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SYNERGISTIC BIOGAS GENERATION FROM ALKALINE TREATED COTTONSEED HULL AND COW DUNG IN A MESOPHILIC BATCH REACTOR

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ABSTRACT

This work examines the production of biogas by the anaerobic co-digestion of cottonseed hull (CSH) treated with $\text{Ca}(\text{OH})_2$ and cow dung (CD) in a mesophilic condition with a 45-day hydraulic retention period in an atmospheric environment. In a batch reactor fashioned like a bottle, the anaerobic digestion of cow dung mixed with cottonseed hull that had been treated with $\text{Ca}(\text{OH})_2$ was studied. The entire biogas output generated is covered in depth once the numerical results are plotted against the hydraulic retention duration. The numerical results' validations have been compared to previously published research efforts reported in the literature, and the results show a high degree of agreement. The study demonstrates that the total amount of biogas produced in batch digesters operating in atmospheric circumstances exceeds the experimental output produced in a lab setting. The temperature swings between 30°C and 40°C during the testing time, which is a mesophilic environment. The use of pre-treated 25% cottonseed hull at 6% calcium hydroxide is said to be able to replace 25% of the cow dung consumption in the current biogas plant with additional biogas. The obtained biogas yield under atmospheric conditions is 15.75% higher than that of the laboratory study.



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I. INTRODUCTION

Given the expanding global population, rising energy consumption, and serious environmental effects of energy production, bioenergy is the most promising solution for supplying energy in the future in a sustainable manner. In many under developed nations, it meets the energy needs for cooking and space heating. Moreover, only a small percentage of the world's energy needs can be satisfied by biodegradable waste biomass, which represents a major energy deficit. Biodegradable waste biomass will be essential in clearing the global backlog of bioenergy from fossil fuels to renewable energy [1],[2]. Pollution from agricultural waste has become a global concern. Putting in place a compensation plan to incentivise individuals to recycle agricultural waste is a practical solution to this issue. AD is a biochemical method that is frequently used to process different biomasses, particularly agricultural and agro-industrial wastes, to recover energy [3]. The process of anaerobic digestion has been studied in great detail as a means of producing biogas from lignocellulosic material, such as agricultural leftovers. Choosing the right pre-treatment technique is essential to increasing the amount of biogas produced during the anaerobic digestion of agricultural waste [4].

Anaerobic digestion is a widely known waste treatment method that allows for both pollution reduction and energy retrieval. Anaerobic digestion is a suitable process for many types of agricultural and industrial waste due to the high concentrations of biodegradable elements they contain. The performance of the batch anaerobic digestion process can be improved through animal wastes especially cow dung [5]. The increase/decrease in temperature inside the anaerobic digester may result in a decrease/increase in the biogas production where the cattle manure is used as feedstock [6]. Microbes are affected by temperature fluctuation inside the digester, which in turn, reduces the biogas yield [7]. Proteins, lipids, fats, carbohydrates (hemicellulose and cellulose), and various particulate and fibrous components, as well as soluble ones, make up cow dung. Biodegradable lignocellulosic biomass accounts for forty to fifty percent of the volatile solids in dairy manure; this biomass can be converted into methane. The lignin content of CD causes mono-digestion to give less biogas than the theoretical yield. Increasing the biogas yield from CD mixed with other biodegradable materials was best accomplished through anaerobic co-digestion, which also aided to balance the CN ratio improve the process efficiency [8]. Using a batch digester mixture consisting of 85% cow slurry, 10% olive pomace, and 5% apple pulp, with a hydraulic retention duration of 40 days, a consistent biogas output of around 400 l/kg was achieved.

Discreet Substances [9]. Previous studies have shown that a pH range of 6.5 to 7.5 is optimal for biogas production [10]. India is the world's largest cotton grower and ranks second, producing around 6,162,000 tons each year and major residues were left in the agricultural land. Anaerobic co-digestion has developed as an efficient process with the potential to address issues such as nutrient imbalance among feedstock materials, quick acidification, and the deposition of inhibitory compounds, which resulted in biogas improvement using anaerobes [11]. The anaerobic co-digestion of crop straw and animal waste is becoming more popular as a source of biogas and green energy, as well to reduce pollution [12]. Most of the researchers performed anaerobic digestion process on different feedstocks such as cow dung + horse dung, agricultural biomass residues, cow dung, coffee-pulp + cow-dung, cow dung + food waste [13]. Despite these studies, only a few studies investigated the anaerobic digestion of cottonseed hull in the presence of a basal medium in a batch digester to produce biogas. Changing the temperature of the digesters has a big effect on how fast biogas are made. Three distinct temperature ranges are used for the anaerobic digestion process: thermophilic, mesophilic, and psychrophilic were (50–60°C), (30–40°C) and (15–20°C) respectively. The rate at which chemical reactions accelerate in response to temperature increases governs the biological breakdown and conversion process [14].

There shouldn't be any sudden temperature changes throughout the digestive process because methanogenic bacteria are temperature sensitive. A quick temperature change will hinder the methanogenic bacteria and reduce the amount of methane produced. According to research, the range of 30 to 40 °C is ideal for the methanogen development rate during anaerobic digestion [15]. Methanogenic bacteria are abundant in CD, but the organic compounds needed for bacterial growth and methane production—such as lignin, cellulose, and hemicelluloses—are present in low amounts. Alternatively, CSH has more cellulose, hemicelluloses, and lignin than other sources, but it doesn't have a big enough bacterial population to decompose the harmful substances and produce biogas. These realities led us to believe that combining CD and CSH would result in a synergistic effect toward increased biogas production. Chemical pretreatment procedures, which are more popular than physical or biological pretreatment methods, make it easier for agricultural waste to break down naturally [16]. It was found that alkaline pretreatment of lignocellulose materials was superior to acidic pretreatment in terms of improving biodegradability and increasing biogas generation by breaking the ester bond that holds lignin, hemicellulose and cellulose together. According to earlier studies, biogas yield is increased when $\text{Ca}(\text{OH})_2$ is treated with larger concentrations of lignocellulosic materials [17],[18].

Anaerobic digestion of corn stover that had been microbiologically processed and combined with cow dung produced the most amount of biogas when compared to untreated, untreated plus cow dung, and untreated alone. It was also greater than cow dung alone, according to earlier studies. Various combinations of CSH and CD were anaerobic co-digestion of experimentally investigated in an incubator maintained at 35 ± 2 °C were 100% CD, 100% CSH, 50% CD + 50% CSH, 75% CD + 25% CD + 25% CSH, and 25% CD + 75% CSH, respectively. The combination of 75% CD + 25% maximal biogas output of CSH was 86 ml/g. Kinetic research used a variety of kinetic models, including the Fitzhugh model, logistic kinetic equation, Gompertz model, and cone model, to disclose all the combinations. The most biogas were produced when $\text{Ca}(\text{OH})_2$ was 6% preserved with 75% CD and 25% CSH according to a previous study [19]. The current go bar gas facility can be mono digestion of CD in replaced by chemically treated 25% CSH through the CSH treated $\text{Ca}(\text{OH})_2$ at 6%. This study's primary goal is to examine the effects of anaerobic co-digestion $\text{Ca}(\text{OH})_2$ of 6% preserved 25% CSH + 75% CD under ambient conditions while taking daily radiation and temperature into account.

II.THEORETICAL REFERENCE

II.1 MATERIALS AND METHODS

II.1.1 Feedstocks and Experimentation

Cow dung and cottonseed hull were collected at nearby fields of Karur, India. Inoculum was collected in the same location, where cow dung was used as the primary substrate at small household gobar gas plants' substrates were air dried, shredded and pre-treated with $\text{Ca}(\text{OH})_2$ as per the previous literature [20],[21]. As shown in Figures 1 and 2, the experiment is conducted in 1000 ml bottles sealed with a rubber stopper and attached to a control valve to create a tight, air-free environment, or an anaerobic environment. Once the valve was opened, biogas from the digester was directed through a rubber tube to the inverted measurement cylinder. We compute biogas yield with the water displacement method. Subtract the average biogas yield from the digesters from the average biogas yield from the inoculum to determine the biogas yield. A floating measuring cylinder in a beaker is supported by a retort stand. To get a 1.5 gm of final blend VS per litre, once 600 ml of inoculum has been put to each container, the excess volume is flushed with nitrogen and substrates are added. For the 75:25 ratio of CD to 6% $\text{Ca}(\text{OH})_2$ treated CSH, this experiment is repeated twice.

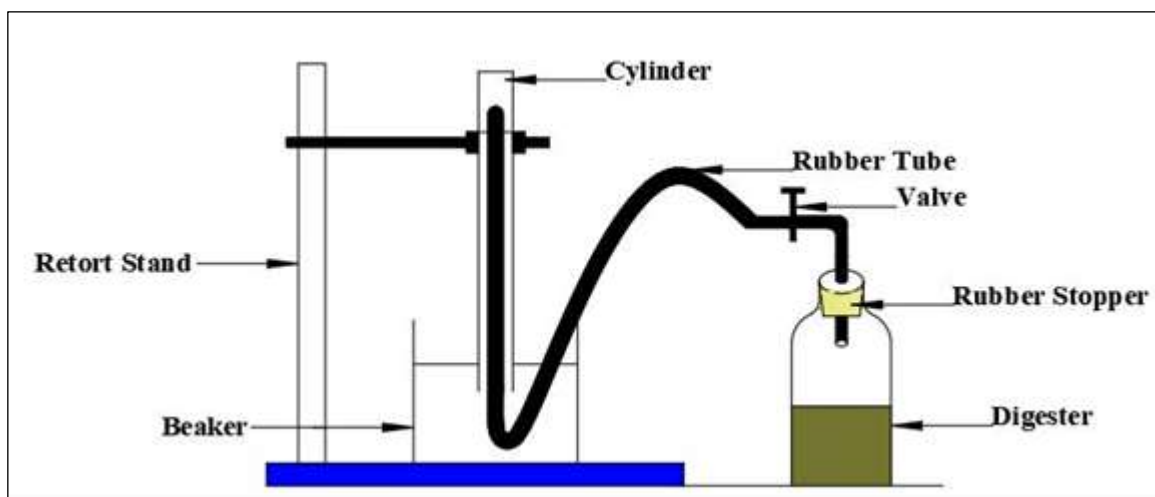


Figure 1: Line diagram for the experimentation.
Source: Authors, (2026).

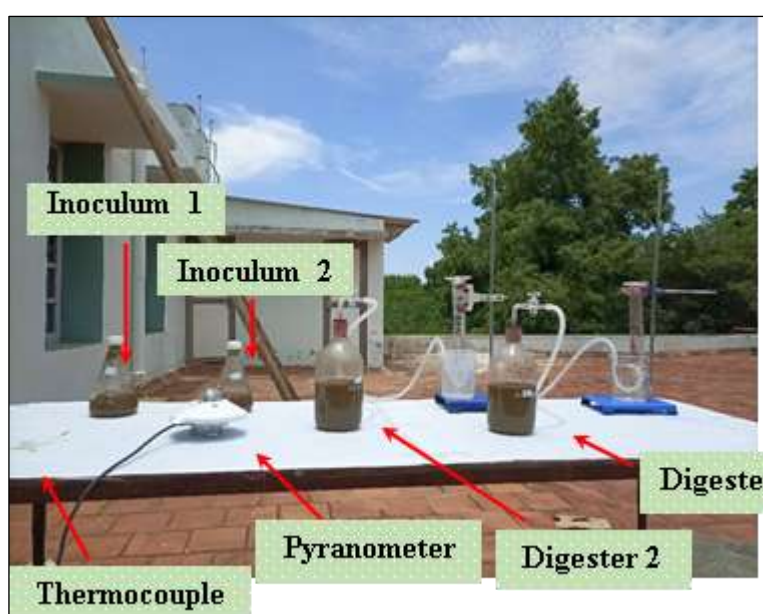


Figure 2: Experimental setup for the BMP test.
Source: Authors, (2026).

II.1.2 Analytical Methods

Total solids (TS), volatile solids (VS), carbon-to-nitrogen ratio, pH analyses were used to evaluate the physicochemical properties of CD, CSH, and inoculum. The sample must be dried in an oven set at 105°C for four hours before being analysed for TS. The sample was placed in desiccators to cool at room temperature after 4 hours of drying. For the TS calculation, the sample weight difference was measured. The mass of the sample that remained after the dried sample was heated at 550°C for 4 hours served as the indicator for the volatile solids [22]. The C/N ratio was calculated based on the values obtained from the Vario EL III Germany Elemental analyser. pH meter readings are taken from the slurries. The biogas concentration in each bottle is determined by dissolving the gas in water.

III. RESULTS AND DISCUSSION

III.1.1 Feedstock Characteristics

Maximum total solid is found for CSH, i.e. 90% as compared to CD, i.e. 14%. Similarly, the volatile solid content of CSH, i.e. 90% was higher as compared to CD, i.e. 68%. The C/N ratio of CD i.e. 32.76, is lower than CSH, i.e. 36.38. The C/N ratio, which must range between 10 and 40, provides the nutrients needed for the processes of acidogenesis and hydrolysis [23]. The pH of the medium (75% CD + 25% Ca(OH)₂ treated CSH) is found between 7.11 to 7.31 during anaerobic digestion [24],[25]. The optimal pH range for the AD process was reported to be 6.8 to 7.4. The rate of microbial development is greatly impacted by pH fluctuations [26].

III.1.2 Feedstock Characteristics

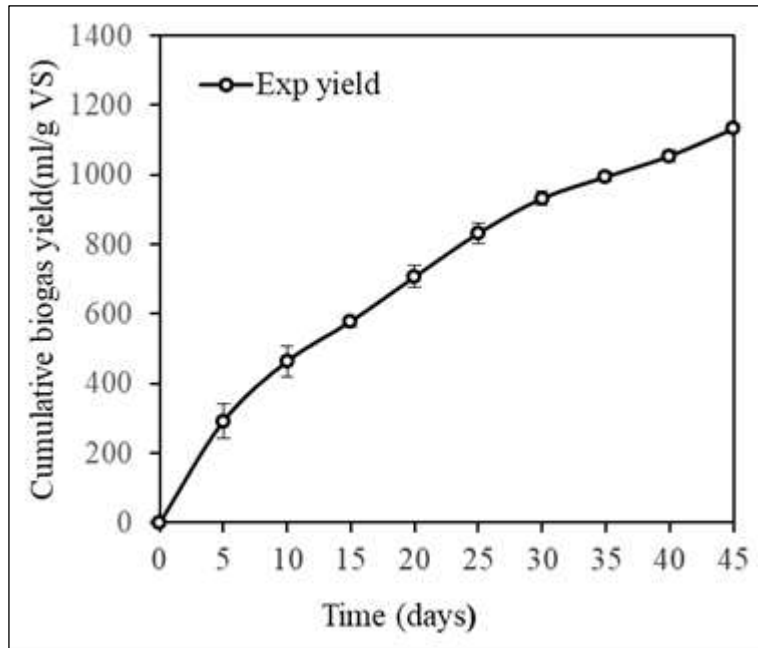


Figure 3: overall production of biogas from the reactor.
Source: Authors, (2026).

Figure 3 depicts cumulative biogas production (CBP), while results of anaerobic co-digestion of 75% CD with $\text{Ca}(\text{OH})_2$ -6% concentrated and 25% CSH are shown in Figure 4, along with the average daily biogas generation. The following are the changes in parameters observed between August and September 2021: Temperatures range from 30 to 40°C, with standard deviations ranging from 0.07 to 2.83. The average temperature and radiation are all around 35 °C (Mesophilic), and 747 W/m², respectively. The parameters that influence daily biogas production from the reactor are listed in Table 1. BMP test indicates that the reactor produces around 1132 ml/g VS of biogás [27].

This result is more in line with a previous study of around 978 ml/g Vs, in which the reactor was kept at a temperature of $35 \pm 2^\circ\text{C}$ [28]. Between the experiments conducted in the batch digester at atmospheric and laboratory environments, the biogas yield differed by 154 ml/g [29],[30]. The obtained biogas yield at atmospheric condition is 15.75 % more than that of laboratory study In comparison to the previous study without doing any pre-treatment, the obtained biogas yield is 3 times greater than CD alone, 17 times greater than CSH alone, 15 times greater than 50% CD + 50% CSH, 7 times greater than 75% CD + 25% CSH, and 25 times greater than 25% CD + 75% CSH [31],[32].

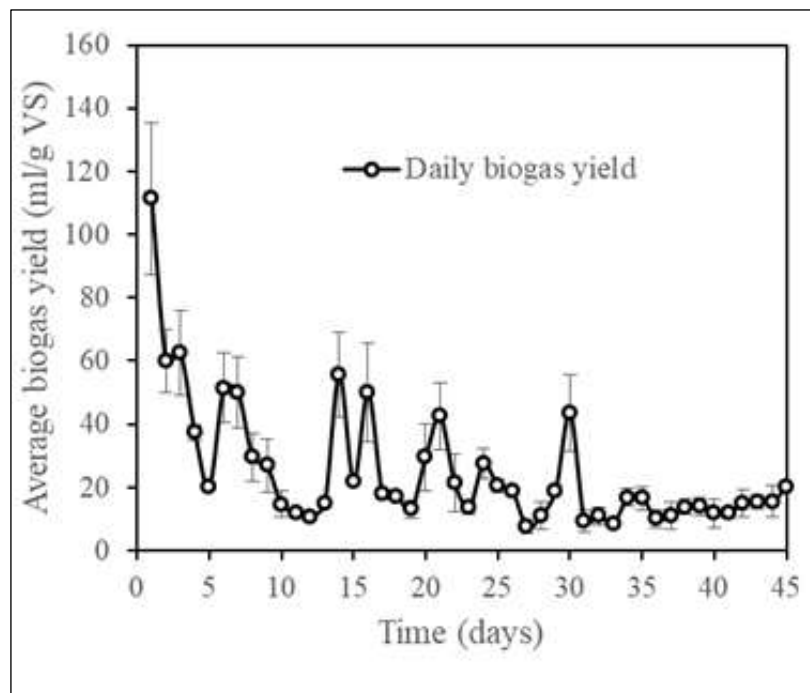


Figure 4: Average daily biogas production from the reactor.
Source: Authors, (2026).

Table 1: Parameters influencing the daily biogas Generation.

Days	Temperature (°C)	Solar radiation (W/m ²)	Yield of Biogas (ml/g VS)	Overall yield of biogas (ml/g VS)
1	32.7	754	111.5	111.5
2	32.1	748	60	171.5
3	36.3	773	62.5	234
4	33.55	794	37.25	271.25
5	34.65	769	20.25	291.5
6	36.3	752	51.45	342.95
7	37.4	712	50	392.95
8	34	783	29.45	422.4
9	33	711	26.9	449.3
10	33.65	754	14.65	463.95
11	29.45	721	11.9	475.85
12	30.65	758	10.5	486.35
13	29.8	756	15	501.35
14	34.5	713	55.5	556.85
15	40.05	791	22	578.85
16	36.15	738	50	628.85
17	35.45	739	18	646.85
18	35.65	744	17.25	664.1
19	33.9	704	13	677.1
20	36.15	740	29.5	706.6
21	36.8	711	42.5	749.1
22	34.2	703	21.5	770.6
23	34.1	775	13.5	784.1
24	34.05	782	27.4	811.5
25	34.45	758	20.45	831.95
26	33.3	741	18.85	850.8
27	33.7	725	7.5	858.3
28	31.8	771	11	869.3
29	34	781	19	888.3
30	36.8	741	43.5	931.8
31	34.95	771	9.35	941.15
32	35	734	11	952.15
33	34.9	726	8.5	960.65
34	34.85	793	16.75	977.4
35	36.8	711	16.5	993.9
36	34.65	734	10	1003.9
37	35.8	711	11	1014.9
38	37	722	13.75	1028.65
39	35.75	800	14	1042.65
40	35.3	768	11.75	1054.4
41	33.75	774	11.75	1066.15
42	35.1	703	15	1081.15
43	37	768	15.5	1096.65
44	37.15	799	15.5	1112.15
45	35.2	707	20	1132.15

Source: Authors, (2026).

A higher amount of biogas output of 291.5 ml/g VS was seen over the first five days, while an average cumulative production of 128.1 ml/g VS was seen between days 6 and 30. The average lowest cumulative biogas generation, measuring 66.8 ml/g VS between 31 and 45 days, was found. The temperature fluctuates between $35 \pm 2^\circ\text{C}$ at an average retention time of five consecutive days, the mesophilic bacteria produced the greatest biogas production. Based on the cumulative biogas generation obtained at a retention period of 45 days, it is concluded that, in contrast to earlier lab-scale studies, the effects of radiation on anaerobic digestion are negligible.

IV. CONCLUSION

Cow dung and $\text{Ca}(\text{OH})_2$ treated cottonseed hull were co-digested at a ratio of 75:25, resulting in significant biogas output. The application of pre-treated 25% cottonseed hull with 6% calcium hydroxide is purported to substitute 25% of the cow manure utilized in the existing biogas facility, resulting in increased biogas production.

Compared to cottonseed hull that has not been chemically pre-treated, treated cottonseed hull produces more biogas with a shorter digestion period. The biogas output varied by 154 ml/g VS between studies carried out in batch digesters at ambient and laboratory conditions for the hydraulic retention time of 45 days.

IV.1 DECLARATIONS

This study was conducted without any external funding support and the authors no conflicts of interest.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Venkateshkumar R.

Methodology: Musthafa B.

Investigation: Veera Subhash Geddiam.

Discussion of results: Nandhakumar R.

Writing – Original Draft: Venkateshkumar R, Musthafa B.

Writing – Review and Editing: Srinivasan S, Nandhakumar R.

Resources: Veera Subhash Geddiam.

Supervision: Venkatesan

Approval of the final text: Venkateshkumar R, Nandhakumar R, Veera Subhash Geddiam, Venkatesan, Musthafa B and Srinivasan S A.

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