Design of a two-phase digester system to optimize biogasification of rice straw

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Abstract
The two-phase bench scale digester system to optimize the biogasification process was successfully fabricated. The system comprised two main reactors, namely, hydrolysis (acidification) and methanation reactors. The reactor performance was evaluated in terms of its efficiency for biogas production using rice straw for about two months and it was found that biogas production increased by ~10% over the conventional dry batch reactor system. The maximum biogas production was 2.6 L/kg on the 30th day in the two-phase reactor system. Total gas production over 62 days was 81 L/kg and 74 L/kg, for two-phase reactor system and the dry batch reactor system, respectively. Further optimization of gas production in terms of gas quality (with increased methane) and quantity could easily be achieved by controlling the operating parameters of the system since the three processes involved in the anaerobic process are separated to two anaerobic chambers. The nutritive value of the digested material (anaerobically digested straw) was evaluated and N, P and K percentages were increased in digested straw. However, no significant increase in yield was observed in the field trial conducted with okra for the evaluation of digested material as organic manure.
Key Words: anaerobic digestion, two-phase digester, biogas, rice straw

Introduction

Anaerobic digestion is a microbial process which can degrade organic matter into simple organic compounds producing biogas, containing mainly methane, in the absence of oxygen. Since biogas contains methane it can be used as an energy source. Biogas, which can be easily produced by anaerobic digestion of organic wastes, i.e. kitchen wastes, agricultural waste, animal or human excreta etc., is a good alternative for energy requirements in household needs.

More than 70% of energy requirement in Sri Lanka is provided by biomass. Domestic energy consumption is more than 65% of the energy consumption in the country.[1] Food preparation consumes an enormous amount of energy which is obtained by the burning of biomass, which could lead to increased deforestation. At the same time, smoke produced in the burning of biomass in rural unventilated kitchens is responsible for respiratory problems, especially for housewives.

Straw has been shown as a good organic material for biogas production[2,3]. Dry batch digesters have shown its capability to produce biogas from rice straw which, in most cases, is burnt or applied directly to paddy fields as organic fertilizer. However, the direct application of rice straw into paddy fields is not an appropriate method since it influences the uncontrolled methane emission to the atmosphere.

Biogas is an outcome of anaerobic digestion of which there are basically three processes namely hydrolysis, acidification and methanation. In the case of dry batch biogas digesters, all these three processes occurred in one chamber. However, the separation of these three processes into different individual reactors can increase the overall efficiency of the anaerobic digestion process. The phase separation will probably increase the biogas production with higher methane content. Most of the farmers are

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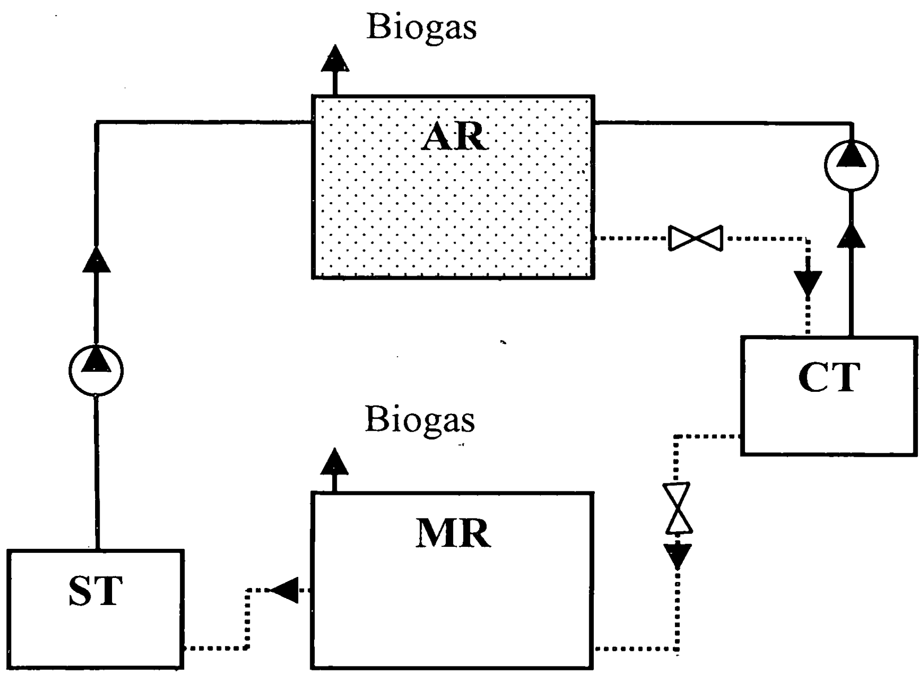
abandoning agriculture since it is no longer a profitable business. This is basically because of the higher cost of inputs such as agrochemicals and fertilizers. The digested material of anaerobic reactors is a good source of fertilizer and can easily replace the expensive, environmentally unfriendly chemical fertilizers. Thus, the input cost of farming can be reduced, in turn increasing the farmers' income. At the present time, more consumers are willing to buy food stuffs free from chemical residues. Therefore, the use of rice straw as a feeding material for biogas generators has added advantages over the direct application of rice straw into paddy fields.

The objectives of this study were to develop a two-phase digester system to maximize the biogas generation of rice straw, while minimizing the methane emission from rice fields, to cater to the energy needs of rural farmers and evaluate the digested material in terms of an organic fertilizer for low country vegetables.

Materials and methods

Digester design

A solid and liquid two-phase bench scale digester was designed and fabricated for the study. The main reactors were the acidification reactor in which hydrolysis and acidification processes of anaerobic digestion occur, and the methanogenic reactor in which leachate from the acidogenic reactor are further reduced to basically methane and carbon dioxide by the methanogenic process. The schematic diagram of the reactor system is shown in figure 1.



AR–Acidogenic Reactor; MR–Methanogenic Reactor; CT–Circulating Tank; ST–Stock Tank

Fig. 1 Schematic diagram of the two-phase reactor system

The acidogenic and methanogenic reactors were 500 L PVC tanks while the circulating and stock tanks were 25 L PVC buckets. All reactors and tanks were connected to each other with PVC pipes and special attention was given to avoid leakages.

Digester feeding

Straw was chopped (3-5 cm), weighted about 20kg, mixed with urea (adjust C:N ratio) and cow dung (as an inoculum) and fed to the acidogenic reactor. Total solid (TS) content of the acidification reactor was also adjusted to ~ 10% by the addition of the required amount of water. Proper C:N ratio is of paramount important for anaerobic digestion since it can affect the microbial metabolism. C: N ratio of 30-25:1 is considered to be an optimum ratio[4]. To keep the microorganisms in the methanogenic reactor, coir fiber was packed up to ¼ of its height. The coir fiber acted as a supportive material for microorganisms to attach themselves onto, and will prevent microorganism washout from the reactor.

Reactor operation

After 24 h, the liquid in the acidogenic reactor was circulated via the circulation tank and discharged to the methanogenic reactor. The liquid displaced by the methanogenic reactor was transferred to the stock tank from where it was pumped to the acidogenic reactor. The leachates in the methanogenic reactor were subjected to the methanation process by which basically, methane and carbon dioxide were produced, while microorganisms in the acidogenic reactor acted on rice straw and produced volatile fatty acids (VFA). Even though the main outcomes of the acidogenic reactor were VFA, a small amount of methane was also produced.

To compare the efficiency of the two-phase anaerobic reactor system, a conventional dry batch reactor was also constructed using a PVC 500 L tank and fed with 30 kg of chopped rice straw with urea and cow dung. The daily biogas production in both reactors was measured during the study period using the water displacement method.

Crop cultivation

The digested materials were applied as an organic fertilizer for okra, a low country vegetable crop. The four treatments, namely without fertilizer as a control (CON), only straw as fertilizer (ST), digested straw (DST), cow dung (CD), and biogas slurry (BS) obtained from a cow dung biogas digester, with five replicates were laid out. The randomized complete block design was used to evaluate the performance of different organic fertilizers. Plant height was measured at weekly intervals to assess the growth performance and final pod yield was also recorded.

Analytical methods

The methane content of biogas was determined by biogas meter (DRAGER Pac Ex Gas Detector, Germany). Nitrogen, phosphorus and potassium were analyzed by micro Kjeldhal and colorimetric methods[5]. The statistical analysis was performed using SAS V 8.1 software.

Results and discussion

Gas production in the two-phase and dry batch reactor systems

The biogas production in the two-phase reactor system (TPRS) and the dry batch reactor system (DBRS) were monitored for about 61 days and 81 days respectively (Fig. 2). The total gas production in TPRS was comparatively lower than the gas production in the dry batch system. This is basically due to the higher amount of straw (30 kg) fed to DBRS than TPRS (20 kg). The lag phase in TPRS and batch systems was about 6 days and 10 days, respectively. The reduction of the lag phase in TPRS is apparent and is an added advantage since it reduces the non biogas production period.

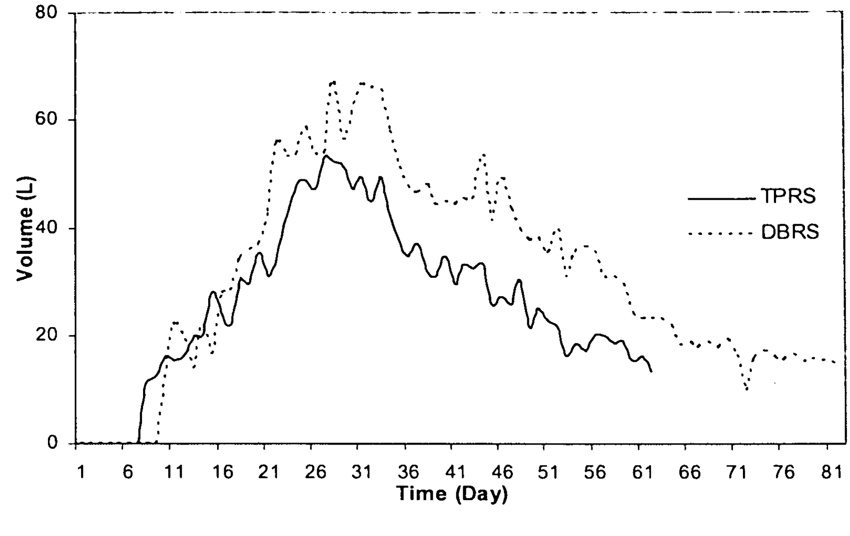


Fig. 2 Biogas production in TPRS and DBRS

The unit biogas production (biogas per one kilogram of straw) in TPRS is shown in Figure 3. It clearly shows a higher biogas production in TPRS over DBRS. The overall total biogas production in 62 days was 81 L/kg and 74 L/kg for TPRS and DBRS respectively. Therefore, it can be concluded that the biogas production can be increased through process optimization by separating the acidification and methanation processes into two chambers. The maximum biogas production in TPRS and DBRS were observed on 30th and 35th days, respectively.

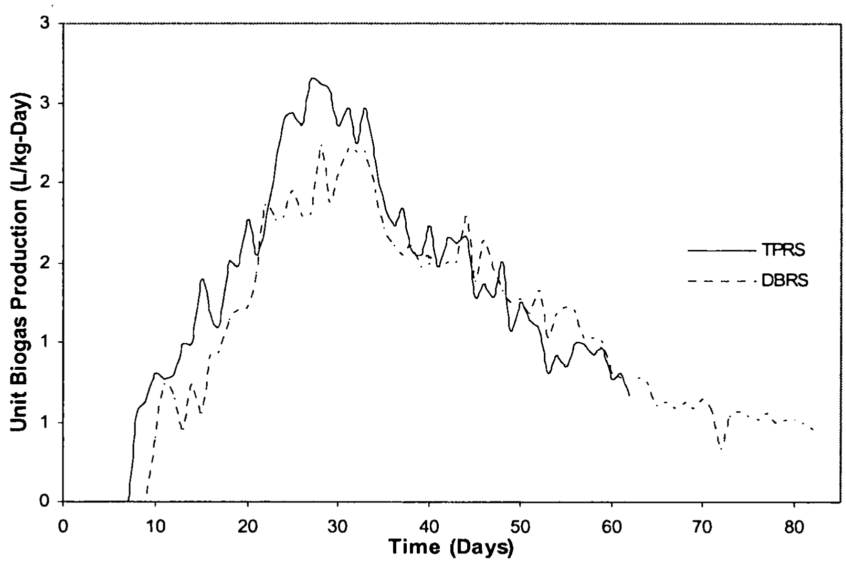


Fig. 3 Unit biogas production in TPRS and DBRS

Methane content of biogas

The methane content in biogas is very important since it decides the energy value. Normally methane content varies from 50% to 75%[6]. The methane content of biogas in DBRS was about 30% in the early stage of the study while it reached its maximum value of 75% at the later stage (~ 75 days). The active metabolism of methanogens resulted in an increase of methane content in the later stage of the study. Methanogens are responsible for converting VFA into methane. Initially, rice straw was subjected to the processes of hydrolysis and acidification, which produce VFA. Therefore, at the early stage of the experiment, no significant amount of VFA is available for the metabolic activity of methanogens, resulting in less methane content in biogas. However, the methane percentage of biogas produced from TPRS was almost constant (~ 65 %) during the entire study period. It reveals that all microbial processes were actively involved in the straw digestion process. Therefore, it appears that TPRS is more efficient in terms of production of quality biogas (higher in methane) than the conventional batch system which produces biogas containing less amount of methane.

Nutritive value of digested straw

The nutritive value of straw, digested straw, and biogas slurry were determined and are shown in Table 1.

Table 1. Nutritive value of different organic fertilizers

	N %	P %	K %	C %
Straw	0.69	0.09	0.61	46.80
Digested Straw	2.10	0.14	1.60	54.10
Slurry	0.48	0.14	0.16	5.90

Nitrogen, phosphorus and potassium contents of digested straw were higher than the other organic fertilizers used. The increased nitrogen content could basically be due to the addition of external nitrogen sources to straw for adjusting the CN ratio. However, the content of P and K has been increased by the anaerobic digestion. The reduction of carbon content in straw due to production of biogas (CH_4 and CO_2) comparatively increased phosphorus and potassium in digested straw.

Evaluation of digested straw as an organic fertilizer

The height of okra plants was recorded as a growth parameter and results of different growth stages are shown in Table 2.

Table 2. The effect of different organic fertilizers on Okra plant height and yield

Treatments	Plant height (cm)						Yield(Pods)
	1st wk	2nd wk	3rd wk	4th wk	5th wk	6th wk	
CON	15.4^{c}	18.6^{c}	21.8^{c}	25.2^{b}	33.4^{b}	34.8^{c}	19^{b}
ST	18.2^{bc}	22.8^{bc}	28.8^{bc}	32.8^{b}	42.8^{b}	49.2^{b}	46^{a}
DST	21.6^{ab}	26.6^{ab}	31.6^{b}	34.8^{b}	40.0^{b}	42.8^{bc}	35^{a}
CD	25.4^{a}	32.4^{a}	39.8^{a}	48.0^{a}	55.4^{a}	59.2^{a}	78^{a}
BS	18.4^{bc}	22.8^{bc}	27.2^{bc}	32.2^{b}	42.8^{b}	45.6^{b}	40^{a}
P-value >	0.002	0.0015	0.0017	0.0024	0.0017	0.0007	0.14

The values of the same letters in each column are not significantly different

It is apparent that the application of cow dung as an organic fertilizer has enhanced the growth of okra. However, in the first two weeks, the efficiency of digested straw and cow dung over the plant height of okra did not show any significant changes. At the later growth stages, cow dung has shown better performances with regard to plant height than other organic fertilizers. The pod yield was also recorded and no considerable increase was observed in all the treatments. Therefore, it is apparent that all the organic fertilizers have shown similar performances as organic fertilizers for okra.

It is reported that digested straw in dry batch biogas digesters have increased rice yield as much as twice over straw alone[7]. It is obvious that different crops show different results with regard to growth and yields, since nutrient types and amounts are different for different crops. Therefore, it is necessary to further investigate the application of digested straw for other crops too.

Conclusions

A two-phase solid and liquid phase anaerobic digester system was developed and evaluated for biogas production using rice straw. TPRS increased biogas production by ~10% over DBRS when rice straw is used as feeding material. Also, the methane content of biogas produced in TPRS was almost constant during the study period, while in DBRS it varied from 30% at the early stage to 75% at the later stage of the study. Based on the results obtained, it can be concluded that the performance with regard to the volume and quality of biogas in TPRS is comparatively better than that of DBRS. Even though the nutritive value of digested straw is higher than that of other organic fertilizers used, no significant increase in yield was observed in okra. The fertilizer value of digested straw was almost the same as other organic fertilizers used. Since the different crops need different amounts of nutrients for their growth and development, it is necessary to evaluate the other crops for growth and development with digested material such as organic fertilizers. Finally it can be concluded that TPRS can be used effectively to enhance the biogas production in terms of its volume and quality. However, before implementing the system to field level on a commercial scale, it is necessary to further evaluate the reactor at field level.

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