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EFFECT OF SINGLE AND MIXED INOCULUM ON BIOGAS YIELD DURING DRY ANAEROBIC DIGESTION OF ORGANIC MUNICIPAL SOLID WASTE

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Abstract

Organic municipal solid waste (OMSW) - a potential energy source - is creating serious environmental hazards across Bangladesh, but it can be digested for biogas production to meet the ever-increasing energy demand of the country. The present study applied the dry anaerobic digestion (DAD) process for biogas production from OMSW with inoculum cow manure (CM) and anaerobic sludge (AS) in single and mixed modes. The performance of the DAD process was evaluated in batch digesters with a multilayer inoculum flow pattern maintained at the constant mesophilic condition of 37 °C. Firstly, CM and AS were studied individually, and later on, both of them were used together in different ratios (AS:CM = 1:1, 1:2, 1:3, and 2:1) to maximize the biogas yield from the DAD process. CM alone produced a total of 2.91 ml biogas/ g of biomass over 35 days of DAD while this yield was increased to 3.19 ml/g for mixed inoculum at the ratio of 1:3. These results imply that mixed-mode inoculums would be a promising option in the DAD process for biogas production which will reduce both the energy scarcity and the burden of municipal solid waste (MSW) management.

***Keywords**: Municipal solid waste (MSW); Dry anaerobic digestion (DAD); Biogas; Mixed inoculum; Mesophilic condition*

1. Introduction

The energy crisis in a developing country like Bangladesh is worsening day by day due to limited energy sources and large population density. Situated in the north-eastern part of South Asia, Bangladesh is the world's most densely populated nation with a population of 160 million, and its population density is 1265 persons per square kilometers as of 2019 [1]. About 63% of this large population lives in rural areas [1].

Most of this rural population does not have access to the national grid for natural gas supply for their cooking. They mostly dependent different agricultural and forest–derived waste biomass such as rice straw, wheat straw, bagasse, timber, bark, and sawdust, for their cooking fuel; they directly burn those waste biomasses for energy generation for cooking and other household purposes. Improper burning of this biomass not only wastes heat energy but also produces a significant amount of greenhouse gas emission.

Total waste biomass consumption per year within the country for this purpose is about 39 million tons; about 50% of this comes from the agricultural residues [2]. Additionally, Bangladesh has relatively-small coverage of forest – about 15% of the total area of the country- and actual tree coverage recorded not more than 7 – 8%. But 90% of the total fuel-wood supply comes from the different homestead and conventional forests [3]. Thus, the heavy dependency of a large percentage of people only on biomass threatens Bangladesh both economically and environmentally.

On the contrary, a large amount of municipal solid waste (MSW) is generating every day across the country. It was reported that a total of 7690 tons MSW is generated daily at the six major cities of the country, namely, Dhaka, Chittagong, Khulna, Rajshahi, Barisal, and Sylhet, in 2005 which has been augmented to at least threefold in recent time due to rapid urbanization of the country [4]. The MSW generation reached 23,688 tons/day and average 0.56 kg/cap/day in 2014 [5]. This MSW is creating serious environmental hazards – occupying agricultural and habitable lands and polluting large water bodies – since it has been dumped to different landfilling areas illegally without proper planning. But this MSW has large energy potential since it contains about 75% of readily digestible organic waste. Therefore, if a large amount of MSW can be digested for bioenergy (biogas) generation effectively, in a way it will

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supply cooking fuel – biogas – as well as it will reduce the environmental concern raised from MSW.

Among different digestion processes, anaerobic digestion has been enlisted as one of the effective methods to stabilize the biodegradable components of organic waste solids and to produce renewable energy in the form of biogas [6]. Anaerobic digestion (AD) can be characterized as either wet (Wet–AD) or dry anaerobic digestion (DAD) depending on the moisture and total solids (TS) content; wet digestion typically is characterized by TS < 20%, semi-dry process with TS of 20%, and high solids or dry digestion with TS over 20%, also cited as solid-state AD [7]. Wet–AD has a lower operating efficiency but higher operating costs due to a large amount of moisture content of the waste. It also has problems related to handling large quantities of slurry, large digestion volume, and this process requires water greater or equal to the amount of biomass being processed during digestion [8].

Due to these limitations, recently researchers have focused on the DAD process for biogas production from MSW. It has lower water input, smaller digestion volume, and higher TS content in the digestate compared to Wet–AD [9]. Additionally, the DAD process does not present problems of foaming, sedimentation, surface crust, and does not require any size-reduction, removal of inert materials, and plastics [10]. In contrast, one of the disadvantages of the DAD process is the low yield of biogas compared to the Wet–AD process.

Therefore, in this study, the locally available low-cost but effective natural inoculum was used in the DAD process for biogas yield enhancement. The Cow manure (CM) and anaerobic sludge (AS) were used in single and mixed mode to find out the optimum inoculum for biogas yield maximization.

2. Materials and Methods

2.1. Biomass preparation

An extensive literature review shows that municipal solid waste generated across Bangladesh contains an average of 74.5% organic waste (Food and vegetable waste), 9.1% paper, 5.1% plastics/rubbers, 1.2% metals, 0.8% glass/ceramic and remaining 9.3% are other wastes; which includes dirt, fabrics, woods, bricks or stones, etc. [11]. In light of that waste percentage, a synthetic municipal solid waste was created for this study. Kitchen waste was used as the main source of the organic waste which was collected from the students' catering cafeteria and nearby teachers' residence of the Shahjalal University of Science and Technology (SUST), Sylhet, Bangladesh. For the inorganic waste, plastic bottles, PVC sheets, and papers were collected from the designated landfilling area of the Sylhet City Corporation. Later, those inorganic wastes were shredded into small pieces and mixed with the organic waste to create the synthetic substrate.

2.2. Inoculum Collection and preparation

Two types of inoculums were prepared for this study where AS and CM was used. The inoculum AS, also known as sewage sludge, is the organic deposit formed in waste water after degrading biologically in the absence of oxygen. AS was collected from sewage drains of the SUST campus and fresh CM was collected from a nearby cattle farm. Both the AS and CM were diluted to 200 ml water individually as the amount of each inoculum specified in Table 1.

2.3. Dry anaerobic digester setup

Laboratory scale digester was set up using a 5L transparent PET bottle as shown in Fig. 1. The top of the bottle was tightly sealed using an air-tight seal and a 0.2inch ID flexible plastic pipe was inserted at one port of the cap of the bottle to collect the produced biogas. Another port at the top of the bottle was used for nitrogen purging to create anaerobic conditions inside the digester. Biogas produced was measured using the "Liquid Displacement Method" [12], where two transparent PET bottles (2L) were used; one for the biogas collection and another one for water collection. Both of the bottles were connected to the digester using a flexible plastic pipe as shown in Fig. 1. The amount of water displaced in the water collector was used as the measurement of the amount of biogas produced due to anaerobic digestion of biomass (MSW) in the digester.

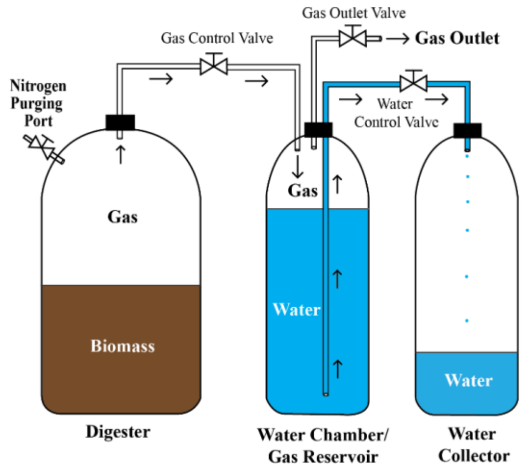

Fig. 1: Laboratory scale digester setup

2.4. Experimental Setup

The digesters were loaded with biomass in required quantity and then inoculums were sprayed in single and mixed-mode as described in Table 1. Additionally, 30 ml of 1.5% (w/w) NaOH solution was sprayed during the biomass loading to maintain the favorable pH and lower the retention time of anaerobic digestion [13].

After loading the biomass, inert nitrogen gas (N2) was purged inside the digester at a rate of 2.5 L/min for 1 min for creating an anaerobic digestion condition. Afterward all the openings of the digester were perfectly sealed and later digester was placed in a water bath maintained at optimum digestion temperature, 37 ºC. The digestion period was fixed at 35 days for all the experiments in this study.

Table 1

Design of anaerobic digestion process with single and mixed mode inoculation

Digestion Parameter	Inoculation Mode					
	CM	AS	AS:CM (1:1)	AS:CM (1:2)	AS:CM (1:3)	AS:CM (2:1)
Amount of Biomass (gm)	1200	1200	1200	1200	1200	1200
Amount of NaOH (mL)	30	30	30	30	30	30
Amount of inoculum (gm) in 200 mL water	100	100	50 gm AS + 50 gm CM	33 gm AS + 67 gm CM	25 gm AS + 75 gm CM	67 gm AS + 33 gm CM
Temperature (°C)	37	37	37	37	37	37

3. Result and Discussion

In all the experiments, the first 5 days' biogas production was excluded as it contained a higher percentage of nitrogen due to initial nitrogen purging for creating an anaerobic atmosphere within the dry fermenter. Additionally, lower biogas yield was reported for the first 5 days of anaerobic digestion due to the lag phase of microbial growth in this period. After this period, biogas yield increases substantially because of the exponential growth of methanogenic microbes [14].

3.1. Biogas yield at single and mixed inoculum

In this study CM and AS were used as inoculum in single and mixed-mode and later biogas yield was recorded in each mode of inoculum. It is seen that the biogas production rate peaked at the 10th day of digestion for each inoculum (Fig. 2); with the values of 350 ml/day, 300ml/day, and 140 ml/day for CM, AS, and CM plus AS mixer correspondingly. Afterward, for the next 5 days, the gas production rate was maintained between 100 and 250 ml/day for each mode of inoculation and a similar trend of biogas production was reported by several authors in the same period of anaerobic digestion [15].

Later, for the 15th to 30th day of digestion, the gas production rate was mostly consistent at 50 – 100 ml/day for each mode of inoculum.

This consistent gas production rate resulted from a stable digestion process when the process was not inhibited at all from 15th to 30th day [16].

After 30 days of digestion, the gas production rate was started to decreasing and finally reached 25 ml/day for both CM and AS while the mixture of CM and AS inoculum reached no biogas production. It is observed from (Fig. 3) that the highest cumulative biogas yield – 2.91 ml/g biomass, was obtained for the CM inoculum while the inoculum AS gave a cumulative biogas yield of 2.56 ml/g biomass over a period of 35 days digestion. When both the inoculums were mixed in 1:1 ratio the biogas yield was decreased significantly; results in a cumulative yield of 1.17 ml/g biomass.

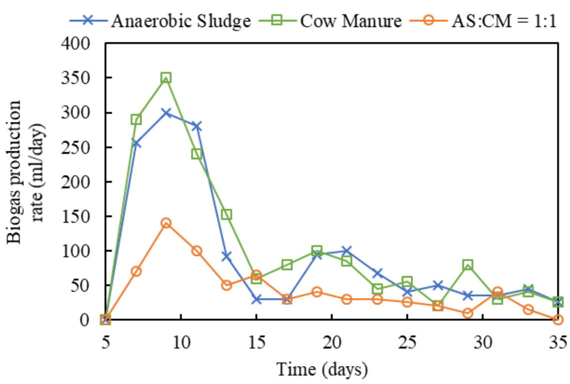

Fig. 2: Biogas production rate for single and mixed inoculum

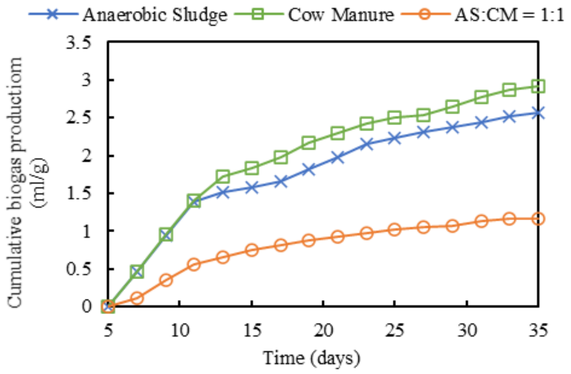

Fig. 3: Cumulative biogas production for single and mixed inoculum

3.2. Biogas yield at different ratio of single and mixed inoculum

In this study, biogas production was monitored for three different ratios of inoculums. Here, both AS and CM inoculums were mixed at 1:2, 1:3, and 2:1 ratio to see their effects on biogas yield.

In this study, the highest peak for biogas production rate was also recorded around the 10th day of the digestion at Fig. 4; with the highest value of 350ml/day for 1:2 inoculum mixer while the lowest biogas production rate was 200 ml/day for 2:1 inoculum mixer.

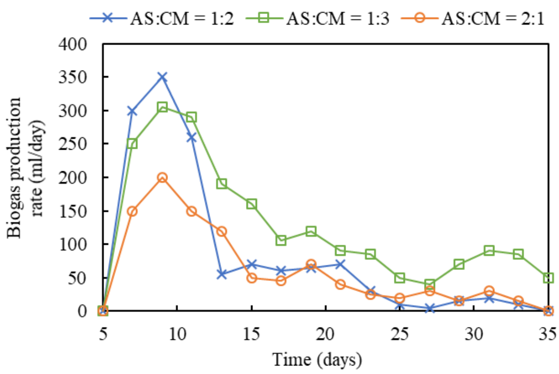

Fig. 4: Biogas production rate for different inoculum ratio

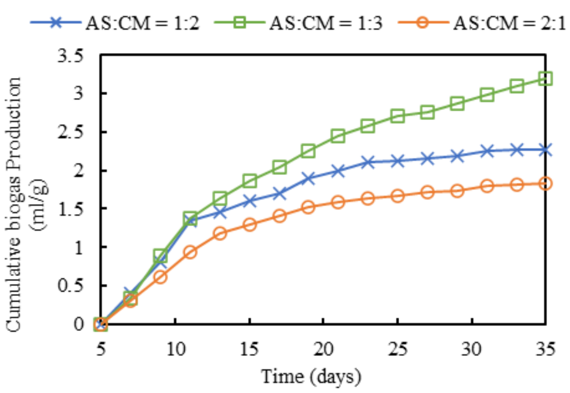

Fig. 5: Cumulative biogas production for different inoculum ratio

Interestingly, although at the 10th day of the digestion biogas production rate for the 1:3 inoculum mixer was 1.2 times lower than the 1:2 mixers, this ratio's subsequent gas production rate was always higher than the others mixture by an average value of 40 ml/day till the end of total digestion period.

This resulted in the highest cumulative biogas production for 1:3 inoculum mixer compared to other mixers in Fig. 5. At the end of the total 35 days of digestion period, the cumulative biogas production was 3.19 ml/g, 2.27 ml/g, and 1.83 ml/g of biomass for 1:3, 1:2, and 2:1 inoculum ratio accordingly.

Results obtained in this study have shown that with the increase of the percentage of CM in the inoculum mixture, both the biogas production rate and cumulative biogas production have increased significantly than the inoculums' single-mode use in anaerobic digestion. Mixed-mode inoculation enhances nutrient enrichment for anaerobic digestion results in higher biogas yield. Similar biogas yield augmentation was reported while mixed inoculum was used instead of mono-inoculum for anaerobic digestion by [17 -18].

4. Conclusion

Biogas yield was observed at mesophilic conditions (37°C) with CM and AS inoculums when both of them were added in single and mixed-mode. The experimental data showed that the highest biogas yield resulted when inoculums were mixed in a 1:3 ratios. It is also seen that CM inoculum alone did not produce a substantial amount of biogas but when it was mixed with AS yield of biogas was increased. Further studies can be performed for biogas yield enhancement by introducing new inoculums, varying both biomass and inoculums amount even biomass composition can be altered for higher biogas yield.

Acknowledgments

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