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Investigation of medicinal plant processing waste for electricity generation through biomethanation

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Abstract

One of the waste-to-energy conversion technologies is the use of waste from the processing of medicinal plants to create biogas, which may then be used to generate electricity. The maximum capacity for producing biogas was exhibited by *Carica papaya*. After 5 weeks, biogas production from *Combretum indicum* and *Azadirachta indica* began, and it continued to increase until the experiment's conclusion. For *Carica papaya* and *Azadirachta indica*, the greatest amounts of biogas produced in the 60-day retention period were 11,320 ml and 10,610 ml, respectively. By contrast, the highest methane yields for *Carica papaya* and *Azadirachta indica* were 7130 ml and 7850 ml, respectively. *Azadirachta indica* has an average methane percentage of 74%, which is the primary cause of the increased biogas production. *Papaya carica* yields more biogas; however, it has a 63% methane content. The 500-m^3 UASB-type biogas plant can process 13,000 to 20,000 l of feedstock per day. Based on 90-day flow meter data, the average biogas production is 560.37 m^3. The biogas facility has an internal rate of return of roughly 7%, indicating a lucrative undertaking. The project's observed BC ratio was 1.22. The project is viable since the BC ratio was more than 1. The computed payback period was 9 years.

Keywords Medicinal plants, Processing waste, Biogas, Methane, Payback period

Introduction

India is one of the richest nations in the world concerning biodiversity, due to its 15 varied agro-climatic zones and different landforms. The biodiversity includes as many as 17,000–18,000 different flowering plant species, out of which about 7000 of them have been used for medicinal purposes from time immemorial [1]. They have been used in multiple folks and documented systems, and ancient Indian practices like Ayurveda see their use. They are also used in the Ayush system of Siddha, Unani and Homeopathy [2].

In many regions of the nation in the past, medicinal plants served as the only source of therapy and have long been a vital component of traditional medicine. As the name implies, they are also one of the primary raw materials in the herbal business [3]. In addition to being used, they have given and still give a significant portion of the Indian populace livelihood and health security. Of the 1178 species of medicinal plants, 242 are thought to be traded at levels exceeding 100 metric tonnes annually for human consumption [4]. They have both domestic as well as export demand, with an estimate of 1.95 million metric tonnes per year of domestic demand in 2014–2015 and an estimate of 1.34 million metric tonnes per year of export demand in the same year as per the National Medicinal Plants Board. With a trade value as high as Rs.

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5500 crore, the total raw consumption of herbal drugs in the country has been 5.12 million metric tonnes for the year 2014–2015. With each passing year, the export value has been increasing due to the increase in the popularity of medicinal plants. The export value has majorly increased from Rs. 345.80 crore to Rs. 3211 crore from the years 2005–2006 to 2014–2015, respectively, hence, showing a massive ninefold increase during the last decade [5].

India is the second-largest country in terms of production of medicinal plants. This is mainly due to various landforms in the country [6]. The area used for planting medicinal plants has increased over the years in India with an annual growth rate of 1.12% per year. The area used for the cultivation of medicinal plants has increased from 2.62 million hectares to 6.33 million hectares, during the years 2005–2006 to 2015–2016, respectively [7]. Hence seeing a good increase over the decade. Due to this the production too has seen a massive increase. The production which was 2.02 million tonnes in 2005–2006 has increased to 10.22 million metric tonnes in 2015–2017 due to which the annual growth rate has been 2.76% per annum [8]. With an increase in production, there has also been an increase in the amount of biowaste [9]. There are large chunks of biomass, extraction of essential oils, and secondary metabolites generates a large amount of biowaste. Thus, if not handled properly it can become a threat to the environment [10, 11].

Since most medicinal plants have therapeutic qualities and can be fed to animals, they are typically regarded as edible. Nevertheless, the remaining wastes from the majority of medicinal plant extraction procedures are no longer acceptable for use as animal feed [12]. They are not useable and are considered to be waste and become an environmental threat. At present, there is no proper method for management of the waste that comes from these plants and they end up being burnt or buried [13]. Some researchers mentioned about the manure production, anaerobic digestion and the extraction of some bio compounds (phytochemicals) like phenolics and some anti-oxidants.

The world's energy demand has increased, but it has increased more in India due to the country's rapid population expansion and growing urbanisation. Together with the rising demand, the supply of conventional fuels is declining [14]. The quality of the air around us has also significantly declined. This has consistently inspired academics to develop and discover new sustainable and clean energy sources. Few studies have proposed that waste from medicinal plants can be used to produce biogas [13, 15]. Sustainability as a topic has seen a major interest in all fields. Hence, biogas produced in this process can be successfully used [16, 17].

Biogas can be immediately converted into useable electricity from biomass and utilised as fuel in a turbine to produce electricity. When organic matter is digested anaerobically in an anaerobic biogas reactor, biogas is created. Biogas is a mixture of flammable gases. Anaerobic digestion of matter results in the treatment and degradation of waste and the production of biogas [18].

The air quality both inside and outside is impacted by the numerous dangerous smoke particles emitted during the burning of these leftover medicinal plant leftovers. At this point in the conversion process, phytochemicals are being extracted and used further. Anaerobic digestion, on the other hand, uses biomass directly to produce energy. Furthermore, the implementation of biogas systems may lead to improved organic waste management and disposal. In this regard, the current effort was an attempt to investigate the use of medicinal plant processing waste for biomethanation-based energy generation.

Materials and methods

The study was conducted to know the performance of a biogas power plant of 500 m^3 capacity in Prakruti Products Pvt Ltd, Navagadde, Agsoor village, Ankola Taluk, Uttara Kannada, Karnataka. We came to know that the major composition of feedstock was liquid waste (liquid discharge of medicinal plant processing procedure and the leachate of medicinal plant processing waste). It also produces a huge quantity of medicinal plant residues, which were not suitable for animal feed and were considered waste and an environmental threat. At present, there is no proper management of the waste of these plants and they were burned or buried.

Experimental details

Wastes from the preparation of several medicinal plants were gathered (Table 1), and their chemical and physical characteristics were examined. After being dried in a hot air oven, the waste's moisture content and total solids

Table 1 Scientific and common names of different medicinal plant processing wastes

Sl. No	Scientific name	Common name
1	*Ocimum tenuiflorum*	Tulsi, Holy Basil
2	*Combretum indicum*	Madhumalti, Rangoon creeper
3	*Justicia adhatora*	Vasaka, Malabar nut
4	*Garcinia gummi-gutta*	Uppange
5	*Carica papaya*	Papaya
6	*Cinnamomum verum*	Cinnamon
7	*Azadirachta indica*	Neem
8	*Menthe spicata*	Mint

were measured. This information was used to weigh the substrate quantities and set up the experimental equipment for the production of biogas.

Five-litre polycarbonate carboys were used to build the biogas units. Each carboy in the unit had a rubber cork attached to its mouth, through which a cork borer was used to create a hole big enough to fit an 8-mm tube. As part of a lab-scale biomethane potential research, a rubber tube with an 8-mm diameter was attached to the tube for collecting biogas into a 1-l measuring cylinder using the water displacement method [19]. The mouth of the carboy and cork were sealed with wax to prevent any gas escaping from the carboy which is shown in Fig. 1.

The reactor's mouth is sealed with a rubber stopper, and the contents make up a 3-l capacity with a 1:1 ratio of substrate to cow dung slurry and space left over for gas escape. The polycarbonate carboy containing the various biogas substrates was then sealed and left in the laboratory to ferment anaerobically for 2 months. The water displacement method was used to calculate the daily gas output, and the readings were recorded.

Characterisation of feedstock

The physical properties of the medicinal plant processing wastes are moisture content, total solids and total volatile solids, pH, per cent nitrogen, per cent carbon, and C:N ratio. The above-mentioned physical and chemical properties were determined using a suitable apparatus.

Determination of moisture content The substrates were dried in a hot air oven at 70°C till a constant weight was achieved and cooled in a desiccator to record its final weight. The moisture content of the sample was calculated as follows.

$$\text{Moisture content}(\%) = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Determination of total solids (TS %) The sample (10 g) was taken and transferred to a crucible and dried to a constant weight at 105 °C in an oven until the constant weight was obtained.

$$\text{TS }(\%) = \frac{\text{Final weight}}{\text{Initial weight}} \times 100$$

Determination of volatile solids (VS %) The dried residue from the total solid analysis was weighed and heated in a crucible for 1 h at 550 °C in a muffle furnace. After cooling crucible residue was weighed.

$$\text{VS }(\%) = \frac{V_3 - V_1}{V_2 - V_1} \times 100$$

where

V_1 = weight of the crucible
V_2 = weight of residue and crucible, and
V_3 = weight of ash and crucible (after cooling).

Determination of pH The pH of the substrates was determined as per the procedure outlined by Jackson (2005). The powdered samples were mixed with distilled water in a ratio of 1:10 and made it to the slurry, stirred for 15 min and the pH was determined by using a digital pH meter.

Estimation of total organic carbon (TOC) The estimation of TOC was done following the wet digestion method of Walkley and Black as described by [20]. The diluted 10-ml sample was digested with 10 ml of 1 N $K_2Cr_2O_7$ with 20 ml of concentrated H_2SO_4 in a 500-ml conical flask and kept for digestion. Then 200 ml of water and 3 to 4 drops of ferroin indicator were added and then

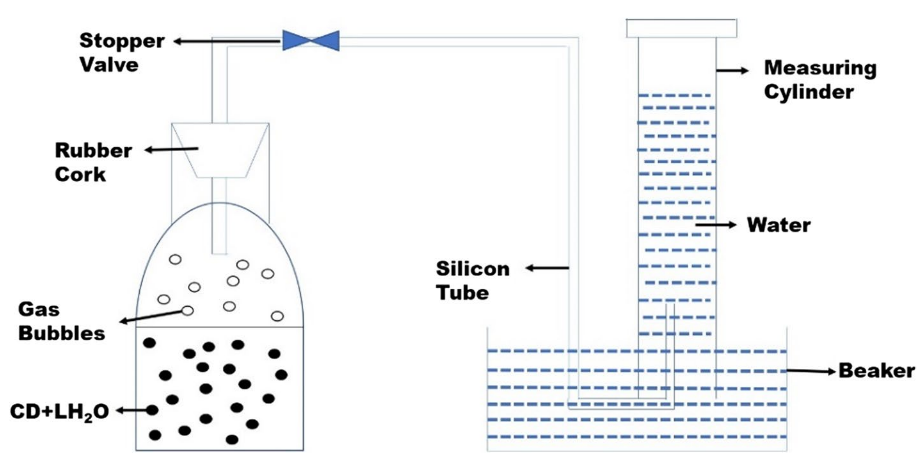

Fig. 1 Laboratory scale experimental setup

the solution was titrated with 0.5 N ferrous ammonium sulphate (FAS).

$$\text{TOC}\ (\%) = \frac{(B_V - S_V)\ \times\ \text{NFAS}\ \times\ 100\ \times\ 0.003}{V}$$

where
Bv = blank titre value,
Sv = sample titre value,
NFAS = normality of FAS, and
V = volume of sample.

Determination of total nitrogen (total-N) The total nitrogen in samples was determined by the semi-micro Kjeldahl method as per the procedure outlined by [21] using the Gerhardt auto analyser. The amount of N in the sample was found by multiplying the volume of acid consumed and N equivalent to 1 ml of 0.05 N H_2SO_4.

$$\text{Nitrogen}\ (\%) = \frac{\text{Titre value}\ \times\ \text{N of}\ H_2SO_4\ \times\ 0.014\ \times\ \text{Dilution factors}}{\text{Weight of the sample (g)}} \times 100$$

Determination of the C:N ratio The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the carbon–nitrogen ratio (C:N ratio).

Methane content of biogas The total methane produced during digestion was estimated using a saccharometer. A saccharometer was filled with concentrated (> 5%) sodium hydroxide solution. Using a standard 5-ml syringe with a long (5 cm) needle, the gas sample was withdrawn from the digestion bottles and carefully injected into the saccharometer in such a way that the gas should move toward the graduated arm of the glass tube. Methane gas was collected at the top of the sacharometer and CO_2 was absorbed by the solution. The displaced volume represented the volume of biogas minus CO_2, which was methane and the remaining gases were of less percentage so we have neglected them [22].

$$\text{Methane content}\ (\%) = \frac{100\ \times\ \text{Volume of gas collected at the top}}{\text{Total volume of gas injected}}$$

Procedure for analysing the performance evaluation of the biogas power plant

Biogas power plant

A 500-m^3 biogas plant of the Up-flow Anaerobic Sludge Blanket Digestion type produces granular sludge that suspends in the tank like a blanket. Anaerobic bacteria in the blanket break down wastewater as it flows upward. With the help of flocculants, the upward flow and gravity's settling action suspend the blanket. Aggregations of bacteria are responsible for the formation of small sludge granules on the surface. The flow characteristics produce a niche where only specific adhering bacteria may thrive and spread. Figure 2 displays the entire plant configuration.

Biogas generation

Anaerobic digestion was a simple method of treating the majority of the liquid wastes from the preparation of medicinal plants, which were organic in nature. The ideal conditions for anaerobic digestion are high moisture content and organic contents [23]. Because the organic wastes' total solids break down quickly, the methanation

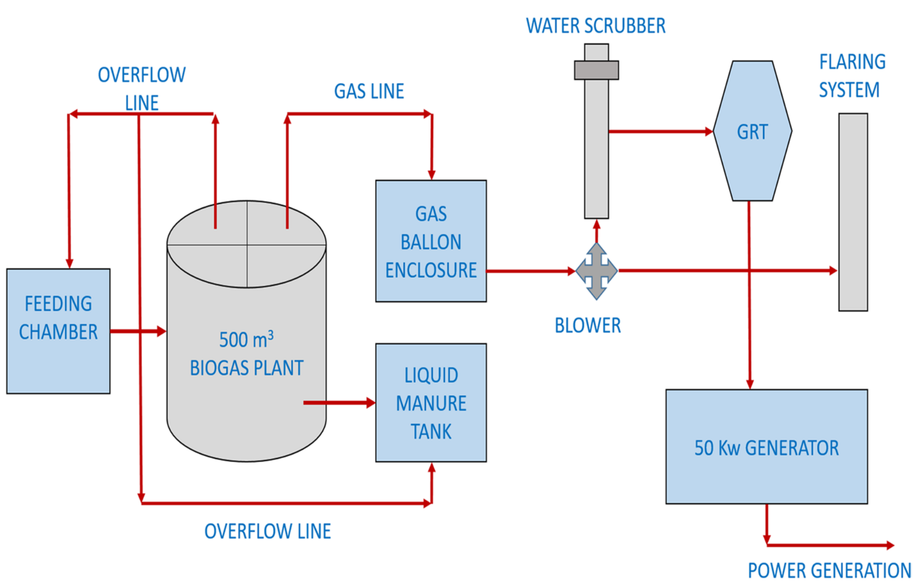

Fig. 2 Flow chart of biogas power generation

process—also known as anaerobic digestion—can be used to treat them. The wastes were processed in enclosed spaces known as anaerobic digesters, where microorganisms break down organic matter into a stable residue in the absence of oxygen and produce biogas that is high in methane. Data on biogas generation was obtained by monitoring the values on the flow meter (m^3/day).

$$\text{Biogas yield}\left(\frac{\text{m}^3}{\text{Day}}\right) = \text{Final reading of flow meter} - \text{Initial reading of flow meter}$$

Purification of biogas

The methane (55–60%), carbon dioxide (35–40%), hydrogen sulphide, and minute amounts of water vapour make up biogas. The carbon dioxide content of the biogas should be eliminated in order to increase the energy content per unit volume of the gas. Because hydrogen sulphide (H_2S) is corrosive, its presence can damage the compression system. A straightforward, economical, environmentally responsible, and useful technique for removing CO_2 from biogas was the absorption of CO_2 in water. It was a continuous procedure that also eliminated H_2S at the same time. In nations like India, sewage sludge-based biogas facilities are the main users of this technique. With this method, high-purity biogas with an 80% methane content may be produced. The scrubber has dimensions of 15 cm in diameter, 3.50 m in height, and a 3-m packed bed length. Its working pressure is around 9 bar, and it can process 50 m^3 of material per hour. It is intended to remove between 60 and 95% of the methane from the biogas. In order to achieve maximal absorption of carbon dioxide in water, pressurised water from the top and pressurised raw biogas from the bottom were sent in a counter-current manner through packing material in the scrubber.

Biogas to electricity generation

The chemical energy of the biogas was converted to mechanical energy in a controlled combustion system by a heat engine. This mechanical energy then activates a generator to produce electric power. This work was done by a generator which was manufactured and marketed by Kirloskar Oil Engines Limited, Pune. This generator is Dual Fuel Mode which is run by both diesel and biogas and produces an output of three-phase current (415 V/50 Hz V). Both an energy meter and a water cooling system are included. This generator generated three phases of current when it was powered by biogas. Pressurising the biogas from the gas storage to the biogas engine inlet was done using the compressor. It was essential to keep the biogas pressure at a specific minimum for effective combustion. Energy meter readings (units per day) were observed in order to collect the data. One unit represents 1 kWh.

$$\text{Unit generated per day} = \text{Current reading} - \text{Previous reading}$$

Economic assessment

Evaluation of investment in biogas in a biogas power plant was made in Net present value, payback period, and benefit to cost ratio for 500 m^3 of biogas plant.

NPV (net present value)

This method is used in capital budgeting to assess an investment's or project's profitability as net present value. It is computed by subtracting the present value of cash outflows over a given period of time from the present value of cash inflows. All that remains of net present value is the net off of the present value of cash inflows and outflows after the flows are discounted at a certain rate.

$$\text{NPV} = \frac{\sum(\text{Cash flows})}{(1+r)_{\text{i}}}$$

where
r = discount rate,
i = time period,
Cash flow = $\sum$
value of cash outflow

Benefit-to-cost ratio

The benefit-to-cost ratio is a financial ratio that is used to determine whether the amount of money made through a project will be greater than the costs incurred in executing the project.

$$\text{BCR} = \frac{\sum \text{Discounted value of cash outflow}}{\sum \text{discounted value of cash inflow}}$$

where
BCR > 1, positive return, and
BCR < 1, negative return.

Payback period

The payback period is the time required to recover the initial cost of an investment. It is the number of years it would take to get back the initial investment made for a project.

$$\text{PBP} = \frac{\text{Initial investment}}{\text{Cash flow}}$$

It was easy to understand with the help of IRR

$$\text{IRR} = \frac{\sum(\text{Cash flows})}{(1+r)^i} - \text{Initial investment}$$

where
r = discount rate and
i = time period.

Results and discussion

Physical properties of feedstock

The physical properties of the feed material have an impact on biogas generation. The moisture content, total solids, and total volatile solids of the gathered medicinal plant processing wastes are its physical characteristics. Using the appropriate equipment, the aforementioned physical attributes were ascertained, and the results were entered and summarised in Table 2.

The amount of moisture content in feedstock influences the anaerobic digestion process and methane yield, 90% of moisture content was recommended for optimum biogas production [24]. But, in this case, all moisture content values were less than 90%. These raw materials require additional water to maintain moisture content. This says lower the moisture content higher the amount of water needed which means a higher mixing ratio and vice versa. It was found that *Ocimum tenuiflorum* waste had a higher moisture content of about 78.36%, whereas *Justicia adhatora* waste had a minimum of about 49.19% among all other collected medicinal plant processing waste. The range of moisture content lies within 50–80% and total solids lie within 20–50% were shown in Fig. 2. The volatile solids concentration shows a positive relation with biogas yield. The higher the volatile solids, the higher the amount of biogas observed in Fig. 3.

Carica papaya (94.46% VS), *Azadirachta indica* (91.66% VS) *and Combretum indicum* (86.17% VS) are the highest volatile solid content waste which produce 11,320 ml, 10,610 ml and 9780 ml of biogas respectively. *Garcinia gummi-gutta* (49.71% VS) and *Cinnamomum verum* (52.79% VS) were the lowest volatile solid content which yielded the lowest biogas yield of 2180 ml and 3760 ml, respectively.

Table 2 Physical characteristics of medicinal plant processing wastes

Sl. No	Medicinal plant processing wastes	Moisture content (%)	Total solids (%)	Volatile solids (%)
1	*Ocimum tenuiflorum*	78.36	21.64	79.32
2	*Combretum indicum*	71.86	28.14	86.17
3	*Justicia adhatora*	49.19	50.81	67.91
4	*Garcinia gummi-gutta*	74.26	25.74	49.71
5	*Carica papaya*	57.71	42.29	94.46
6	*Cinnamomum verum*	51.13	48.87	52.79
7	*Azadirachta indica*	62.73	37.27	91.66
8	*Menthe spicata*	56.71	43.29	79.18

Chemical properties of feedstock

The chemical properties of feed material affect the production of biogas. The Chemical properties of the collected medicinal plant processing waste contain pH, percent nitrogen, percent carbon and C:N ratio. The above-mentioned chemical properties were determined

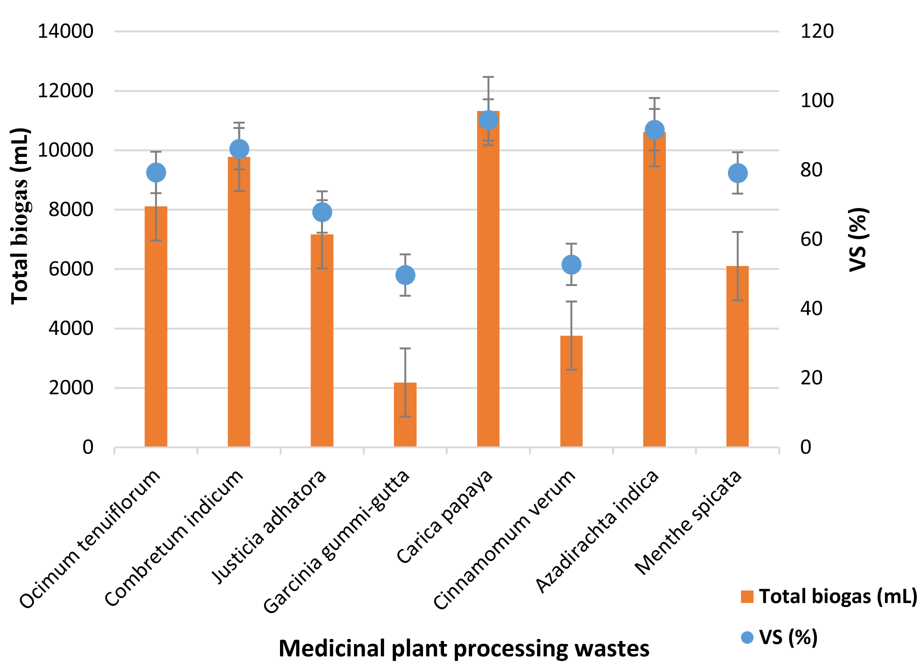

Fig. 3 Volatile solids and total biogas of medicinal plant processing wastes

using a suitable apparatus and data was recorded and tabulated in Table 3

The pH lies within the acidic range mainly because most of the chemicals used in the extraction process were acids and acid-related substances. In this case, the pH value lies within 3 to 6.5 pH. It plays a major part in anaerobic biodegradation by influencing the activity of the hydrolytic enzymes. The optimum pH range in an anaerobic digester was 6.8 to 7.2 [25].

The maximum pH was observed in *Garcinia gummi-gutta* about 6.19 pH, but in the case of *Cinnamomum verum*, *Justicia adhatora* and *Ocimum tenuiflorum* the pH was lies within 5–6 pH which was 4.93, 4.81 and 4.27 pH, respectively. While minimum pH was observed in *Menthe spicata* and *Combretum indicum* which are 3.11 and 3.66 pH respectively. Most of the samples contain carbon within the 40 to 50% range. The higher carbon-containing wastes are *Cinnamomum verum*, *Combretum indicum* and *Menthe spicata* they have 52.7, 50.72 and 50.47%, respectively. The minimum is about 44.73% which is observed in *Ocimum tenuiflorum*. The higher nitrogen content was found in *Ocimum tenuiflorum* and *Azadirachta indica* at about 2.21 and 2.09%, respectively. 0.71% was the lowest observed in *Cinnamomum verum.*

Table 3 Chemical characteristics of medicinal plant processing wastes and total biogas

Sl. No	Medicinal plant processing waste	Carbon (%)	Nitrogen (%)	C:N ratio
1	*Ocimum tenuiflorum*	44.73	2.21	20.24
2	*Combretum indicum*	50.72	0.94	53.96
3	*Justicia adhatora*	47.18	1.48	31.88
4	*Garcinia gummi-gutta*	49.3	0.83	59.40
5	*Carica papaya*	46.33	1.92	24.13
6	*Cinnamomum verum*	52.7	0.71	74.23
7	*Azadirachta indica*	48.92	2.09	23.41
8	*Menthe spicata*	50.47	1.97	25.62

As expected maximum production of biogas was observed in 20–30 C:N ratio. From Fig. 4, *Carica papaya*, *Azadirachta indica*, *Ocimum tenuiflorum* and *Justicia adhatora* were the four out of five samples that yielded higher biogas about 11,320 ml, 10,610 ml, 8110 ml and 7170 ml with respect to 24.13, 23.41, 20.24 and 31.88 C:N ratio. *Garcinia gummi-gutta* and *Cinnamomum verum* had low biogas yields of about 2180 ml and 3760 ml due to the higher C:N ratio of about 59.40 and 74.23, respectively.

Biogas yield and methane content

Weekly production of biogas indicates the weekly production of biogas from each type of medicinal plant processing samples (Fig. 5). Compared with the results, it was determined that biogas could be produced from all medicinal plant processing wastes.

Biogas production was observed from the first week of the experiments. *Carica papaya* had the highest biogas production talent. At the beginning of the experiment, within 6 weeks it showed its higher ability to produce biogas but after 6 weeks biogas production drastically reduced. Biogas production from *Combretum indicum* and *Azadirachta indica* was started after 5 weeks and went on increasing up to the end of the experiment. In the case of *Ocimum tenuiflorum*, *Justicia adhatora* and *Menthe spicata* a little high biogas yield was seen in the middle of the experiment [26]. Biogas production of *Garcinia gummi-gutta* and *Cinnamomum verum* had a low value showing that their hard lignocellulosic tissues make

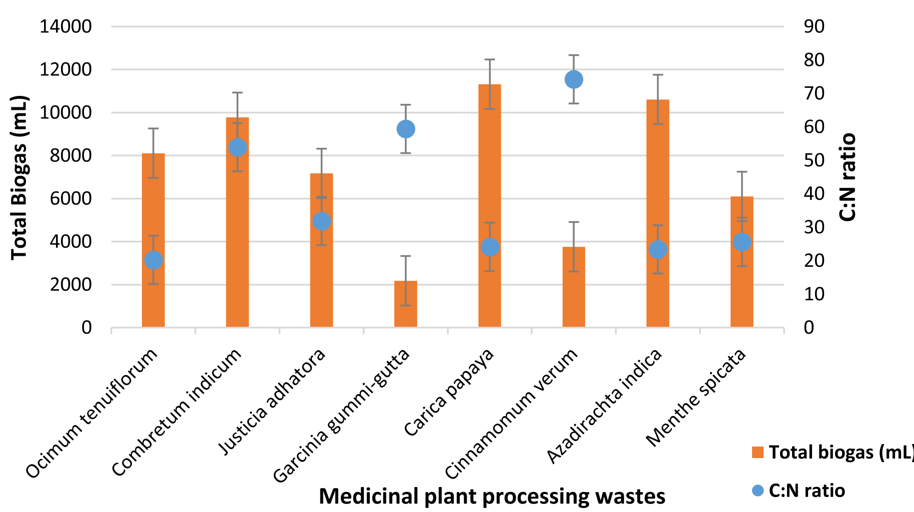

Fig. 4 C:N ratio and total biogas of medicinal plant processing wastes

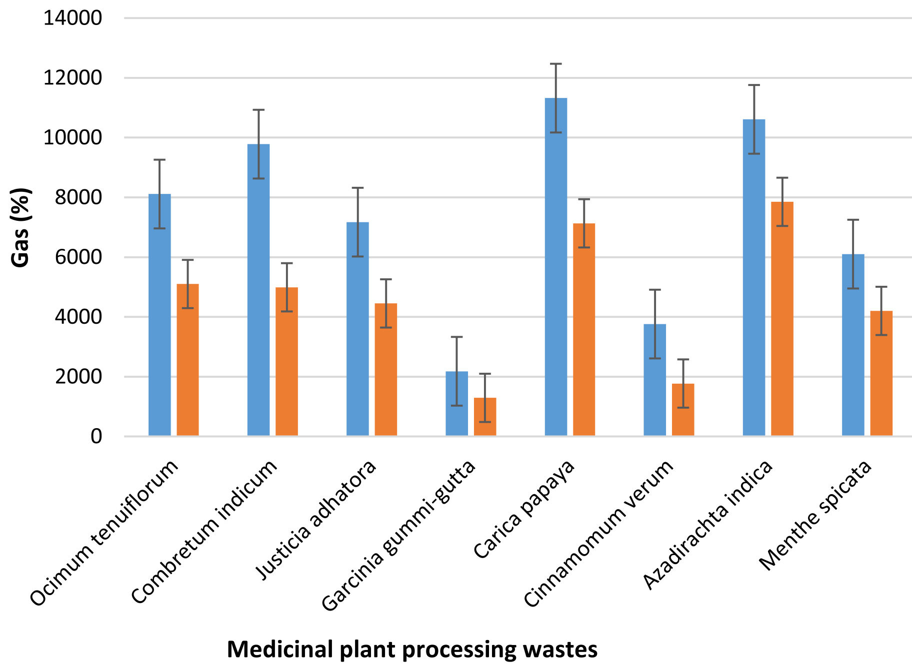

Fig. 5 Methane content in biogas

it difficult to digest by microorganisms [27]. The result shows that *Carica papaya* and Azadirachta *indica* with the production of 11,320 ml and 10,610 ml of biogas, respectively, have the highest production rates. *Combretum indicum*, *Ocimum tenuiflorum*, *Justicia adhatora* and *Menthe spicata* produce 9780 ml, 8110 ml, 7170 ml and 6100 ml of biogas. *Garcinia gummi-gutta* and *Cinnamomum verum* with the production of 2180 ml and 3760 ml of biogas, respectively [28].

Performance evaluation of biogas power plant

This Case study was carried out to understand the performance of the biogas plant which was established in Prakruti Products Pvt. Ltd, Navagadde, Agsoor village, Ankola Taluk-581314, Uttara Kannada district of Karnataka. Primary data was collected and analysed based on this result was provided. UASB-type biogas power plant which has 500 m^3 capacity and an adequate amount of feedstock was provided for the proper running of the biogas plant setting HRT for 12 h for 90 days. Feedstock mainly consists of waste water which was an output of medicinal plant processing procedure and the leachate of medicinal plant processing waste. The range of quantity of the feedstock was between 13,000 and 20,000 l per day. The feedstock was in a liquid state so there was no need for additional water. It saves additional water which was normally used to maintain TS concentration to an adequate level. The gas produced in this process from the plant was observed by flow meter for 90 days daily, average biogas production was about 560.37 m^3. Measuring the methane content helps to understand the quality of biogas. Methane was measured by using a saccharometer. To improve the biogas quality, the elimination of CO_2 and H_2S from the biogas is needed.

It is very important to enhance fuel quality and efficiency. Before the purification of biogas, the methane content was measured using a saccharometer and tabulated. Later, the biogas purification was conducted by water scrubbing method. After maximum removal of CO_2 and H_2S, the methane content of biogas was measured and tabulated (Table 4).

Biogas to electricity generation

The chemical energy of the biogas is converted to mechanical energy in a controlled combustion system by a heat engine. This mechanical energy then activates a generator to produce electric power. This work is done by a generator which is manufactured and marketed by Kirloskar Oil Engines Limited, Pune. This generator is Dual Fuel Mode which is run by both diesel and biogas and produces an output of three-phase current (415 V/50 Hz V). A water cooling system and energy meter are provided.

This data was taken by observing energy meter readings (units/day). One unit represents 1 kWh. From Fig. 6, we can observe the positive relation between biogas production and electricity generation in most of the graphs. But, in between 35 and 56 days, it does not show a

Table 4 Methane content of biogas before and after purification

Sl. No	Day	Methane (%) before purification	Methane (%) after purification
1	1	65.73	80.57
2	15	67.39	85.39
3	30	51.43	76.9
4	45	57.1	74.44
5	60	55.24	69.34
6	75	59.18	77.22
7	90	60.17	81.37
Average		**59.46**	**77.89**

positive relation. It was mainly because the methane content of biogas at that time was low; raw material used at that time had less potential towards methane yield. The Slurry was in a liquid state, and the average slurry output was 16,000 l per day. An average running hour was between 10 and 12 h per day. The anaerobic digestion is the best response at 35 °C and it is the optimum temperature where optimum biogas and methane yield was observed [29, 30]. Most of India belongs to tropical and sub-tropical climatic regions which enables India as a potential biogas producer.

From Fig. 7, we can observe that maximum and minimum temperatures were almost the same, it is because the biogas power plant was in the coastal zone. The average maximum temperature was 29.31 °C and the minimum average temperature was 20.01 °C.

Fuel substitution by biogas

Represented that large-scale biogas plants had more environmental benefit by considering its replacement value of various depleting fossil fuels shown in Table 5.

Economic benefits of biogas power plant

The NPV considers the time value of money. The time value of money simply means that a rupee today is of more value than it will be tomorrow. NPV helps in deciding whether it is worth taking up a project based on the present value of the cash flows. In Table 6, we observe discounting the cash flows over 20 years with 10% of interest, the initial investment was deducted from it. The result shows a positive NPV of about 7%, which means the project was profitable. 1.22 was the observed BC ratio of the project, The BC ratio was more than 1 so the project was viable. It means that for every 1 rupee of investment, we get an additional 0.22 rupee profit. The payback period is a technique of capital budgeting, that derives the number of years it takes to get back the initial investment.

In Table 6, with the help of IRR, we can observe in the 9th year IRR became zero. It was the payback period of the project. This means that after the end of the payback period, the investment shows profitability.

Environmental benefits of biogas power plant

Greenhouse gas reduction

Methane can retain heat more effectively than carbon dioxide. Methane has a global warming potential (GWP) that is 21 times greater than that of carbon dioxide based

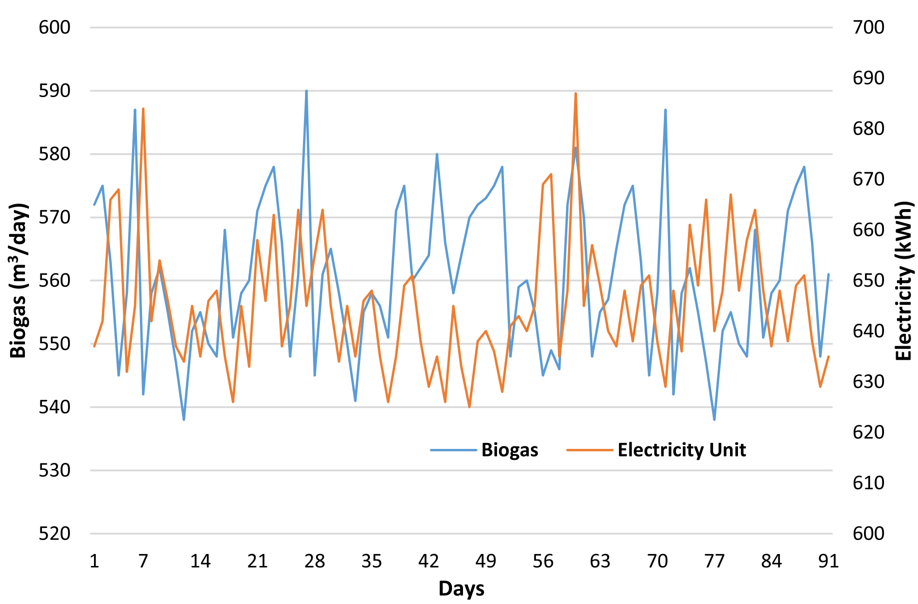

Fig. 6 Biogas and electricity production

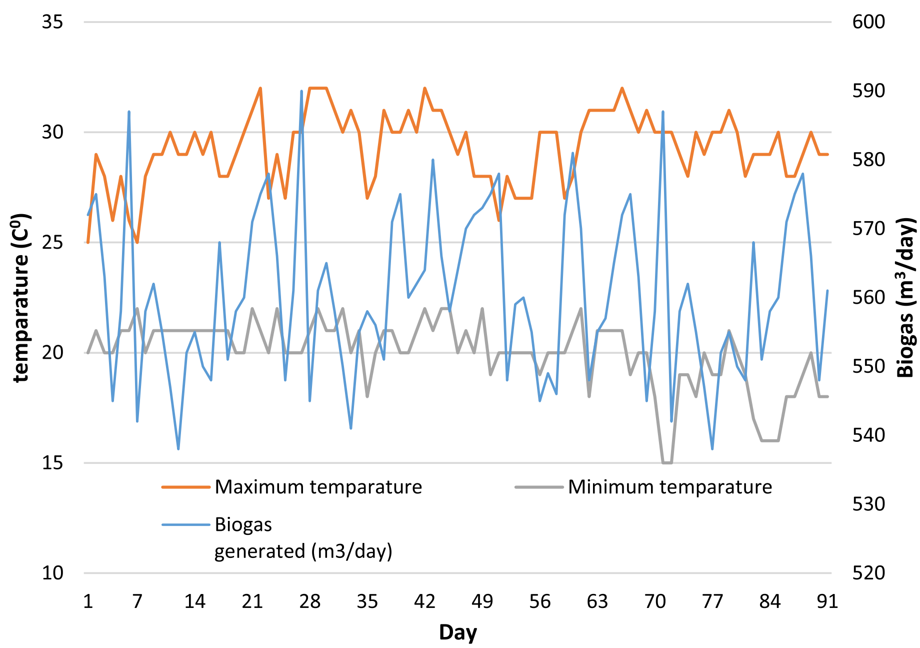

Fig. 7 Temperature and biogas generation

Table 5 Comparison of various fuels with biogas

Sl. No	Name of the fuel	Calorific value (kcal/kg)	Thermal efficiency (%)	Useful heat (kcal/kg)	To replace 1 m^3 of biogas
1	Biogas (m^3)	4713	60	2770	1
2	Kerosene (l)	9600	50	4800	0.62
3	Fuel-wood (kg)	4700	10	470	3.474
4	Charcoal (kg)	6930	28	2079	1.458
5	Soft coke (kg)	6292	28	1889	1.605
6	LPG (kg)	10,882	60	6529	0.433
7	Furnace oil (l)	9041	75	6780	0.4171
8	Coal gas (m^3)	4004	60	2400	1.177

on weight. Because biogas facilities capture methane and use it as fuel to generate power, they considerably reduce the greenhouse effect. Fossil fuels accounted for almost 80% of India's electrical generation. This type of biogas plant contributes to the reduction of fossil fuel dependency, which is the primary driver of global warming.

Fuel substitution by biogas

In Table 5, the calorific value of biogas (4713 kcal/kg) is higher than both fire-wood and coal gas which have 4700 and 4004 kcal per kg, respectively. The thermal efficiency of biogas is about 60% which is equal to LPG. Useful heat produced by biogas is higher than firewood, charcoal, soft coke and coal gas.

Table 7 shows that large-scale biogas plants have more environmental benefits by considering their replacement value of various depleting fossil fuels, such one example was situated in Prakruti Products Pvt. Ltd, Ankola Taluk-581314. This biogas plant produces an average of 560 m^3 biogas per day and can replace kerosene, fuel wood, charcoal, soft coke, LPG, furnace oil and coal gas in a day by 347.20 l, 1945.44 kg, 816.48 kg, 898.80 kg, 242.48 kg, 233.58 l and 659.12 m^3, respectively, for various purpose. This clearly shows that the adoption of biogas helps to reduce pressure on forest trees for fuel wood purposes and reduce the dependency on fossil and improve waste management. This is how the adoption of biogas had multiple environmental benefits.

Summary

The maximum production of biogas was observed in 20 to 30 C:N ratio. *Carica papaya*, *Azadirachta indica*, *Ocimum tenuiflorum* and *Justicia adhatora* are the

Table 6 Cash flow and IRR of biogas project (project lifespan 20 years)

Year	Cash inflow	Cash outflow	Net discounted cash flow	IRR
0	5,800,000	606,720	−5,193,280.00	
1	386,000	1,239,000	781,720.78	−85%
2	386,000	1239,000	716,250.11	−55%
3	386,000	1,239,000	656,131.86	−34%
4	386,000	1,239,000	600,943.69	−22%
5	386,000	1,239,000	550,294.75	−14%
6	440,900	1,362,900	545,947.86	−8%
7	440,900	1,362,900	499,942.43	−5%
8	440,900	1,362,900	457,730.79	−2%
9	440,900	1,362,900	419,009.68	**0%**
10	740,900	1,362,900	286,906.98	1%
11	440,900	1,362,900	350,939.92	2%
12	440,900	1,362,900	321,093.89	3%
13	440,900	1,528,100	341,593.24	4%
14	500,000	1,528,100	300,086.58	5%
15	500,000	1,528,100	274,466.86	5%
16	500,000	1,528,100	250,998.25	6%
17	500,000	1,528,100	229,504.27	6%
18	500,000	1,528,100	209,822.42	6%
19	500,000	1,528,100	191,803.17	6%
20	500,000	1,528,100	175,308.95	**7%**

Table 7 Replacement of fuels by biogas

Sl. No	Name of the fuel	To replace 1 m^3 of biogas	1 day
1	Kerosene (l)	0.62	347.20
2	Fuel wood (kg)	3.474	1945.44
4	Charcoal (kg)	1.458	816.48
5	Soft coke (kg)	1.605	898.80
6	LPG (kg)	0.433	242.48
7	Furnace oil (l)	0.4171	233.58
8	Coal gas (m^3)	1.177	659.12

four out of five samples that yield higher biogas about 11,320 ml, 10,610 ml, 8110 ml and 7170 ml for 24.13, 23.41, 20.24 and 31.88 C:N ratio. A UASB-type biogas plant that has a 500-m^3 capacity with 13,000 to 20,000 l per day feedstock. The biogas production was observed by flow meter for 90 days, and the average biogas production was about 560.37 m^3/day. The chemical energy of the biogas is converted to mechanical energy in a controlled combustion system by a heat engine. This mechanical energy then activates a generator to produce electric power. The slurry was in a liquid state. An average slurry output is 16,000 l per day. NPV of the biogas plant was about 7%, which means the project was profitable. 1.22 was the observed BC ratio of the project. BC ratio was more than 1 so the project is viable. The calculated payback period was 9 years. This means, that after the end of the payback period, the investment shows profitability.

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Authors' contributions
Kartikeya was conducted the experiment, Kavan Kumar prepared the manuscript draft and V Kumargouda has reviewed and corrected final manuscript.

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Availability of data and materials
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Declarations

Competing interests
The authors declare no competing interests.

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