Preliminary studies on the performance of vacuum black water with biochar additives in anaerobic digestion process

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Abstract: *Vacuum black water (VBW) is a modern model of water conservation due to the usage of 1.5 L per flush and highly efficient for energy generation and nutrient resources recovery through anaerobic digestion (AD)by continuous stirred tank reactor (CSTR). In this study we ascertain that via the addition of biochar within the VBW, it can reduce ammonia level, up to 60% (R2) than the control (R1),due to high ammonia level, this can inhibit on methanogenic bacteria for biogas production. Hence, the destabilization of AD performance, and biogas production could cut down tremendously. Furthermore, the agrochemical materials were investigated in this study. We found that the COD concentrations was reduced in the reactor with biochar (R2-4896 mg/L) compared to that without biochar (R1-6336 mg/L). The positive effect of the research shows that VBW anaerobic treatment with biochar can leads to the perpetual purpose of water rescue, high biogas production (~42%) improvement compared to the control (R1) without biochar, and enhance effluent dig estate to heighten plant growth and soil properties for agriculture technological application.*

Key words: *Vacuum (toilet) black water, Bio-char, AD, Biogas production, Agriculture reuse.*

I. Introduction

The limited water and energy resources are posing a significant risk to the national economy, and it is necessary to characterize the patterns of scarcity-induced risk in the national trade system (Y. Liu and Chen 2020). As an essential resource for many sectors such as agriculture, mining, power generation, and utilities, water scarcity poses critical risks to the entire economy, and treated water can also be reused (Zhao et al. 2020). Preserving the water conservation, and converting wastewater to energy offers resourcefulness approach. Vacuum black water (VBM) has considered as the main source for energy recovery in the decentralized sanitation and reuse (Tervahauta et al. 2014). Wastewater from traditional centralized sanitation systems combines all wastewater sources, leading to large wastewater volume with diluted organic and nutrient concentrations, unfavorable for energy and nutrient recovery (Gao et al. 2019). Energy-neutral wastewater treatment can be achieved through integrating AD(AD) technology into on-site source-diverted wastewater treatment as a form of new sanitation (Gao et al. 2020). Bio- gas is considered as a holistic and flexible energy resource that does not only generates electricity, heat and power but also exhibits environmentally friendly properties (Giwa et al. 2020). The high concentration of black water makes anaerobic treatment with subsequent recovery of nutrients a very attractive treatment option. The collection method (toilet) applied will determine the actual black water concentration and with the application of ADtreatment technique there is the feasibility of nutrient recovery (Kujawa-Roeleveld and Zeeman 2006).

VBM has benefits of saving water and concentrating organic matters to maximize black water energy recovery efficiency (Gao et al. 2019). In this context, biogas from waste and residues can play a critical role in the energy future (Achinas, Achinas, and Euverink 2017). AD is the only process, which removes and, at the same time, converts the organic matter in the wastewater to a valuable product, biogas. Consequently, it is beneficial to apply AD within sustainable sanitation (Elmitwalli, Zeeman, and Otterpohl 2011). Although, biogas production through AD has been established for some decades, there is still need for optimization of this process in terms of process stability, higher methane yields, and inhibition problems (Mumme et al. 2014). Major inhibition problem is excessive level of ammonia. Ammonia at high concentrations can act as a strong inhibitor of methane production during anaerobic process. It is generally believed that total ammonia nitrogen (TAN) concentration's below 200mg are beneficial to AD process since ammonia is an essential nitrogen source for anaerobic microorganisms (Sheng et al. 2013) .

Numerous studies have shown that bio-char amendment enhances overall soil quality by improving soil physical, chemical, and biological properties and soil fertility (Guo, He, and Uchimiya 2015). In addition, bio char increases soil organic matter, nutrient content and availability, pH and soil water retention and aggregation (Anawar et al. 2017). Furthermore, bio char as an eco-friendly and low-cost material generally produced from organic wastes such as agricultural wastes, forestry residues and municipal wastes has attracted increasing attention evidenced by its increasing use in different environmental applications (Enaime et al. 2020). Separately collecting the black water in combination with water-conserving toilets (e.g., vacuum toilets) results in a concentrated stream (less than 30% of total household wastewater consumption) that contains the majority of the contaminants (i.e., more than 50% of organic contents and 80-95% of nutrients can be recovered), where as vacuum flush toilets used 0.5-1.2 L water per flush (Gao et al. 2019). Moreover, some studies reflected that owing to high contamination of VBM, it can lead to sublime of ammonia, which can inhibit methanogen bacteria from adequate biogas production.

No studies, however, have experimentally inquired black water (vacuum toilet) with bio-char in continuous stirred tank reactor (CSTR). VBM in most cases is excessive contaminated, and has high chemical oxygen demand (COD), and high level of total ammonia nitrogen. Gao et al. (2019) reported hindrance and inhibition during treatment of concentrated black water in bioprocess, this impacted on the biogas production rate and dig-estate quality. Considering these challenges of high ammonia level, and COD in reactor, we offered to mitigate with bio char additives. Therefore, our aim was biogas production, and mitigation of some physic-chemical parameters such as ammonia and COD in the bioprocess for a decentralized system, by the addition of bio-char additives in the CSTR digester.

II. Materials and Methods

2.1. Sample collection and preparation

2.2. Inoculum

The inoculum is the sludge water which was taken from a local municipal wastewater treatment plant. Large inorganic fragment were removed from sludge after being sieved in 10 mesh and the sludge water had a pH of 8.25. The mixture was homogeneous to obtain a Total solid (TS) and Volatile solid (VS) value of 6.5% and 2.05%, respectively.

2.3.Bio char

Bio-char is obtained from pyrolysis of food waste; a full description about the food waste pyrolysis can be found (Liu et al. 2020). The bio-char was washed with water to lessen contamination level, afterward it was dried at 105 degree celsius and then it was sieved to get 1.5-2 mm particles sizes for the experiment. Subsequently, 0.5g of bio-char was prepared as bio-char additives inserted into the AD.

2.4. Excrement (Faeces and Urine)

The excrement substrate (ES) was collected from Yangtze normal university toilets (Chongqing, Fulling district, China). ES was mixed together with water in standard proportions as thus: faeces, urine and water value of 28g, 200ml and 200 ml, respectively. This lead to the formation of the black water with pH of 8.90 and the TS and VS were determined as 1.4% and 1.02%, respectively. Black water sample residue was stored in fridge and frozen at -^{o}4 degree celsius for future experiment use. The black water obtained was referred to the VBW in this study.

2.5. Experimental set up and operation

The type of reactor used for AD was a CSTR, which its processing volume was 200ml and it was capped with a butyl rubber pin to guarantee that the system is closed. The influent substrate was inoculum and VBM in different fractions by 120 ml and 80 ml respectively. This matches to 60% and 40% of the total volume of reactor. Hereafter bio char was crashed and sieved, then 0.5 gram was measured by using electronic balance. The substrate was inserted into an anaerobic reactor digester. Two reactors was set up, where one reactor was with only substrate, and was named R1 (control) and other reactors which has substrate and bio-char as an additive was named R2.Nitrogen gas with high purity was applied to flush both reactors within five minutes. According to Giwa et al. (2019), by the addition of nitrogen, it leads to the creation of an oxygen-free environment.

The anaerobic reactors was pinned again, each reactor linked with gas bag with the potential of 500 ml in total for biogas collection. We designed two different reactors, one with influent plus biochar as an additive and another one with influent without biochar, R2 and R1 respectively. Reactors kept sedate under 37 celsius degree with stirring rate of once stir per one second. Within couples of days, biogas production was measured for each reactor by taking off the gas bag and discharges the gas by syringe; the biogas accumulation in the syringe was calculated in ml and recorded. Liquid waste sample from reactors were piled up for physio-chemical and biological analysis and others stored in fridge with $-^{o}4$ degree celsius for future parameter use.

2.6. Analytical procedure

The TS and VS substance of the samples used in this study were analyzed by heating them in an oven at 24 hours and in furnace at 550 celsius degree for 7 hours respectively, After the crucibles were taken out from the machines, they were allowed to cool down in desiccator for a while and then measured the weight by using electronic balance, afterwards they were calculated according to the (APHA, 1995). Afterward, VBW and inoculum was mixed in an orbital shaker for 20 minutes, then the potential hydrogen (pH) of influent of the substrate in reactors was measured by pH meter (PHS-3CW microprocessor ph/mV meter, made by LIDA, Shanghai-China). Organic matter removal in terms of COD and NH4+-N concentration were surveyed. Further, the influent was centrifuged at the relative centrifugal force of 2000 rpm rotating for 20 min. The supernatant of the centrifuged samples was taken for determination of COD and NH4+-N concentration. COD concentration was judged by titration, by using different reagents such as Potassium dichromate ($K_2Cr_2O_7$) solution, Silver sulfate-sulfuric acid (Ag_2SO_4) solution, Mercury sulfate (HgSO4) solution added in samples in different portions within text tubes. Thereafter heated in COD digester at 160 celsius degree by 2 hours and the digested samples and blank were cooled down. After that, it was titrated by ferrous ammonium sulfate solution which standardized by Calibration method, by this procedure concentration resolved was (0.09M). Ferro in solution was used as indicator for titration. TheNH4+-N concentration was determined by spectrophotometer. Nessler solution made of Potassium iodine (KI), Mercury iodine (HgI_2) and Sodium hydroxide (Na OH). Where 2ml of Nessler solution and one drop of Ethylene diamine tetra acetic acid (EDTA) was added in the samples, color of the sample changed to orange immediately and was able to react for 10 min thereafter it was pulled into the cuvette. Hence, the NH_4+-N content was investigated under wavelength of 425 nm by showing distinct NH_4+-N concentration absorptions.

III. Results and discussion

4.1. Characteristics of Vacuum black water and Bio char

Influent composition of the VBW and biochar to the CSTR reactor are well illustrated in Table1. Thepyrolysisbio-char from food waste was looking as small bolus after it was crushed and sieved before being used in the AD. The pH of the various influent samples were collected accordingly, and varies in the range of 8.99±0.2 for the biochar, and 8.90 for the VBW, respectively. The biochar pore diameter and surface porosity were equally analyzed to offer understanding on the biochar performance during the AD of the VBW. Meanwhile, the properties of the biochar could be attributed to be effected by the production temperatures (Giwa et al., 2021; Shekhar Bose et al., 2021). Further information concerning the properties of the VBM and the biochar are presented in the table 1.

Table 1: Physical properties of vacuum black water and bio char

Analysis	Unit	Substrates	
		VBW	**Biochar**
TS	wt%	1.35	97.50
VS	wt%	1.23	47.30
pH		8.90	8.99±0.2
Pyrolysis temperature	(°C)	_	500
Particle size	(mm)	_	1.45-1.98
BET specific surface area (m 2 /g)	_	_	91.5
Total pore volume (cm ^{3} /g)	_	_	0.20
Average pore diameter (nm)	_	_	9.50

4.2. Removal efficiency of the CSTR reactor

This study proves that anaerobic treatment of VBM can successfully be achieved in a CSTR reactor. Mainly, it displayed a steady operation and get rid of more than 60% of the COD after AD as presented in R2 of table 2. In the VBW the ammonia nitrogen concentration was as high as 2.064 mg/L Absorption, and pH was decreased in (R1 - 6.45) and slightly stable in (R2-7.85) effluent. While the ammonia nitrogen concentration slightly increased 2.174 mg/L absorption, this might be due to protein hydrolysis, ammonium in the effluent could increase by 10 % when organic nitrogen is converted into ammonium(Wendland et al., 2014).Gao et al., (2019)reported that high ammonia nitrogen can act as a strong inhibitor of biogas production during anaerobic process. Moreover, VBM contains enough alkalinity and pH control is therefore not essential. Majority of bacteria are neutrophils (Frank et al., 2016), meaning they are produced at an optimal pH within (6.5 to 8.5). Details of the influent and effluent characteristics are presented in table 2.

Table 2: Physicochemical properties of the Influent and Effluent of vacuum black water for two different reactors conditions

Parameters	unit	Influent	Effluent	
		VBW &Sludge	**R1**	**R2**
COD	**mg/L**	8928	6336	4896
TS	%	5.40	4.201	4.267
VS	%	1.93	1.408	1.561
pH	wt%	8.56	8.11	7.68
NH_3-H	mg/L	20.64	21.74	12.36
pH	-	7.8	6.45	7.95

4.3.Effect of Bio char up on vacuum black water

In principle, biochar is efficacious at raising the pH of substrates in digester, as the pH of biochar's used in most study is neutral to alkaline. Moreover, it could buffer acidity due to the negative charge on the surface of biochar(Huang and Gu, 2019; Meiirkhanuly et al., 2019).Alkalinity of biochar facilitates the methanogen bacteria in their reproduction phase, which leads to the high biogas production late. Moreover, it produces carbon during the AD. Huang & Gu, (2019)also showed that utilization of biochar in agriculture adds values to biomass pyrolysis and gasification. In this research, the biochar impacted on pH by regulating it around 7.95, which was preferential for bacteria in biogas production. The route of the entire experimental set-up and bioprocess performance are presented schematic form as shown in Fig. 1.

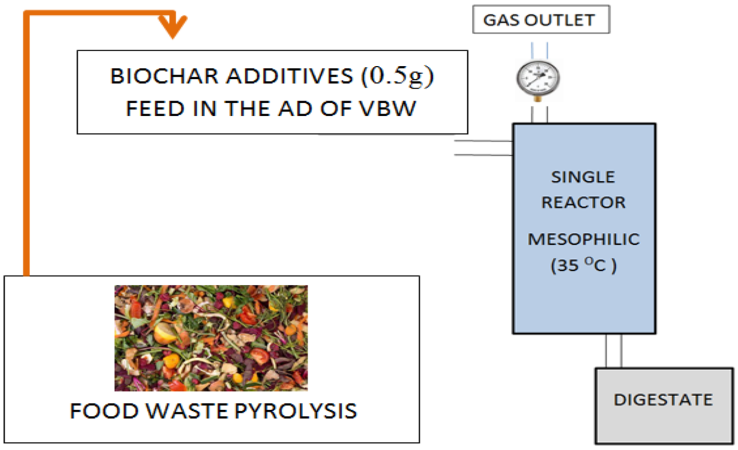

Fig. 1 Simple schematic for the bio-char additive in vacuum black water anaerobic digestion for biogas and stabilized digestate production

Biochar has ammonia nitrogen adsorption capacity(Wang et al., 2015), and similar phenomenon was reported on ammonia nitrogen adsorption with biochar(Taghizadeh-Toosi et al., 2012).Ro et al.(2020) suggested that non-activated biochar can successfully replace commercial activated carbon in removing gaseous ammonia and the removal efficiency will greatly increase if the biochar are activated with phosphoric acid. This study explores the effect of biochar on the volatilizing ammonia nitrogen in different surface soils through the field test method. The responsiveness changes of ammonia volatilization ammonium nitrogen and urease were studied under the influence of biochar and crop cultivation we fund that by addition of small portion of biochar in reactor can deduct ammonia level in reactor roughly 40%. Where the influent of ammonia nitrogen was 20.64 mg/L, afterward its gradual decreases to 12.36 mg/L. Based on (Wang et al., 2020) showed that ammonia nitrogen causes instability of AD performance and considered as the main inhibitor and promote reduction of biogas production.

Several papers have studied the potential purposes of biochar on soilGuo et al., (2015), greenhouse gas emissions Zou et al., (2018), soil fertilityEl-Naggar et al., (2019), crop production Kalus et al., (2019), and soil chemical properties (Chintala et al., 2014). By CSTR treatment 48.8% COD removal was achieved. Owing to the COD of effluent which was 51.1%.Due to the comparison of COD between two reactors after AD, Reactor with bio char (R2) has lower COD than the control reactor (R1) thus elucidating that high contaminant level, with low nutrients was contained in R1 without biochar. Furthermore, biochar significantly increased the Total Nitrogen, Phosphorus and Potassium in soil (Chen et al., 2020).

In addition due to the slightly stable pH value up to 7.95 in the biochar reactor with VBW, it leads to the peak growth of the Microbial community, which stimulates the biogas production. Other CSTR reactors with influents and effluents containing VBW and inoculum were portrayed in table 3.Studies had shown that bio-char as additives in anaerobic digestion could improve the performance and bio-methane upgrade (Giwa et al., 2020, 2019; Mumme et al., 2014).

Table 3: Effect of biochar on the biogas production rate within twenty operational days

Name of reactor	Gas production (mL)	Time (days)
Vacuum Black water with Bio char	296	20
Vacuum Black without Bio char	172	20

IV. Conclusions

In the current study, the biochar additive has shown the capability to improve biogas production in the AD treatment of VBM via enriching the methanogens and offering reactor stability. The reduction in the ammonia-nitrogen concentrations was evidenced in R2- 12.36mg/L compared to the R1- 21.74mg/L. In addition, the R2 maintained pH (7.95) value favorable for AD operational stability, and with a educed COD concentrations in the digestate. Biochar can be considered to be effective and has the competence in the practical application for the treatment of VBM in AD for a decentralized purposes and resources recovery.

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