Thermophilic anaerobic co-digestion of coffee grounds and excess sludge using continuous stirred tank reactor

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1. Introduction

Coffee has become the most popular beverage worldwide. In Japan, the consumption of ready-made coffee drinks in bottles, packs and cans has increased markedly in recent years. Approximately 4×10^5 tons coffee grounds are generated in Japan, and 6×10^6 tons in the world. Therefore developing technology to reuse the coffee grounds for useful purposes is becoming increasingly necessary. Anaerobic digestion is one of the most considerably feasible technologies for waste treatment. However, the failure of coffee waste methane fermentation was reported both for mesophilic and thermophilic process under a long term operation evaluation. Co-digestion with sludge in the anaerobic digestion process has been found to be capable of providing benefits such as improving the nutrient balance, enhancing the buffer system and increasing the biogas yields. The aim of this study was to evaluate the performance of thermophilic co-digestion of coffee grounds with excess sludge.

Table 1. Characteristics of coffee and sludge

	Coffee residue	Sludge
TS (%)	35.03	16.11
VS (%)	34.68	12.80
Organics (%)	99.00	79.45
Carbohydrate(g/g-TS)	0.59	0.31
Protein(g/g-TS)	0.24	0.69
Lipid(g/g-TS)	0.24	0.02
C (%), n=3	55.23±3.71	34.40 ±0.22
H (%) n=3	7.70±0.39	5.47±0.07
O (%) n=3	34.44±4.54	25.69±0.42
N (%) n=3	2.33±0.24	5.93±0.05
S (%) n=3	0.30±0.19	0.70±0.02
C:N	23.7	5.8

2. Materials and Methods

A continuously stirred tank reactor with a working volume of 12L was operated under thermophilic condition (55ºC) for 120 days by shortening the hydraulic retention time (HRT) of 100 days, 50 days, and 30 days, respectively. Diluted coffee waste with total solid 10% was used as the substrate for start-up. Mixed slurry of coffee grounds and sludge (ratio 9:1 and 8.5:1.5, dry matter) with TS 10% was used as CSTR feedstock. The influent and effluent was operated automatically by using pump.

3. Results and discussion

3.1 Biogas production potential of coffee waste

Coffee waste has higher organics and carbohydrate content compared with sludge as shown in the table 1. It gives a potential of higher biogas production four per gram dry matters. In figure 1, the potential of biogas production for different particle size of coffee were presented using biochemical methane potential (BMP) test. The amount of biogas production was not affected by particle size. It means the high hydrolysis rate of this waste substrate. A pretreatment by grinding raw materials was used to mix the substrate to a uniform slurry for pump transportation. Biogas production could be expressed with the first order rate kinetic. Using the Gompertz model, the methane production potential of coffee is 476 ml CH_4/ g-TS giving average conversion efficiency of 81%.

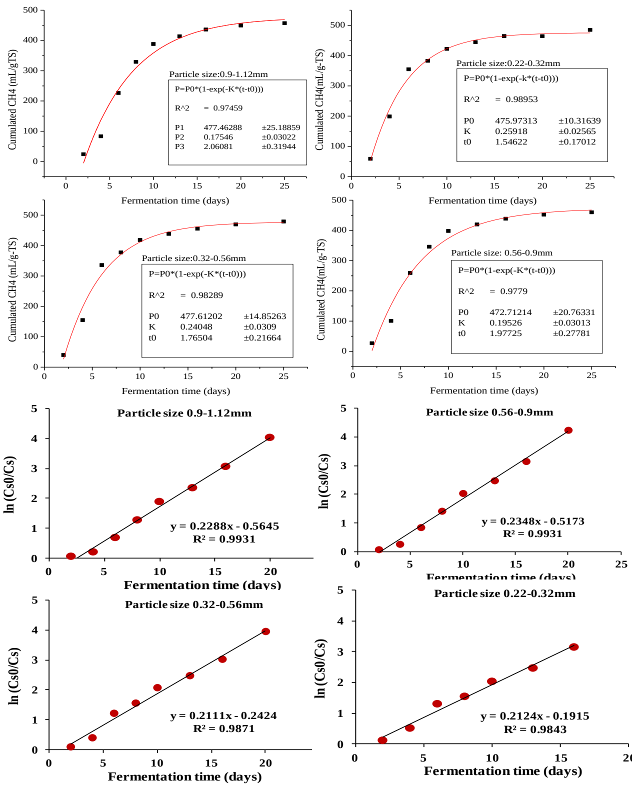

Fig 1. Biogas production potential of coffee

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3.2 Reactor performance under long term operation

A long term evaluation of the co-digestion process was operated for about 130 days. The high biogas production potential given from BMP test cannot be achieved under different HRT and OLR condition. Summary of the whole experiments performance was shown in table 2. Biogas production, methane content, pH, ammonia and alkalinity were shown in figure 2. Low ammonia and pH was found after operating for 50 days feeding low sludge composition (10%) in phase 1. The high carbon to nitrogen ration of coffee did not provide necessary ammonia to maintain alkalinity even mixed with 10% sludge. Adding NH_4HCO_3 could increase ammonia and alkalinity to recover the reactor. While the daily biogas volume can not climb back to the peak even controlling pH around 7.2. A sharp biogas decreasing phenomena were founded from day 92 to 107. That was speculated because of the toxic materials in the coffee. During this period, VFA started to accumulate, especially propionic acid exceeding 1500mg/L. The accumulated propionic acid could inhibit the fermentation process and result in ecology unbalance between acidogenesis and methanogenesis. Reducing OLR, temporary stopping influent and supplying traces metal did not work to overcome the inhibition. Through the long term phase 1, substrate with low sludge composition (10% based on TS) was manifested to be not suitable to provide necessary ammonia and resist potential toxic inhibition.

From day 108 in phase 2, substrate was changed by increasing sludge to 15% based on TS. After 20 days under OLR of 2.5 kg COD/m^{3}d and HRT of 60 days, the reactor starts to recover, biogas conversion efficiency was 0.33 L/g-COD giving a COD removal efficiency of 58%. From day 119, the reactor was operated under HRT of 30 days and OLR of 5.0kg-COD/m^{3}d, a gradually increasing biogas production was found. At day 130, biogas production ratio of 0.31 L/g-COD (CH_4 61%) and COD conversion efficiency of 54% were achieved. pH in this phase maintain at 7.0-7.2. The total alkalinity was around 1200mg/L. The capacity of the buffering will increase by degrading excess VFA accumulated in inhibition stage.

Table 2. Summary of reactor performance

Parameter	Unit	Start-up	Phase 1			Phase 2	
		1-16 d	17-25 d	26-34d	35-107d	108-118d	119-130d
HRT	days	100	100	50	30	60	30
OLR	Kg-COD/m^{3}d	1.6	1.5	3.0	5.0	2.5	5.0
COD conversion	%	40	61	62	/	58	54

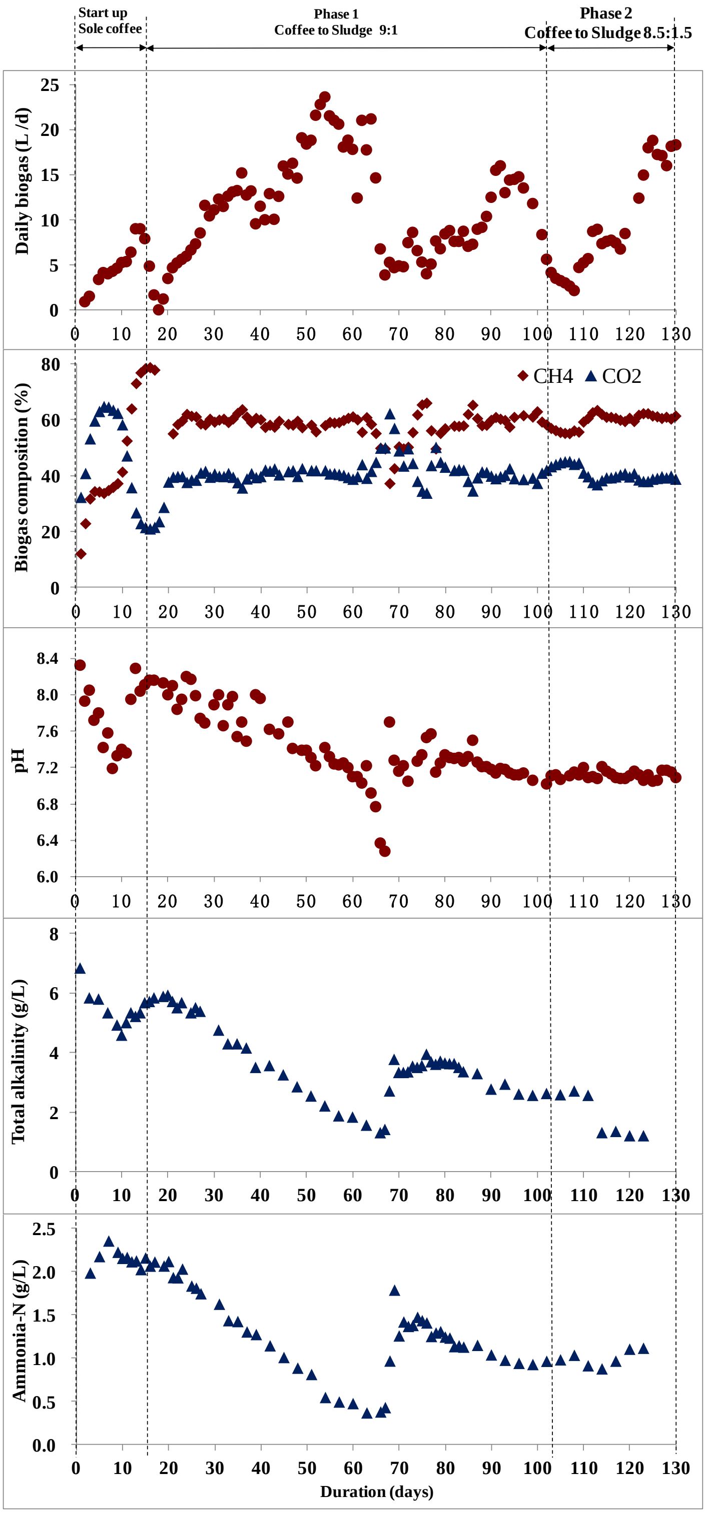

Fig 2. Reactor performance under long term operation

4. Conclusions

(1) Coffee residue has high organic content and biogas production potential. Mixing with sludge as substrate is necessary for coffee residue methane fermentation to maintain the process stable.

(2) Sludge proportion in a mixture of coffee and sludge substrate should be higher than 15% to alleviate VFA accumulation and potential toxic inhibition from coffee organic matters.

(3) Higher performance of biogas production over 0.31 L/g-COD and COD conversion efficiency over 54% are expected by operating the reactor under extended and stable condition.