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Evaluation and comparison of biogas production potential of two types of full-scale biogas plants utilising cow dung as feedstock

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Abstract
The purpose of the current study was to compare the effectiveness of two innovative full-scale biogas digester designs, horizontal and up-flow anaerobic sludge blanket reactors in producing biogas from cow dung throughout the course of two seasons, particularly summer and monsoon. The horizontal flow digester (35 d) had the greatest hydraulic retention time (HRT), whereas the up-flow sludge blanket reactor had the shortest HRT (25 d). According to the results, the up-flow anaerobic sludge blanket reactor digester produced the most biogas when compared to another digester. The up-flow sludge blanket reactor produced the most biogas (61.05±0.45 m^3) in the summer. The horizontal flow type reactor produced the least biogas (5.07±0.12 m^3) during the monsoon, and there was a significant difference between the digesters. Summer was the season with the highest methane production (60.50 percent), which was substantially different from the other seasons, and the lowest concentration was generated by the horizontal flow type biogas digester (55.28 percent). The methane proportion was higher than during the monsoon and summer had the lowest carbon dioxide levels. The pH of the substrate varied considerably ($p<0.01$) during the summer and monsoon seasons, measuring 7.35±0.09 and 6.35±0.09 percent, respectively. In two seasons, sludge had a lower crude fibre value than the substrate, and the up-flow sludge blanket reactor had the lowest value (15.74±0.16). The amount of phosphorus in the substrate was determined to be 0.70±0.01 and 0.69±0.00 percent during the summer and monsoon seasons, respectively. For all two digesters in all two seasons, the phosphorus content of the sludge was greater than the substrate, with the up-flow sludge blanket reactor having the highest levels (1.96±0.01). In all seasons for the two digesters, the volatile solid content of the sludge was lower than that of the substrate. Biogas production is greatly influenced by temperature, and in high altitudes when temperatures are low, external heating can be used to increase output.

Keywords: Biogas, biogas plants, substrate, season, biogas composition, pH, methane

1. Introduction
The most critical challenge of our day is climate change. It puts at risk rural communities in underdeveloped countries, whose existence depends heavily on natural resources. The sustainability of the livestock industry, species viability, and ecosystem health are all impacted by the long-term effects of climate change (Chaidanya K and Sejian V, 2015) [4] emphasising the enormous contribution of fossil fuel emissions as a major factor in global warming. Sources confirm that emissions from fossil fuels are a major cause of climate change, making this a worldwide problem. This demonstrates the important part that pollution from fossil fuels plays as a major contributor to global warming. Sources confirm that emissions from fossil fuels are a major cause of climate change, making this a worldwide problem (Soeder D.J. and Soeder D.J., 2021) [29]. In addition to environmental issues, overuse of petroleum-based fuels also causes resource depletion and growing costs. The effects of environmental pollution are especially pertinent in the context of India, which depends largely on fossil fuels for its energy requirements. Recent publications highlight the fact that coal and natural gas are important sources of carbon emissions in the United States, and to some extent, India holds the same challenge (Perera F, 2018) [20]. In order to solve this, there is increased interest in renewable energy sources like biogas, which is produced by anaerobic digestion of organic waste. Given the huge agricultural sector and an abundance of organic waste materials, India has a significant potential for producing biogas. Given the various agro-climatic conditions around the nation, research and development in this sector are in need of attention.

Finding appropriate substrates, fermenters, and operating systems is crucial for ensuring sustained biogas generation in India, according to recent publications (Holechek *et al.*, 2022) [9]. In short, the switch to cleaner energy sources, like biogas, is a worldwide necessity, but India's significance and potential make that country a key hub for sustainable energy production and minimising the negative effects of fossil fuel pollution on both a national and international level.

2. Materials and Methods

2.1. Experimental Location

The research was performed in the School of Bio-energy and Farm Waste Management, Kerala Veterinary and Animal Sciences University's Biogas Research Laboratory at Pookode, Wayanad, which is 867 metres above mean sea level and located at 11°32′18.5" North Longitude and 11°32′18.5" East Latitude. High levels of humidity in the area produce heavy rain and generate more pronounced fluctuations in temperature throughout the course of the year. The ambient temperature ranged from 21.26 °C to 25.16 °C, with an average of 23.83 °C over the summer. Throughout the monsoon, the average atmospheric temperature was 21.16 °C, with temperature variations between 20.07 °C and 24.28 °C. The RH percentage was high as a result of the monsoon's significant precipitation. The greatest mean RH measured throughout the monsoon was 88.40 percent. Over the course of the summer, an average relative humidity (RH) measurement of 92.09 percent was observed. The mean RH value was 82.40 percent in the summer, which was the lowest season.

2.2. Experimental digester design

Both digesters were made of fiberglass, had a 1 m^3 capacity, and had various forms. The top and bottom of the tank served as baffles to divide the three identically sized compartments that made up the entire horizontal flow biogas plant. In the horizontal flow biogas plant, the slurry alternately flowed up and down between the walls. In the horizontal flow biogas plant, the slurry alternately flowed upward and downward between the walls. A high-rate suspended anaerobic reactor with a sludge bed, a sludge blanket, a settling area, and a gas-liquid separator system is known as an up-flow anaerobic sludge blanket reactor (UASB). The UASB reactor utilises an upward flow rather than the usual horizontal flow. This method of operation improves the interface between anaerobic deposited sludge and influent wastewater, which in turn makes it easier to remove suspended solids because the sludge blanket traps solid and dissolved anaerobically biodegradable organic particles. This method of operation promotes the interaction between anaerobic accumulated sludge and influent substrate, which in turn enhances the removal of suspended particulates because the sludge blanket could trap both solid and dissolved anaerobically biodegradable organic particles. Gaseous wastes from the anaerobic digestion process going upward create enough turbulence to maintain the fluidity of the reactor's contents (Zeeman and Lettinga, 1999) [7].

2.3. Experimental Period

The study was carried out in both the summer and monsoon seasons, from March 2023 to August 2023. According to the study utilised the Wayanad climatic categorization suggested by (Jyothi *et al.*, 2017) [10].

2.4. Substrate for digesters

Each season of the experiment lasted for 40 days. The two different types of biogas digesters considered as treatments were combined to create a horizontal flow type biogas plant (T_1) and an up-flow anaerobic sludge blanket reactor (T_2) biogas plant. Every morning during the experiment, 30 L of a 15 Kg mixture of fresh cow dung and water was mixed with a 1:1 ratio added to the T_1 and T_2. Following a two-week adaptation period, daily measurements of the biogas production were taken. The multi-gas analyser (Pallan *et al.*, 2021) [19] was used to conduct weekly analyses of the biogas composition.

2.5. Analytical methods

The automated weather station at the College of Veterinary and Animal Sciences, Pookode, provided the climatic characteristics. A EUROLAB multi-thermometer was used each day at nine in the morning before loading to measure the substrate's temperature (Model No. ST-9269B). Daily, at nine o'clock in the morning, before loading, the substrate's pH was measured using the Eutech digital pH tutor instrument (Serial No.2258061). Fresh samples of the substrate were taken before the experiment began, and they were examined for moisture content as well as volatile and non-volatile solid components. According to A.O.A.C. (2012) [1], the analysis was conducted on a dry matter (DM) basis. The duration of a volume of substrate introduced to a digester before it is expelled as sludge is known as the hydraulic retention time (HRT). It was computed as the digester's volume divided by the amount of substrate fed each day, and the result was recorded in days (Nijaguna, 2012) [17]. It was computed as the digester's volume divided by the amount of substrate fed each day, and the result was recorded in days (Nijaguna, 2016) [17]. Each day in the morning, the amount of gas generated by each treatment was measured (9 A.M.). A SMART BIOGAS Meter (v1.0.6-125-0522-0378, Device ID: yro6rE) from Inclusive Energy Ltd. was used to calculate the volume of biogas generated. An electronic multi-gas analyser (PGA100, Precision Analysing Enterprises Ltd.), which analysed and reported the percentages of methane, carbon dioxide, and other gases, was used to analyse the composition of biogas on a weekly basis.

3. Results and Discussion

3.1 Climatological data

In Pookode, which is situated at a height of 867 meters above mean sea level, the mean ambient temperature was low in the monsoon (20.07 °C to 24.28 °C). In contrast to the summer, when it was between 21.26 °C and 25.16 °C. High-density monsoon clouds may be the primary cause of the decline in air temperature, reports Smitha (2010) [28]. Danesh and Pavan (2011) [5], who examined the climatic changes in Wayanad, discovered similar trends. Climate trends at Pookode were similar according to Jyothi (2017) [10] and Shradha (2020) [34]. A high mean RH of 81.30 to 92.09 percent was observed at Pookode during monsoon season. The RH fluctuated from 60.04 and 98.10 percent in the monsoon and between 81.30 and 92.09 percent in the summer. Similar observations were made by Jyothi (2017) [10]. The outcomes are consistent with Shradha's estimates (2020) [34]. In Pookode, which is situated at a height of 867 metres above mean sea level, the mean ambient temperature was low in the monsoon (19.36 °C to 22.83 °C). In contrast to the summer, when it was between 21.26 °C and 25.16 °C, the average atmospheric temperature during the monsoon season varied from 20.07 °C to 24.28 °C. High-density monsoon clouds may be the primary cause of the decline in air temperature, reports Smitha (2010) [28]. A high percentage of relative humidity is produced during the monsoon season by the southwest monsoon's heavy precipitation. Values are depicted in Table 1.

Table 1: Mean Temperature (°C) and Relative Humidity (%) of Pookode

Seasons	Temperature (°C)	Relative Humidity (%)
Summer season	23.83	82.40
Monsoon season	22.16	92.09

3.2 Physico-chemical analysis of substrate

According to A.O.A.C. procedures (2012) [1], the substrate's physico-chemical properties are examined on a dry matter basis. The substrate's dry matter (DM) concentration was highest during the monsoon season (18.5±0.5 percent) and lowest during the summer (18±1.0 0 percent). The moisture and DM content of the substrate was influenced by a number of variables, such as the environment, season (atmospheric temperature and relative humidity), moisture content of feeds and fodder, water intake, and physiological water conservation. This disparity could happen as a result of the various feeding and watering regimens and seasons. The highest volatile solid concentration was found during the monsoon season (83.01±0.05), followed by the summer season (82.26±0.05). While volatile solids go through digestion during the anaerobic fermentation process, non-volatile components are not impacted by it (Khoiyangbam *et al.*, 2015) [13]. Jyothi made similar observations (2017) [10]. In the summer and monsoon seasons, cow dung contained 17.73±0.42 and 16.99±0.27 percent non-volatile solids, respectively.

In the summer, cow dung typically has a pH of 7.35±0.02 and a pH of 6.35±0.02 during the monsoon. The cow dung from the two seasons differed significantly ($p<0.01$) in every measure. Cow dung showed a similar pH trend, according to Shejir (2014) [26]. Saedi *et al.* (2008) [24] and Anzar (2014) [2] found that the ideal pH range for mesophilic digestion was between 6.5 and 8.0. They observed that the pH drops to 6.2 when anaerobic digestion begins. After 10 days of digestion, the pH began to rise and ultimately stabilised between 7.0 and 8.0. Khoiyangbam *et al.* (2015) [13] found that the optimal pH range for anaerobic fermentation was between 6.8 and 8.0, and that successful digestion occurred nearly at neutral pH.

Cow dung had a crude protein value of 17.09±0.88 percent during the monsoon season and 15.80±0.14 percent during the summer. Our findings concurred with those of Saxena *et al.* (1989) [22]. He stated that many factors, such as the feed of the cows, might affect the crude protein level of cow dung. Cow dung from cattle fed a high-concentrate diet may contain more crude protein as compared to cows on a low-concentrate or all-roughage ration.

When the substrate was analysed, it had crude fibre concentrations in the summer and monsoon seasons of 16.69±0.67 and 16.62±0.50 percent, respectively. Shejir's experiment revealed that the substrate's crude fibre value was lower (2014) [26]. The variation in feeding and watering schedules and seasons may be responsible.

Cow dung in the summer and monsoon seasons had an ether extract concentration of 2.02±0.04 and 2.01±0.08 percent, respectively. The findings of Saxena *et al.* (1989) [22] agreed with our findings. The ether extract values of cow dung were greater than our findings, according to Udebuani *et al.* (2018) [31].

Cow dung samples examined during the summer and monsoon seasons had phosphorus contents of 0.70±0.01 and 0.69±0.00 percent, respectively. According to Shejir (2014) [26], the value was greater than what we discovered. The seasonal variations in feeding and drinking regimens may be too significant. Values are depicted in Tables 2 and 3.

Table 2: Physico-chemical characteristics of the substrate

Cow dung	Summer	Monsoon	p-value
pH	7.35±0.018	6.35±0.09	<0.001**
Moisture (%)	82.0±1.0	81.5±0.50	<0.001**
Dry matter (%)	18.0±1.0	18.50±0.50	<0.001**
Volatile solid content (%)	82.27±0.01	83.02±0.01	<0.001**
Non-volatile solid content (%)	17.73±0.42	16.99±0.27	<0.001**

Mean with significantly at 1% level (**)

Table 3: Physico-chemical characteristics of the substrate – Proximate analysis

Cow dung	Summer	Monsoon
Crude protein	15.79±0.13	17.08±0.87
Crude fibre	16.68±0.66	16.61±0.49
Ether extract	2.02±0.04	2.01±0.08
Phosphorus	0.7±0.01	0.69±0.00
Total ash	82.26±0.05	83.01±0.05

3.3. Analysis of sludge

3.3.1. Physico-chemical characteristics of the sludge

On a dry matter basis, the physico-chemical characteristics of the sludge were analysed.

The moisture content of sludge from the horizontal flow type, up flow sludge blanket reactor, in the summer season was 78.5±3.5 and 80.5±0.5 percent respectively. The moisture content of sludge from horizontal flow type and up flow sludge blanket reactor in the monsoon season was 82.0±1.0 and, 77.5±2.5 percent respectively. Each season's sludge moisture content was comparable between the two experimental digesters, however, there were differences when comparing the seasons. Monsoon and summer trends were quite similar.

In the monsoon season, there was less dry matter in the sludge from the horizontal flow type and up-flow sludge blanket reactor. According to Khoiyangbam *et al.* (2015) [13], the sludge's ideal dry matter percentage ranges from 8 to 10.

The pH of the sludge from the horizontal flow type and up flow sludge blanket reactor was observed to be higher in the summer but lower in the monsoon seasons. The summer showed a similar trend in values, according to Shejir *et al.* (2014) [26]. According to Kouzi *et al.* (2020) [14], the pH may stabilise or even rise as the digestive process continues and bacteria continue to metabolise the organic stuff in the cow dung. For efficient biogas generation during anaerobic digestion, pH management is essential. To foster the growth of methane-producing microbes, it was typically advised to maintain a neutral or slightly alkaline pH level. The ideal pH for the formation of biogas from cow dung, according to Yan *et al.* (2022) [33], often falls between 6.5 and 7.5. The pH ranges from slightly acidic to neutral was excellent for the development and activity of the methane-producing bacteria (methanogens) needed to produce biogas. The best biogas output is ensured by maintaining this pH range. Our experiment's pH was within the range considered to be ideal. Lower biogas production seasons saw a lower pH. This suggested that the sludge may be used as manure and applied directly to the soil.

Sludge from horizontal flow type and up-flow sludge blanket reactors were both analysed for their volatile solid contents. We found that the values in this experiment were lower than the substrate. Obileke *et al.* (2022) [18] found that the organic content of cow dung that has undergone anaerobic digestion is measured using a crucial parameter known as volatile solid content (VSC). Organic substances decompose in the absence of oxygen. The VSC concentration normally drops when organic waste is transformed into biogas throughout this process. The efficacy of the anaerobic digestion process is shown by the decrease in VSC.

Similar values for crude protein were found in the sludge from all digesters during all seasons. When compared to the values of the substrate during the summer, the crude protein values of sludge were higher. Selvankumar *et al.* (2017) [25] discovered that the content of the sludge may be affected by how effectively biogas is produced. Biogas is created during the breakdown of organic materials by anaerobic digestion. Proteins may still make up a significant amount of the residual sludge's original nutrients.

When the crude fibre content of sludge from all of the digesters from both seasons was studied, it was discovered that there had been a modest decline in sludge's crude fibre value when compared to substrate value. Okewale *et al.* (2018) [35] discovered that while microbes target a variety of organic components during anaerobic digestion, including carbohydrates, proteins, and lipids, their main goal is to break these materials down into simpler chemicals. During this process, fibre, a complex carbohydrate, was also degraded.

The results of the ether extract analysis of the sludge from the horizontal flow type and up flow sludge blanket reactor were somewhat less low in sludge than the substrate. Similar findings were reported by Okewale *et al.* (2018) [35], who claimed that the formation of biogas is aided by the breakdown of organic matter, particularly fats and lipids. These complex organic chemicals are broken down by the microbes into simpler ones, which are ultimately released as biogas.

Analysis of the sludge's phosphorus concentration revealed that it was higher than that of the substrate. Lin and coworkers (2015) [17] discovered that the transition of organic components, including phosphorus, into various forms is caused by anaerobic digestion. For instance, part of the organic phosphorus may be changed into less difficult-to-access inorganic forms for plants. The amount of sludge generated after anaerobic digestion, which was less than the amount of input, was practically identically measured in all digesters during each season.

Table 4: Physico-chemical characteristics of the substrate

	Summer		Monsoon		
Biogas Digesters	**T_1**	**T_2**	**T_1**	**T_2**	
Parameter	**Sludge**	**Sludge**	**Sludge**	**Sludge**	**P-Value**
pH	7.45±0.018	7.35±0.018	6.25±0.018	6.35±0.018	<0.001**
Moisture (%)	78.5±3.5	80.5±0.5	81.5±0.5	80.5±1.5	<0.001**
Dry matter (%)	21.5±3.5	19.5±0.5	18.5±0.5	19.5±1.5	<0.001**
Volatile solid content (%)	76.17±0.01	76.15±0.01	74.84±0.05	74.54±0.05	<0.001**
Non-volatile solid content (%)	23.84±0.92	23.84±0.68	25.15±0.62	25.46±0.56	<0.001**

T_1-Horizontal flow type

T_2-Up-flow sludge blanket reactor

Mean with different significantly at 1% level (**)

Table 5: Physico-chemical characteristics of the sludge – Proximate analysis

	Summer		Monsoon	
Biogas Digesters	**T_1**	**T_2**	**T_1**	**T_2**
Parameter	**Sludge**	**Sludge**	**Sludge**	**Sludge**
Crude protein	17.22±0.13	17.24±0.19	16.76±0.17	15.77±1.24
Crude Fibre	15.69±0.30	15.75±0.17	15.62±0.25	15.92±0.44
Ether extract	2.08±0.08	2.02±0.08	1.78±0.23	2.87±1.20
Phosphorus	1.67±0.20	1.72±0.06	1.87±0.09	1.96±0.01
Total ash	23.84±0.92	23.84±0.68	25.16±0.62	25.46±0.56

The cause was that when cow dung is broken down during the anaerobic digestion process, biogas and leftover sludge are produced as a byproduct. The liquid and solid waste products left behind after the digestive process were known as sludge. Leggett (2006) [15] observed that while some of the organic matter was transformed into biogas and the remaining particles settled as sludge, the amount of sludge was often lower than the amount of cow dung input. Values are depicted in Tables 4 and 5.

3.2.1. Mean Temperature of substrate and sludge

In comparison to the monsoon seasons, the temperature of the substrate and the sludge was noticeably higher throughout the summer. The temperature variation in the substrate was caused by the seasonal variations in the environmental conditions. Similarly, Jyothi *et al.* discovered a pattern that was brought on by seasonal variation (2017) [10]. In comparison to the monsoon season, the temperature of the substrate and sludge was greater in the summer. Sludge temperature and biogas generation are positively correlated, claim Yadvika *et al.* (2007) [32]. The difference in ambient temperature, which in turn had a significant effect on the sludge temperature, was what produced the seasonal shift in substrate temperature.

3.3 Biogas production and composition during summer and monsoon seasons

Under the local environment at Pookode (ambient temperature range of 20–24 ºC), the proportion of carbon dioxide in biogas was lower for both of the two digesters than methane. Thy (2003) [30] pointed out that the type of feedstock used affected the biogas's composition. The substrate compositions were altered, which resulted in considerable differences in the methane and carbon dioxide concentrations. The ratio of methane to carbon dioxide in biogas produced from cow dung is frequently higher in colder climates. This occurred due to mesophilic methanogenic bacteria, which generate methane as a metabolic byproduct, being able to grow in low-temperature environments. In these conditions, the biogas methane content was promoted, leading to a higher methane-to-carbon dioxide ratio. In contrast, thermophilic methanogenic bacteria can increase the content of the biogas by producing more carbon dioxide and thriving at higher temperatures.

The biogas production from cow dung was greater in the summer (44.78±0.41 m^3) compared to the monsoon season (38.51±0.39 m^3). The summer season was determined to be the most advantageous for the generation of biogas and the emission of methane by both Hamad *et al.* (1981) [8] and Khoiyangbam *et al.* (2011) [12]. They had asserted that higher air temperatures always favoured methanogenic activity. This was also in line with the findings of Divya *et al.* (2014) [6], who reported that a decrease in biogas production was brought on by a drop in ambient temperature during the colder months. By investigating the factors impacting digester temperature and methods to stop heat losses during the cold season, Pham *et al.* (2014) [21] study offered insights into seasonal difficulties. Summer temperatures can boost the microbial activity in UASB reactors, thereby increasing the generation of biogas. However, as mentioned by Schmidt *et al.* (2019) [23], monsoon conditions may dilute the influent, influencing the organic load and gas generation. Values are depicted in Table 6.

Table 6: Biogas production in different biogas digesters during different seasons

Sl. No.	Seasons	Type of digesters	Biogas Production (m^3)
2	Summer Season	Horizontal flow type	8.82±0.16
		Up-flow sludge blanket reactor	61.05±0.45
3	Monsoon Season	Horizontal flow type	5.08±0.12
		Up-flow sludge blanket reactor	55.83±0.50

3.4. Hydraulic retention time (HRT)

Results of the HRT computation in two different kinds of digesters. The HRT of the horizontal flow type was the longest (35 days), whereas the up-flow sludge blanket reactor had a shorter HRT (25 days).

Khoiyangbam *et al.* (2011) [12] found that when the average temperature rises, so does the relative methane content. Additionally, during the course of the summer, the equivalent slurry displacement from biogas plants' slurry displacement chamber rose. Lower temperatures are known to slow down the process's microbial growth, rate of substrate utilisation, and methane production. As a result of the production of volatile gases like ammonia and the consequent suppression of methanogenic activity, however, exceptionally high summer temperatures also decreased the output of biogas. Temperature significantly affected the microbial population, the kinetics and stability of the process, and the generation of methane, according to Khalid *et al.* (2011) [11]. Seasonal temperature fluctuations, according to Browne *et al.* (2015) [3], may dramatically affect the trend of biogas generation, with higher temperatures often resulting in improved efficiency and methane concentration. The seasonal fluctuation and trend of biogas generation from dairy cow slurry are significantly influenced by storage duration and temperature, with temperature being a key element for the best outcomes. The composition of biogas can shift with seasonal fluctuations, according to Schmidt (2019) [23]. Due to slower microbial activity during colder months, biogas often contains more methane (CH_4) and is hence more energising. In contrast, due to increased microbial activity and accelerated digestion, warmer seasons might result in biogas with lower CH_4 content and greater carbon dioxide (CO_2) levels. In our experiment, we found that the summer season had a higher methane percentage.

The best biogas production and enhanced methane content would require thermal insulation of all digester types in high-altitude regions like Pookode, where the mean ambient temperature ranges between 20 and 24 ºC.

4. Conclusion

In our study, when comparing the production potential of two different types of biogas digesters, according to the results, the up-flow anaerobic sludge blanket reactor digester produced the most biogas when compared to the horizontal flow type. The up-flow sludge blanket reactor produced more biogas (61.05±0.45 m^3) in the summer. The horizontal flow type reactor produced the least biogas (5.07±0.12 m^3) during the monsoon, and there was a significant difference between the digesters. The up-flow anaerobic sludge blanket reactor is the best model of digester for best biogas production. When comparing the seasons, we found that season had a profound effect on the production of biogas. Summer season is the best time for high production of biogas

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