CHEMICAL ENGINEERING TRANSACTIONS
VOL. 83, 2021

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-81-5; **ISSN** 2283-9216

DOI: 10.3303/CET2183097

Anaerobic Co-Digestion of Food Waste with Crude Glycerol for Biogas Production

Muhammad Khairul Nizam Jensani[a], Aziatul Niza Sadikin[a,*], Norzita Ngadi[a], Muhammad Fakhrullah Azman[a], Zarina Abd Muis[b], Umi Aisah Asli[c]

[a]School of Chemical and Renewable Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor, Malaysia.
[b]Process Systems Engineering Center, School of Chemical and Renewable Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor, Malaysia.
[c]Innovation Center in Agritechnology for Advanced Bioprocessing, School of Chemical and Renewable Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor, Malaysia.
aziatulniza@utm.my

Biogas production from anaerobic co-digestion of food waste and crude glycerol was investigated in this study. The effect of different combination ratios of substrates on biogas production were examined with the inoculum to substrate ratio of 1:2. The batch experiments were carried out at temperature of 35 °C and 55 °C to determine the influences of temperature on biogas production. The pH of the digesters was recorded in the range between 6.5 to 8.0. Based on the results, the co-digestion of food waste and glycerol using combination ratio of 3:1 at 35 °C gave the highest total biogas yield. The highest percentage of total solid (TS) and chemical oxygen demand (COD) reduction were 32.6 % and 35.8 % which also achieved by the combination food waste and glycerol ratio of 3:1 at 35 °C. The results revealed that co-digestion of food waste and glycerol is promising in the experimental conditions studied and can potentially be used to enhance biogas production while contributing to the management and treatment of these wastes.

1. Introduction

Food waste represents a major share of municipal solid waste. Recently, with great economic growth and rapid urbanization in Southeast Asia, the problem of huge food waste disposal has become more serious in most megacities. Statistically, approximate 33 % of food is wasted in the developing countries (Yang et al., 2016). It was reported that in average a household in Malaysia throw away around 0.5 – 0.8 kg/d uneaten food (Cassendra et al., 2017). Food waste can be defined as all edible food materials produced for human consumption but left uneaten throughout the food supply chain, either lost or discarded. Food consumptions are relatively stockpile in communities, restaurants and canteens of schools, universities or enterprises. This problem is expected to increase in a few years while corresponding to economic development, population growth, and urbanization as Malaysia's population is expected to reach 33.4 M by year 2020. The disposal of large amounts of food waste has caused significant environmental pollution in Malaysia and globally. Recovering energy and nutrients from food waste is an essential requirement for the sustainable development of human society and economic. On the other hand, biodiesel has become one of the most attractive fuels since the renewability of its nature has been understood globally. Glycerol is a major by-product of biodiesel production that is often considered a waste stream that has a substantial cost of waste disposal (Athanasoulia et al., 2014). The substantial increase in biodiesel production has led to a glycerol surplus resulting in a dramatic drop in the price of crude glycerol (Yazdani and Gonzalez, 2007). In addition, glycerol is a readily digestible substance that can be easily stored for a long period of time and can be characterized as an ideal co-substrate for the anaerobic digestion process (Athanasoulia et al., 2014).
Anaerobic digestion is a biochemical process in which microorganism break down the biodegradable material into biogas under the absence of oxygen. Biogas production from organic substrates involves redox reaction

Paper Received: 10/08/2020; Revised: 16/11/2020; Accepted: 16/11/2020
Please cite this article as: Jensani M.K.N., Sadikin A.N., Ngadi N., Azman M.F., Ab Muis Z., Asli U.A., 2021, Anaerobic Co-Digestion of Food Waste with Crude Glycerol for Biogas Production, Chemical Engineering Transactions, 83, 577-582 DOI:10.3303/CET2183097

that converts organic molecules to CH_4 and CO_2. For the simplest case, the conversion of carbohydrates, such as sugars and starch or cellulose, an equal amount of CH_4 and CO_4 is produced as per Eq(1):

$$C_nH_{n-2}O_{n-1} + nH_2O \rightarrow ½\ nCH_4 + ½nCO_2 \quad (1)$$

The anaerobic digestion is now a widely used technology, to address both energy and environment challenges. Methane could be a source of renewable energy producing electricity in combined heat and power plants (Clemens et al., 2006). The anaerobic digestion is strongly dependent on the environmental conditions (Mata-Alvarez et al., 2011) such as pH, temperature, nutrients content, carbon/nitrogen ratio, and presence of inhibitors, microelements availability and particles size. All types of biomass are suitable to be used as substrates for biogas production. Sewage sludge from aerobic wastewater treatment, animal manure, harvest residues, energy crops, organic wastes from agriculture-related industries, poultry industrial wastes, seafood processing wastewater (Dinh and Luan, 2020), beverages industry waste (Wiwatwongwana et al., 2019), municipal wastewater treatment (Dinh and Le, 2020) are the substrates commonly used for anaerobic digesters. The theoretical biogas yield varies with the content of carbohydrates, lipids and proteins that present on organics wastes. Carbohydrates are the main components of food waste is strongly depending on the ratio between the acidification process rate and methanogenic process rate. Lipids are commonly present in biodiesel wastewater could provide the highest biogas yield, but require a long retention time due to their slow biodegradability.

A great option for improving yields of anaerobic digestion of solid wastes is the co-digestion of multiple substrates. Anaerobic co-digestion is a promising strategy, which involves simultaneously digesting two or more different types of wastes to produce energy rich biogas. Numerous studies demonstrate that using co-substrates in anaerobic digestion system improves the biogas yields due to positives synergisms effect in the digestion medium and the supply of missing nutrients by the co-substrates. Co-digestion increases the load of mixed nutrients and accelerates biodegradation rate by bio-stimulation (Hartmann and Ahring, 2005). Because of increased biodegradable organic matter, the rate of digestion increases which results in higher biogas yield (Lo et al., 2010). The sludge of better quality is also produced in co-digestion process. Several studies of anaerobic digestion have demonstrated that this process is particularly well adapted to effluents with a high load, such as those from biodiesel production, which have additional favourable characteristics such as high organic content, relatively high temperature and good biodegradability (Siles et al., 2009).

Studies of co-digestion of food waste found that inclusion of food waste was beneficial for methane yield (Maranon, 2012), while digestion processes with food waste as the sole substrate were often found to be unstable (Zhang et al., 2011). Anaerobic co-digestion of food waste and glycerol may enhance the stability of the anaerobic process through the carbon-to-carbon balance. Lamichhane et al. (2017) stated that the carbon supplied by the crude glycerol in the water balances the nutrients (nitrogen) in the sewage wastewater which can improves biogas production as well reducing organics and nutrients, economizing subsequent treatment processes such as nitrification and denitrification in wastewater treatment plant. The food waste has theoretical methane production rate typically ranges from 0.4 to 0.5 L CH_4/gVS (Nagoa et al., 2012), suggesting great potential for energy recovery. The main objective of this research work was to measure the biogas production from co-digesting food waste and glycerol as compared to digesting food wate and glycerol separately by using anaerobic batch digester under mesophilic and thermophilic temperature.

2. Materials and methods

2.1 Substrates preparation

Simulated food waste was prepared by processing a mixture of waste matter consisting of 55 % rice, 24 % potato and 21 % watermelon by weight. The FW samples were then reduced to a particle size of 1 mm by a food processor (Phillips R17630) and mixed well to achieve certain degree of homogeneity. The homogeneous food waste was stored in a freezer before use as a feed material. Such procedure was important to ensure that the substrate composition was maintained invariant during the experiments. Crude glycerol was prepared in laboratory. Then, the crude glycerol was stored in a room temperature. Anaerobic sludge was collected from palm oil mill wastewater treatment plant for use as the inoculums for biogas production. The inoculum was stored at 4 °C to maintain microbial activity. It was reactivated at 35 °C for 5 days prior to use. The cultivation of inoculums was obtained by treating anaerobic sludge at pH 5.5 at thermophilic condition to remove methanogenic bioactivity.

2.2 Batch co-digestion

Biogas studies were conducted in batch mode to assess the impact of co-digestion on the anaerobic digestion performance. The batch anaerobic co-digestion process was conducted in 250 mL Schott Duran bottles with working volume of 180 mL for 14 d at temperature of 35 °C and 55 °C. The five different substrates (A, B, C, D, E) were prepared with ratio food waste (FW) to glycerol (GLY) of 4:0, 3:1, 1:1, 1:3 and 0:4 (Table 1).

Table 1: Ratio of food waste to crude glycerol

Substrate	FW:GLY
A	4:0
B	3:1
C	1:1
D	1:3
E	0:4

Then, the inoculum was added into each of the digester with inoculum to substrate ratio (ISR) of 1:2. In addition, one bottle was labelled as control with ISR 1:0. The purpose of the control was to determine the ability of the inoculum alone towards the biogas production. The initial pH was recorded as neutral before the start of anaerobic digestion. Nitrogen gas was purged through to expel oxygen from the digester and make it air tight in order to ensure anaerobic conditions in the headspace of anaerobic digesters. All of the bottles were placed in the water bath that will be heated to a required temperature. The biogas production was recorded daily and the digesters were shaken afterward about 1 min to prevent formation of dry and inactive layer. During the digestion, the biogas production was monitored daily. Daily produced biogas in batch digestion was determined by water displacement method. The substrates were subjected to analysis of the chemical parameter such as Total Solids (TS) and Chemical Oxygen Demand (COD) was estimated according to APHA (1998).

3. Results and discussion

The daily biogas production for temperature 35 °C and 55 °C were plotted in the Figure 1. The biogas production starts immediately during the first day of the digestion from all digesters for both temperature conditions. At 35 °C the highest volume of biogas production was recorded after 24 h of the digestion for all digesters including Control, A, B, C, D and E which are 0.6 mL/g, 3.4 mL/g, 3.7 mL/g, 1.0 mL/g, 0.7 mL/g, and 0.4 mL/g. The overall trend of the biogas production from all digesters keep decreasing until the two weeks of the digestion day and most of the digesters stopped their biogas production after the seven day of the digestion. However, there was slight increasing in the biogas production from digesters A and B starting from the sixth day and stopped after twelfth and thirteenth day. While at temperature of 55 °C, the highest volume of biogas production was also recorded after 24 h of the digestion for all digesters including Control, A (FW:GLY=4:0), B (FW:GLY=3:1), C (FW:GLY=1:1), D (FW:GLY=1:3) and E (FW:GLY=0:4) which are 0.4 mL/g, 1.4 mL/g, 1.7 mL/g, 0.6 mL/g, 0.4 mL/g and 0.3 mL/g. Then, the biogas production tends to decrease from all digesters until the two weeks of the digestion day. The biogas production of from digester A and B stopped until fifth day and sixth day, while the other digesters already stopped their biogas production after second and third day of the digestion. However, this phenomenon is predictable due to the death phase of microorganism growth due to lack of nutrients (Castillo et al., 1995).

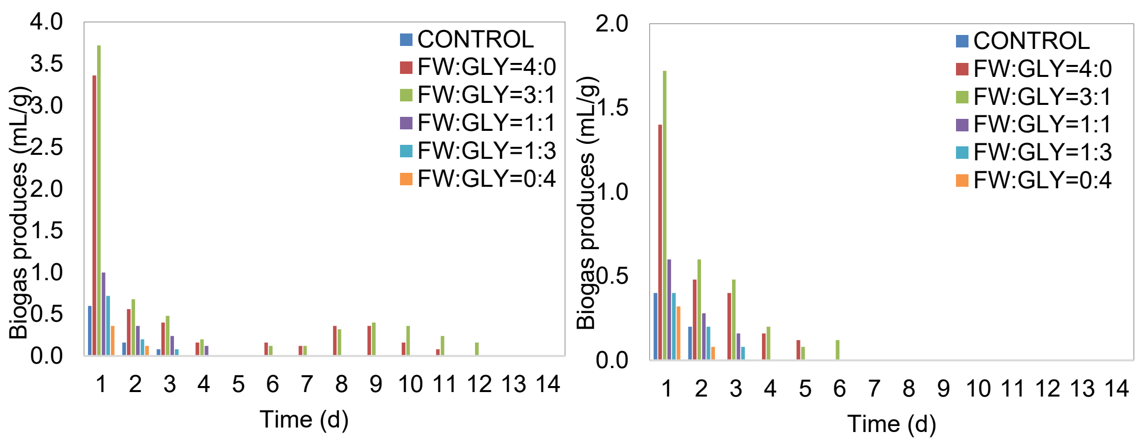

Figure 1: Daily biogas production during the batch co-anaerobic digestion with various ratios of food waste to crude glycerol at (a) 35 °C, and (b) 55 °C

The cumulative or total biogas production for temperature 35 °C and 55 °C were displayed in Figure 2. From the Figure 2a, the total biogas production at 35 °C from the digester Control, A, B, C, D and E are 0.8 mL/g, 5.7 mL/g, 6.8 mL/g, 1.7 mL/g, 1.0 mL/g, and 0.5 mL/g. Figure 2b shows the total biogas production at 55 °C from the digester Control, A, B, C, D and E are 0.6 mL/g, 2.6 mL/g, 3.2 mL/g, 1.0 mL/g, 0.7 mL/g, and 0.4 mL/g. The total biogas production of food waste to glycerol ratio of 3:1 was the highest in both temperature 35 °C and 55 °C, which are 6.8 mL/g and 3.2 mL/g. The total biogas production of the food waste to glycerol ratio of 3:1 at temperature 35 °C was apparently higher than the biogas production at temperature 55 °C. The performance was low at 55 °C due to fast hydrolysis that inhibits the methanogenic activities.
The results indicated that proper ratio food waste and glycerol and suitable temperature could be beneficial to improve digestion performances. Result shows that the co-digestion of food waste and glycerol can be obviously improved comparing with their mono-digestion. Food waste is a promising organic substrate in the anaerobic digestion owing to its easily digestible containing material. The digestion of food waste as sole substrate can reduce the biogas production. The results are in agreement with those of Fountoulakis and Manios (2009), who added 1% (v/v) of glycerol to an anaerobic reactor fed with organic solid waste and found that the increase in biogas production occurred only because of digestion of glycerol. Addition of glycerol enhanced the growth of active biomass due to addition of the extra organic carbon source. Co-digestion of organic waste is an efficient technique to balance the C/N ratio in the digester and avoid resurgence of NH_3.

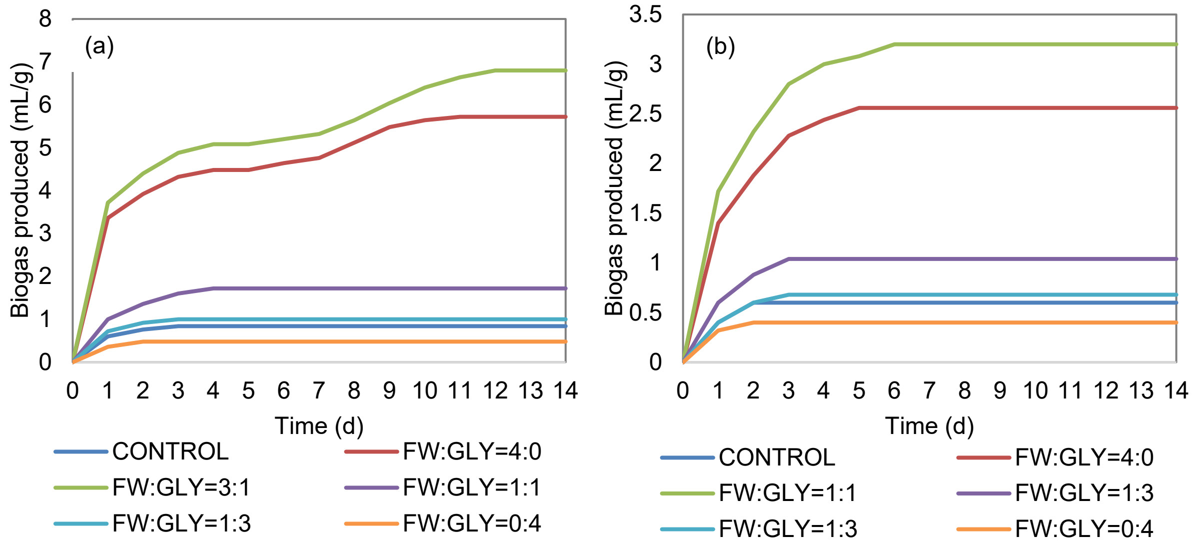

Figure 2: Cumulative biogas production during the batch co-anaerobic digestion with various ratios of food waste to crude glycerol at (a) 35 °C, and (b) 55 °C

Another way of assessing the performance of anaerobic digester is to determine the efficiency of the Total Solids (TS) and Chemical Oxygen Demand (COD) reduction. During the digestion process of food waste and crude glycerol, total solids and chemical oxygen demand are degraded to a certain extend and converted into biogas. The summarized reduction values of TS and COD at 35 °C is shown Table 2. The reduction values of TSS and COD at 55 °C is shown in the Table 3. The graph of the percentage of total solids (TS) and chemical oxygen demand (COD) removal efficiency were plotted in the Figure 3.

Table 2: Total solid and chemical oxygen demand for 35 °C

	TS (%)		COD (mg/L)		pH	
FW:GLY	Initial	Final	Initial	Final	Initial	Final
Control	2.74	2.43	66,000	50,700	7.3	7.1
A (4:0)	11.45	8.66	94,700	71,000	6.8	6.3
B (3:1)	18.70	12.60	330,600	212,200	7.1	6.7
C (1:1)	29.41	25.18	530,600	450,900	7.5	6.8
D (1:3)	41.17	36.06	793,900	691,100	7.6	6.8
E (4:0)	54.50	50.02	935,600	906,000	7.8	7.3

In term of COD, the reduction percentage ranged between 2.8 - 35.8 % as shown in Table 2. The co-digestion of food waste and glycerol using a combination ratio of 3:1 at 35 °C give the highest percentage of COD removal efficiency which was 35.8 %. At 55 °C, the reduction percentage ranged between 3.3 – 24.5 % as shown in Table 3. The lowest percentage of COD removal efficiency was achieved from the digester D at 55 °C which the ratio of food waste to glycerol is 1:3, the COD removal efficiency was 3.3 %. The decreasing of COD shows that the anaerobic digestion is quite effective due to degradability of biomass sample which implies a high potential for methane productivity.

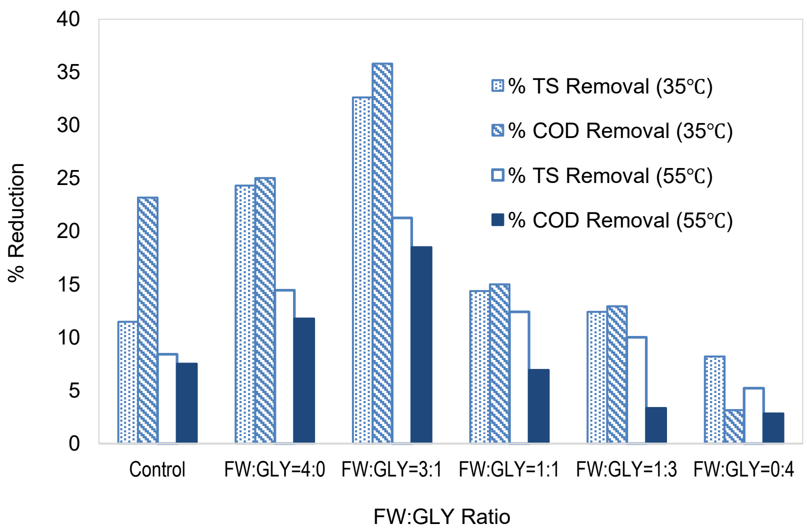

Figure 3: Reduction of TS and COD with various ratios of food waste to cruse glycerol at 35 °C and 55 °C

Table 3: Total solid and chemical oxygen demand for 55 °C

	TS (%)		COD (mg/L)		pH	
FW:GLY	Initial	Final	Initial	Final	Initial	Final
Control	3.44	3.15	69,000	63,800	7.5	7.2
A (4:0)	11.39	9.75	101,000	89,100	6.5	6.2
B (3:1)	15.77	12.42	371,200	280,200	7.2	6.5
C (1:1)	25.69	22.50	561,200	522,200	7.4	6.9
D (1:3)	33.89	30.49	811,400	784,200	7.7	7.5
E (4:0)	51.50	48.82	987,500	909,400	8.0	7.9

4. Conclusion

Anaerobic co-digestion of wastes from food waste and crude glycerol were studied in a batch digester system with different substrates ratio at 35 °C and 55 °C. The present work shown that the highest cumulative biogas production of 6.8 mL/g was obtained in the anaerobic digester containing mixture ratio of food waste to glycerol of 3:1. This work shows that co-digestion of food waste and glycerol was more effective than mono-digestion using batch anaerobic digester with suitable food waste to glycerol ratio and under mesophilic temperature, which is around 35 °C. This ratio improved the removal efficiency up to 32.6 % and 35.8 % for TS and COD. The results revealed that co-digestion of food waste and glycerol is promising and can potentially be used to enhance biogas production while contributing to the management and treatment of these wastes. Moreover, the experimental does not produce any additional by-products that attract disposal requirements as no chemicals are used in the study.

Acknowledgments

The authors would like to express their appreciation for the support of the sponsors from Ministry of Education (Vot No: R.J130000.7851.5F184).

References

APHA, 1998, Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association, Washington, DC, USA.

Athanasoulia E., Melidis P., Aivasidis A., 2014, Co-digestion of sewage sludge and crude glycerol from biodiesel production, Renewable Energy, 62, 73-78.

Cassendra P.C.B., Ho W.S., Hashim H., Lim J.S., Ho C.S., William S.P.T., Lee C.T., 2017, Review on the renewable energy and solid waste management policies towards biogas development in Malaysia, Renewable and Sustainable Energy Reviews, 70, 988-998.

Castillo R.T., Luengo P.L., Alvarez J.M., 1995, Temperature effect on anaerobic of bedding manure in a one phase system at different inoculums concentration, Agriculture, Ecosystems and Environment, 54, 55-66.

Clemens, J., Trimborn M., Weiland P., Amon B., 2006, Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry, Agriculture, Ecosystems and Environment 112, 171-177.

Dinh N.T., Le N.H., 2020, The Performance of an Anaerobic Digester Treating Bio-Sludge Generated from a Municipal Wastewater Treatment Plant in a Pilot Scale, Chemical Engineering Transactions, 78, 541-546.

Dinh N.T., Luan T.N.B., 2020, Study on the Performance of Internal Circulation (IC) Anaerobic Digester Treating High Strength of Food Processing Wastewater: Effect of Organic Loading Rate, Chemical Engineering Transactions, 78, 505-510.

Fountoulakis M.S., Manios T., 2009, Enhanced methane and hydrogen production from municipal solid waste and agroindustrial by-products co-digested with crude glycerol, Bioresources Technology, 100, 3043–3047.

Hartmann H., Ahring B.K., 2005, Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste: Influence of Co-digestion with Manure, Water Research, 39(8), 1543–1552.

Lamichhane K.M., Furukawa D., Cooney M.J., 2017, Co-Digestion of Glycerol with Municipal Wastewater, Chemical Engineering and Process Technology, 3(1), 1034.

Lo H.M., Kurniawan T.A., Sillanpaa M.E.T., Pai T.Y., Chiang C.F., Chao K.P., Liu M.H., Chuang S.H., Banks C.J., Wang S.C., Lin K.C., Lin C.Y., Liu W.F., Cheng P.H., Chen C.K., Chiu H.Y., Wu H.Y., 2010, Modelling biogas production from organic fraction of MSW co-digested with MSWI ashes in anaerobic bioreactors, Bioresources Technology, 101, 6329–6335.

Marañón, E., 2012, Co-digestion of cattle manure with food waste and sludge to increase biogas production. Waste Management, 32, 1821–1825.

Mata-Alvarez J., Mace S., Llabres P., Astlas S., 2011, Co-digestion of solid wastes: a review of its uses and perspectives including modelling, Critical Review Biotechnology, 31, 99–111.

Nagao, N., Tajima, N., Kawai, M., Niwa, C., Kurosawa, N., Matsuyama, T., Yusoff, F.M., Toda, T., 2012, Maximum organic loading rate for the single-stage wet anaerobic digestion of food waste, Bioresources Technology, 118, 210–218.

Rafidah S., Newati W., 2016, Anaerobic Co-digestion of Food Waste and Palm Oil Mill Effluent for Phosphorus recovery: Effect of Reduction of Total Solids, Volatile Solids and Cations, Transactions on Science and Technology, 3(1-2), 265-270.

Siles López, J.A., Martín Santos, M.A., Chica Pérez, A.F., Martín Martín, A., 2009, Anaerobic digestion of glycerol derived from biodiesel manufacturing, Bioresources Technology, 100, 5609–5615.

Wiwatwongwana F., Toomthong V., Vivanpatarakij S., 2019, Biogas Production of Co-digestion from Beverage Industry Waste and Organic Fertilizer Raw Material, Chemical Engineering Transactions, 74, 31-36.

Yang Z., Koh S.K., Ng W.C., Lim R.C., Tan H.T., Tong Y.W., Dai Y., Chong C., Wang C.H., 2016, Potential application of gasification to recycled food waste and rehabilitate acidic soil from secondary forests on degraded land in Southeast Asia, Journal of Environmental Management, 172, 40 – 48.

Yazdani, S. S., Gonzalez, R., 2007, Anaerobic fermentation of glycerol: a path to economic viability for the biofuels industry. Current Opinion in Biotechnology, 18, 213-9.

Zhang L., Lee Y. W., Jahng, D., 2011, Anaerobic co-digestion of food waste and piggery wastewater: Focusing on the role of trace elements, Bioresources Technology, 102, 5048–5059.