Generation of Biogas Using Pine Needles as Substrate in Domestic Biogas Plant

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Abstract- Biogas is generated from anaerobic digestion of complex organic wastes. The present study focuses on efficient and cost effective use of biogas digester for the production of biogas from recalcitrant lignocellulosic waste (pine needles). Although production of biogas using anaerobic digestion has been employed in Himachal Pradesh but it is not as yet a successful technology due to various limitations. In the present study feasibility of a compact design of biogas plant is verified with the help of biogas plant installed in our university campus. It is found that biogas plant used for the study is suitable for places with low population density. The cellulose content in pine needles is found to be around 55% making it suitable biomass for energy generation. Pine needles used here as substrate were mechanically comminute to very fine size (1-2mm) before being co-digested with sewage waste water. It is noticed that biogas production peaked from1.4 l\day to1.9 l\day during winter month, where as it was7.3 l\day during months of March and April. The reduction in volatile solids was also noticed during the months of March and April which was close to 64% during April higher compared to its value in winters. The design of biogas plant was found suitable to a major part of Himachal Pradesh.

Keywords- Pine needles, anaerobic digestion, Biogas, Lignocellulose, Total solids, Volatile solids.

1. Introduction

Himachal Pradesh (latitude-31.007; longitude-77.088) – a northern hilly state of India had total population of 6,856,509 and out of this 6,167,805 (90%) is rural population as per 2011 Indian census. Himachal Pradesh has 67% of its total geographical area covered by forests [1]. Rural population depends on wood (more than 0.5 tonnes/capita/annum) for cooking which results in deforestation. Therefore, it is required to explore region specific best possible alternate energy resources e.g. bio-fuels which have emerged as an ideal choice to cater the energy requirements. In this context, biogas technology offers a very attractive route to utilize certain categories of biomass available in Himachal Pradesh for meeting partial energy needs.

In the present study Pine needles are utilized as feedstock for biogas production. The most distinguishing fact about Pine trees is their perennial nature of biomass. *Pinus roxburghii* is the one of the most dominant species in India covering an area of 8900 km^2 [2]. *Pinus roxburghii* grows at an altitude of 450-2300 m above mean sea level with best forests between 650 m to 1500 m above mean sea level [3]. Approximately 0.107 metric tonnes\ha of pine needles fall in a year. The pine needles fall mostly during pre-monsoon period (March to May) and as the fall of needles coincides with the hottest months of the year there are chances of pine needles causing forest fires [4]. The pine needles can also cause abortion in cattle and they may also inhibit the growth of various beneficial agricultural microbes [5, 6]. Removal of pine needles from forest floor is required to eliminate these hazards. As pine needles are locally available, it could very well support the survival and economic feasibility of biogas production for medium and small scale applications of energy production [7].

In fact proper functioning of pine-needle based biogas system can provide multiple benefits to the users and the community resulting in resource recovery and environmental protection. More than 35,000 biogas plants (Deenbandu design) were installed in rural areas in Himachal Pradesh during 1990s by the state Government, but as on today, most of the biogas plants are non functional due to various reasons explained thereafter. Cow dung as a substrate was used as feedstock in these biogas plants. In this study a new design of domestic biogas plant is tested, that is suitable for low population density (123/km^2) regions of Himachal Pradesh where rural households are segregated and have small family size. A portable, easy to maintain and economical biogas unit is installed and fabricated with 1000L fermentation tank and 750L gas holder at Jaypee University of Information Technology (JUIT) campus. The present study is aimed to develop and test the fabricated model of biogas unit for generation of biogas so that it may be utilized at house hold level in an efficient manner.

The recalcitrant pine needles were co-digested with sewage waste water. Co-digestion was adopted because it enhances pH buffer capacity, improves nutrient balance and optimizes rheological qualities that increase biogas production in a synergistic manner [8, 9]. In addition to this; mixing different wastes can dilute toxic compounds that may inhibit digestion such as ammonia and other organic compounds (oils and fats, lignin and lignin related compounds) [10].

2. Materials and Methods

2.1. Installation & Fabrication of Biogas Plant

A portable biogas plant was installed & fabricated at Jaypee University of Information Technology Waknaghat campus which is located at an altitude of 1544 m above sea level. Biogas plant consists of two plastic tanks: a digester of 1000 L capacity as fermentation tank and a gas holder of 750 L. Construction of the biodigester involved the contribution of various PVC fittings. These fittings include 12.5 mm galvanized iron elbow, barrel piece of 40 mm diameter, rigid PVC pipes of 90 and 63 mm diameter, 90 mm T with cap, 90 mm PVC socket, gas cork, nipple of 12.5 mm diameter, epoxy resin and hardner, PVC adhesive solution, Teflon Tape, gas rubber pipe and biogas stove. This model was initially developed by “Appropriate Rural Technology Institute”, Pune, Maharashtra, India (www.arti-india.org). This is an open access technology for sustainable development of society. Figure 1 shows the schematic view of biogas plant installed at Jaypee University Campus.

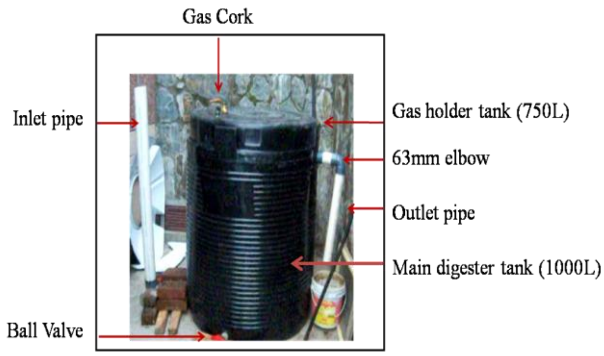
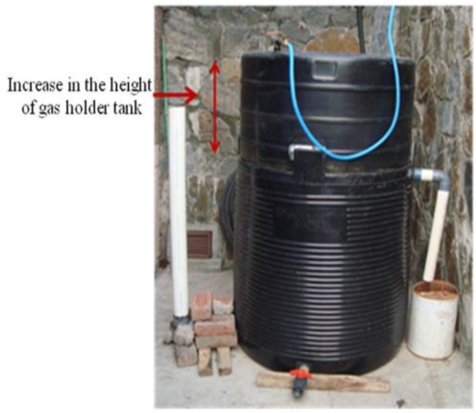


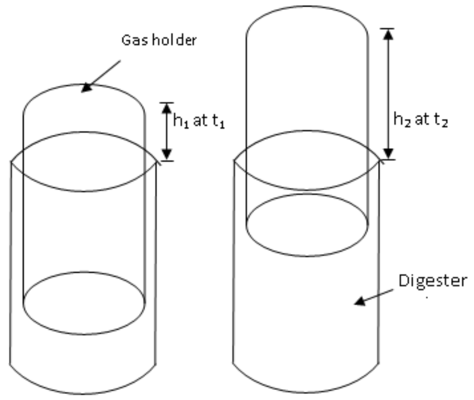
Fig. 1. Biogas plant installed at Jaypee University Campus

2.2. Preinoculum

Cow dung slurry was used as a preinoculum. Approximately 40kg of cow dung was mixed with almost 40L of water and all extraneous matter was removed from the mixture. All the lumps were broken and then mixture was filled in the digester. The digester tank was then completely filled with tap water. Gas holder tank was placed in inverted position over the digester tank with opened gas cork, and when gas holder tank sunk half way into the digester tank gas cork was closed and left as such for next 10 – 12 hr for checking the leakage from joints. After this gas cork was opened and tank was allowed to sink fully in digester (fermentation) tank and gas cork was closed. Thus gas production was indicated by the upliftment of gas holder tank. The Hydraulic retention time (HRT) was 25 days. Figure 2 (a & b) indicates the upliftment of the gas holder as a result of gas production.



(a)



(b)

Fig. 2. (a) Production of biogas indicated by increase in height of gas holder tank, (b) Upliftment of the gas holder at time t_1 and t_2

The volume of gas collected (V_g) in the gas holder at any instant of time may be computed by using the following equation (1):

$$V_g = \pi r^2 h \quad (1)$$

Here, r = radius of gas holder tank (0.45 m in present study)

$h = (h_2 - h_1)$

h = net increase in the height of gas holder in time $\Delta t = (t_2 - t_1)$

h_1 = initial position (height) of the gas holder at time t_1

h_2 = final position (height) of the gas holder at time t_2

2.3. Feedstock

Pine needles (*Pinus roxburghii*) were collected from the university campus. The needles were then dried overnight at 70ºC in an Incubator. Pine needles were ground to fine particles (1-2 mm in size) using an electric grinder (Fig 3a and b). 100 g of pine needles mixed with 2 litre of tap water and 1litre of sewage waste water was used as feed stock every alternate day.

(a)

(b)

Fig. 3. (a) Fallen pine needles on forest floor, (b) Ground pine needles.

2.4 Flame Test:- Flame test was carried out using the biogas produced from the digester. The rubber pipe (diameter – 0.5 inch) was connected to gas-stove for heating applications.

3. Results and discussion

The analysis of the samples taken from effluent was carried out. The ambient temperature and temperature inside the digester was determined every day using mercury glass thermometer. Total solids (TS), volatile solids (VS), cellulose, hemicellulose and lignin content of pine needles were determined using standard methods [11,12,13]. The total gas production was measured daily by the method described earlier.

As explained previously, pine needles collected from university campus were used as feedstock for biogas production. *Pinus roxburghii* needles (fresh) have cellulose – 55.73%, hemicelluloses – 11.80% and lignin – 21.5%. The holocellulose and lignin content in *Pinus roxburghii* determined in a previous study was determined to be 64.12% and 27.79%, respectively [6]. As pine needle has high amount of cellulose content that's why in the present study pine needles were used as a lignocellulosic biomass for biogas production. Before using pine needles, cow dung mixed with water was put into the digester for enriching the inoculum for a month. Hydraulic retention time was 25 days and the organic loading rate was 0.09gDS\L\day. Upliftment of gas holder was recorded daily. 200 L of biogas was measured in gas holder before addition of pine needles as feedstock. The study was based on the method of continuous feeding to the digester. Loading of the digester was done on alternative days. Every alternate day, slurry of 100g pine needles was made with 3litre tap water which was further mixed with 1litre waste water (3:1) and fed into the digester. The average temperature of the digester gradually decreased from 25^{0}C (mesophilic) in October to 14^{0}C (psychrophilic) in December. During the month of January and February the average digester temperature increased to 21^{0}C. The month of March (28^{0}C) and April (32^{0}C) showed the highest temperature inside digester. The biogas production was determined from the onset of winters (from late October) to the onset of summers (mid April). Figure 4 demonstrate the biogas production and the trend in temperature and solids reduction during different months. By considering 200 L as base line, a production of 100 L gas was noticed in a period of three months (October to December 2013). In the month of January and February, feedstock was added every alternate day from 20th January'14 to 26th February'14. A total of 70 litres of biogas was produced in this time period. In the month of March and April feedstock was added in the same way from 16th March'14 to 20th April'14. The total increment in the biogas production was found to be 250 litres. The study showed that during the start of digestion (October) there was low biogas production. The average biogas production during winters (October to February) was 1.7L\day compared to 7.1 L\day (March and April) during summers. This increment in biogas production during summers was mainly due to increase in average daily temperature and average temperature inside digester (Fig 5).

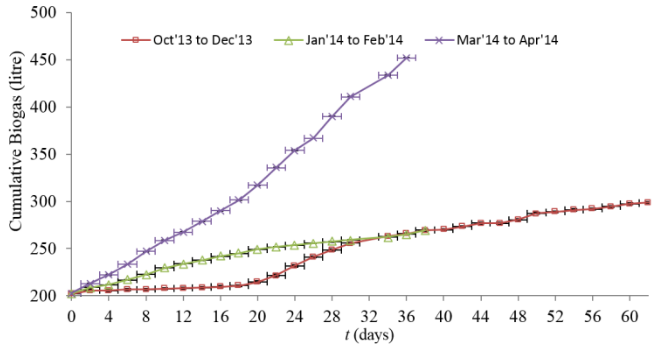


Fig. 4. Biogas production from October'2013 to April'2014 [Avg pH:- 7.3 (Oct'13 to Dec'13), 6.9 (Jan'14 to Feb'14), 7.5 (Mar'14 to Apr'14)]

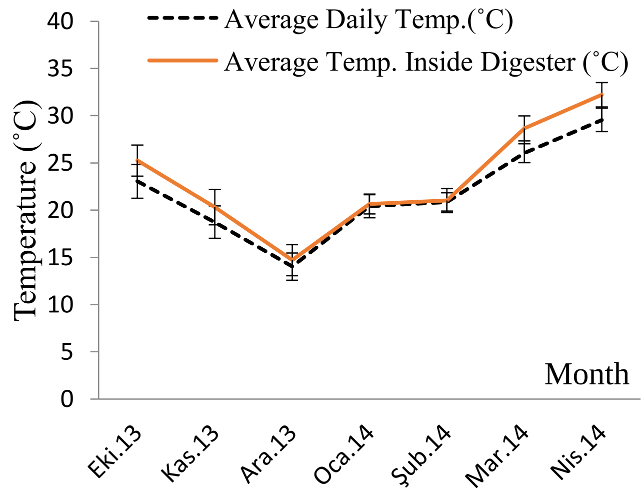


Fig. 5. Average daily temperature and average daily digester temperature during different months.

The fall in ambient temperature during winters also retarded the growth of active microbial population inside the digester that resulted in less solids reduction as shown in Fig. 6. These results were in accordance to some previous studies where it was shown that biogas production declined by 23-37% in winters [14]. The reason for low biogas production might be related to the chemical composition of pine needles as pine needles are recalcitrant type of feedstock which also contains about 10 to 13% tannins [15]. It has been reported in various studies that increased tannin concentration directly inhibits methanogens and reduces methanogenesis through a reduction in hydrogen availability [16].

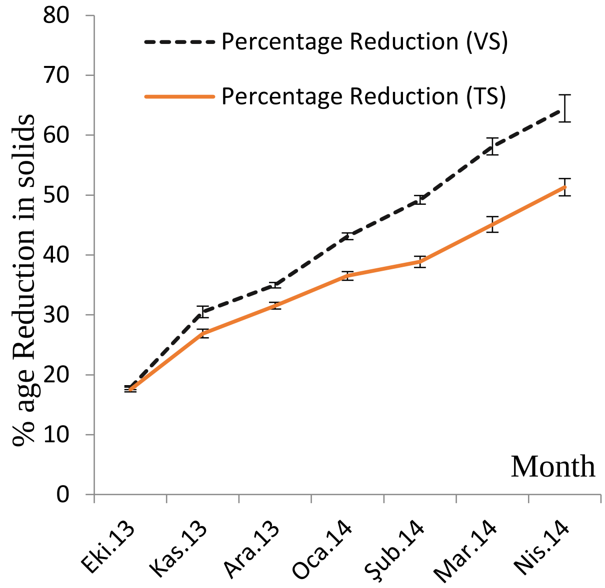


Fig. 6. Average percentage reduction in Total solids (TS) and Volatile solids (VS) during different months.

The relatively low biogas production can also be attributed to the psychrophilic digestion conditions inside the digester. Several studies conducted also reported that anaerobes in a biogas digester are active mostly under mesophilc and thermophilic conditions and the biogas production decreases drastically during winters when the condition inside the digester is mostly psychrophilic [17, 18, 19]. This is the first report on biogas production from pine needles using compact digester in hilly terrain. The present study was conducted in a natural environment without intentionally changing any parameters (pH, temperature and consortium). The study could very well serve as a reservoir for providing psychrophilic communities that are adapted for cold climates to produce biogas using recalcitrant substrate such as pine needles. Use of above ground portable model of biogas unit leads to easy maintenance.

All earlier approved models of biogas plants could not sustain in Himachal Pradesh (HP), India due to various limitations such as need of deep excavation., and small family size of rural house holds [15]. 'Floating Drum Type model' could not be implemented successfully due to heavy gas holder weight. Most popular biogas plant was Fixed Dome Type (Deenbandu Plant) in 1990s which was made up of bricks with cement-sand and mortar. However due to leakage, poor mainatenance, difficulty in construction having hard stony strata and no way to control the gas pressure, this design did not proove sustainable. Thereafter, Flexi Type biogas plants made up of neoprene rubber were also rejected due to fraglie design and low biogas efficiency. Lack of technical know-how was one of the main reason in the failure of all previous designs.

The biogas unit fabricated in the present study has several advantages over the previous conventional biogas plants. It is compact, leakage proof, runs on starchy/sugary waste, digestion takes 1-2 days under ideal environmental conditions compared to conventional biogas plants that run on low calorie substrates such as cow dung, human excreta with HRT 30-40 days. Gas measurement is easy and upliftment of gas holder is an indication of it (Fig. 2). The ignition of flame confirms the presence of methane in the digester. Spent slurry is used as a fertilzer. It can be placed on roof-top of a house, has low cost (INR 10000) and 2 kg of left over biodegradable kitchen waste prouduces around 200l of biogas that is equivalent to 45minutes of burning period [20]. A rural household saves 3 tonnes of wood/year which is equivalent to 5 tonnes of CO2/year. Cooking on biogas also reduces indoor pollution which is prevalent in rural households due to use of traditional stoves, wood, kerosene.

4. Conclusion

In the present study a portable biogas plant is suggested for production of biogas especially in hilly terrain having cold climate prevailing most of the time in the year (e. g. Himachal Pradesh). Pine needles are available in abundance in that area. These pine needles are used as a co-substrate with waste water in the study. The average biogas production during winters was decreased significantly compared to summers. This clearly indicated on one hand the applicability of pine needles to be used as a substrate for biogas production and on the other hand the effect of temperature on the amount of biogas produced. The results show that temperature is the major limiting factor for pine needles to be used as substrate for biogas production. However, the amount of cellulose content in fresh pine needles which was found to be greater than 50% makes it ideal for energy generation. The biogas plant suggested is compact and could be very suitable to be used as a source of energy generation in hilly terrains where the population is very sparse. Pine needles can be used very efficiently by rural people of Himachal Pradesh for biogas production. The biogas plant used in this study could be very easily used in local communities and schools.

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