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# Biogas generation from floral waste using different techniques

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**ABSTRACT**

There is a great need to implement low-cost and user-friendly methods for further propagation of biogas technology in India. Environment unfriendly disposal of floral waste causes serious environmental pollution. Literature shows a limited research work regarding the anaerobic digestion of floral waste for biogas generation. The present experimental work aims to propagate floral waste as a sustainable source of biogas energy in India. Using different techniques like novel alkaline pretreatment, solar heating of the digester and co-digestion with food waste give enhanced biogas production from floral waste. A novel alkaline pretreatment of the floral waste using sodium carbonate and sodium bicarbonate gives an improvement in biogas output by 106%, with a saving in the cost of chemical pretreatment up to 96%, compared to traditional sodium hydroxide pretreatment. Also, solar heating of the digester increases the biogas output by 122% as compared to digesters in ambient conditions. Co-digestion of the floral waste with food waste also improves biogas output by 32.6%. Raw biogas from floral waste contains over 57% methane, which is higher than the previous studies. Large-scale application of the techniques can benefit the society.

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## INTRODUCTION

Huge quantities of floral waste are available from famous temples across India. These flowers have a short lifespan and the floral waste is seldom used for other applications. Conventional methods of floral waste disposal include disposal in nearby water sources or in the landfill. Both the methods create environmental pollution and emission of greenhouse gases into the atmosphere due to aerobic decomposition of the waste material. Thus there is a need for an environment-friendly and energy efficient solution to the problem of floral waste disposal. Literature shows a limited research work regarding anaerobic digestion of floral waste for biogas generation. Research studies mention the effectiveness of anaerobic digestion as alternative and efficient technology, which combines biofuel production and sustainable waste management (Bharathiraja *et al.,* 2018). Anaerobic digestion process of organic waste materials has a potential to produce useful biogas with considerable methane percentage (50 to 70%) and to reduce the environmental emissions, otherwise caused by

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aerobic decomposition of organic waste materials. Besides this, according to the Kyoto Protocol, methane is one of the key greenhouse gases with global warming potential 25 times more than the carbon dioxide potential. Thus, utilization of methane serves the two-fold purpose of fulfilment of energy needs and also a reduction in the methane emission into the atmosphere (Rashed and Torii, 2015). In addition to reduced methane emissions, biogas technology in the agricultural sector creates impact on environment, social and hygienic issues. Anaerobic digestion process has four different operational aspects which include the pretreatment, digestion, gas upgrading and digestive treatment (Monnet, 2003). Multi-disciplinary advances in microbiology, biochemistry, and engineering science help for better understanding and process control of the anaerobic digestion phenomenon (Wang *et al.,* 2012). The total biogas production in India is 2.07 billion $m^3$/year, which is very less compared to its estimated potential of 29–48 billion $m^3$/year (Mittal *et al.,* 2018). Ample literature is available regarding the anaerobic digestion of different waste materials, the methods used for improving biogas output and co-digestion of different waste materials. But the availability of similar literature regarding the anaerobic digestion of floral waste is limited. A laboratory scale experimental study investigates the biogas production potential of various waste materials, like animal dungs, kitchen wastes and waste flowers (Mandal and Mandal, 1997). Another experimental research focuses on the potential of floral waste as an alternate energy source, using a prototype digester of 2 $m^3$ capacity. Fresh and untreated flower waste cannot produce maximum digestion and biogas production. Floral waste needs alkaline chemical pretreatment for biogas production, which is carried out by using calcium carbonate ($CaCO_3$). Biogas production and methane ($CH_4$) content in biogas are less in winter, because of reduced microbial activities at lower digester temperature (Singh and Bajpai, 2011). A useful laboratory scale experimental research work attempts to find out the feasibility of biogas generation from the floral waste of Marigold, *Datura, Ankra*, Rose and leaves of bel. The experimental set-up comprises laboratory scale digesters of 1.5 liters (L) capacity, maintained at 30°C, with 35 days retention time. The experiments were carried out without pretreatment and also with pretreatments like drying, milling and chemical pretreatment using sodium hydroxide (NaOH). The results indicate that the floral waste has a good biogas generation potential. Drying, mechanical pretreatment and alkaline chemical pretreatments are necessary for biogas production (Singh *et al.,* 2007). Biogas generation potential of various supermarket waste materials in an anaerobic digester to recover a source of renewable energy is studied in experimental work. The highest methane output of 0.40 L per gram of volatile solids is obtained from fruit, vegetable, flower waste (FVFW) at 5% total solid contents (Alkanok *et al.,* 2014). Another laboratory experimental investigation uses one liter (L) capacity anaerobic digester using vegetable wastes and flowers of jasmine, sunset flower, Roselle, African wattle, Nile tulip flower and silk tree mimosa. The floral waste gives higher biogas yield than the vegetable waste (Ranjitha *et al.,* 2014). Basil leaves also have a biogas generation potential. The experimental study use laboratory scale digesters of 2.5 L capacity with a retention time of 30 days and operate at ambient temperature using basil leaves as the feedstock (Swapnavahini *et al.,* 2014). The digester temperature, pH of the slurry, retention time, feeding frequency and the use of catalysts for biogas generation has a major impact on volume and quality of biogas produced (Sambo *et al.,* 1995); (Mandal and Mandal, 1998; Laskari and Nedjah, 2015; Zealand *et al.,* 2017). Various pretreatments like mechanical pretreatment, chemical pretreatment, thermal pretreatment or biological pretreatment applied to the feedstock are effective for enhancement of biogas production from the digester. Pretreatment of the feedstock increases its biodegradability by opening its structure, making it more accessible for the enzymatic attack (Sambusiti *et al.,* 2013). Experimental investigation of alkaline pre-treatment of ensiled sorghum forage using sodium hydroxide increases methane production (Sambusiti *et al.,* 2012). Application of two mechanical pretreatments in the form of biomass washing with tap water and further manual chopping gives twice the biomethane generation from marine micro algae (Pastare *et al.,* 2016). Improvement in biogas production has been obtained from rice straw using sodium carbonate pretreatment. Maximum biogas production of 292 ml of $CH_4$ per gram of volatile solids is obtained by using 0.5 Molar sodium carbonate at 110°C for 2 h duration. Untreated rice straw produced 130 ml of $CH_4$ per gram of volatile solids, with an increase in biogas production of 125.38% (Dehghani *et al.,* 2015). Acidic chemical pretreatment causes hemicellulose solubilization and alkaline chemical pretreatment is more effective in lignin removal. The alkaline chemical pretreatment creates the saponification and cleavage of lignin-carbohydrate linkages, increases the porosity and internal surface area of biomass, and decreases the degree of polymerization and crystallinity of feedstock. The residual alkali in biomass with alkaline pretreatment can help to prevent a drop in pH during the acidogenesis step (Rodriguez *et al.,* 2017). Biogas production from paddy straw (PS) increased by 54.4% by applying sodium carbonate pretreatment. Paddy straw was pretreated with different concentrations of sodium carbonate by soaking in sodium carbonate solution for durations of 24 h and 48 h to enhance the digestibility (Kaur and Phutela, 2016). Biogas production from sugarcane bagasse is increased by 339% due to pretreatment with 0.5 Molar sodium carbonate at 140°C. Sodium sulfite and sodium acetate were used as other two chemicals for pretreatment (Nosratpour *et al.,* 2018). The biogas production depends on the digester temperature. Use of solar energy for digester heating gives higher biogas output (Agrahari and Tiwari, 2011; Kocar and Eryasar, 2007; Kumar and Kasturi Bai, 2008). Co-digestion of suitable substrates for biogas generation can give improved biogas output, as compared to output given by a single substrate (Mashad and Zhang, 2010; Nayono *et al.,* 2010; Shitu *et al.,* 2015; Wu, 2010). One of the experimental study suggests that vermicomposting of temple waste is an excellent and ecofriendly method of temple waste management (Gurav and Pathade, 2011). Another attempt has been made for converting the floral waste into activated carbon by direct pyrolysis process and chemical activation with sulfuric acid and phosphoric acid (Elango and Govindasamy, 2018). Still another attempt has been made for natural dye recovery from temple waste and various household wastes (Singh *et al.,* 2017). Removal of carbon dioxide and hydrogen sulfide by using an appropriate technique improves the biogas quality (Tippayawong and Thanompongchart, 2010). Removal of hydrogen sulfide from biogas is highly recommended because it causes health hazards and also the corrosion of burners, storage tanks, and engine components (Shah and Nagarseth, 2015). It is recommended to remove hydrogen sulfide from biogas for all the applications like boiler, kitchen stove, stationary engines, vehicular applications or injection into natural gas grid (Wellinger and Lindberg, 2000). It is seen that there are many substrates of plant and animal origin suitable for biogas generation, like food waste, energy crops, aquatic plants and many more. Comparatively, less attention has been paid towards the use of floral waste as a source of bio-energy. A limited amount of research work related to the anaerobic digestion of floral waste suggests the use of drying, mechanical and alkaline chemical pretreatment for biogas generation. But the attempts for improvement in biogas production, use of a variety of chemicals for pretreatment, or the attempts towards a reduction in the pretreatment cost are not seen from the literature. Also, the techniques for improving biogas yield such as co-digestion with other substrates and solar heating of the digester are not experimented with floral waste feedstock. The research related to these aspects is still in an early stage and there is a need to explore more widespread, cost-effective and user-friendly methods for generating biogas from floral waste. The objective of this study is addressed to evaluate the potential of floral waste feedstock for becoming a practical source of biogas energy in India. The study further aims to get improved biogas production from floral waste by using novel alkaline pretreatment, solar heating of digester and co-digestion with food waste. The details regarding the same are discussed in the following sections. The present experimental study has been carried out at Pandharpur, District Solapur, Maharashtra, India in 2015.

## MATERIALS AND METHODS

The present experimental study comprises a series of experiments conducted for biogas production, and enhancement in biogas output using floral waste as the feedstock. The prominent constituents of the floral waste available from the local *Vitthal Rukmini* temple include *aster* flowers, marigold flowers and basil leaves. The moisture content in the flowers is between 75 to 80% or the solid content in the flowers is in between 20 to 25%. Carbon: Nitrogen ratio for the floral waste is measured before start up experiments in the laboratory and its value is found to be 21:1, which shows its suitability as a feedstock for the anaerobic digestion process. For this purpose the floral waste is dried and the sample contents are analyzed in the laboratory by using dry combustion method. The laboratory reports indicate organic carbon content of 48.32% and nitrogen content of 2.32% (C:N ratio is 21:1). The experiments for biogas generation are conducted in floating drum type digesters of 3.5 L capacity. Initially pilot experiments are conducted to understand the suitable conditions for further experimental work and the need of different pretreatments for anaerobic digestion of the floral waste. It is understood from the first pilot experiment and also from the literature that biogas generation cannot take place from untreated flowers. The drying pretreatment of flowers helps efficient cutting of the feedstock into smaller pieces by using mechanical pretreatment. Drying, mechanical pretreatment and alkaline chemical pretreatments are applied to the feedstock. Sodium hydroxide is used for alkaline pretreatment during the pilot experiments, as the reference from the literature. Then sodium carbonate and sodium bicarbonate have been used for alkaline chemical pretreatment of floral waste during the actual experimental work. To obtain improved biogas production solar heating of the digester and co-digestion of floral waste with food waste has been carried out. Following text gives the details of experimental studies conducted by the authors.

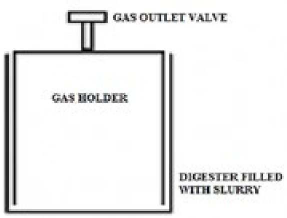


Fig. 1: Floating drum digester (drum in drum type) of 3.5 L capacity

*Experimental set up*

Experimental work for anaerobic digestion of floral waste is carried out using floating drum digester of 3.5 L capacity, shown in Fig. 1.

The gas holder of 3 L capacity is kept inverted over the feedstock slurry in the digester. A gas outlet valve provided at the top of the gas holder facilitates removal of biogas produced and also removal of air inside the gas holder at the beginning of the experiment. The drum in drum type digester is convenient from the manufacturing aspect and also suitable for measurement of biogas volume generated. The digester and the gas holder are made up of plastic (polyethylene) material to ensure minimum corrosion caused by the slurry and the chemicals. The initial experimental results got for

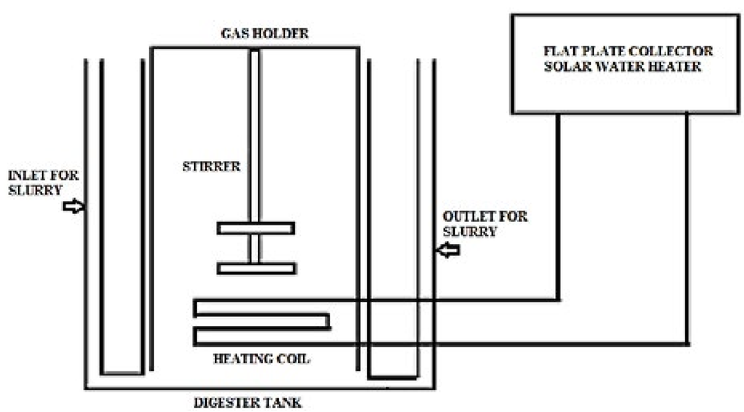


Fig. 2: Schematic representation of the prototype digester of 230 L capacity with a stirrer and solar heating of the digester

the chemical pretreatment and solar heating of the digester are verified on a larger scale in a prototype digester shown in Fig. 2.

The prototype digester has a capacity of 230 L and the gas holder capacity is 200 L. Both the digester and the gas holder are made of plastic (polyethylene) material to avoid the corrosion problem. The gas holder is provided with an inbuilt stirrer and a gas outlet valve. The inbuilt stirrer fitted inside the gas holder facilitates stirring of the digester slurry, caused by up and down motion of the gasholder. The gas holder with inbuilt stirrer is particularly useful for scum breaking and eliminates the need for manual stirring. Provision of digester heating using hot water from a solar water heater aims to improve the biogas output in winter or at low-temperature conditions of the digester. A heating coil of 12 mm diameter and length 3.4 m, made up of galvanized iron is inserted through the digester slurry (Fig. 2). Hot water from flat plate solar water heater (300 L per day capacity) is circulated through the coil. The temperature of hot water from solar water heater is around 60°C. Flow rate of hot water through the coil is adjusted, so as to maintain the slurry temperature (around 30°C) above the ambient temperature in winter.

*Preparation of the feedstock slurry and digester feeding*

The floral waste is initially dried and then given the mechanical pretreatment of crushing by a hand-operated device, which eliminates the use of electricity for the pretreatment. The dried and ground floral waste is soaked in an alkaline solution of one of the chemicals like sodium hydroxide (NaOH), sodium carbonate (or caustic soda, $Na_2CO_3$) or sodium bicarbonate (or baking soda, $NaHCO_3$) for 24 hours (h). Slurry for the digester feeding is prepared from chemically treated flowers by adding an adequate quantity of water. Total solid content in the slurry is maintained around 5-7% by mass. Gasholder is then placed inverted on the feedstock slurry. The air present inside the gasholder in the initial condition is removed by opening the gas valve provided on the top of the gasholder. After removal of the initial air, closing of the gas valve isolates the slurry from atmospheric air, to ensure anaerobic conditions for biodegradation of the slurry. To start the process of anaerobic digestion, an inoculum containing anaerobic bacteria from existing biogas plant is added to the slurry. The inoculum to feedstock ratio maintained is 10% by volume during start-up of the experiment. The contents of inlet slurry include organic carbon 3.2%, nitrogen 0.17% and crude fat 0.43% while these contents in the digested slurry have the values 0.75%, 0.12% and 0.08% respectively. Thus the reduction of total solids during the anaerobic digestion is 77%.

Table 1: Details of the pilot experiments performed and their outcomes

| Aim of pilot experiment | Reactors description | Pretreatments used | Feedstock and chemicals used | Findings |
|---|---|---|---|---|
| To ensure the necessity of all pretreatments | Fixed dome digester of 40 L capacity | No pretreatments | A mixture of fresh flowers | No biogas generation from fresh and untreated flowers |
| To check the usefulness of floating drum digester | Floating drum digester using buckets | Drying, mechanical and chemical pretreatments | A mixture of flowers with NaOH pretreatment | Biogas generation seen for the first time. Gasholder floating observed |
| To check the effectiveness of only chemical pretreatment | Floating drum digester of 5 L capacity | Chemical pretreatment only using NaOH | A mixture of flowers with NaOH pretreatment | Only chemical pretreatment gives less biogas output |
| To find out biogas generation potential of six types of flowers | Floating drum digester of 5 L capacity | Drying, mechanical and NaOH chemical pre-treatment | Rose, velvet, *nishigandh, shevanti,* aster and marigold flowers. | Aster and marigold flowers have good biogas generation potential and available in large quantity |
| Use of domestic substances for chemical pretreatment | Floating drum digester of 5 L capacity | Drying, mechanical and chemical pretreatments | Aster flowers and Chemicals $Ca(OH)_2$ (calcium hydroxide) and tomato juice | Very little biogas generation observed |
| Optimizing the dose of NaOH pretreatment and cost calculations | Floating drum digester of 5 L capacity | Drying, mechanical and chemical pretreatments | Marigold and aster flowers. Chemical used- NaOH | For 100 g (grams) flowers 8 g NaOH for marigold and 4 g NaOH for aster |

*Measurement of biogas volume, contents and the flame test*

The uplift of the gas holder confirms biogas generation from the reactor. Also, any leakage of biogas from the gas holder is indicated by a downfall of gasholder. The volume of biogas generated can be measured by multiplying the cross-sectional area of the gas holder and its uplift caused due to gas generation. Biogas generated is taken out from the gas outlet and tested for flammability by bringing the gas into contact with a flame. The biogas from floral waste becomes flammable after 6 to 8 days from the beginning. Use of a modified LPG (Liquefied petroleum gas) stove eliminates the need for a separate biogas stove. The contents of biogas are checked by using gas chromatography.

*Pilot experiments*

The literature availability about the anaerobic digestion of floral waste is limited. Hence, pilot experiments are conducted initially to decide the future course of action for further experimental work. Pilot experiments include use of fixed dome and floating drum digesters, six different types of flowers as a feedstock, digestion of the waste with and without pretreatments, use of different materials for chemical pretreatment and optimization of NaOH dose for alkaline pretreatment etcetera. A brief overview and findings from pilot experiments are represented in Table 1.

*Experiment for biogas enhancement using solar heating of the digester*

The first experiment comprises enhancement in biogas generation from aster and marigold flowers using solar heating of the digester. The reactors used include eight stainless steel digesters, each of 5 L capacity. Out of eight digesters four digesters are kept in ambient conditions and the remaining four digesters are kept in hot water bath from solar water heater. The digesters are fed with 150 g of pre-treated aster or marigold flowers. Initially, the flowers are given drying and mechanical pretreatments. For alkaline chemical pretreatment the flowers are soaked for 24 h, in a separate container with NaOH solutions of varying concentrations. The feedstock after chemical pretreatment is then fed to the digester. The concentration of NaOH used for chemical pretreatment of aster flowers is 0.04 g/g-TS and 0.0533 g/g-TS, while that for marigold flowers is 0.08 g/g-TS and 0.1066 g/g-TS. Reactors with the same feedstock composition and pretreatment are placed in ambient conditions and also in a hot water bath maintained at 50°C. The cumulative volume of biogas generated is calculated by multiplying the cross sectional area of the gas holder and rise in its level due to biogas generation. Observations about the volume of biogas generated in ambient conditions and hot water bath are as shown in Fig. 3.

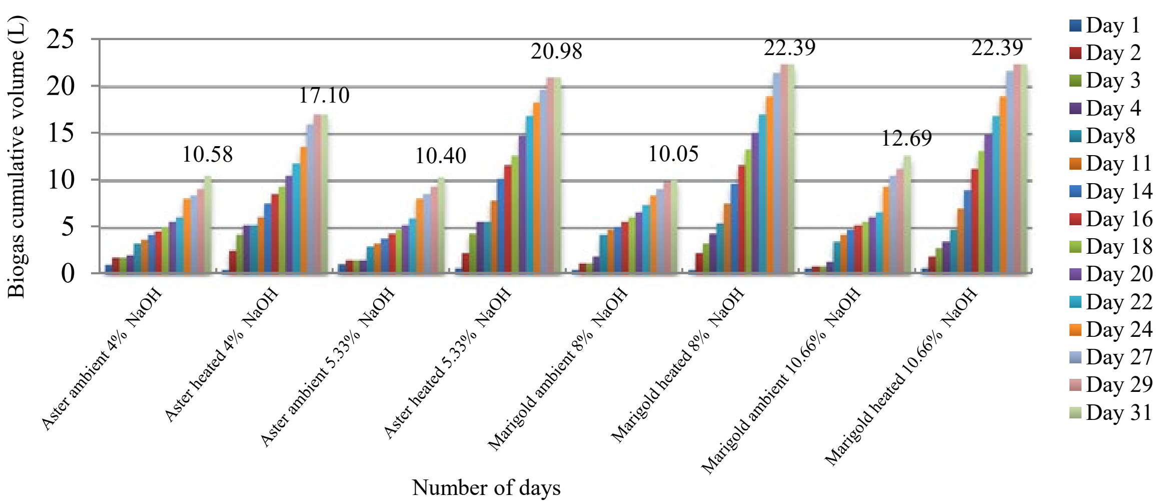


Fig. 3: Biogas generation from aster and marigold flowers (150 g) with and without solar heating of the digester

*Experiment for alkaline pretreatment of floral waste using sodium carbonate*

The literature mentions about the use of chemicals sodium hydroxide and calcium carbonate for alkaline pretreatment of floral waste. The second experiment comprises alkaline pretreatment of floral waste by using a new chemical, sodium carbonate or caustic soda ($Na_2CO_3$). The application of sodium carbonate (and sodium bicarbonate) pretreatment is intended to reduce the acidic nature of the untreated floral waste and to improve its biodegradability. The selection of sodium carbonate for chemical pretreatment is advantageous because it is less corrosive, available in the local market and cheap as compared to sodium hydroxide. Initially, 150 g of aster and marigold flowers are given drying and mechanical pretreatment. Chemical pretreatment is then applied by soaking the flowers for 24 h in sodium carbonate solution in a separate container outside the digester. The flowers after chemical pretreatment are fed to the digester. The concentration of sodium carbonate used for chemical treatment of aster flowers is 0.12 g/g-TS and 0.16 g/g-TS of $Na_2CO_3$. Fig. 4 shows the observations regarding biogas generation during the experiment. The biogas generation and the chemical pretreatment costs are compared with those calculated using NaOH pretreatment during pilot experiments. The comparison of chemical pretreatments is represented in Table 2. Authors believe that sodium carbonate (and also sodium bicarbonate mentioned in the further text) has been used for the first time for alkaline pretreatment of floral waste and have filed an Indian patent for the system and method of biogas generation.

*Operation of a prototype digester*

The third experiment comprises implementation of the findings from the first and the second small-scale experiments in a prototype digester of 230 L capacity. Fig. 2 shows the prototype digester of 230 L capacity with a stirrer and a provision for solar heating. The digester operates with a daily feeding of 350 g of dried temple waste, which contains a mixture of different flowers and basil leaves. The prototype digester runs with no operational troubles and produces flammable biogas used for cooking. The operational parameters measured during the run of prototype digester include temperature and pH of the digester slurry, ambient temperature and cumulative volume of biogas produced from the digester. During continuous operation for 29 days the prototype digester produces 628 L of biogas. The slurry temperature is maintained between 26-32$^{o}$C whereas the minimum ambient temperature ranges between 21-24$^{o}$C. The pH of the slurry inside the digester ranges between 5.5 and 6.4 during the operation.

*Experiment for alkaline pretreatment of floral waste using sodium bicarbonate*

In the fourth experiment, sodium bicarbonate or baking soda ($NaHCO_3$) has been used for alkaline pretreatment of aster flowers. Floral waste is initially given drying and mechanical pretreatment. Then it is soaked for 24 h in a separate container outside the digester as before. The chemically treated floral waste is then fed to the digester. The sodium bicarbonate concentration for alkaline pretreatment of aster floral waste is varied as 0.12 g/g-TS, 0.16 g/g-TS, 0.20 g/g-TS and 0.24 g/g-TS. Sodium bicarbonate pretreatment of the floral waste is also believed to be a novel pretreatment which gives improved biogas output at reduced pretreatment cost as shown in Fig. 5.

Table 2: Comparison of Sodium Hydroxide and Sodium Carbonate pretreatments for Aster and Marigold flowers

| Name of flower | Volume of biogas generated per kg of dried flower (L) | | | Cost of pretreatment per liter of biogas ($US) | | | Mass of chemical per kg of dried flower (g) | | Cost of 1 kg chemical ($US) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | NaOH Pretreatment | $Na_2CO_3$ Pretreatment | Rise in volume (%) | NaOH Pretreatment | $Na_2CO_3$ Pretreatment | saving in cost (%) | NaOH | $Na_2CO_3$ | NaOH | $Na_2CO_3$ |
| Aster | 41.14 | 84.83 | 106.2 | 0.011 | 0.001 | 90.3 | 40 | 160 | 10.92 | 0.55 |
| Marigold | 49.36 | 100.4 | 103.4 | 0.018 | 0.00066 | 96.3 | 80 | 120 | | |

*Experiment for Co-digestion of floral waste and food waste*

The fifth experiment explores the feasibility of co-digestion of floral waste with food waste, for getting improved biogas output. The major source of the floral waste in India is the temples at holy places. The availability of food waste is also abundant at these places. Four different reactors of 3.5 L capacity are fed with a 100 g mixture of aster flower waste and food waste. The aster flowers in each reactor are given 0.16 g/g-TS of $Na_2CO_3$ pretreatment. The mass of the food waste in the mixture is maintained at 0%, 10%, 20% and 30%. The limiting proportion of food waste has been chosen as 30%, considering that the food waste at holy places is less available in comparison with the floral waste. The experimental results for co-digestion of floral waste and food waste are represented in Fig. 6.

## RESULTS AND DISCUSSIONS

*Pilot experiments and related findings*

Table 1 summarizes the details of the pilot experiments performed and their outcomes. Based on the findings of pilot experiments, authors have selected aster and marigold floral waste as feedstock, floating drum digester, drying, mechanical and alkaline chemical pretreatments of the feedstock for conducting further experiments related to improvement in biogas volume.

*Enhanced biogas production using solar heating of the digester*

Fig. 3 shows the comparison of results between the biogas volume generated from reactors in ambient conditions and the reactors placed in hot water bath. Reactors kept in hot water bath give higher biogas generation than the reactors kept in ambient

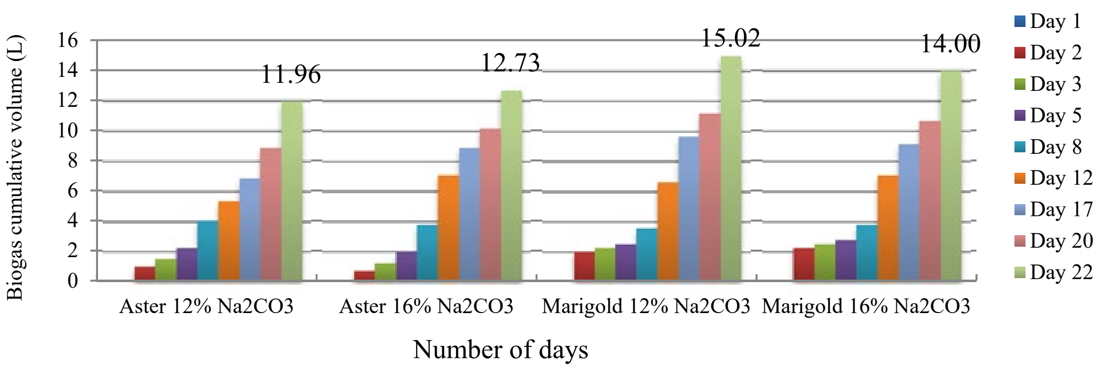


Fig. 4: Biogas generation from aster and marigold flowers (150 g) using sodium carbonate pretreatment

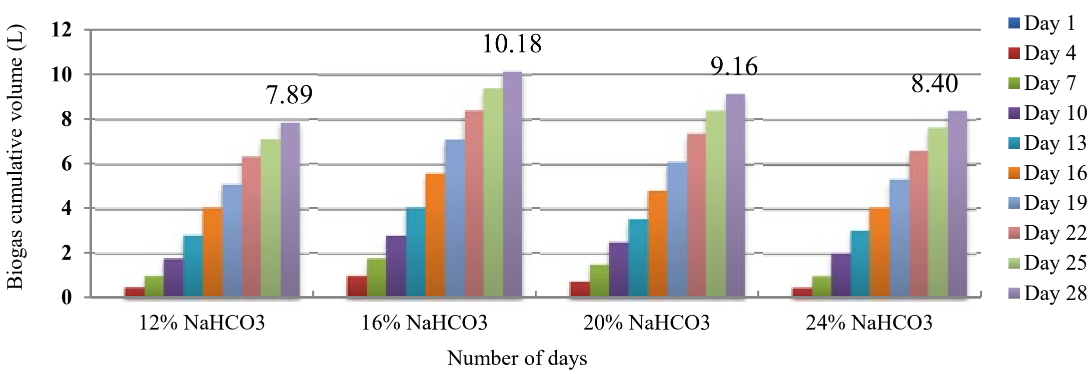


Fig. 5: Biogas generation from aster flowers (100 g) using sodium bicarbonate pretreatment

conditions. Biogas generation from all the reactors continues upto 31st day from the beginning. Thereafter negligible generation of biogas takes place from the reactors. The other experimental runs in the present work show biogas generation for 28 days or less. The effect can be attributed to increased biodegradation of the feedstock due to increased microbial activities at elevated temperature inside the digester.

The first pair of reactors comprises aster flowers treated with 0.04 g/g-TS of NaOH. The reactor kept in hot water bath gives 61.63% improvement in biogas production due to the digester heating. The second pair of reactors comprises aster flowers treated with 0.0533 g/g-TS of NaOH. The reactor kept in hot water bath gives 101.73% improvement in biogas production due to the digester heating. In case of the third pair of reactors comprising marigold treated with 0.08 g/g-TS of NaOH the solar heating of the digester gives 122.79% more biogas. The fourth pair of reactors comprising of marigold flowers treated with 0.1066 g/g-TS of NaOH shows 76.44% improvement in biogas production due to the digester heating. The maximum volume of biogas produced is 22390 ml per 150 g of feedstock, or 149.26 Nml/g-TS of dried flower waste, using solar heating of the digester. This is an important finding which enables to increase the biogas output in winter or at low ambient temperature conditions, by using solar heating of the digester.

*Alkaline chemical pretreatment using sodium carbonate*

Fig. 4 shows the cumulative volumes of biogas produced by 150 g of floral waste. Biogas generation from all the reactors continues upto 22nd day from the beginning. Thereafter negligible generation of biogas takes place from the reactors. The reduction in retention time and improvement in biogas output are obtained by sodium carbonate pretreatment.

The calculated volumes of biogas per gram of dried floral waste are 79.73 Nml/g-TS, 84.86 Nml/g-TS, 100.40 Nml/g-TS and 93.33 Nml/g-TS for the reactors 1, 2, 3 and 4 respectively. Sodium carbonate pretreatment gives higher biogas output as compared to sodium hydroxide pretreatment and gives a considerable reduction in the cost of chemical pretreatment. Table 2 mentions the details of biogas output and the associated chemical pretreatment costs.

It is observed that by using sodium carbonate pretreatment the volume of biogas generation can be increased up to 106% with at least 90% reduction in the cost of chemical pretreatment, as compared to sodium hydroxide pretreatment. The laboratory reports indicate methane content of 57.52% and carbon dioxide content of 26.28% in biogas produced by the anaerobic digestion of floral waste.

*Alkaline chemical pretreatment using sodium bicarbonate*

Fig. 5 shows the results of biogas generation from 100 grams of aster flower with sodium bicarbonate pretreatment.

Thus the calculated volumes of biogas per gram of dried floral waste are 78.9 Nml/g-TS, 101.8 Nml/g-TS, 91.6 Nml/g-TS and 84 Nml/g-TS for the digesters 1, 2, 3 and 4, respectively.

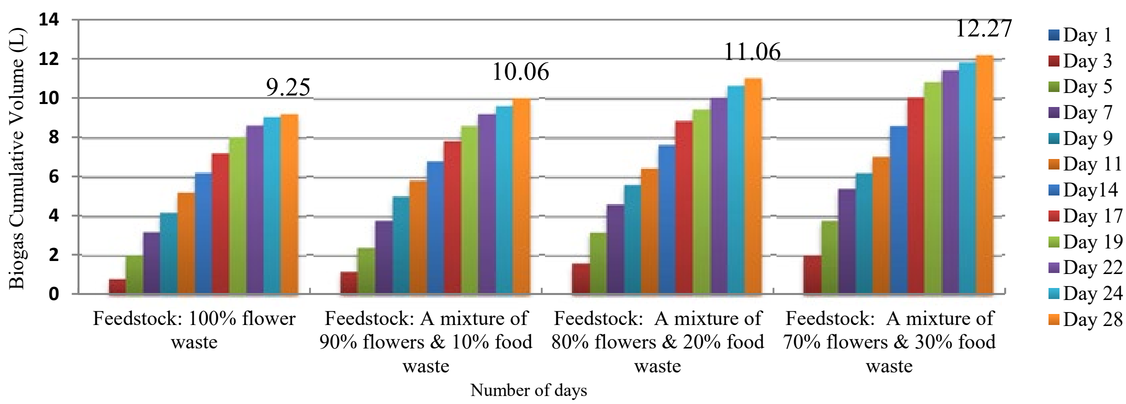


Fig. 6: Biogas generation from co-digestion of mixture of floral waste and food waste (100g)

Table 3: Comparison of results and details of experimental work for the present and previous works

| Results obtained | Details of experimental work | References |
| --- | --- | --- |
| ■ Max. biogas production from 75 g (25% by weight in 0.3 liters slurry) of flower waste and equal quantity of cow dung is 2.6 L<br>■ Biogas generation capacity of flowers arranged in ascending order is: sunflower, season flower, mixture of flowers, marigold, modar flower<br>■ Biogas generation capacity of different waste materials arranged in ascending order is: banana peels, potato leaves, modar flower, horse dung<br>■ Results of biogas content analysis are not provided | ■ Laboratory scale digesters of 0.5 L capacity<br>■ Study on different waste materials like animal dung, kitchen waste, waste flowers and waste leaves<br>■ Flowers used: Mixture of flowers, sunflower, marigold, modar flower and season flower<br>■ Slurry volume: 300 ml. Contains 50% water, 25% flowers and 25% cow dung by weight.<br>■ Retention time: 90 days<br>■ Total solid content: 50% (25% cow dung + 25% waste flowers). Ratio of flowers: cow dung: water is 1:1:2 by weight<br>■ Inoculum quantity: 25% by weight<br>■ Pretreatments not described | Mandal and Mandal, 1997 |
| ■ Floral waste needs drying, mechanical and alkaline chemical pretreatment for biogas generation<br>■ Max. biogas production from 120 g (8% total solids in 1.5 liters slurry) of dried and ground flower waste is 12.9 L<br>■ Results of biogas content analysis are not provided | ■ Laboratory scale digesters of 1.5 L capacity<br>■ Retention time: 35 days<br>■ Flowers used: Marigold, Dhatura, Ankra, Rose and leaves of *bel*<br>■ Total solid content: 8%<br>■ Inoculum quantity: 10% of digester volume<br>■ Physical pretreatment (drying & grinding) and chemical pretreatment<br>■ Chemical used: Sodium Hydroxide (NaOH)<br>■ Optimum dose of NaOH chemical pretreatment: 6% of the feedstock mass<br>■ C:N ratio of 30.59:1 | Singh *et al.,* 2007 |
| ■ Fresh and untreated flower waste cannot produce maximum biogas<br>■ Floral waste needs mechanical and alkaline chemical pretreatment for biogas generation<br>■ Biogas with methane content of 50% can be efficiently produced from flower waste<br>■ Methane content and biogas yield is affected by seasonal variations<br>■ Methane content of 44-50% is obtained in winter and methane content of 50-54% is obtained in summer | ■ Prototype digester of 2 $m^3$ capacity<br>■ Working of the digester started with 2 kg of flower waste, 5 kg of cow dung and 30 L water<br>■ Continuous operation in winter and summer with daily feeding of 2 kg flowers<br>■ Flowers used: Marigold, Rose and Sunflower<br>■ Retention time: 35 days<br>■ Total solid content: 8%<br>■ Innoculum used: cow dung<br>■ Physical pretreatment of chopping and chemical pretreatment<br>■ Chemical used: Calcium carbonate ($CaCO_3$)<br>■ Biogas contents analysis by using gas chromatography | Singh and Bajpai, 2011 |
| ■ Withered flowers have higher biogas yield than vegetable wastes<br>■ Withered flowers can produce 16.69 g/kg of biogas in 4.5 days<br>■ Unit conversion gives 14.51 L biogas per kg of withered flowers in 4.5 days<br>■ No data available about biogas contents analysis | ■ Laboratory digesters of 1 L capacity and cow dung inoculum<br>■ Anaerobic digestion of vegetable waste and flower waste<br>■ Flower waste contains Jasmine, Sunset flower, Roselle, African Wattle, Nile Tulip flower and silk tree mimosa<br>■ Substrate concentration: 5%, 7% and 10% | Ranjitha *et al.,* 2014 |
| ■ Enhanced biogas production by using sodium carbonate and sodium bicarbonate up to 106% and reduction in pre-treatment cost up to 96%<br>■ Solar heating of the digester improves biogas yield by 122%<br>■ Co-digestion of flower waste and food waste improves biogas output by 32.60%<br>■ Methane content in biogas is 57%<br>■ Methane content is further enriched up to 96.91% by using chemical absorption technique (not described in this manuscript) | ■ Pilot experiments and further experiments in floating drum digesters of 3.5 L capacity<br>■ Use of sodium carbonate and sodium bicarbonate pretreatment for alkaline pretreatment<br>■ Biogas yield improvement using solar heating of the digester and co-digestion with food waste<br>■ Biogas contents analysis using gas chromatography | **Present work** |

From Figs. 4 and 5 it is observed that the dried aster flowers produce 84.86 Nml/g-TS of biogas with 0.16 g/g-TS of $Na_2CO_3$ pretreatment, and 101.8 Nml/g-TS of biogas with 0.16 g/g-TS of $NaHCO_3$ pretreatment.

*Co-digestion of floral waste and food waste*

The experimental results from Fig. 6 show that the co-digestion of floral waste and food waste gives improved biogas output in comparison with the pure floral waste. Biogas generation from all the reactors continues upto 28$^{th}$ day from the beginning. Thereafter negligible generation of biogas takes place from the reactors. The calculated volume of biogas from feedstock in the reactors 1, 2, 3 and 4 are 92.5 Nml/g-TS, 100.6 Nml/g-TS, 110.6 Nml/g-TS and 122.7 Nml/g-TS respectively. The maximum improvement in the biogas output of 32.60% is achieved by using 30% of food waste in the feedstock mixture, compared to the biogas output from 100% floral waste. In actual practice, the availability of food waste cannot exceed more than 30% of the availability of food waste. Thus the optimum results for co-digestion can be considered for a mixture of 70% of floral waste and 30% of food waste.

*Summary of the experimental investigation results*

The anaerobic digestion of floral waste can produce biogas with methane content in the range of 55% to 60%. Fresh flowers without any pretreatment cannot produce biogas. Different pretreatments like drying, mechanical pretreatment and alkaline chemical pretreatment are necessary for anaerobic digestion of floral waste. Use of floating drum type digester for different experiments facilitates the simplicity of operation and biogas volume measurement. Application of two new chemicals sodium carbonate and sodium bicarbonate for chemical pretreatment of floral waste gives an improvement in biogas output between 103% and 106%, along with a considerable reduction in chemical pretreatment cost between 90% and 96%, in comparison with sodium hydroxide pretreatment. Use of solar energy for heating of the digesters increases the biogas generation between 61% and 122%, in comparison with reactors placed in ambient conditions. Implementation of co-digestion of 30% food waste with 70% floral waste also improves the biogas output up to 32.60%, compared to the output from 100% floral waste. The increase in biogas yield is proportional to the percentage of food waste in the sample.

*Comparison of the present work and other similar works*

The experimental study in the present work can provide the following advantages in comparison with other similar studies (refer Table 3):

- The present experimental study tries to provide details about various aspects of the anaerobic digestion of floral waste and biogas yield improvement in a series of experiments. Some of these aspects are not present in the previous similar studies.
- Use of floating drum digester for biogas generation provides ease of construction, operation, and measurement of biogas volume. The floating drum digesters (drum in drum type) are transportable and this can increase the feasibility of use by the common end users.
- Techniques of biogas improvement such as solar heating of the digester and co-digestion are not used in previous studies related to floral waste.
- The volume of biogas generated per kg of the substrate is more as compared to the studies which mention this type of data.
- The percentage of methane in raw biogas is 57.52%, which is better than the previous studies which provide this type of data.

## CONCLUSIONS AND FUTURE WORK

Anaerobic digestion of floral waste is a viable source of biogas energy and also for reducing environmental pollutions. The present set of experimental work attempts to present a simplified and user-friendly method of anaerobic digestion of floral waste for biogas generation. The improvement in biogas generation using sodium carbonate and sodium bicarbonate pretreatment is encouraging and in accordance with similar experimental work performed for other feedstock materials. This chemical pretreatment is not previously used for floral waste treatment. The reduction in chemical pretreatment cost using sodium carbonate can enable spread of this method amongst the common end users. Literature does not show implementation of the techniques of biogas improvement (like solar heating of the digester and co-digestion with other waste materials) to floral waste feedstock. An attempt has been made in the present work to find out the effectiveness of these techniques when applied to floral waste feedstock. The methane content in raw biogas is higher than the previous similar studies. Pretreatments like drying, mechanical and alkaline chemical pretreatment using sodium carbonate and sodium bicarbonate are advantageous for anaerobic digestion of floral waste. The overall combination of floating drum digester, solar heating of the digester, use of new chemicals for chemical pretreatment and co-digestion with food waste results in improved biogas output from floral waste. Simplicity associated with the chemical pretreatment and digester operation can enable a widespread use of this method by common people to fulfil the energy demands.

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## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. In addition, the ethical issues; including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy have been completely observed by the authors.

## ABBREVIATIONS

| | |
|---|---|
| *bel* | A type of leaf (Aegle Marmolas) |
| $CaCO_3$ | Calcium carbonate |
| $Ca(OH)_2$ | Calcium hydroxide |
| $CH_4$ | Methane |
| *g* | gram(s) |
| *g/g-TS* | grams of chemical per gram of total solids (Unit for chemical pretreatment) |
| *h* | Hour |
| $H_2S$ | Hydrogen sulfide |
| *kg* | kilogram(s) |
| *L* | Liter |
| *LPG* | Liquefied petroleum gas |
| *ml* | Milliliter |
| *mm* | Millimeter |
| $m^3$ | Cubic meter |
| $Na_2CO_3$ | Sodium carbonate |
| $NaHCO_3$ | Sodium bicarbonate |
| *NaOH* | Sodium hydroxide |
| *Nml/g-TS* | Milliliter per gram of total solids (Unit of specific gas specific gas production) |
| *pH* | Potential of hydrogen (measure of acidity or alkalinity of a substance) |
| *ppm* | Parts per million |
| *°C* | Degree Centigrade |
| *%* | Percent |

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