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The Use of Carbon based Materials for Improving Methane Production from Ethanol Anaerobic Fermentation: Viability Analysis and Fertilizer Recovery

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The impacts of carbon-based sources on anaerobic digestion methane generation were investigated in this study. The study revealed that bio-solids and hydrochars may increase accumulative methane output by 16% to 30%. Nevertheless, there is no significant difference (statistically) ($p > 0.05$) in methane production from hydrochars and biosolids generated at, unlike temperatures. Biosolids and hydrochars augmented microorganisms that may contribute indirect interspecies electron transfer. Microorganisms' direct interspecies electron transfer (DIET) in a stable environment created by carbon-based compounds with homogeneous dispersion and electrons were transported *via* an aromatic functional group on the surface of the material. From the fermented effluent, sludge recapture was 0.09 m^3 sludge/m^3 wastewater. The time required to recoup investment was calculated to be 3.72 years. This study suggested that the impact of surface characteristics of carbon-based sources on methane generation in anaerobic fermentation and proposes a novel method for reusing discarded tea grounds.

Keywords: Anaerobic digestion, Biosolids, Methane, Direct Interspecies electron transfer.

INTRODUCTION

At the moment, the world is grappling with two related issues: appropriate waste management in industry and a scarcity of innovative energy sources to meet expanding energy demands [1]. Concurrent environmental issues and depleting fuel supplies have driven substantial research to boost energy reserves [2]. Biomass is predicted to play a large role in commerce by 2050 (UNIDO). The industrial potential of biomass is estimated to be 18.3 EJ/y [3]. Fig. 1 shows the biomass potential sector breakdown for 2050, with the top 47% harvested by OECD countries. Controlled fermentation of agro-industrial waste produces a gas that can be used as an electrical thermal energy source due to its high methane content [4].

Anaerobic digestion is a popular method for treating organic wastes and generating high calorie biogas [5]. Gas generated by the fermentation process may be refined into home natural gas, resulting in a significant economic gain [6]. As a result, the anaerobic process was seen as a viable sustainable energy generation technique, particularly since Chinese government

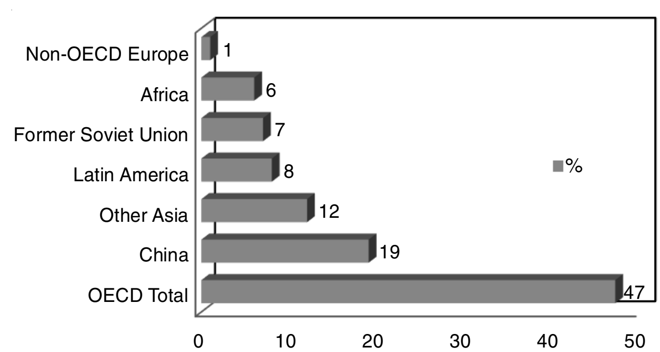

Fig. 1. Without interregional trade, a regional estimate of biomass latent for 2050 (UNIDO), 2012)

began to develop and promote technologies at a quick pace. However, the rate of biogas generation during fermentation is rather low for the unstable biological system [7], limiting the expansion of biogas facilities in Malaysia.

Many researchers have recently discovered that increasing the interspecific electron transfer mechanism among syntrophic microbes during anaerobic digestion boosts methane production

[8]. The direct interspecies electron transfer system is possible to happen during ethanol anaerobic digestion, according to Siddique & Wahid [9]. Direct interspecies electron transfer was an exceptionally effective electron transfer method that involves extracellular and intercellular electron transfer among symbiotic bacteria [10].

Some methane-producing microbes choose to use direct interspecies electron transfer in the fermentation process to metabolize chemicals [11]. Besides, with the presence of microbes that may contribute to direct interspecies electron transfer, the anaerobic digestion system was more steady [12]. Carbon based compounds like activated carbon, biosolids, hydrochars, graphite felts and graphenes were also conducive for enriching direct interspecies electron transfer, thereby enhancing the productivity of methane [13].

Biobased carbon compounds, like biosolids or hydrochars, had been intensively explored because of their simple and inexpensive preparation technique and a clear improvement in anaerobic digestion methane production efficiency [14]. Carbon based materials are made from waste biomass using low-cost preparation techniques like pyrolysis and hydrothermal carbonization. Besides, the production of carbon based compounds may aid in the resource recovery of biomass. The following three features of carbon based sources may assist biogas generation in the anaerobic process [15].

Biosolids acts as the "capacitor" platform that contributes to the electron transfer system between anaerobic microbes because of the redox-simulated groups on their surface [16]. This hypothesis is comparable to the concept proposed by Li *et al.* [17], where electrons are moved *via* conductive pili *via* hopping. Besides, the functional group on the surfaces of the material acts as an adsorption site, reducing the toxicity of inhibitor compounds produced by or present in the fermentation system, like phenol and therefore stabilizing the operational process [18].

Biosolids or hydrochars with the graphite arrangement, as a graphitized material, allow electrons to be exchanged among microbes *via* the graphene of the substance [19]. This approach was described by Cai *et al.* [20], in which electrons were transmitted through conductive pili *via* metal-like conduction. Biosolids can promote the enhancement of direct interspecies electron transfer. According to Sathishkumar *et al*. [21], which could be due to the huge definite surface area of the surfaces of the materials. Because of the intricacy of biological interactions, there were a variety of viewpoints on how carbon based sources can be promoted to the fermentation system [22].

The anaerobic digestion process may be influenced by several elements that work together [23]. Biosolids and hydrochars have varying qualities depending on how they are prepared. Because of hydroxyl radical (•OH) of the environment, there were more •OH functional groups on the surface of hydrochars [24]. The exterior mesoporous of biosolids formed at the time of pyrolysis at temperatures greater than 300 ºC was typically bigger compared to hydrochars formed at temperatures between 200 and 300 ºC [25]. A few studies looked at the influences of biosolids made at various temperatures on the fermentation process and discovered that biosolids made at greater temperatures may be superior [26].

Furthermore, the temperature at which carbon based materials are prepared has an impact on the formation of the mesoporous structure and higher preparation temperatures may damage the material's systematic crystal structures [27,28]. The systematic graphene structures of biosolids, as previously stated, may have an impact on the electron export mechanism. Nevertheless, just limited works have linked biosolids' structural flaw to anaerobic digestion and its feasibility and fertilizer recovery. The current catalyst reforming method may alter the material's functional group features, as well as physico-chemical qualities such as explicit surface area [29]. More research into the mechanism of influence of carbon-based sources on the fermentation process is needed and the improved approach can help with that.

As a result, the goal of this study is to find out how the feasibility and features of biobased carbon materials boost methane production during anaerobic digestion and recovering fertilizer, as well as potential strategies for improving the electron transfer process during the process. The direct interspecies electron transfer (DIET) relationship between anaerobic bacteria was established using ethanol as the substrate. Methane generation was discovered after biosolids and hydrochars made from discarded tea ground were fed to the fermentation process. The impact of five different types of reformed biosolids on the fermentation process was also investigated. Anaerobic fermentation process supplemented with various carbon based materials indicates the impact of material features on anaerobic microbe electron exchange.

EXPERIMENTAL

Sample and seeding source: Tea grounds were used to make carbon based compounds for the present work since it is stable waste biomass. A neighborhood tea house located in Terengganu, Malaysia (5.3117ºN, 103.1324ºE) contributed to the tea ground. It was dried for 12 h at 105 ºC before usage. Anaerobic sludge from the Tertak Batu landfill in Terengganu, Malaysia (5.1765°N, 103.1501°E) was used as the inoculum. The anaerobic sludge had the following characteristics: total solids of 20.91 g/L (1.82 g/L), volatile solids of 6.31 g/L (0.11 g/L). Before use, 4 L anaerobic sludge was seeded in a 5 L glass bottle with 2 g (about 2.54 mL) of ethanol at 35 ºC until no biogas was produced.

Carbon based materials preparation and modification

Hydrochar preparation: In three 500 mL reactors, 0.02 kg tea ground and 100 mL distilled water was taken. The mixture were sealed and heated to 200, 230 and 260 ºC, correspondingly, for 2 h. Once cooling to ambient temperature, the heated mixtures were rinsed with distilled water to eliminate the ash and excess oil, then made it dry at 105 ºC for 12 h. Before being used, the dry samples were processed to sieve with a 0.18 mm sieve and kept in a drier. The samples will be referred to as Hc200, Hc230 and Hc260, with the suffix number indicating the heat of preparation.

Biosolids preparation: To create an anaerobic environment, 0.02 kg tea ground was kept in 3 containers, wrapped with tin foil and enclosed. The wrapped containers were kept in the furnace and subjected to several treatments. The resultant products were rinsed with distilled water for removing the ash and oil then made dry at 105 ºC for 12 h after cooling to room temperature. Before being used, the dry samples were processed to a sieve with a 0.18 mm sieve and kept in a dryer. These samples will be referred to as Bs300, Bs500 and Bs700, with the suffix indicating the heat of preparation. Table-1 shows the manufacturing states of biosolids in detail. By using the prior procedure, Bs700 Biosolids were transformed by oxidation (Ox), reduction (Re), pore-forming (Po), acidic (Ac) and alkali (Al) correspondingly [30].

Setup and operation of the reactor: In a digester with a total reaction volume of 0.4 L and 0.1 L, the experiment was carried out. There were 7 experimental samples and 1 blank sample. In each reactor, 37 mL BA medium and 63 mL incubated anaerobic sludge was introduced. The medium was made in the same way as before [31]. Hydrochars or biosolids (Hc200, Hc230, Hc260, Bs300, Bs500 and Bs700) were added to each digester at a rate of 0.50 g. The substrate was ethanol and the waste to inoculum proportion was 0.5 (w/w) in the reactor. Nitrogen was continually pushed into the digester for 0.5 h before start-up to make it airtight. The test was conducted out in triplicates at a mesophilic state (35 ºC). The BPC-Model AMPTS® II & AMPTS® II Light-Methane potential (BMP) test system/biogas/anaerobic digestion (BPC, Japan) was used to measure methane generation. The result was adjusted to exclude methane generated by internal bacterial respiration and organic matters from carbon based material. Anaerobic fermentation studies with reformed Biosolids were performed in 250 mL vials to investigate the influence of characteristics of carbon based sources on methane generation. Six experimental groups (Bs700, Ox700, Re700, Po700, Ad700 and Ak700) were altered with 10 g/L biosolids, whereas 1 blank group was kept without biosolids. Anaerobic seed slurry from a waste treatment plant (Ironcon (M) Sdn Bhd, Sewage Treatment Plant Malaysia) in Negeri Sembilan, Malaysia (2.7258ºN, 101.9424ºE) was used as the inoculum. The anaerobic sludge has the following characteristics: total solids of 17.31 g/L (0.31 g/L), volatile solids of 9.41 g/L (0.31 g/L).

Ethanol (S/I = 0.5) was employed as the substrate. Nitrogen was continually pushed into the digester for 0.5 h before start-up to make it airtight. Every sample had a biogas sample bag attached to it. The samples were shaken at 70 rpm at 35 ºC for each group, which was done in triplicate. A gas chromatography (Shimadzu GC-2014, Japan) fitted with a thermal conductivity detector was utilized to measure the composition of biogas and contents of biogas samples every three or four days. A wet gas flow meter was used to measure biogas output (Roxar, USA).

Characterization: The pH and conductivity of carbon-based compounds were determined using a 1:10 w/v mixture of material and water. After the dispersion of 0.1 g carbon-based matter in 10 mL distilled water, the zeta potential was evaluated by the Zetasizer Nano (Malvern, ZS90, UK). The catalysts were mapped by a Catalyst Analyzer BELCAT II with a laser with a wavelength of 634 nm. The accumulating duration and accumulation for Raman mapping were 2 seconds and once, correspondingly (mapping area was 1010 m). Fourier transform infrared spectroscopy (FTIR spectrometers-Shimadzu, Japan) was used to determine the functional groups. X-ray photoelectron spectroscopy was utilized to determine the configuration and chemical bonding of C and O elements (X-ray photoelectron spectrometer (XPS), Shimadzu, Japan).

Analytical statistics: The student's t-test on the significance of results was performed using ANOVA.

Environmental & economic benefits: The parameters of co-digested waste fractions were obtained using the reported method [32], after anaerobic digestion with carbon based material supplementation. The detailed characterization may allow for the supplementary use of endproducts, which meet existing Environmental Quality Guidelines requirements. Furthermore, laboratory data on recovery rates and the volume of these wastes produced by industrial facilities can be used to calculate the amount of liquid and slurry that can be recovered if the corn stalk is reprocessed using anaerobic fermentation.

Analytical methods for basic parameters: Total solids (TS) was determined using APHA's established techniques [33]. A pH meter was used to keep track of the pH level. A gas analyzer was used to determine the amount of biogas produced (Agilent 6820).

RESULTS AND DISCUSSION

Physical characteristics: The Brunauer-Emmett-Teller surface areas of the carbon based materials were determined. In terms of hydrochars, Hc230 had a greater Brunauer-Emmett-Teller surface area (9.1 m^2/g). Bc700 showed a greater Brunauer-Emmett-Teller surface area (79.80 m^2/g) for biosolid. Oxidant biosolid has a surface area of 31.93 m^2/g, reduction biosolid has a surface area of 67.27 m^2/g and acid biosolid has a surface area of 76.88 m^2/g. Alkali biosolid has a surface area of 57.21 m^2/g). These four biosolids surface area was similar to Bs700. Po700 has a greater specific surface area than Bs700 (331.02 m^2/g). Biosolids surface was more angular and had a rougher texture than that of hydrochar. During the preparation process, the higher temperatures caused steady lignocellulose pyrolysis, which produced wide pores and angular structures. The physical arrangement of the surface of biosolid was unaffected by oxidant

TABLE-1
MANUFACTURING STATES OF BIO-SOLIDS

Aimed temperatures	300 °C		500 °C		700 °C	
	Temp. (°C)	Time (min)	Temp. (°C)	Time (min)	Temp. (°C)	Time (min)
Warming phase 1	25-300	40	25-300	40	25-300	40
Fixed heating phase 1	300	25	300	10	300	10
Warming phase 2	–	–	300-500	30	300-700	60
Fixed heating phase 2	–	–	500	25	700	25
Cooling phase	300-200	40	500-200	60	700-200	120

and reduction modifications. The surface of biosolid was smoothed by acid and alkali treatment. The sample Po700 had deeper pores on its surface, giving it a greater specific surface area.

Chemical characteristics: In anaerobic digestion system, the carbon based materials are spread in the liquid state to affect the electron transfer process. As a result, detecting the characteristics of components scattered in the liquid phase is critical. The zeta potential of material scattered in a fluid is shown in Fig. 2. Both hydrochars and biosolids preparation temperatures enhanced the absolute value of zeta potential. The absolute zeta potential of biosolids reduced dramatically after alteration (for instance, Bs700 was 37.91 ± 1.21 mV and Ox700 was 21.18 ± 1.39 mV). The sample Po700 has the minimum absolute value of zeta potential (-6.04 0.29 mV). The absolute value of the zeta potential of biosolids synthesized at higher temperatures was higher in previous work [34], which was consistent with the findings in this investigation. The stability of colloidal dispersion was corresponding to the degree of zeta potential. The more the absolute level of zeta potential, the more charges the particle has to resist aggregations, resulting in a stable system. Contrarily, the lesser the zeta potential, the less positive or negative the particles were and the more possible they were to thicken, disperse and be demolished [34]. The pH of carbon-based compounds scattered in the fluid is shown in Fig. 3. The pH rose as the preparation temperatures increased (6.19 ± 0.14 – 9.22 ± 0.35), in addition to Hc200. Acid-modified Biosolids had a pH of 5.27 ± 0.09, whereas alkali treated biosolids had a pH of 10.42 ± 0.08. The graphite structures of carbon-based materials appear to have an impact on the electron transmission mechanism [35]. As a result, research is needed to see if the crystal defects of material created at the time of manufacturing procedure affect electrons' transport.

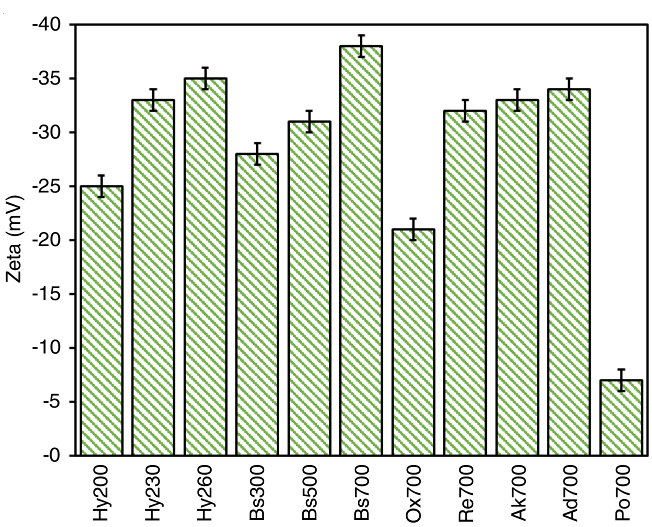

Fig. 2. Characteristics of carbon-based materials dispersed in liquid state (zeta potential)

Methane generation: The application of carbon-based material increased both methane generation and yield (Fig. 4). The accumulative methane generation with biosolids supplementation of fermentation process was boosted as the manufacturing heart of carbon-based materials increased (the highest

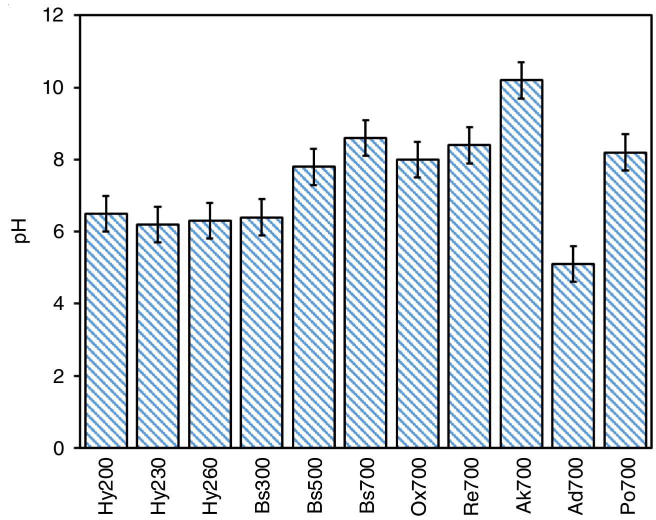

Fig. 3. Characteristics of carbon-based materials dispersed in liquid state (pH)

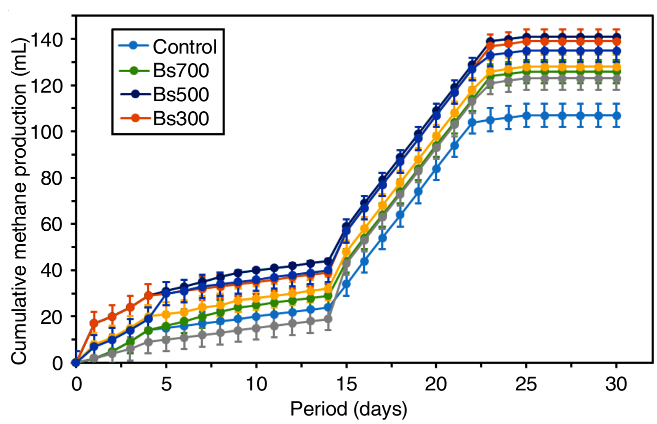

Fig. 4. Accumulative methane generation with hydrochar and bio-solids supplementation

was Bs700, 133.96 ± 0.28 mL). The highest accumulative methane generation of fermentation systems with hydrochars addition ranged from 122.59 ± 0.68 mL to 132.89 ± 0.34 mL, while that of fermentation systems by biosolids supplementation ranged from 131.11 6.66 mL to 133.96 ± 0.28 mL. Previously, the influences of biosolids and hydrochars on anaerobic digestion methane generation were investigated [36]. The findings revealed that hydrochars boosted methane generation substantially more than biosolids. Different biomass was used to make two types of carbon-based compounds. Alkaline sludge was used as a biosolids raw material and could result in a decreased proportion of anaerobes in the biosolids set that had poor methane generation capability. Nevertheless, it appears that biosolids and hydrochars had equal effects on anaerobic digestion methane production performance in this investigation. Fig. 5 depicts the anaerobic digestion system's methane output performance after adding Bs700 and modified biosolids.

Sample Bs700 outperforms all other biosolids in terms of methane generation (largest accumulative methane generation was 159.99 ± 5.33 mL). Samples Ad700 and Ak700 were fewer (84.52 ± 0.55 mL and 68.46 ± 1.39 mL, correspondingly) than

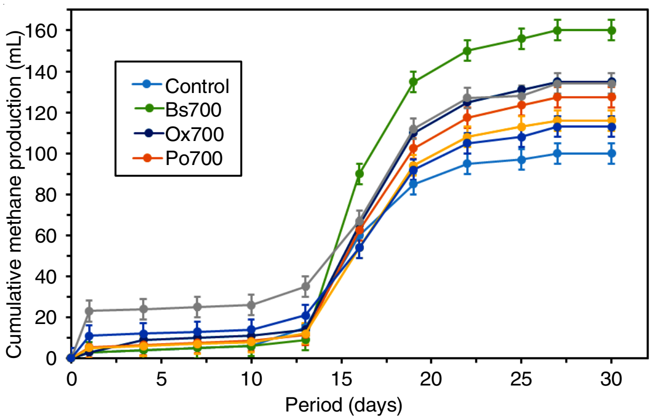

Fig. 5. Accumulative methane generation trend with Bs700 and modified bio-solids supplementation

the untreated set (101.74 ± 23.30 mL), which could be owing to the inhibitory influence of these two types of biosolids on fermentation. Samples Po700 (109.69 ± 21.93 mL), Ox700 (114.39 ± 29.35 mL) and R700 (116.23 ± 0.27 mL) all had marginally greater methane output than the blank set. When compared to biosolids, the encouraging influence of reformed biosolids on anaerobic digestion system methane generation reduced and some modified biosolids even prevented it. The methane proportion of generated biogas at the time of fermentation for the impact of various ingredients is shown in Fig. 6. Samples Ad700 and Ak700 set generated essentially zero biogas over the first 10 days of fermentation. The methane concentration of the generated biogas steadily enhanced as the anaerobic digestion progressed (Ad700 was 41.06 ± 4.07% – 54.23 ± 3.57%, Ak700 was 39.18 ± 1.96% – 51.6 ± 1.39%). The methane concentration of the Po700 and R700 systems changed greatly in the initial stages (on the 2nd day, Po700 was 30.1 ± 22.21% and R700 was 31.73 ± 22%), possibly

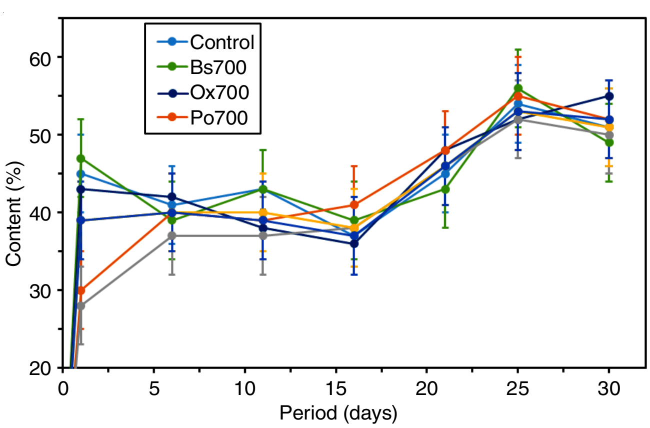

Fig. 6. Methane content trend with Bs700 and modified bio-solids supplementation

because of inhibition of acidic intermediates [37]. Methane concentration of the Po700 and R700 groups then steadily enhanced, following the same pattern as the control, Bs700 and Ox700 groups. The greatest CH_4 proportion in Bs700 was (56 ± 0.5%) on day 22. Sample Bs700 had the highest biogas quality, while samples Ad700 and Ak700 had poorer quality compared to the blank set. Table-2 displays the significant comparison between the properties of unlike trial sets based on cumulative methane production.

There was no statistical difference in methane generation between hydrochars and biosolids ($p > 0.05$), representing that there was no numerical change among these sets. The difference between the blank and Bs700 biosolid results was significant ($p < 0.01$). These two groups' accumulative CH_4 productions were significantly different. All modified Biosolids and Bs700 had statistically significant changes ($p < 0.05$). The difference between Bs700 and Po700 was the most significant ($p < 0.01$).

Many factors may influence biosolids' ability to decrease the lag period and boost methane output [38]. Carbon-based compounds were found to improve anaerobic digestion's methane generation performance in this investigation. It is reported that reactors combined with Biosolids created at 400 and 900 ºC produced identical amounts of methane, which matched the outcomes of the present work [39]. The present work demonstrated that carbon-based materials manufactured at heats ranging from 200-700 ºC have a similar boosting effect on methane generation.

Moreover, the pore structures on the surfaces of biosolids could promote the development of microbes and hence affect methane generation efficiency [40]. From the BET results of carbon based materials in present work, the specific surface area of biosolids steadily enhanced with the manufacturing heat. The pore structures on the surfaces of biosolids generated at a higher temperature may account for the huge specific surface area. Although the conspicuous pore structure may facilitate microbial enrichment, for example sample Po700 with the biggest specific surface area did not produce the most methane. As a result, the enhancement of microbes might not be attributed solely to the wide pore structures on the surfaces of biosolids but may be influenced by other factors as well.

Since the irregular discrete structure of Po700 was not favourable to the electron transmission procedure between microbes, the Po700 with an enormous specific surface area couldn't significantly increase methane generation. Bs700, on the other hand, with its regularly discrete structure, delivers an excellent atmosphere for electron transport that could be a key reason for Bs700's higher CH_4 production than Po700. In case electrons were transported between microbes and archaea *via* the graphene structures of carbon-based materials, the

TABLE-2
SIGNIFICANCE OF CUMULATIVE METHANE PRODUCTION BETWEEN DIFFERENT SAMPLES (α = 0.01)

Sample	Hy200-Hy230	Hy230-Hy260	Hy260-Bs300	Bs300-Bs500	Bs500-Bs700	Control-Bs700
Significance	0.071	0.475	0.689	0.957	0.271	0.001**
Samples	Bs700-O700	Bs700-R700	Bs700-P700	Bs700-Ac700	Bs700-Al700	
Significance	0.034*	0.048*	0.003**	0.018*	0.033*	

*Significant, **Very significant.

material's flaws may prevent electron transfer. As a result, the generation of methane can't be optimal. Nevertheless, the CH_4 generation efficiency of Bs700 having more flaws was comparable with Hc260, demonstrating that the uniform graphene structures of carbon based materials are unrelated to electron transmission among microbes and that the metal like oxidation [41] can't be appropriate to direct interspecies electron transfer processes facilitated by carbon based material. According to literature [27,42], aromatics on the surface of biosolids may play a role in the fermentation system' DIET. The sample Bs700 increased the methane generation better was presumably because of the abundance of aromatic functional groups. Biosolids' aromatic hydrocarbons were degraded during oxidation, resulting in the formation of additional oxygen functional groups. Because Ox700 had fewer redox aromatic functional groups, electron transmission between bacteria was difficult. Methane generation was much lower under the impact of Ox700 than under the influence of Bs700, implying that aromatics on the surfaces of Biosolids play a role in the electron transfer system. Acidogens and methanogenic microbes adjusted to thrive in the pH ranges of 5.51-8.49 and 6.61-7.49, correspondingly, while anaerobic microbes adapted to flourish in neutral pH conditions [43,44]. Because the pH of Ad700 and Ak700 was outside the diverse limit for anaerobes, functional microbes on their surfaces may have been suppressed. The inhibition induced by volatile fatty acids generated during the acidogenesis phase of fermentation can be alleviated by weakly alkaline biosolids. As a result, acid-modified biosolids had a marginal buffering influence in an acidic atmosphere and even worsened acidification, impeding methane synthesis. However, extreme alkalines in Ak700 biosolids might prevent anaerobes from adapting to the atmosphere, resulting in low methane generation. As a result, these two sets performed significantly poor than the blank set in terms of methane production. Table-3 shows the evaluation of methane latent and pollutant removal efficiency with and without the supplementation of biochar with that existing in the literature.

Carbon based compounds on microbes: The overall relative concentrations of *Bacillaceae* that might engage in direct interspecies electron transfer [45] were alike in reactors supplied with unaltered materials. In hydrochars and biosolids modified reactors, *Methanosarcina* influenced the archaeal. All ingredients can enrich *Methanosarcina* as compared to the control group (65.52%). *Methanosarcina* could be involved in the direct interspecies electron transfer system of ethanol-category fermentation [46,47]. By boosting bacteria that may engage in the DIET, the supplementation of carbon based sources might stimulate methane generation in fermentation.

The surface of biosolids had a lot of functional groups and a lot of aromatic hydrocarbons, which helped it take electrons from bacteria and stimulate methane generation. In the Bs700 modified reactor, electrons generated by *Pseudomonadaceae*, *Bacillaceae* and *Clostridiaceae* were likewise enhanced (65.72% *versus* 34.69% of blank set). *Methanosarcina* was enriched because the aromatics on the surfaces of carbon based material can work as electron donors, supplying electrons to *Methanosarcinas*.

Electrons can be transmitted more efficiently with the effect of biosolids with a great absolute value of zeta potential was scattered more homogeneously in the liquid state. Biosolids, like telecom signal towers, aids in the electronic exchange of microbes on a tiny scale. Yang *et al.* [48] reported that aromatic hydrocarbons in biosolids may act as the electron acceptor during long-range electron exchange, while also acting as the electron donors. The previous method of electron transfer through the pili filaments reported that the electrons were transported between functional groups by hopping on the surface of biosolids [49]. Electron transfer is controlled by the aromatic functional group.

Environmental benefits & fertilizer recovery: There are two categories of ecological profits, which can be obtained from substrate fermentation. For starters, their contaminants will not be released into the environment. Second, the treated outflowing waste can be processed quickly to provide irrigation water and leftover sludge for fertilizer. To evaluate the degrees of pollution connected to drugs like those deliberate in the present work, a certain parameter named equivalent population is usually utilized. The European Directive 91/271/CEE of May 21, 1991, identifies biodegradable wastewaters with a BOD5 of 59.99 g/day [50]. The extent of contamination generated may be measured by determining the BOD_5 of food waste from landfills. Food waste from landfills had been observed to generate

TABLE-3
EVALUATION OF METHANE LATENT AND POLLUTANT REMOVAL EFFICIENCY WITH AND WITHOUT THE SUPPLIMENTATION OF BIOCHAR WITH THAT EXISTING IN THE LITERATURE

Wastewater	Increase in methane potential (%) with biochar	COD, VS removal efficiency (%) or zeta potential (mV)	Ref.
Synthetic iron-based biochar was applied in fermentation of synthetic salty organic wastewater, (bio-char preparation at 700 °C) under mesophilic condition for 160 days	26	66	[40]
Biochar was used in the anaerobic fermentation of organic solid wastes (bio-char preparation at 400-500 °C) under mesophilic condition for 10 days	24	55	[41]
Wheat-straw biochar was applied to food waste co-digestion (biochar preparation at 550 °C) under mesophilic condition for 30 days	23	42	[43]
Biochar from bamboo, rice husk, miscanthus straw pellets and sewage sludge was used to co-digest food waste (bio-char preparation at 550 °C); under mesophilic condition 30 days	21	43	[44]
Bio-solids and hydrochar were added for enhancing methane generation from ethanol anaerobic Fermentation (bio-char preparation at 200, 230 and 260 °C); under mesophilic condition for 30 days	30	38	This study

TABLE-4
PHYSICO-CHEMICAL PROPERTIES OF DECOMPOSED SLURRY TREATED WITH CARBON-BASED MATERIALS

	Solid portion		Water portion
Recovery of sludge (m^3 sludge m^{-3} substrate)	0.08	Recovery of water (m^3 water m^{-3} substrate)	0.84
Moisture (%)	96	COD (g/L)	0.31
Zn (g/kg dry weight)	0.59	Turbidity (unfiltered turbidity, UNF)	1291
Ni (g/kg dry weight)	0.19	Suspended solids (g/L)	0.06
Cu (g/kg dry weight)	0.20		
Cr (g/kg dry weight)	0.04		
Hg (g/kg dry weight)	0.003		
Pb (g/kg dry weight)	7.4×10^{-3}		
Cd (g/kg dry weight)	2.7×10^{-4}		

6.27 g BOD_5/L of waste and 957000 t/year of trash in Malaysia (USEPA). This level of pollution corresponds to a population of 274162 people. As a result of wastes from landfills' biodegradation, the contamination potential of these people can be avoided. Agriculture irrigation fluids and fertilizer could be produced by co-fermenting organic substrates [3]. As a consequence, Table-3 displays the features of fermented garbage. From fermented waste, sludge recapture was 0.08 m^3 sludge/m^3 wastewater, while water recapture was 0.84 (m^3 sludge/m^3 wastewater). To determine their prospective application, the qualities of the sludge were compared to the standards given in the current Malaysia recommendations. Sludge can be used as an agricultural input if the heavy metal concentration is below the limitations outlined in Appendix K3 of the Environmental Quality Guidelines 2009 (PU (A) 433) (Environmental Requirements, 2010) [3]. The fermented slurry can be utilized as fertilizer and the liquid produced by the fermentation can be used for irrigation.

Economic feasibility analysis: The findings of the various proposed co-fermentation processes are summarized in Table-4. From an economic standpoint, manufacturing co-fermentation with carbon-based materials appears to be a feasible company. It was estimated that it would take 3.72 years to recoup costs. Table-5 summarizes the results of a feasibility study utilizing the method of carbon based material supplemented anaerobic digestion [32]. The economic viability of this study is predicated on the following assumptions: calculation of electric and thermal power, installation expenses, annual costs and annual benefits.

Calculation of electric and thermal power: The anaerobic fermentation plant was estimated to run for 8000 h per year to determine the electric and thermal power. The electric and thermal efficiencies were found to be 38 and 45%, correspondingly, with the calorific value of methane being 31 MJ/N m^3. Although this parameter has been stated to be 35 MJ/m^3 elsewhere, a lesser value will be used for the worst-case situation.

Installation expenses: The building costs of the anaerobic digestion (AD) plant was estimated at 4000 and 3000 Euros/installed kWe. Complementary expenditures for viability studies (10,000 euro) and administrative and authorization procedures (20,000 euro) should be counted.

Annual costs: The cost of engine maintenance is expected to be 12.5 Euros per MWh of power (EVE, 2001). The costs of operating and maintaining the anaerobic digestion plant were anticipated to equal 2% of the total construction expenditures.

TABLE-5
FEASIBILITY OF THE BIO-SOLIDS AND HYDRO-CHAR SUPPLEMENTED ANAEROBIC DIGESTION

	Bio-solids and hydro-char-treated anaerobic digestion of algae slurry
Waste for treatment (m^3 y^{-1})	11130
Electrical engine (kWe)	85.2
Electricity generation (MWh/year)	6670
Thermal energy potential (GJ/year)	2751
Required Heat for AD plant (GJ/year)	1969
Water heating capacity (m^3/year)	3386
System cost (Euro)	363340
Yearly income (Euro)	165664
Yearly cost (Euro)	68124
Yearly benefits (Euro)	97540
Payback period (yrs)	3.72
GCW (Million of dollars)	0.59
IRR (%)	27

The yearly payment debt for the anaerobic digestion plant installation expenditures was computed using a 6% interest rate over 15 years. Labour is estimated to be worth 12,000 Euros per year. It should be noted that these wastes are not acceptable for any anaerobic process because they have a detrimental impact on anaerobic digestion. Finally, for the anaerobic digestion plant, transportation costs were calculated as follows: 1.35 euro/km for an empty truck and 1.59 euro/km for a fully-loaded vehicle.

Annual benefits: The heating process will be absorbed 93% of the electric power produced in the anaerobic digestion plant. Electricity savings (0.12 Euros/kWh) were used to calculate the economic advantages. The AD plant consumed the remaining 7% of the generated electrical energy. Benefits from avoided solid waste treatment expenses (12 cEuros/kg solid wastes), as well as savings in water heating for cleaning activities (6.49 euro/m^3 heated water), were also examined.

The heat needed to keep the anaerobic reactor at 37 ºC was calculated as the heat needed to increase the temperature of wastes from 16 to 37 ºC plus 62% and 5% increments owing to heat losses in the reactor and extra margin, correspondingly.

Conclusion

The tea ground-based biosolids and hydrochars generated at unlike heats had alike boosting influences on methane generation during ethanol-type fermentation. The material's steady dispersal mechanism creates an ideal atmosphere for electron transmission between bacteria. Nevertheless, the specific surface areas of carbon-based material did not affect the enhancement of microbes when the material's surface pH was altered by acid and alkali. The redox hydrocarbons found in carbon based sources might have a role in the electron transmission system between microbes, enhancing the fermentation of ethanol and the production of methane. The fermented slurry might be used for irrigation purposes.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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