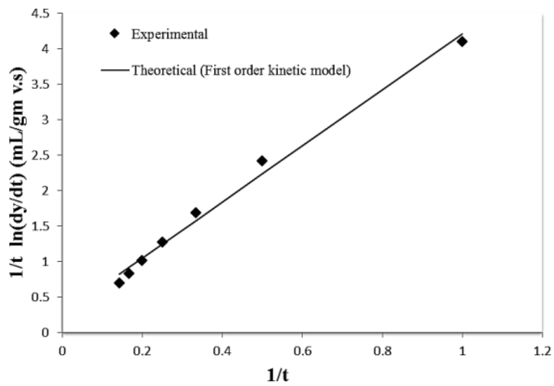

Fig. 17. Comparison of experimental data and First order kinetic model for methane production

Table 5. Comparison of data obtained from the present study and those

Type of waste	Measured value mL/gm V.S	*B*, mL/gm v.s	*Rb*, mL/gm v.s day	λ, days	R^2	Reference
MSW	489	482	72	1.7	0.995	Zhu et al., 2009
Horse and cow dung	353	360	36.99	8.07	0.997	Yusuf et al., 2011
Wastewater	111.649	109.37	23.466	0.803	0.988	Budiyono et al., 2013
Th.S/OFMSW	450	455.652	35.161	5.054	0.998	Hussein , 2014
WH/OFMSW	1039.80	1083.09	272.71	1.533	0.999	Merawi , 2015
Algae/OFMSW	946.001	1016.76	221.716	0.916	0.998	Present Study, 2016

Table 6. Electricity generated from different types of fuel

Type of fuel	Electric generation	Reference
Oil	12.2 kWh/L	Virginia Energy Patterns and Trends available, 2007
Coal	10.3 kWh/Kg	
Natural gas	10.8 kWh/m^3	Packer, 2011
Methane	3.73 kWh/m^3	Ostrem, 2004
Methane	2.81 kWh/m^3	Murphy, 2004
Methane	2.5 kWh/m^3	Udomsri, 2011
Methane	3.22 kWh/m^3	Present study, 2016

Where: *emethane* is the electricity generated from methane (KWh/m^3), *E methane* is the calories value of methane (33810 BTU/m^3), η is the electricity conversion efficiency (25- 40%). Thus for accumulative methane production of (946.0012 mL/gm vs= 946.0012 m^3/ton vs) the electricity generated will be:

1.For 25% conversion efficiency:

emethane = 33810 BTU/m^3 × 0.000293KWh/BTU× 0.25 = 2.48 kWh/m^3 Thus, the overall electricity generation = 2.48 × 946.0012 = 2346.0829 kWh/ton vs.

2.For 40% conversion efficiency:

$$emethane\ [kWh] = E\ methane\ [BTU] \times 0.000293\ \left[\frac{kWh}{BTU}\right] \times \eta \qquad (2)$$

emethane = 33810 BTU/m^3 × 0.000293KWh/BTU× 0.4 = 3.96 kWh/m^3 Thus, the overall electricity generation = 3.96 × 946.0012 = 3746.1647 kWh/ton vs.

3.For average conversion efficiency is 32.5%:

emethane = 33810 BTU/m^3 × 0.000293KWh/BTU× 0.325 = 3.22 kWh/m^3 Thus, the overall electricity generation = 3.22 × 946.0012 = 3046.1238 kWh/tone vs. Table (6) shows the comparison of electricity generated from methane with other energy sources.

The methane production was used as a fuel in electric generator. The generator was worked for 33 minute.

CONCLUSIONS

Anaerobic digestion of the mixture of algae biomass and OFMSW increased the cumulative biogas yield when compared to OFMSW alone by percent of 36.67%. The maximum value of biogas generated was observed in digester at condition of mixing ratio, pH, temperature and total solid percent were (1:2, 7.5, 32 ºC, and 8%). Application of the multiple correlations, first order kinetic, and modified Gompertz models to predict the theoretical methane biogas time and different parameters. Multiple correlations equation was applied and gave a desired value of correlation coefficient (R^2) of 92.5% which means better correlation between the experimental and predicted values. The negative value of biodegradation rate constant (k = -0.2543) of first order kinetics model assessed that the biodegradation of the mixture of Algae and OFMSW was fast with a correlation coefficient (R^2) of 99.06%. A correlation coefficient (R^2) of 99.8% indicates that Gompertz model fitted very well with the experimental data.

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