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Effect of Solid Loadings and Urea addition on Biogas production from the Co-Digestion of Rice Straw with Cow Dung

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Abstract

This paper investigated the anaerobic co-digestion of RS and CD at lower solid loadings of 5, 10% and 15% TS. It also studied the effect of urea addition on biogas yields after 20 days retention time. These experiments were also carried out at different substrate mixing ratios of RS-CD 1:1 and RS-CD 1:2. The anaerobic digestion was carried out in a digester designed and fabricated locally with retention time of between 40-60 days with results showing a maximum biogas yield of 116 L/kg TS and 104 L/kg TS for 10% TS at RS-CD 1:2 and RS-CD 1:1 respectively. Experiments carried out at 15% TS showed the lowest biogas yield of 72.1 L/kg and 81.2 L/kg for RS-CD 1:1 and RS-CD 1:2 respectively. Results also showed that studies carried out at RS-CD 1:1 showed higher biogas yields for substrate concentrations of 5%, 10 % and 15% TS when compared to corresponding experiments carried out at a mixing ratio of RS-CD 1:2. This study also showed that supplementing the anaerobic digestion with 0.5% urea increased biogas yield by 15-19%.

Keywords: Biomass, Biogas, Total Solids, Lignocellulose, Valorization,

Introduction

The production of rice in Nigeria has increased significantly with an estimated rice production of 8.17 million tonnes in 2020 [1]. Rice is considered a popular staple food for consumption in Nigeria and it is expected that its production will continue to increase as the country strives towards self suffiency in production [2-3]. However, this increased production is marked by increased waste generation from straw, stalks and other residues like husks that can be generated from the processing of rice in mills. Besides plant waste, animal waste from cattle, piggery and poultry offer enormous environmental challenges with attendant sanitation. There is therefore a requirement for proper treatment and utilization as value added materials [4-5].

Biogas production offers an alternative waste disposal option for agricultural residues. Besides the biogas produced, organic fertilizers are also produced from the anaerobic digestion [6]. While the production of biogas from animal and plant waste have gained significant traction as a renewable energy resource for cooking, compressed natural gas and electricity generation in more developed economies in European, Asian and other western countries, Its usage across Africa is low. The production of biogas from biomass involves the biological decomposition of plant and animal materials in the absence of oxygen. Biomaterials composed of carbohydrates, proteins and lipids are broken down by microorganisms through the following stages; Hydrolysis, acidogenesis, acetogenesis and methanogenesis. Biogas is typically composed of 50-60% methane (CH_4) and 30-40% Carbon IV oxide (CO_2) and some trace amount of water vapour, Ammonia and Hydrogen Sulphide [7-8]. Majority of studies on biogas production has being from mono-digestion involving the breakdown of one organic matter however there has been an increasing interest in combining two or more organic materials for biogas production in a process termed co-digestion [9]. Co-digestion as an alternative anaerobic process is believed to offer a number of advantages over mono digestion. These include possible dilution of inhibitory substances, improved synergy of microorganisms from the different substrates and increasing biodegradability of organic matter [10]. Co-digestion also offers a better alternative to waste management of different resources especially agricultural residues. Co-digestion is reported to enhance biogas production from 25% to 400% over the mono-digestion of the same substrates [11-12].

Several papers have investigated the combination of rice straw and other animal waste at labouratory scale in quantities between 250 mL and 1 L [13]. Most of these studies are usually carried out at constant temperature. This paper will consider a series of batch experiments carried out in 25 L volumes. In our previous work, we investigated the anaerobic digestibility of rice straw and cow dung at different mixing ratios. Our objective was to compare the cumulative gas yields (CGY) per gram of biomass used. Our initial study was also carried out using total solid contents of 20% [14]. Results from this study showed a maximum cumulative gas yield (CGY) of 32 L/kg. This paper as an extension of this study will focus on using lower total solid content (TS) with an objective of improving biogas yield. Studies have suggested that anaerobic digestion is basically divided into three categories depending on the content of total solids (TS) in the raw biomass: wet (less than 10% TS), semidry (10–20% TS), and dry (> 20% TS) processes [15-16]. Some of these investigations have suggested that dry anaerobic digestion (DAD) provides better yield when compared to wet anaerobic digestion (WAD) especially when the digester has proper stirring as it produces high volumetric methane productivity, reduced energy requirements for heating, less wastewater generation, and a low moisture digestate that is easier to handle [17-18]. Itodo and Awulu [19] suggested that for biogas produced from cattle, poultry and piggery, lower Total solids (TS) leads to higher specific biogas yield. However, some studies have reported that biogas production was improved at higher TS content. Arelli *et al.* [20] showed an improvement of 70–85% in biogas production by increasing the TS content from 25% to 30% in the anaerobic co-digestion of food waste and cattle manure. Duan *et al.* [21] also reported a higher methane yield similar to those of wet anaerobic systems from dewatered sludge of TS of 20%. It is therefore important to investigate the influence of TS content on performance of the anaerobic digestion systems as it is expected to be peculiar for different organic matters.

The goal of this study is to examine the effects of total solids on biogas yield as well as study the effect of urea addition on the biogas yield. There are little or no papers in literature that have studied the effect of total solids or urea addition on biogas yields from rice straw.

Materials and Methods

Cow dung (CD) was collected from a local farm located in Ankpa Quarters Makurdi Benue State Nigeria while Rice Straw (RS) was collected from a demonstration farm in University of Agriculture Makurdi, Benue State with GPS coordinates 7°46'45.8"N 8°36'45.6"E. The rice straw was air dried and then pounded with a mortar and pestle to reduce particle size. Moisture content was determined using standard analytical protocols [22]. A 25 L drum type digester system was designed and fabricated locally as described and shown in our previous work [14, 23]. It has three main parts, the inlet chamber, the body and the outlet chamber and inserted with a thermometer and pH metre. A thermometer was inserted through a drilled hole at the top of the drum to measure the temperature. The measuring cylinder inverted with water was used for volume measurement of gas through a process called upward delivery and downward displacement. A series of batch experiments were carried out at ambient temperatures at different total solid concentrations. The biomass weight was suspended in 20 Litres of water making different total solid suspensions of 5%, 10% and 15%. Different mixing ratios of Rice straw (RS) and cow dung (RS) were used for the experiments as shown in Table 1.

Table 1: Mixing ratios of Rice Straw and Cow Dung at different Total Solid Concentrations

Substrate blending →	RS-CD 1:2		RS-CD 1:1	
	RS (kg)	**CD (kg)**	**RS(kg)**	**CD (kg)**
5% TS	0.250	0.750	0.500	0.500
10% TS	0.666	1.334	1.000	1.000
15% TS	1.000	1.000	1.500	1.500

The substrate was thoroughly mixed in the digesters. Each digester was manually agitated once a day to avoid stratification. The input slot was closed well with wax and hose clips to prevent leakage. The daily biogas production was recorded by measurement of displaced water both in the mornings and afternoons. This is done by noting the quantity of water displaced from the gas collected in the measuring cylinder. Collection of biogas for analysis was done by collecting it in a balloon for storage. The ambient temperature, digester temperatures and pH were measured at least twice a day both in the mornings and afternoons. Further experiments were also carried out by supplementing with addition of 0.5% Urea. Urea was added to the bioreactor at a retention time of 20 days and Biogas yield monitored for an additional 40 days for those experiments. The composition of the biogas was determined with a gas chromatograph Chemito GC-8610 model using a thermal conductivity detector with oven at temperature of 50^{0}C and injector temperature of 200^{0}C. Calibration curve was used to determine concentration of methane.

Results and Discussion

The moisture content analyzed showed moisture content to be 8.12% giving a total solid of 91.98%. Biogas yields are expressed in litres of biogas produced per total solids (TS). The Biogas production yields were given as Cumulative Gas Yields (CGY) expressed per gram TS of biomass loaded (L/kg TS) in the digester.

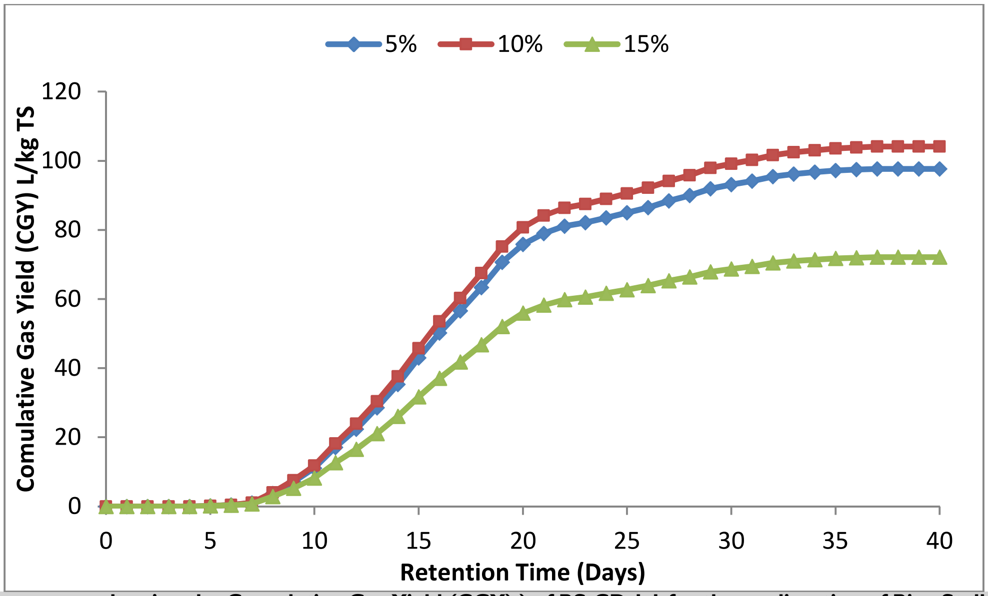

Figure 1. Progress curve showing the Cumulative Gas Yield (CGY)) of RS-CD 1:1 for the co-digestion of Rice Stalk (RS) and Cow Dung (CD) at different Total Solid concentrations with a retention time of 40 days

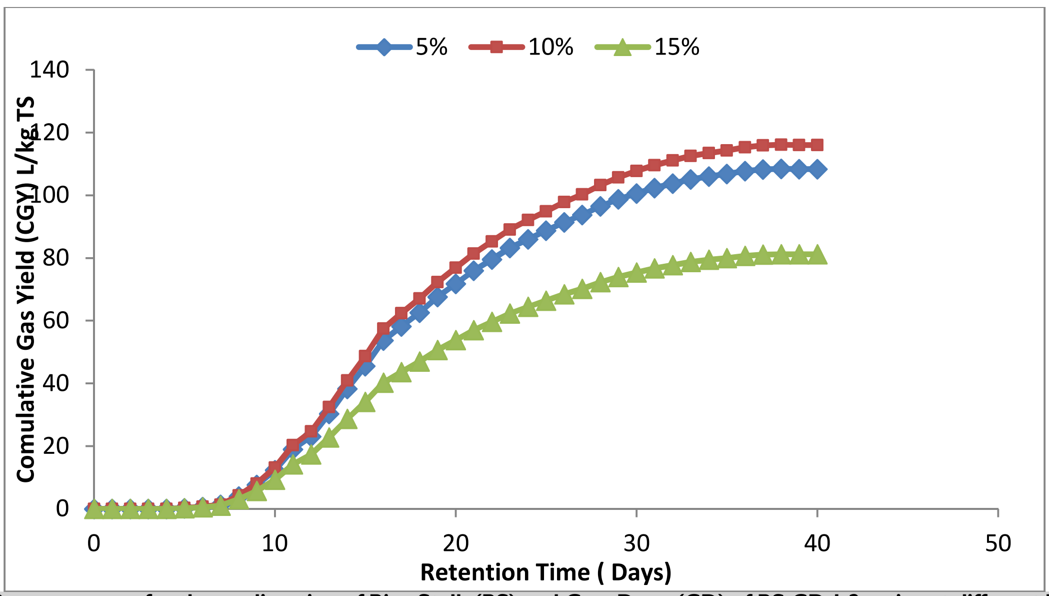

Figure 2: Progress curve for the co-digestion of Rice Stalk (RS) and Cow Dung (CD) of RS-CD 1:2 ratios at different Total Solid Concentration with a retention time of 40 days.

Results from Figure 1 shows that experiments carried out with Rice Straw (RS) and Cow Dung (CD) combined at substrate mixing ratio of RS-CD 1:1 had the maximum cumulative gas yield (CGY) of 104.1 L/kg TS for experiment carried out at 10% TS. The CGY for experiments carried out at 5% TS is 97.7 L/kg TS while the lowest CGY of 72.1 L/kg TS was observed for experiments carried out at biomass concentration of 15% TS. These results demonstrate a significant increase in biogas yield when compared to experiments carried out at 20% TS and 37.5% TS as shown in our earlier studies [14, 23]. A similar trend is also observed with experiments with a mixing ratio of RS-CD 1:2 as shown in Figure 2. The trend shows that anaerobic digestions carried out at 10% TS shows the highest CGY compared to experiments carried out at 5% TS and 15% TS. Studies on mono-digestion of cattle manure have suggested different values of TS for optimum production of biogas. While Zennaki *et al.* [24] and Budiyano *et al.* [25] showed that 7%-9% gave better biogas yields, Singh *et al.* [26] suggested that a total solid of 9-13% gave better yields of biogas from cattle manure. Another study by Santana and Pound [27] reported 8% TS as the most effective concentration for optimum biogas production when experiments are carried out between 1-8% TS

of cattle manure. However, it must be noted that all these studies were carried out with cow dung as mono-digestion. Co-digestion studies with cattle manure and wheat straw carried out by Sun *et al.* [28] showed that higher biogas yield were observed with 10% TS when compared to experiments carried out at 7.4% TS. This same study however reported that mono digestions with only cattle manure showed faster biogas production rate with 7.4% TS when compared with experiments carried out at 10% TS.
The much lower biogas yield observed for co-digestion at 15% TS when compared to substrate concentrations of 5% TS and 10% TS is most probably due to substrate inhibition, mass transfer limitations and higher mixing difficulties present with higher total solids concentration [29-31]. Lower total solids concentrations lead to lower viscosity of the biomass slurry and this causes better movement of the microorganisms and with this better mass transfer. As total solids increase, viscosity increases and lower mass transfer and substrate inhibition is likely leading to lower biogas yields. Adequate mixing in the bioreactor reduces the mass transfer limitations [32-33].

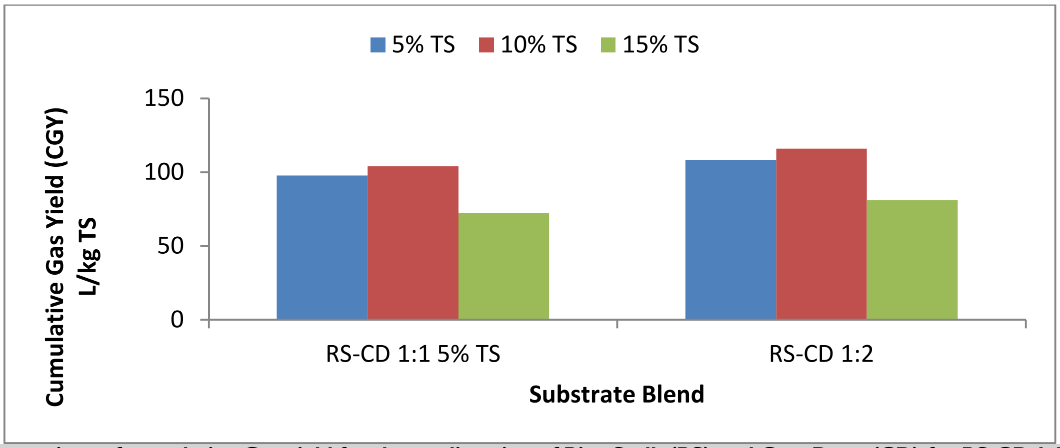

Figure 3: Comparison of cumulative Gas yield for the co-digestion of Rice Stalk (RS) and Cow Dung (CD) for RS-CD 1:1 and RS-CD 1:2 ratios at different Total Solid Concentration with a retention time of 40 days.

Anaerobic digestion is also prone to process instability issues like acidification and this can play a significant role at different total solid concentration. The marginal difference in biogas yield between 5% TS and 10% TS observed in Figures 1-3 and most obviously in Figure 3 can be attributed to differences in pH changes as the reaction progresses. It can be observed from the pH profile in Table 2 that pH changes drops significantly in experiments carried out at 5% TS. pH changes are usually caused by the formation of volatile fatty acids which are the main metabolic intermediates of anaerobic digestion. Differences in pH derived from imbalanced rates between hydrolysis/acidogenesis/acetogenesis and methanogeneis is a major issue resulting in instability in biogas processes. The drops observed in 5% TS after day 20 shows that accumulation of VFA could affect the methanogenesis step. If the VFAs are depleted, then the other steps can then be completed synchronously.

Table 2: pH Profile for the co-digestion of Rice Stalk (RS) and Cow Dung (CD) at different Total Solid Concentrations with a retention time of 40 days.

Substrate blending ratio and total solids concentration	RS-CD 1:1			RS-CD 1:2		
	5%TS	10% TS	15% TS	5%TS	10% TS	15% TS
Average pH at start	7.48	7.49	7.47	7.23	7.26	7.24
Average pH at day 20	**5.91**	6.23	**6.22**	**5.83**	6.21	**6.11**
Average pH on day 40	5.74	5.55	5.70	5.62	5.64	5.51

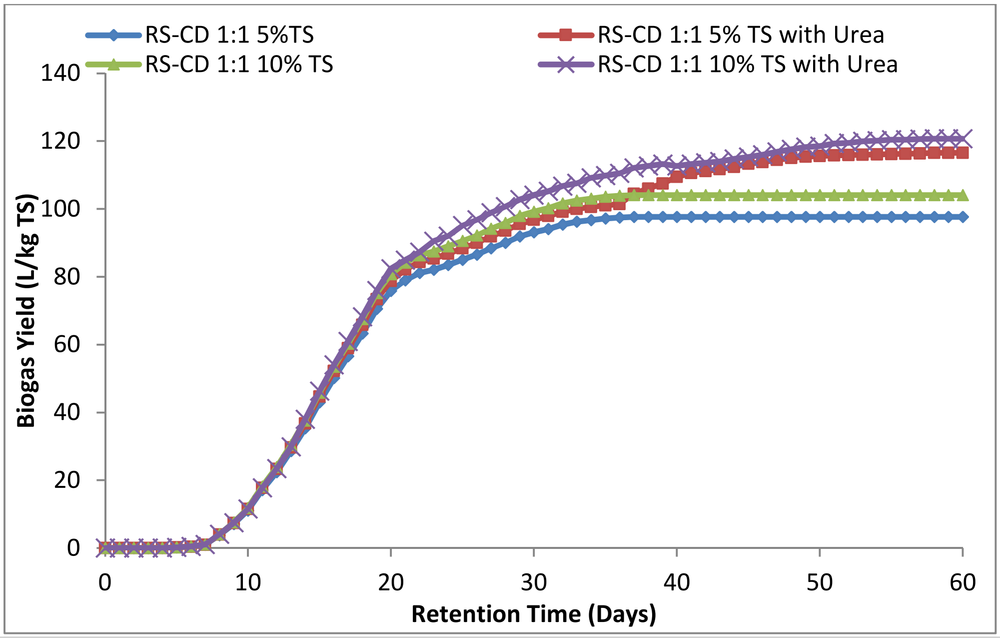

Figure 5. Progress curve showing the Cumulative Gas Yield (CGY) for the co-digestion of Rice Stalk (RS) and Cow Dung (CD) at different Total Solid concentrations with a retention time of 60 days after an addition of 0.5% Urea

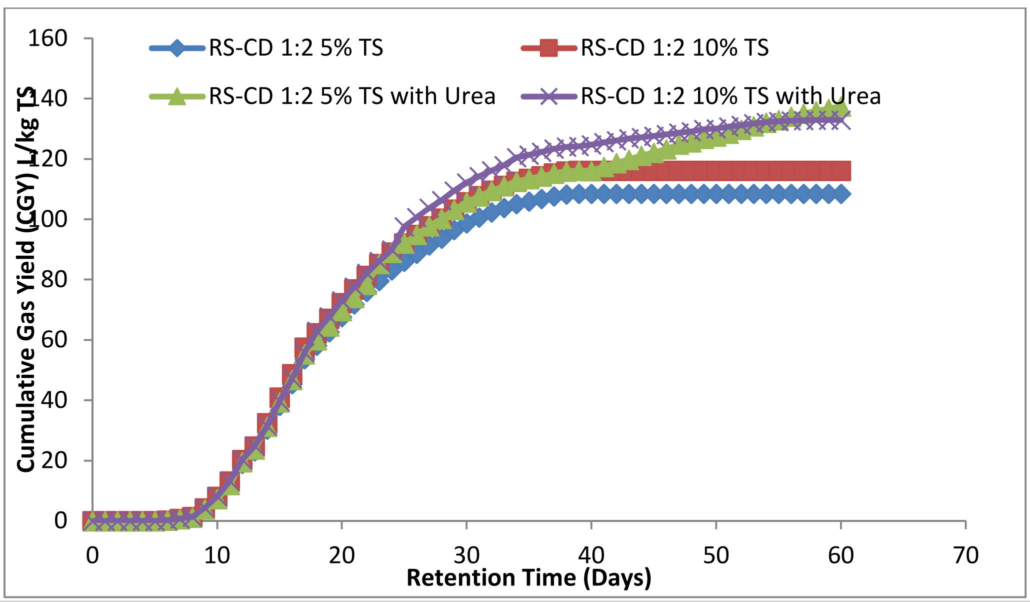

Figure 6: Progress curve for the co-digestion of Rice Stalk (RS) and Cow Dung (CD) RS-CD 1:2 ratios at different Total Solid Concentration with a retention time of 60 days after an addition of 0.5% Urea.

To minimize the effect of acidification and possibly improve biogas yield, the effect of urea addition on biogas yield was studied as shown in Figures 5 and 6. Results show that biogas yield is improved beyond day 40 to a residence time of 60 days. For experiments carried out at substrate ratio of RS-CD 1:1, biogas yield increased from 97.7 L/kg for 5% TS to 116.4L/kg representing an increase of 19.14% biogas yield where urea was added to the experiment. For experiments at 10% TS, there is an increase in biogas yield from 104.1 L/kg to 120 L/kg representing an increase in 15.7%. Similarly for experiments at RS-CD 1:2, the addition of urea resulted in an increase of 26.5% and 14.5% for experiments carried out at 5% TS and 10% TS respectively. These results show that the increase in biogas yield is more significant with experiments carried out at 5% TS than at experiments carried out at 10% TS. Besides the increase in pH observed in these experiments, this result agrees with a study that investigated the effect of different concentrations of urea on the biogas production from pineapple pulp and cow dung where the biogas production was increased by at least 19% [34]. It must also be noted that the addition of Urea also increases the Nitrogen content of the substrate therefore increasing the C;N ratio for the microbes. It will be interesting to investigate effect of different concentrations of urea on the co-digestion of rice straw and cow dung.

An analysis of the gases produced was analyzed by gas chromatography for the experiments at 10% TS shows that methane gases varies between 55% and 65% with higher values of methane observed for experiments supplemented with urea. This might be due to the increased C:N ratio expected from the higher Nitrogen content for the microbes.

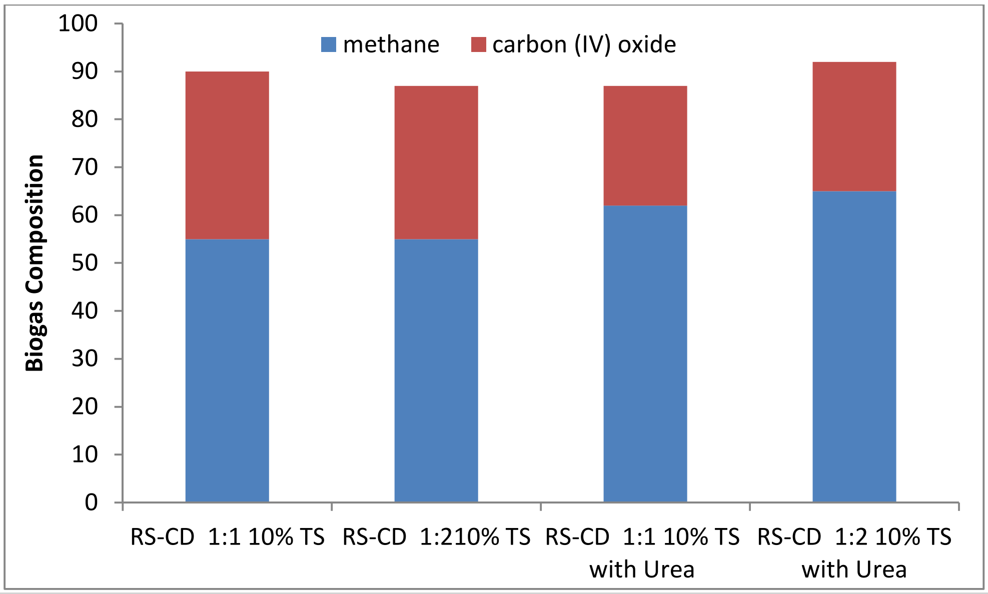

Figure 7: Comparison of Biogas Composition from the co-digestion of Rice Stalk (RS) and Cow Dung (CD) for RS-CD 1:1 and RS-CD 1:2 ratios at 10% TS

Conclusion

This paper studied the effect of different total solid concentrations on biogas production from the anaerobic digestion of rice straw and cow dung. It showed that total solid concentrations of 10% TS gave better cumulative gas yields when compared to 5% TS and 15 % TS. These results showed that substrate blending and pH are important parameters that affect biogas yield in co-digestion experiments. The paper also investigated the supplementing of the substrate with an addition of urea and found that this leads to an increase of between 15%-19% biogas yield. The potential to use the enormous biomass waste available for biogas production cannot be overemphasized.

Declaration of conflicting interest

The authors declared no potential conflicts of interest.

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