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Modelling and evaluation of anaerobic digestion process of tomato processing wastes for biogas generation

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Abstract Anaerobic digestion is the most attractive technique for biogas production from organic materials. This research studies and models such production from anaerobic digestion of tomato processing wastes in a single-stage laboratory digester and the variation of pH of the process. The single-stage digester was designed and built on a laboratory scale and the tomato processing wastes used as feed materials for digestion were collected from the Zoshk Khorasan Company (Mashhad-Iran). Some properties of digested materials were determined. The results revealed that the tomato processing wastes could be an appealing option for production of biogas by anaerobic digestion process. The digester was controlled under mesophilic conditions (35 °C) with continuous mixing. Also, the percentage of total solids content was adjusted 8%. The amount of production of biogas from the waste was approximately 142.00 L (130.00 L in STP conditions) which is equivalent to 0.14 m^3 per kilogram of volatile solids (m^3/kg vs). The methane content in the produced biogas was approximately 60.50% (about 86.00 L).

Keywords Tomato processing waste · Anaerobic digestion · Biogas · Renewable energy

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Introduction

Due to the increasing use of fossil fuels in the world and their environmental impact and cost, it is of utmost importance to replace fossil-based fuel with new sources of renewable energy which are accessible, not pollutant and practically inexhaustible [1–3]. Therefore, the resources of energy are important for the future of developing countries [4]. Due to the increasing need for energy, fossil energy limitations, maintaining a healthy environment, reducing air pollution and providing remote villages with fuels, such sources of energy seems remarkable in Iran. The biogas is one of the best alternatives to fossil fuel due to its advantages [5]. Considering the low cost of anaerobic digestion system, its technology simplicity, climate, and types of wastes in Iran, enriched fertilizer in form liquor or solids and part of the needed energy for the community will be provided if such system is selected. Moreover, such trends can reduce both greenhouse gases and biological and chemical pollutants. Removing bad odors and harmful insects from the suburbs is the other benefit of using anaerobic digestion system. Due to the increasing amount of different organic wastes in Iran (about 15 million tons per year), the waste management and the production of biogas is inevitable. Unlike other renewable energy production systems, biogas neither needs any sophisticated technology nor it is dependent on geographical constraints [6]. When the biogas is burned as a fuel source, it becomes odorless and smokeless. Moreover, controlling diseases, eliminating or reducing harmful insects and being environmentally friendly, are considered as its advantages [7]. The collection of gases produced in the absence of oxygen from the microbial decomposition and fermentation of organic waste materials such as human, animal and plant waste materials in the fermentation container is called

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biogas, which consists of mainly CH_4 (40–75%), CO_2 (25–40%) and traces of other gases such as N_2, H_2, NH_3, H_2S and water vapour [8–10]. On average, the amount of heat energy produced from burning one cubic meter of biogas is 5500–6500 kcal. The energy contained in 0.65 L of diesel fuel, 0.74 L of oil and 0.6 m^3 of natural gas fuel is equivalent to the energy contained in one cubic meter of biogas [11]. Basically, anaerobic digestion is a versatile biochemical process. The process under anaerobic conditions is capable of converting almost all types of biodegradable organic matter into an energy-rich biogas consisting of CH_4 and CO_2 [12, 13]. The hydrolysis, acidification, acetogenesis and methanogenesis are four successive stages in the process of anaerobic digestion and methane production. During the hydrolysis stage, the fermentative bacteria transform complex compounds into simple molecules. In the acidification stage by fermentation of microorganisms, products, such as organic acids, short-chain fatty acids, alcohol, and hydrogen, are produced. During acetogenesis stage, the products of the previous stage are converted to hydrogen, carbon dioxide and especially acetic acid or acetate. In the final step of anaerobic digestion, methane is produced by methanogens from acetate and CO_2/H_2 [14].

The process of anaerobic digestion with a proper management plan could be used to solve the problems of waste disposal and converts it into an asset [13]. The production of biogas by the anaerobic process in comparison with aerobic process has many advantages such as requiring lower energy to run the process, lower initial investment costs and producing lower sludge volume. Therefore, biogas production using anaerobic digestion is an economical technology and also it is a good alternative source of renewable energy [15].

In 1989, the generation of methane gas from tomato processing wastes using anaerobic degradation process was investigated by Sarada and Nand [16]. Their results showed that the stepwise adding of feedstock over 10–12 weeks of digestion will lead to a good start up of digestion of tomato-processing waste. The operation resulted in a steady state gas yield of 0.597 m^3/kg VS added with 72% methane content. The production of biogas of some food industry wastes such as carrot, orange, phaseolus, pea and tomato wastes was evaluated during a 40-day fermentation period in 60-L anaerobic contact-type reactors [17]. The average volumes of production of biogas per day were 205, 422, 457, 342 and 383 m^3/ton vs for orange, phaseolus, tomato, pea and carrot wastes, respectively. Saev et al. investigated co-digestion of tomato-processing waste and animal manure by semi-continuous mesophilic anaerobic digester [18]. Their results showed that the conversion percentage of the organic solids fed into the digester at 20 days hydraulic retention days was 72.5%. Also, the average 220 L as per kg VS added was obtained. The highest amount of methane was obtained when the ratio of cattle dung to tomato waste was 80:20.

The city of Mashhad in Iran is always recognized as one of the most important poles of the food processing industry, especially the processing of tomato. The annual amount of processing waste generated in the city is approximately 20 million tons. Therefore, production of methane by anaerobic digestion can be used as a waste management method to reduce the amount of organic waste and production of energy. The purposes of this research are: (1) determining the properties of tomato-processing wastes in the anaerobic digestion; (2) modelling of variation of pH, CH_4 and biogas during the process of anaerobic digestion and (3) evaluating and determining the amount of production of biogas from tomato-processing wastes in Iran.

Materials and methods

Waste materials

The tomato-processing wastes were collected from the Zoshk Khorasan Company (Mashhad-Iran). The sampled materials were chopped into 2–10 mm fragments. To stop the activity of microorganisms, the samples were stored in the refrigerator at a temperature of 0 °C. Some of the properties of materials that are commonly used in the anaerobic digestion such as moisture content, total solids, volatile solids, nitrogen content, carbon content and pH are determined.

Chemical analysis

The pH, total solids (TS) and volatile solids (VS) were determined according to standard methods [19]. Total Kjeldahl nitrogen (TKN) was measured by Kjeldahl method and total organic carbon was determined according to the standard No 13320 specified in the Institute of Standards and Industrial Research of Iran (ISIRI). The tests of physical and chemical properties of waste materials were performed in the municipality of Mashhad, recycling and transformation of materials organization (RTMO).

Laboratory digester

In this study, the single-stage batch digester with continued stirring was used for anaerobic digestion of tomato-processing wastes. The main digester tank was made of steel with working volume of 6 L (total volume 8 L). The hot water coil was used to warm it up. To maintain the temperature in the digester at mesophilic temperature and proper insulation of digester from the environment, the

Fig. 1 The pilot digester was used in this research

digester was covered with aluminium foil and a layer of fiberglass. The cap of the chamber was steel plate equipped with a pH-regulating valve, a gas output valve, a seal of the shaft mixer and an installation location of temperature sensor. The discharge valve of the material is mounted at the bottom of the digester vessel (Fig. 1).

The system includes the following components (Fig. 2): a water pump for circulating warm water to the space between the walls of the digester and transferring it in a water bath, a temperature sensor located inside the digester to measure its temperature, a digital thermostat used to control the temperature of digestion process (35–37 °C), a digital timer used to control the timing and frequency of the stirring of the material during the digestion and a motor used to stir the materials.

Inoculation material

The slurry of digested cow dung containing 25% by weight of water volume in the digester was used as an inoculation material. Because of the absence of volatile components in the inoculation material, it has no great effect on the amount of biogas produced [20]. Also, the inoculation material increases the reaction rate and modifies pH changes at the start of the reaction.

Loading of digester

Zennaki et al. reported that the best concentration of total solids for anaerobic digestion in the digester measured by standard methods is 7–10% [21]. In this study, the concentration was adjusted 8%. The water was used to achieve the desired concentration. The characteristics of the input materials loaded into the digester are given in Table 1.

Based on the desirable pH of the input materials, the mesophilic anaerobic conditions were provided for the loading materials. The materials were stirred intermittently and automatically using the vertical stirrer during the process of digestion (5 min in 150 min, 120 rpm).

Measurements

The daily production of biogas was measured using water displacement method. The percentage of methane in the produced biogas was determined by the gas analyzer (GA 2000, Keison Products, UK). The pH of digester materials

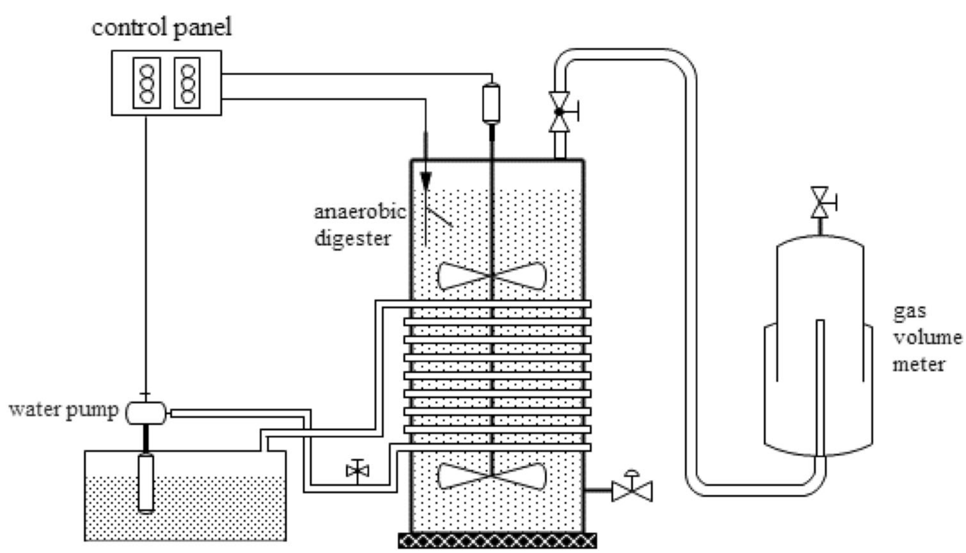

Fig. 2 The schematic of the digestion system

Table 1 The characteristics of the materials in the digester

Total solids (%)	Water was added (ml)	Inoculum (ml)	Wet weight of material (g)
8	3191.43	1380	1428.57

during digestion was measured using a pH meter (Lutron, Taiwan; pH-201 model, accuracy 0.1%) every 3 days.

Results and discussion

The composition of the tomato processing waste loaded into the digester is given in Table 2. As can be seen, the volatile solids (VS) content of the materials was high. The volume and methane contents of the biogas produced are dependent on the volatile solids [22]. The high ratio of volatile solids to total solids (VS/TS) reveals that the tomato-processing waste is a suitable material for production of biogas by anaerobic digestion. The carbon to nitrogen (C:N) ratio is next important factor affecting the digestion process. This ratio depends directly on the type of waste. The ideal ratio of C:N is around 20:1–30:1 [23]. Also, the pH of the materials is the most important factor in the production of biogas. It is noteworthy that the best pH range for the activity of the methane-forming bacteria and anaerobic organisms during anaerobic digestion is between pH 6.8 and 7.2 [23]. At the beginning of loading, the pH of the input materials to the digester was adjusted to the desired pH with inoculum. After starting the anaerobic digestion process, the pH of the materials is adjusted automatically by the process [24].

Model of pH changes

The pH of the input materials to the digester was brought to 7.2 by adding inoculum. As seen in Fig. 3, based on the variation of pH value, two stages and four phases can be observed for the anaerobic digestion process. The first stage of the variation of pH is more consistent with the second model (Eq. 1). The quadratic model was able to explain 94.70% of the variation of the pH. The first stage consists of two phases, reducing and then increasing the pH. The first stage is called self-compatibility stage. During this stage, first there is a decreasing trend in the pH because of production of the volatile fatty acids (VFA). In this study, pH decreases from 7.2 and reaches its lowest level of 5.75 in 12 days, and then increases gradually. In the second phase of the first stage, the activity of the methane-forming bacteria starts to grow and consumes VFA and converts them to CH_4 and CO_2 [24]. The first stage is completed in the 24th day of the process. After this stage, the second stage, namely the stabilization stage begins. The best model for explaining the variation of pH with time in the stage was a power model (Eq. 2). The first phase (Fig. 3c) showed that the increasing trend of pH was slow and then reached to constant value approximately 8 in the d phase. In previous stage, the activity of the methane-

Table 2 The composition of tomato-processing waste and the mixtures

pH	C:N ratio	Total nitrogen (%)	Total carbon (%)	Volatile solids (%)	Total solids (%)	Moisture content (%)
5.95	13.04	3.13	40.83	96.2	33.6	66.4

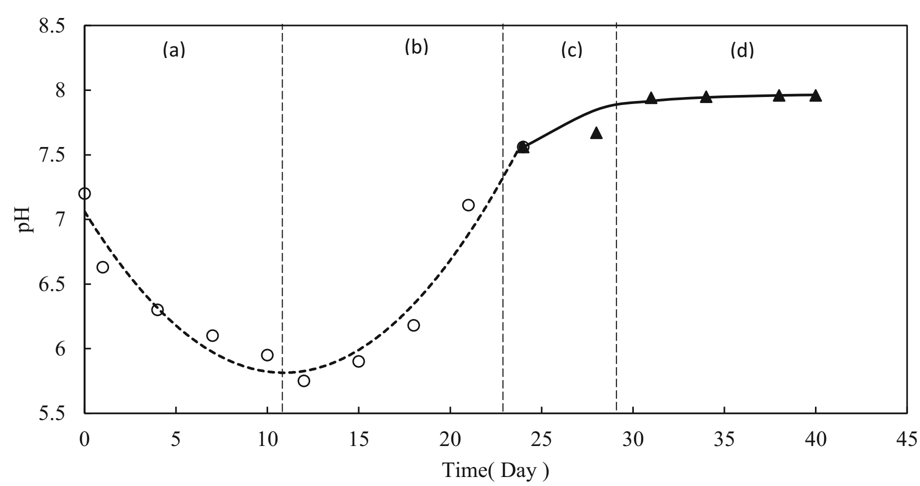

Fig. 3 The variation of the pH during anaerobic digestion

forming bacteria leads to conversion of the VFAs and decreases their concentration.

$$\text{stage 1}: \text{pH} = 0.0105\text{Day}^2 - 0.229\text{Day} + 7.062, \quad R^2 = 0.947 \tag{1}$$

$$\text{stage 2}: \text{pH} = -2.937 \times 10^{10}\text{Day}^{-7.864} + 7.971, \quad R^2 = 0.932 \tag{2}$$

Biogas production

Figure 4 shows the trend of production of biogas from tomato-processing waste for the duration of retention time. This trend was consistent with the other results reported by Omrani and Taleghani and Shabani Kia [6, 25]. As can be seen in Fig. 4, the variation form of the biogas production versus retention time is assumed to be a Gaussian function. Therefore, the result of fitting Gaussian function to the measured data is given in Eq. (3). The high coefficient of determination ($R^2 = 0.951$) indicates that it is adequate to estimate the value of biogas. The amount of biogas generated per kilogram of volatile solids was equal to 0.14 m^3. Also, the total amount of biogas produced in the duration digestion time was approximately equal to 141.87 L. The digestion period lasted 40 days. Given that the batch system was used in the study and optimization of biogas production was not a goal, thus the amount of biogas produced was remarkable. Sarada and Nand were able to produce 0.597 m^3 biogas per kg of volatile solid, it would appear that the amount was considerable [16]. The amount is not unexpected due to the high efficiency of the continuous system as well as the use of cow manure as an inoculation to optimize the ratio of carbon to nitrogen (C:N). Also in another study by Saev et al. [18], 0.22 m^3 biogas per kg of volatile solid was generated by co-digestion of the cow manure and the tomato-processing waste during the 20 days of digestion.

$$V_{\text{biogas}} = 5.233 \exp\left(-\left(\frac{\text{Day} - 25.833}{8.353}\right)^2\right), \quad R^2 = 0.951 \tag{3}$$

Generally, the amount of methane in the biogas represents the quality of the biogas. Also, the percentage of methane content in the biogas from organic waste ranges from 40 to 75%. The results showed that the amount of production of methane from the tomato-processing waste was equal to 85.5 L which was equivalent to 60.26% of biogas. Thus, the quantity of biogas and methane derived from wastage can lead the existing waste management methods towards optimal methods like anaerobic digestion given the research objectives and the high quantity of wastage in the studied region. The results obtained by anaerobic digestion of tomato-processing waste with cow manure as an inoculation material in the continuous system showed that the amount of methane generated is about 72% of biogas [16]. The cow manure by optimizing the ratio of carbon to nitrogen can increase the production of biogas and the content of methane in biogas. Saev et al. reported that anaerobic co-digestion of tomato waste and cow manure in the semi-continuous system produced the 67.7% methane from the total biogas mixture [18]. Figures 5 and 6 show the daily variation of content of methane and CO_2 in the biogas produced during a 40-day period, respectively. The variation trend of the biogas and methane production was the same during the period of the anaerobic digestion (Figs. 4, 5). The Gaussian and quadratic models were fitted to the experimental data. The results are consistent with other findings [6, 16, 18].

$$\text{PC}_{\text{CH}_4} = 64.08 \exp\left(-\left(\frac{\text{Day} - 23.8}{12.15}\right)^2\right), \quad R^2 = 0.989 \tag{4}$$

$$\text{PC}_{\text{Co}_2} = 0.0564\text{Day}^2 - 4.446\text{Day} + 106.2, \quad R^2 = 0.951 \tag{5}$$

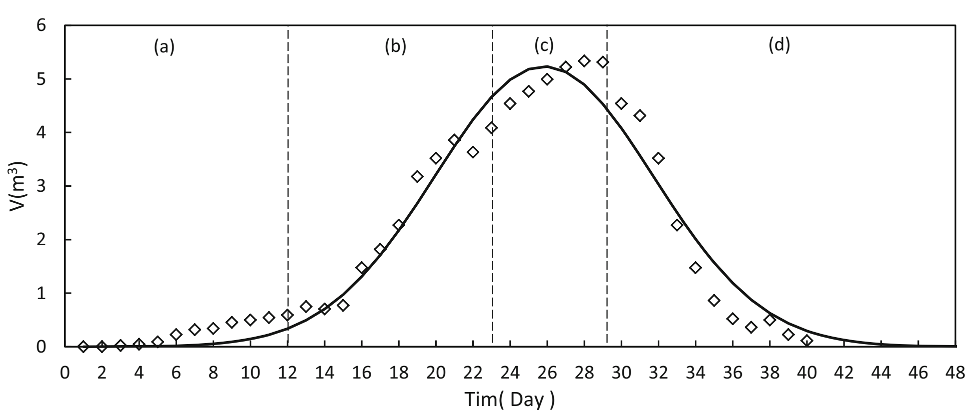

Fig. 4 The variation trend of the biogas during anaerobic digestion

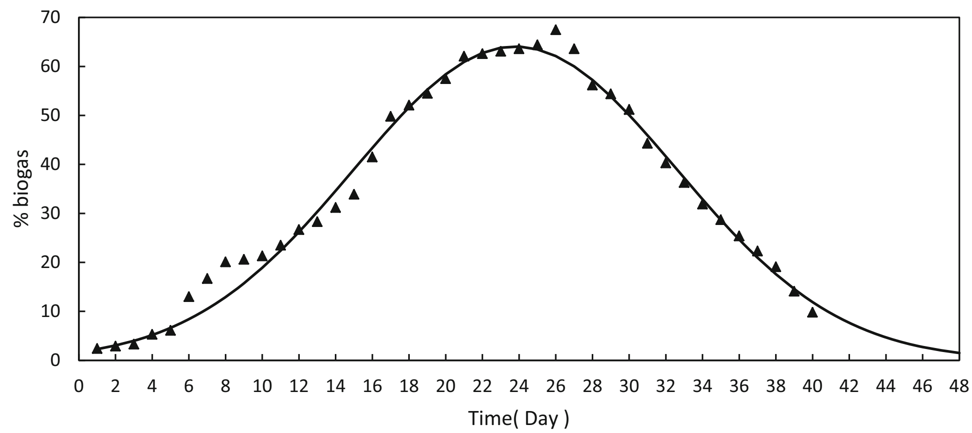

Fig. 5 The variation of the content of methane in the biogas produced per day during anaerobic digestion

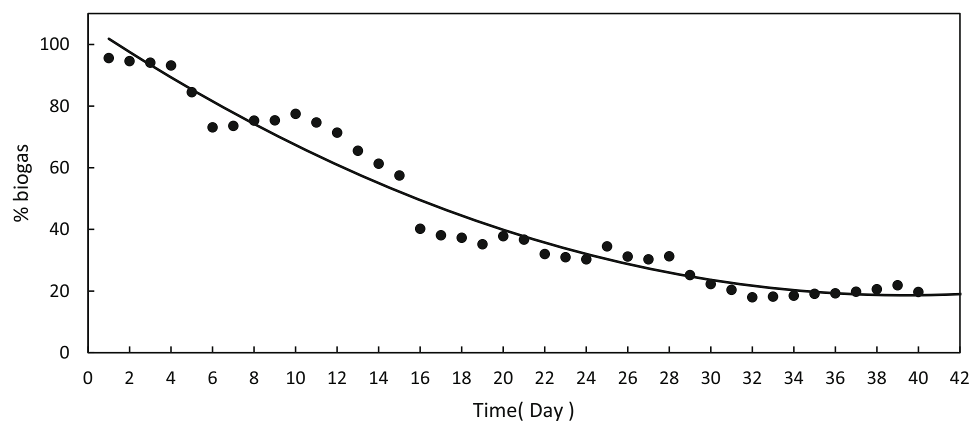

Fig. 6 The variation of the content of CO_2 in the biogas produced per day during anaerobic digestion

Model validation

To validate the models of pH, biogas, CH_4 and CO_2, different percentages of whole data (100, 80, 60 and 40%) were randomly used for the calibration or estimation of the model parameters. Also, the remaining data were used to assess the generalizability of the models. Results of model validation are presented in Table 3. The coefficient of determination between laboratorial values and the values predicted by the models was used as the assessment criterion. As the results show, the models could produce acceptable R^2 in each of the two steps through reducing the size of calibration dataset and increasing test datasets. Therefore, it can be concluded that the selected models are in accordance with the reality variations of pH, biogas, CH_4 and CO_2, and that the models were quite well generalizable.

Table 3 Coefficients of determination for the models at three steps of calibration, test and total

%data for calibration	pH			Biogas		
	Calibration	Test	Total	Calibration	Test	Total
100	0.94	–	0.94	0.93	–	0.93
80	0.93	0.99	0.94	0.92	0.90	0.92
60	0.96	0.87	0.94	0.91	0.95	0.93
40	0.99	0.99	0.92	0.93	0.86	0.87
%data for calibration	**CH_4**			**CO_2**		
	Calibration	Test	Total	Calibration	Test	Total
100	0.98	–	0.98	0.95	–	0.95
80	0.98	0.98	0.98	0.95	0.96	0.95
60	0.98	0.98	0.98	0.93	0.97	0.95
40	0.97	0.99	0.98	0.95	0.94	0.95

Conclusion

The conversion of tomato-processing wastes and other agricultural processing wastes to biogas by the use of anaerobic digestion process could be a viable option for the management of wastes in Iran. In this research, the potential of such conversion was evaluated. The values of the properties of the tomato-processing waste and the mixtures in the digester revealed that the materials could provide good conditions for beginning and continuing the anaerobic digestion process. The results of modelling of the pH during the anaerobic digestion process showed that the process was done in two stages and four phases, and that the Gaussian and the quadratic models are the most appropriate forms of model for variation of the biogas and CO_2 versus time of digestion, respectively. The results revealed that the 0.14 m^3 biogas produced per kg of volatile solids using batch anaerobic digestion under mesophilic condition. Also, the results of gas analysis showed that the methane content of the produced biogas was 60.3%. Therefore, the biogas production from tomato-processing waste by anaerobic digestion process is an efficient and attractive option for conversion of the tomato-processing waste into energy, valuable outputs and waste prevention.

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References

1. Jury C, Benetto E, Koster D, Schmitt B, Welfring J (2010) Life cycle assessment of biogas production by monofermentation of energy crops and injection into the natural gas grid. Biomass Bioenerg 34:54–66
2. Kim DH, Oh SE (2011) Continuous high-solids anaerobic co-digestion of organic solid wastes under mesophilic conditions. Waste Manage 31:1943–1948
3. Richter F, Fricke T, Wachendorf M (2011) Influence of sward maturity and pre-conditioning temperature on the energy production from grass silage through the integrated generation of solid fuel and biogas from biomass (IFBB): 1. The fate of mineral compounds. Biores Technol 102:4855–4865
4. Rao PV, Baral SS, Dey R, Mutnuri S (2010) Biogas generation potential by anaerobic digestion for sustainable energy development in India. Renew Sustain Energy Rev 14:2086–2094
5. Arbabi M, Omrani QA (2011) Biogas technology. Fanavaran, Tehran
6. Taleghani G, Kia AS (2005) Technical–economical analysis of the Saveh biogas power plant. Renew Energy 30:441–446
7. Fazli F (1986) Biogas in China. Ministry of Planning and Budget, Tehran
8. Jiang X, Sommer SG, Christensen KV (2011) A review of the biogas industry in China. Energy Policy 39:6073–6081
9. Arthur R, Baidoo MF, Brew-Hammond A, Bensah EC (2011) Biogas generation from sewage in four public universities in Ghana: a solution to potential health risk. Biomass Bioenergy 35:3086–3093
10. Ossai OS (2013) Comparative evaluation of qualitative and quantitative biogas production potential of oil palm fronds and co-digestion with cow dung. J Energy Technol Policy 3:25–33
11. Kurmanov A (2014) The biogas production effectiveness increase. Life Sci J 11(11s):24–29
12. Mshandete A, Björnsson L, Kivaisi AK, Rubindamayugi MS, Mattiasson B (2006) Effect of particle size on biogas yield from sisal fibre waste. Renew Energy 31:2385–2392
13. Singh S, Prerna P (2009) Review of recent advances in anaerobic packed-bed biogas reactors. Renew Sustain Energy Rev 13:1569–1575
14. Christy PM, Gopinath L, Divya D (2014) A review on anaerobic decomposition and enhancement of biogas production through enzymes and microorganisms. Renew Sustain Energy Rev 34:167–173
15. Coskun C, Bayraktar M, Oktay Z, Dincer I (2012) Investigation of biogas and hydrogen production from waste water of milk-processing industry in Turkey. Int J Hydrog Energy 37:16498–16504
16. Sarada R, Nand K (1989) Start-up anaerobic digestion of tomato-processing wastes for methane generation. Biol Wastes 30:231–237
17. El-Shimi S, El-Housseini M, Ali B, El-Shinnawi M (1992) Biogas generation from food-processing wastes. Resour Conserv Recycl 6:315–327
18. Saev M, Koumanova B, Simeonov M (2009) Anaerobic co-digestion of wasted tomatoes and cattle dung for biogas production. J Univ Chem Technol Metall 44:55–60
19. Federation WE, Association A (2005) Standard methods for the examination of water and wastewater. American Public Health Association (APHA), Washington, DC
20. Forster-Carneiro T, Pérez M, Romero L, Sales D (2007) Dry-thermophilic anaerobic digestion of organic fraction of the municipal solid waste: focusing on the inoculum sources. Bioresour Technol 98:3195–3203
21. Zennaki-Bensouda Z, Zaid A, Lamini H, Aubineau M, Boulif M (1996) Methane fermentation of cattle manure: effects of hydraulic retention time, temperature and substrate concentration. Tropicultura 14:134–140
22. Dueblein D, Steinhauser A (2008) Biogas from waste and renewable resources. Wiley-VCH Verlag GmbH and Co 276, KGaA
23. Zhang C, Su H, Baeyens J, Tan T (2014) Reviewing the anaerobic digestion of food waste for biogas production. Renew Sustain Energy Rev 38:383–392
24. Gerardi MH (2003) The microbiology of anaerobic digesters. In: Gerardi (ed) Wastewater microbiology series. Wiley, Hoboken, NJ
25. Omrani G (1996) Basics biogas production from urban and rural waste. University of Tehran Publication, Iran