CHEMICAL ENGINEERING TRANSACTIONS

VOL. 115, 2025

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

Guest Editors: Carlo Pirola, Antonio Espuña, Sabrina Copelli

ISBN 979-12-81206-16-8; **ISSN** 2283-9216

DOI: 10.3303/CET25115005

Exergy Analysis of Biogas Production from Food Waste through Anaerobic Digestion

Karittha Im-orb[a,*], Pakorn Piroonlerkgul[b],

[a]Program in Food Process Engineering, School of Food-Industry, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand
[b]Patum Vegetable Oil Company Limited, Lat Lum Kaeo, Pathum Thani 12140, Thailand
karittha.im@kmitl.ac.th

The anaerobic digestion (AD) of food waste with different fat concentration was studied. The impact of hydraulic retention time (HRT) and organic loading rates (OLR) at thermophilic condition of 55 °C on CH_4 concentration, CH_4 yield, and exegetic performance of AD system was investigated using the model developed in Aspen Plus software. The CH_4 concentration and yield decreased as fat concentration increased. The CH_4 yield increased with increasing OLR while the CH_4 concentration did not change for each fat concentration. The maximum CH_4 yield of 1.36E-5 kmol/h was found at OLR 1.5 l/day and HRT of 15 days when food waste with 5% fat concentration was used. The exergy analysis indicated that the irreversibility of AD caused the highest exergy loss, followed by the biogas, liquid sludge and net waste heat released from the system. The highest exergy efficiency of 35.52% was derived when OLR and HRT were set at 0.5 l/day and 25 days, respectively, and food waste with 5% fat concentration was used. At this condition the exergy destruction of 1.34 kW was found.

1. Introduction

The problems of global warming caused from GHG emission and the reduction in fossil fuel availability enforce many countries to put the issue of renewable energy production as one of their top agenda to be able to move toward sustainability. Food waste is an organic waste that has massive environmental impact because it is a large source of potent GHG emissions. One-fifth of food produced for human consumption was globally wasted which generated up to 10 percent of global GHG emission (UNEP, 2024). Due to characteristic in term of high organic content (including protein, carbohydrate and fat) and fast degradability, food waste can be potentially converted to biogas via the AD. The biogas which mainly consisted of CH_4 and CO_2 can be directly used as fuel for cooking or upgraded to biomethane and used for power generation. Moreover, biogas can be raw material for H_2 production (Rajendran et al., 2012). Therefore, reducing food waste by converting to biogas not only benefits to reduce GHG emission but also enhances the renewable energy production.

Several studies investigated the biogas production from food waste via AD using the mathematical model. Moretta et al. (2022) studied an anaerobic co-digestion feedstock blending using the process model. The best blending conditions offering the highest methane yield was obtained. Menacho et al., (2022) investigated the influence of different fat concentration, HRT and OLR on concentration of methane. The result presented that the highest methane concentration of 77.1% was obtained at fat concentration of 60% and OLR of 5 l/day when the HRT was in a range of 10-20 days. Aguilar et al. (2017) studied the AD of the blended primary sludge and food waste at thermophilic and mesophilic conditions. It was found that at constant primary sludge: food waste ratio of 2:1, the methane concentration derived from mesophilic condition was 25% higher than thermophilic one. Moreover, the influence of food waste composition at HRT of 15 days on biogas production was investigated by Harun et al. (2019). The result indicated that the methane concentration of 53% and 55% was obtained at fat and carbohydrate concentration of 50% and 54.95%, respectively. The pH, which is an important parameter that can be adjusted by using sodium hydroxide and hydrochloric acid, influences biogas production from food waste. The optimal pH range of AD for biogas generation is between 6 and 8. Zhang et al. (2021) reported that pH control was important for achieving optimal process stability and maximizing methane recovery under high load. Maximum methane recovery was obtained with pH control at 7.5 under high load.

Paper Received: 21 October 2024; Revised: 04 January 2025; Accepted: 25 February 2025
Please cite this article as: Im-Orb K., Piroonlerkgul P., 2025, Exergy Analysis of Biogas Production from Food Waste Through Anaerobic Digestion, Chemical Engineering Transactions, 115, 25-30 DOI:10.3303/CET25115005

Although there were some studies examined the production of biogas from food waste, they were restricted in the parametric analysis investigating the influence of operating parameters on biogas yield. Nonetheless, the intensive study of the biogas production from food waste via the AD in term of exergetic performance to discover the drawback for enhancement of thermodynamic performance was limited. Therefore, the objective of this study is to perform the exergy analysis of the biogas production from food waste through AD at thermophilic condition of 55 °C. The effect of OLR (0.5, 1.0, and 1.5 l/day), HRT (15, 20 and 25 days), and fat concentration (5%, 10% and 15%) which has strong influence on methane content (Rasapoor et al., 2020), on the CH_4 concentration, CH_4 yield, and exergetic performance of the AD was investigated.

2. Model development

The production of biogas from food waste via the AD consisted of 4 major steps i.e. 1) hydrolysis of organic substrates, 2) Acidogenesis of hydrolyzed monomers, 3) Acetogenesis of volatile fatty acids (VFA), and 4) Methanogenesis of acetogenesis products (Rajendran et al., 2014). Modeling of the biogas production through AD was performed in Aspen Plus software version 8.8 and a Non-Random Two-Liquid (NRTL) property method was selected to estimate the properties of substances. Firstly, the food waste (FW) was fed to a stoichiometric reactor (B1) that simulated the hydrolysis reactions operating at thermophilic conditions (55 °C) by specifying the stoichiometry and fractional conversion of reactants into products on a scale of 0.0-1.0, and then the hydrolyzed products entered a continuous stirred tank reactor (B2) that simulated acidogenesis, acetogenesis, and methanogenesis reactions by specifying kinetic constants obtained from previous literature. The first-order rate law was used to calculate the rate of reaction. Finally, the biogas (BIOGAS) and liquid sludge (LIQUID) were separated as final products. The reactions occur in AD were summarized in Table 1. And the flowsheet of AD model developed in aspen plus is shown in Figure 1. In this study, the rate of biogas production predicted from the developed AD model was validated against the experimental results which used cow manure as a substrate in a 5 l reactor with HRT of 12 days at OLR of 0.33 l/day and the biogas production of 353.5 l/ kg_{VS}day was produced (Kaparaju et al., 2009). It was found that the 369 l/ kg_{VS}day of biogas production calculated from the model was approximately 4% deviated from experimental data.

Table 1: The related reactions in AD process (Rajendran et al., 2014)

Reactions	Compound		Eq.
hydrolysis reactions		**Conversion**	
$2C_2H_6O + CO_2 \rightarrow 2C_2H_4O_2 + CH_4$	Ethanol	0.6 ± 0.1	(1)
$C_5H_8O_4 + H_2O \rightarrow C_5H_{10}O_5$	Hemicellulose	0.6 ± 0.0	(2)
$C_5H_8O_4 + H_2O \rightarrow 2.5C_2H_4O_2$	Hemicellulose	0.5 ± 0.2	(3)
$C_5H_{10}O_5 + C_5H_4O_2 \rightarrow 3H_2O$	Xylose	0.6 ± 0.0	(4)
$C_6H_{12}O_6 + H_2O \rightarrow 2C_2H_6O + 2CO_2$	Cellulose	0.4 ± 0.1	(5)
$(C_6H_{12}O_6)_n + H_2O \rightarrow nC_6H_{12}O_6$	Cellulose	0.4 ± 0.1	(6)
$(C_6H_{12}O_6)_n + H_2O \rightarrow nC_6H_{12}O_6$	Starch	0.6 ± 0.2	(7)
$I.P. + 0.3337H_2O \rightarrow 0.25C_2H_5NO_2 + 0.047C_3H_7NO_2 + 0.172C_3H_7NO_3 + 0.067C_3H_6NO_2S + 0.048C_4H_7NO_4 + 0.047C_4H_9NO_3 + 0.074C_5H_9NO_4 + 0.111C_5H_9NO_2 + 0.074C_5H_{11}NO_2 + 0.045C_6H_{14}N_4O_2 + 0.046C_6H_{13}NO_2 + 0.07C_6H_{13}NO_2 + 0.036C_9H_{11}NO_2$	Insoluble protection (I.P.)	0.6 ± 0.1	(8)
$C_{13}H_{25}O_7N_3S + 6H_2O \rightarrow 6.5CO_2 + 6.5CH_4 + 3H_4N + H_2S$	Soluble protein	0.5 ± 0.2	(9)
$C_{37}H_{68}O_5 + 4.3H_2O \rightarrow 2.2C_3H_8O_3 + 0.9C_{16}H_{34}O + 0.9C_{18}H_{32}O_2$	Palmito-linolein	0.6 ± 0.2	(10)
$C_{37}H_{70}O_5 + 4.1H_2O \rightarrow 2.1C_3H_8O_3 + 0.9C_{16}H_{34}O + 0.9C_{18}H_{34}O_2$	Palmito-olein	0.6 ± 0.2	(11)
$C_{51}H_{98}O_6 + 8.436H_2O \rightarrow 4C_3H_8O_3 + 2.43C_{16}H_{34}O$	Tripalmate	0.5 ± 0.3	(12)
$C_{57}H_{104}O_6 + 3H_2O \rightarrow C_3H_8O_3 + 3C_{18}H_{34}O_2$	Triolein	0.5 ± 0.2	(13)
Acidogenesis reactions		**Kinetic constant (s^{-1})**	
$C_2H_5NO_2 + H_2 \rightarrow C_2H_4O_2 + H_3N$	Glycine	1.28 x 10^{-2}	(14)
$C_2H_5NO_2 + 0.5H_2O \rightarrow 0.5CO_2 + H_3N + 0.75C_2H_4O_2$	Glycine	1.28 x 10^{-2}	(15)
$C_3H_6NO_2S + 2H_2O \rightarrow 0.5H_2 + H_2S + H_3N + C_2H_4O_2 + CO_2$	Cysteine	1.28 x 10^{-2}	(16)
$C_3H_7NO_2 + 2H_2O \rightarrow H_3N + CO_2 + C_2H_4O_2 + 2H_2$	Alanine	1.28 x 10^{-2}	(17)
$C_3H_7NO_3 + H_2O \rightarrow H_3N + H_2 + C_2H_4O_2 + CO_2$	Serene	1.28 x 10^{-2}	(18)
$C_4H_9NO_3 + H_2 \rightarrow H_3N + C_2H_4O_2 + 0.5C_4H_8O_2$	Threonine	1.28 x 10^{-2}	(19)
$C_4H_9NO_3 + H_2O \rightarrow C_3H_6O_2 + H_2 + CO_2 + H_3N$	Threonine	1.28 x 10^{-2}	(20)

$C_4H_7NO_4 + 2H_2O \rightarrow C_2H_4O_2 + 2CO_2 + 2H_2 + H_3N$	Aspartic acid	1.28 x 10^{-2}	(21)
$C_5H_9NO_2 + H_2O + H_2 \rightarrow H_3N + 0.5C_2H_4O + 0.5C_3H_6O_2 + 0.5C_5H_{10}O_2$	Proline	1.28 x 10^{-2}	(22)
$C_5H_9NO_4 + H_2O \rightarrow C_2H_4O_2 + 0.5C_4H_8O_2 + CO_2 + H_3N$	Glutamic acid	1.28 x 10^{-2}	(23)
$C_5H_9NO_4 + 2H_2O \rightarrow CO_2 + 2C_2H_4O_2 + H_2 + H_3N$	Glutamic acid	1.28 x 10^{-2}	(24)
$C_5H_{11}NO_2S + 2H_2O \rightarrow CO_2 + C_3H_6O_2 + CH_4S + H_2 + H_3N$	Methionine	1.28 x 10^{-2}	(25)
$C_5H_{11}NO_2 + 2H_2O \rightarrow 2H_2 + H_3N + C_4H_8O_2 + CO_2$	Valine	1.28 x 10^{-2}	(26)
$C_6H_8N_3O_2 + 4H_2O + 0.5H_2 \rightarrow C_2H_4O_2 + CH_3NO + 0.5C_4H_8O_2 + CO_2 + 2H_3N$	Histidine	1.28 x 10^{-2}	(27)
$C_6H_8N_3O_2 + 5H_2O \rightarrow 2C_2H_4O_2 + CH_3NO + 2H_3N + 0.5H_2 + CO_2$	Histidine	1.28 x 10^{-2}	(28)
$C_6H_{13}NO_2 + 2H_2O \rightarrow C_5H_{10}O_2 + CO_2 + 2H_2 + H_3N$	Isoleucine	1.28 x 10^{-2}	(29)
$C_6H_{13}NO_2 + 2H_2O \rightarrow C_5H_{10}O_2 + CO_2 + 2H_2 + H_3N$	Leucine	1.28 x 10^{-2}	(30)
$C_6H_{14}N_4O + H_2 + 3H_2O \rightarrow 0.5C_2H_4O_2 + 0.5C_3H_6O_2 + 0.5C_5H_{10}O_2 + CO_2 + 4H_3N$	Arginine	1.28 x 10^{-2}	(31)
$C_6H_{14}N_4O_2 + 6H_2O \rightarrow 2C_2H_4O_2 + 2CO_2 + 3H_2 + 4H_3N$	Arginine	1.28 x 10^{-2}	(32)
$C_6H_{14}N_2O_2 + 2H_2O \rightarrow C_2H_4O_2 + C_4H_8O_2 + 2H_3N$	Lysine	1.28 x 10^{-2}	(33)
$C_9H_{11}NO_3 + 2H_2O \rightarrow C_6H_6O + C_2H_4O_2 + CO_2 + H_2 + H_3N$	Tyrosine	1.28 x 10^{-2}	(34)
$C_9H_{11}NO_2 + 2H_2O \rightarrow C_6H_6 + C_2H_4O_2 + CO_2 + H_2 + H_3N$	Phenyalanine	1.28 x 10^{-2}	(35)
$C_{11}H_{12}N_2O_2 + 2H_2O \rightarrow C_8H_7N + C_2H_4O_2 + CO_2 + H_2 + H_3N$	Typtophan	1.28 x 10^{-2}	(36)
Acidogenic reactions			
$C_3H_8O_3 + 0.0005H_2 + 0.0291CO_2 + 0.4071H_3N \rightarrow 0.04071C_5H_7NO_2 + 0.94185C_3H_6O_2 + 1.09308H_2O$	Dextrose	1.01 x 10^{-2}	(37)
$C_6H_{12}O_8 + 0.1115H_3N \rightarrow 0.744C_2H_4O_2 + 0.5C_3H_6O_2 + 0.1115C_5H_7NO_2 + 0.4409C_4H_8O_2 + 1.0254H_2O + 0.6909CO_2$	Glycerol	9.54 x 10^{-3}	(38)
Acetogenic reactions			
$C_3H_6O_2 + 0.314336H_2O + 0.06198H_3N \rightarrow 0.660412CH_4 + 0.9345C_2H_4O_2 + 0.06198C_5H_7NO_2 + 0.00055H_2 + 0.160688CO_2$	Propionic acid	1.95 x 10^{-7}	(39)
$C_4H_8O_2 + 0.0006H_2 + 0.8038H_2O + 0.0653H_3N + 0.5543CO_2 \rightarrow 0.446CH_4 + 1.8909C_2H_4O_2 + 0.0653C_5H_7NO_2$	Isobutyric acid	5.88 x 10^{-6}	(40)
$C_5H_{10}O_2 + 0.8044H_2O + 0.0653H_3N + 0.5543CO_2 \rightarrow 0.4454CH_4 + 0.8912C_2H_4O_2 + C_3H_6O_2 + 0.0653C_5H_7NO_2 + 0.0006H_2$	Isovaleric acid	3.01 x 10^{-8}	(41)
$C_{16}H_{34}O + 0.1701H_3N + 0.482CO_2 + 15.253H_2O \rightarrow 8.4402C_2H_4O_2 + 0.1701C_5H_7NO_2 + 14.9748H_2$	Palmitic acid	3.64 x 10^{-12}	(42)
$C_{18}H_{32}O_2 + 0.1701H_3N + 15.356H_2O + 0.482CO_2 \rightarrow 9.02C_2H_4O_2 + 0.1701C_5H_7NO_2 + 10.0723H_2$	Linoleic acid	3.64 x 10^{-12}	(43)
$C_{18}H_{34}O_2 + 15.2396H_2O + 0.2501CO_2 + 0.1701H_3N \rightarrow 8.6998C_2H_4O_2 + 0.1701C_5H_7NO_2 + 14.4978H_2$	Oleic acid	3.64 x 10^{-12}	(44)
Methanogenic reactions			
$14.4976H_2 + 0.0836H_3N + 3.8334CO_2 \rightarrow 3.4154CH_4 + 0.0836C_5H_7NO_2 + 7.4996H_2O$	Hydrogen	2.39 x 10^{-3}	(45)
$C_2H_4O_2 + 0.022H_3N \rightarrow 0.945CH_4 + 0.022C_5H_7NO_2 + 0.945CO_2 + 0.066H_2O$	Acetic acid	2.39 x 10^{-3}	(46)

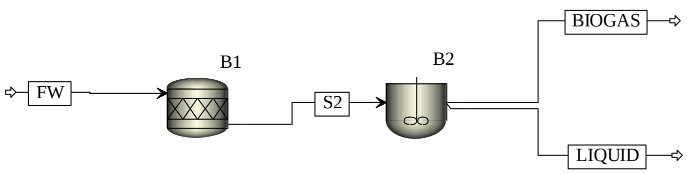

Figure 1: Aspen plus model flowsheet of the AD.

3. Exergy analysis

Exergy analysis regarded to the first and the second law of thermodynamic was done to assess the thermodynamic performance of the energy production process. Exergy analysis was studied by doing exergy balance for steady state process. The equations used in exergy analysis were summarized in Table 2.

Table 2: The equations used in exergy analysis (Kasemanand et al., 2017)

		Eq.
Exergy balance	$(\sum \dot{E}x_i)_{in} = (\sum \dot{E}x_j)_{out} + \sum \dot{E}x_{dest}$	(47)
Exergy of material	$Ex = Ex_{ph} + Ex_{ch}$	(48)
Physical exergy	$Ex_{ph} = (H - H_0) - T_0(S - S_0)$	(49)
Chemical exergy	$Ex_{ch} = \sum_i x_i(Ex_{ch,i} - RT_0 \ln x_i)$	(50)
Exergy related to heat transfer	$\dot{E}x_Q = \dot{Q}(1 - \frac{T_0}{T})$	
Exergy efficiency	$\psi = \frac{\sum Ex_{output}}{\sum Ex_{input}} \times 100$	(51)
Exergy destruction	$Ex_{dest} = (\sum Ex_i)_{in} - (\sum Ex_i)_{out}$	(52)

4. Results and discussions

4.1 Effect of OLR and HRT on CH_4 concentration and yield

The effect of OLR (0.5, 1.0 and 1.5 l/day) of AD of food waste with different fat concentration of 5%, 10% and 15% on CH_4 concentration and yield was investigated at constant HRT of 15 days. Figure 2(a) indicated that the CH_4 concentration decreased as fat concentration increased at constant OLR but CH_4 concentration did not change with OLR. The CH_4 yield increased with OLR while slightly decreased as the fat concentration increased (Figure 2(b)). At HRT of 15 days, the highest CH_4 concentration of 43.68 %mol and CH_4 yield of 1.4E-6 kmol/h was achieved at OLR of 1.5 l/day when food waste with 5% fat concentration was used.
The effect of HRT (15, 20 and 25 days) of AD of food waste with different fat concentration of 5%, 10% and 15% was examined at constant OLR of 0.5 l/day. Figure 3(a) showed that the CH_4 concentration decreased as fat concentration increased whereas increased with increasing HRT. The result was consistent with the previous literature (Harun et al., 2019). The CH_4 yield decreased as fat concentration increased whereas increased with increasing HRT as illustrated in Figure 3(b). At OLR of 0.5 l/day, the suitable condition offering maximum CH_4 concentration of 43.79 %mol and yield of 5.0E-6 kmol/h was achieved at HRT of 25 days when food waste with 5% fat concentration was used.

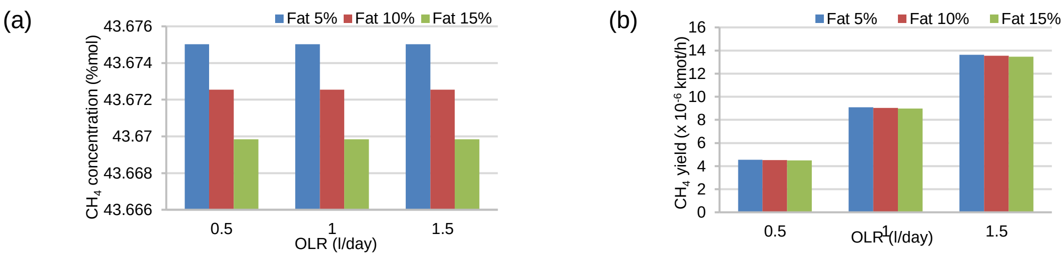

Figure 2: Effect of OLR on (a) CH_4 concentration and (b) CH_4 yield at HRT of 15 days

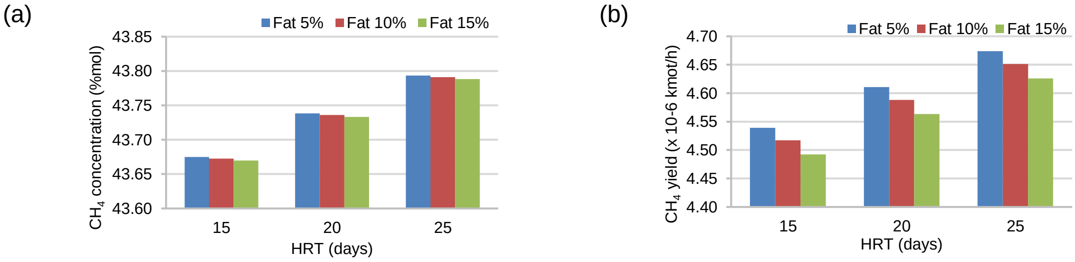

Figure 3: Effect of HRT on (a) CH_4 concentration and (b) CH_4 yield at OLR of 0.5 l/day

4.2 Effect of OLR on exergy efficiency and destruction of AD

The effect of OLR on exergy efficiency and destruction of the AD was studied by varying the OLR in a range of 0.5-1.5 l/day at HRT of 15 days. Table 2 showed that at OLR of 0.5 l/day, the exergy efficiency increased with increasing fat concentration whereas the opposite trend was found when OLR was in a rage of 1.0-1.5 l/day. For the exergy destruction, the fat concentration had slightly effect on the exergy destruction for each OLR but the exergy destruction increased with increasing OLR due to an increase in irreversibility of AD for biogas production. The highest exergy efficiency of 34.52% was attained at OLR of 0.5 l/day when food waste with fat concentration of 15% was used. At this condition the lowest exergy destruction of 1.34 kW was found.

Table 2: Effect of OLR on exergy efficiency and destruction of AD at HRT 0f 15 days

Fat concentration (%mol)	**OLR (l/day)**					
	0.5		**1.0**		**1.5**	
	ψ **(%)**	Ex_{dest} **(kW)**	ψ **(%)**	Ex_{dest} **(kW)**	ψ **(%)**	Ex_{dest} **(kW)**
5	34.512	1.355	34.512	2.709	34.512	4.064
10	34.516	1.348	34.506	2.696	34.506	4.044
15	34.522	1.340	34.502	2.681	34.502	4.021

4.3 Effect of HRT on exergy efficiency and destruction of AD

The effect of HRT on exergy efficiency and destruction of the AD was examined by varying the HRT in a range of 15 to 25 days at OLR of 0.5 l/day. Table 3 indicated that the exergy efficiency increased as HRT increased for each fat concentration whereas the exergy destruction showed contrary trend. At OLR of 0.5 l/day, the highest exergy efficiency of 35.312% was achieved at HRT of 25 days and food waste with fat concentration of 5% was used. At this condition the exergy destruction of 1.34 kW was found.

Table 3: Effect of HRT on exergy efficiency and destruction of AD at OLR of 0.5 l/day

Fat concentration (%mol)	**HRT (days)**					
	15		**20**		**25**	
	ψ **(%)**	Ex_{dest} **(kW)**	ψ **(%)**	Ex_{dest} **(kW)**	ψ **(%)**	Ex_{dest} **(kW)**
5	34.512	1.355	34.937	1.346	35.312	1.338
10	34.516	1.348	34.932	1.339	35.307	1.331
15	34.522	1.340	34.927	1.332	35.302	1.324

4.4 The exergy flows through the AD

The exergy flows through the top two high exergy efficient AD units of food waste i.e., case 1) food waste with 5% fat concentration, OLR 0.5 l/day, HRT 25 days (Figure 4), and case 2) food waste with 15% fat concentration, OLR 0.5 l/day, HRT 15 days (Figure 5), were investigated. The highest exergy loss caused from irreversibility of anerobic digestion, followed by the biogas, liquid sludge and net waste heat released from the AD unit, respectively. For case 1, the exergy loss associated with irreversibility of AD, the biogas, liquid sludge and net waste heat accounted for 64.69%, 23.19%, 9.16% and 2.96%, respectively. For case 2, the exergy loss associated with irreversibility of AD, the biogas, liquid sludge and net waste heat accounted for 65.49%, 22.46%, 9.16% and 2.89%, respectively.

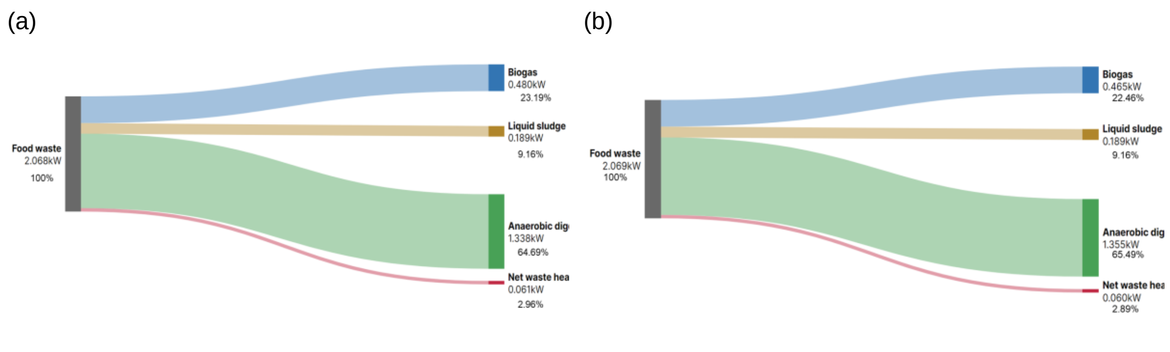

Figure 4: Exergy flow through the AD of food waste a) case1, and b) case2

5. Conclusions

The AD of food waste with different fat concentration was investigated in this study. The influence of fat concentration of food waste (5%, 10%, and 15%), HRT (15, 20, and 25 days) and OLR (0.5, 1.0, and 1.5 l/day) on the CH_4 concentration, CH_4 yield and exergetic performance of AD at thermophilic condition of 55 °C was investigated using the model developed in Aspen plus. The CH_4 concentration and CH_4 yield decreased as fat concentration of food waste increased. The exergy flows through the AD indicated that the highest exergy loss caused from irreversibility of AD, followed by the biogas, liquid sludge, and net waste heat released from the AD unit. The maximum exergy efficiency of 35.52% was attained at OLR of 0.5 l/day and HRT of 15 days when food waste with fat concentration of 5% was used. At this condition, CH_4 concentration and yield were 43.67 %mol and 1.36E-5 kmol/h, respectively. Nevertheless, to justify which condition was the most suitable condition, the economic analysis should be further performed.

Nomenclature

Ex – exergy of material, kW
Ex_{ch} – chemical exergy, kW
Ex_{ph} – physical exergy, kW
Ex_{dest} – exergy destruction, kW
Ex_{input} – exergy input to the system, kW
Ex_{output} – exergy output to the system, kW
$\dot{E}x_Q$ – exergy related to heat transfer, kW
H – enthalpy, kW
H_0 – enthalpy at reference condition, kW
$\dot{Q}$ – net heat transfer, kW
R – gas constant, *8.314* J/mol K
S – entropy, J/mol K
S_0 – entropy at reference condition, J/mol K
H_0 – enthalpy at reference condition, kW
T – operating temperature, °C
T_0 – reference temperature, °C
x_i – mole fraction of component *i*, -
ψ – exergy efficiency, %

Acknowledgments

This work was supported by School of Food industry, King Mongkut's institute of Technology Ladkrabang.

References

Aguilar M.C., Wang Y.D., Roskilly T., Pathare P.B., 2017, Biogas from anaerobic co-digestion of food waste and primary sludge for cogeneration of power and heat, Energy Procedia, 142, 70–76.
Harun N., Hassan Z., Zainol N., Ibrahim W.H.B.W., Hashim H., 2019, Anaerobic Digestion Process of Food Waste for Biogas Production: A Simulation Approach, Chemical Engineering & Technology, 42(4), 1834-1839.
Kasemanand S., Im-orb K., Tippawan P., Arpornwichanop A. 2017, Exergy analysis of the biogas sorption-enhanced chemical looping reforming process integrated with a high-temperature proton exchange membrane fuel cell. Energy Conversion and Management, 149, 485–494.
Kaparaju P., Ellegaard L., Angelidaki I., 2009, Optimisation of biogas production from manure through serial digestion: Lab-scale and pilot-scale studies, Bioresource Technology, 100, 701–709.
Moretta F., Goracci, A., Manenti F., Bozzano G., 2022, Anaerobic co-Digestion Feedstock Blending Optimization, Chemical Engineering Transactions, 96, 295-300.
Menacho W.A., Mazid A.M., Das N., 2022, Modelling and analysis for biogas production process simulation of food waste using Aspen Plus, Fuel, 309, 122058.
Rajendran K., Aslanzadeh S., Taherzadeh M.J., 2012, Household biogas digester-a review, Energies, 5(8), 2911–2942.
Rahbari A., Venkataraman M.B., Pye J., 2018, Energy and Exergy analysis of concentrated solar supercritical water gasification of algal biomass, Applied energy, 228, 1669–1682.
Rajendran K., Kankanala H.R., Lundin M., Taherzadeh M.J., 2014, A novel process simulation model (PSM) for anaerobic digestion using Aspen Plus, Bioresource Technology, 163, 7–13.
Rasapoor M., Young B., Brar R., Sarmah A., Zhuang W.Q., Baroutian S., 2020, Recognizing the challenges of anaerobic digestion: Critical steps toward improving biogas generation, Fuel, 261, 116497.
Zhang W., Wang X., Xing W., Li R., Yang T., 2021, Responses of anaerobic digestion of food waste to coupling effects of inoculum origins, organic loads and pH control under high load: Process performance and microbial characteristics, Journal of Environmental Management, 279, 111772.
UNEP, 2024, Food waste index report, UN Environment Program < https://www.unep.org/resources/publication/food-waste-index-report-2024> accessed 22.08.2024.