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# Utilization of a Vegetable Oil Species Residue for Biogas Production

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***Abstract –*** *Bioenergy generation from available biomass to screen and select a plant species as potential biomass candidate that is mainly unexplored is emphasized presently. The study endeavours the scope of producing biogas from by-products of hingan fruit-a potential vegetable oil species considered for biodiesel preparation. The work done in the laboratory is aimed at reducing the cost of vegetable oil by increasing the efficiency of utilization of the species for energy generation. A trial is made to generate biogas using the outer cover of hingan fruit an unutilized component of the fruit. Substantial quantity of biogas can be developed form the biomass using an anaerobic digestion process. The gas yield of 50-54 litres is observed during the trial per kg of biomass fed in the digester. Mixing of cow dung with the biomass will slightly enhance the quality and quantity of gas yield. Each hingan tree has a potential of producing 4200 litres of biogas from the unutilized by-product of the fruit. It is also recorded that the gas yield from the digester is a function of temperature and relative humidity. The gas generated is clean and smokeless and can be effectively used for different energy application. The sludge remaining after the digestion has good manurial value.*

***Keywords –*** Biomass, digester, ester, gasification, yield.

## 1. INTRODUCTION

The rapid decrease in resources of fossil energy has led to the development of renewable energy sources, sustainable development and eco-friendly concepts. In present scenario biofuel obtained from biomass was realized to be a viable, domestic, energy resource that has the potential of reducing oil consumption and import of petroleum oil.

Various biofuel energy resources explored include biomass, biogas, primary alcohols, vegetable oils, biodiesel, *etc.* [1]. Biomass is any photosynthetically derived material of biological origin. The major organic compound in most of the biomass is the polysaccharides (celluloses) and the lignin, proteins (polypeptides) and triglycerides (lipids or fats). Chemically the oils/fats consist of triglyceride molecules of free long chain fatty acids that are ester bonded to a single glycerol molecule. These fatty acids differ by the length of carbon chains, the number, orientation and position of double bonds in these chains [2]. An alternative biomass fuel must be technically feasible, economically competitive, environmentally acceptable, cost competitive and readily available. Liquid biofuels presently are available in two forms, bio-alcohols and biodiesel. The first form is mostly used in combination with gasoline, and the second corresponds to a vast form of fatty acid esters or biodiesel obtained from vegetable oils for use in Diesel engines. The use of vegetable oils as alternative fuels has been around for 100 years when the inventor of the diesel engine Rudolph Diesel first tested peanut oil, in his compression ignition engine [3]. Another important biomass conversion technology is gasification. Gasification of lignocelluloses biomass allows transforming its physical and chemical properties into a new fuel much more suitable to obtain mechanical (electrical) energy in a process described a time ago [4]. Third important biomass conversion technology is anaerobic digestion of biomass to gaseous products. Certain fermentative micro organisms are capable of converting biomass to methane ($CH_4$), the dominant fuel component in natural gas as a gaseous fuel. Biogas is the mixture of methane and carbon dioxide produced as a result of anaerobic decomposition organic matter. Sen *et al.* [5] studied the possibility of generation of biogas and power alcohol. The study revealed that the green plant contains 0.0185 starch which is lost through photochemical decomposition on drying of green plant. This can be utilized for bacterial fermentation, and gas production after fermentation can be used for power production. These low cost biomass conversion technologies are ideally sited to the developing countries, for providing fuel, electricity and high grade manure [6]. The cost consideration is an important aspect for every biofuel. But apart from the costs of biomass energy fuels, another and probably more important factor that should be considered when assessing market prices for biomass energy and biofuel, is the accumulated, tangible socioeconomic benefits of the commercial utilization of a local or regional energy resource for the local or regional economy.

Biodiesel prepared from vegetable oil has been accepted as an alternative renewable fuel for diesel engine. India's national mission on biodiesel has set the target of producing 20% biodiesel of the total diesel demand, from non-edible oil seeds by year 2012 [7]. The utilization of biodiesel as a diesel substitute is restricted

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due to the cost of vegetable oil which is still higher than the petroleum diesel [8]. The effective utilization of by-products after oil extraction and during biodiesel preparation plays important role in deciding the overall cost of the biodiesel. The cost of the biodiesel can be brought down significantly with effective utilization of various byproducts.

Microbial conversion of organic matter to methane through anaerobic digestion is one promising option. Anaerobic digestion takes place in the absence of oxygen, and micro-organism that perform the process are mixed population of anaerobic bacteria. The process of anaerobic digestion occurs in a sequence of stages involving distinct types of bacteria. Hydrolytic and fermentative bacteria first break down the carbohydrates, proteins and fats present in biomass feedstock into fatty acids, alcohol, carbon dioxide, hydrogen, ammonia and sulphides. This stage is called hydrolysis (or liquefaction). Next, acetogenic (acid-forming) bacteria further digest the products of hydrolysis into acetic acid, hydrogen and carbon dioxide. Methanogenic (methane-forming) bacteria then convert these products into biogas [9].

For rural area of many developing countries like India, biogas technology serves as an important source of alternate energy, mainly for fulfilling cooking energy requirement. Anaerobic digestion of animal waste in biogas plants for energy, manure and sanitation has made a significant impact on quality of rural life. This process is carried out by action of various groups of anaerobic bacteria. Insufficiency of animal dung resources limits the use of this technology to only an eighth of the overall Indian rural population [10], [11]. Yet the convenience of a biogas plant in rural households has led research and development efforts to extend the use of biogas plants to other non-animal dung biomass feedstock and agricultural residues. In addition to the existing potential of 12 million biogas plants in India operating on cattle dung, by using commonly available biomass feedstock, it is possible to meet the cooking energy needs of the rest of the rural families [12]. In immediate future, the need for organic manure to sustain soil fertility will also be an important driving force behind adaptation of this technology. Karve *et al.* [13] highlighted the fact that the conventional biogas systems use organic wastes such as human or animal excreta, distillery effluents, or municipal solid waste. These feedstock materials cannot be completely digested by the bacteria in the system. Further the feedstock is very poor in nutritive value as the digestion process is already completed. These systems require 40-60 kg of feedstock and need a hydraulic retention time of about 40 days, to produce daily 1000 litres of biogas. The generated biogas contains of very high amount $CO_2$; of the order of 40-50 % by volume. These biogas plants generate daily 80-100 litre of effluent slurry. Longer hydraulic retention time and large size of the gas plant results in to increased cost of the plant. High cost, large quantities of dung required per day and the huge amount of slurry to be disposed per day are the factors putting limitations on widespread use of conventional plants. Haridasan *et al.* [14] studied the scope of generating biogas from jatropha oilcake through anaerobic digestion. It was noted that one kilogram of jatropha oil cake produce 0.5 litres of biogas per day. The composition of biogas formed from the trial is found to be $CH_4$-65% and $CO_2$-35%.

In the present study an unutilized component of a virgin biomass resource ‘hingan’, botanical name ‘*Balanites Aegyptiaca (L) Del*’ has been utilized for production of biogas.

## 2. MATERIALS AND METHOD

### *Hingan Biomass*

The *Balanites Aegyptiaca (L) Del* shrub or tree is also called as ‘hingan tree’ in central India. ‘Hingan’ is a multipurpose tree known by its many uses as fuel wood, charcoal, timber, fodder, *etc.* The fruits are edible and the seeds are crushed to produce oil. The tree grows naturally up to a height of 6–8m. The first fruiting is at 5–6 years, the tree lives for more than 100 years, for 75 years annually producing crop of 125 kg of fruit. On dry basis composition of the fruit is in the tune of 10–13% outer cover, 30–35% pulp, 35–40% shell and 15–17% kernel. The kernel of the balanites yields highly stable 45–47% oil. The ester developed from hingan oil by transesterification is characterized and utilized as fuel for CI engine. The important properties of hingan oil methyl ester are quiet closer to diesel. The engine performance using ester as fuel is in line with diesel [15]. The hingan tree has an estimated potential biodiesel yield of 3,025 litres per hectare or per km of road length per annum [16]. Investigation is performed for utilizing the shell of hingan fruit for development of producer gas in the downdraft gasifier. The study proved that the diesel engine is capable of successful running in dual fuel mode of operation with shell of hingan fruit as biomass in the gasifier. Substantial amount of diesel replacement in the tune of 60-70% is achieved with the use of hingan shell producer gas as a fuel in diesel engine in dual fuel mode operation [17]. Zeev Wiesman *et al.* [18] investigated extract and fraction of *B. Aegyptiaca* fruit pulp that contain high total saponins, demonstrate the utility of pulp for controlling/killing A. aegypti mosquito that causes dengue. Hingan plant species are available in ample amount in central India. These trees share 6% of the total tree population in this part [15]. This present work deals with the utilization of outer cover of hingan fruit that contributes nearly 10-13% of the total mass of the fruit is investigated for biogas production to suggest the complete utility of the species for bioenergy generation**.**

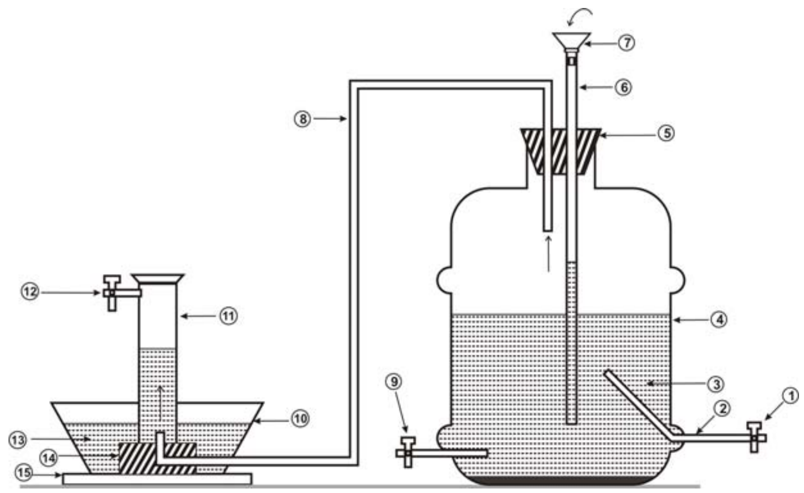
## 3. BIOGAS PRODUCTION

### *Feed Material for biogas Production*

In present study, materials exploited for biogas production are the outer cover of hingan fruit (OCHF) and OCHF + cow-dung (CD) in the proportion of 4:1, as cow-dung is usually used for biogas production. An anaerobic digestion process was adopted to examine the utility of these feed materials for biogas production.

### *Laboratory Setup*

The biogas production is carried out in the Methane reactor, a 20-litre capacity plastic bottle shown in Figure 1. Arrangements for feeding tube and effluent extraction tube were so made that, they were just 3-4 cm above the bottom of the bottle. The tip of effluent extraction tube is kept lower than feeding tube. The opening of methane reactor bottle is sealed perfectly to maintain anaerobic conditions. The volume of gas produced is measured by water displacement method. The gas collecting unit consists of 1 litre capacity calibrated measuring glass jar, which is interconnected with methane reactor. The gas produced in methane reactor displaces the water in the jar into the water vessel in which the inverted jar is placed.



**1. Supernatant removal cock 2. Supernatant removal pipe 3. Influent and feed material mixture 4. Methane reactor 5. Air tight cock 6. Feeding tube 7. Effluent feeding funnel 8. Gas pipe 9. Sludge removal cock and pipe 10. Water vessel 11. Gas collecting flask 12. Gas exit pipe 13. Water 14. Hallow gas pipe holder 15. Stand**

**Fig. 1. Experimental setup of the biomass digester unit.**

**Fig. 2. Powdered OCHF (feed material for biogas production).**

### *Preparation of Innoculum*

Initially, the methane reactor is seeded with septic tank effluent to 10-litre capacity. Methane fermentation occurs in the digestive tracts of ruminants and human. The adaptation of night soil slurry for inoculating the biomass digester has been already proved. Septic tank effluent is a mixture of human waste and water, which contains several species of fermentative, acetogenic and methanogenic bacteria that are necessary to anaerobically digest the complex substances in the biomass. The pH of the content is adjusted to nearly 7 by addition of lime as the methanogenic bacterial growth is best in the pH range 6.4 to 7.4 [19]. Alkalinity as $CaCO_3$ is measured and adjusted between 2,000 to 4,000 mg/l by using sodium bicarbonate. Daily 200ml of content from digester is removed and 200 ml of feed solution is added. For feed solution, potato (which contains starch and glucose, starch acts as nutrient where as glucose is considered as growth stimulant) is chopped into small slices and allowed to remain in 200 ml of water for 2-3 hours. The solution obtained after screening is used as feed solution for digester. In addition to feed solution, small quantity of urea and superphosphate (acts as buffering material which tends to prevent drop in PH) are added everyday to the digester. It took approximately 25 days from seeding to reach quasi steady state condition.

***Operation of the Process***

The OCHF is separated from the collected fruits of hingan and kept for sun drying. When the OCHF is sun-dried, it is converted into powder form. The powdered OCHF is shown in Figure 2.

The study on biogas production from OCHF is carried out in Reactor-I and Reactor-II using OCHF and OCHF+CD as feed material respectively.

Digestion Process in Reactor-I: The biomass OCHF is given the alkali pre-treatment to improve the digestibility. The OCHF contains lignin that prevents the fermentation of lignocelluloses biomass. An alkali pre-treatment is firstly carryout to remove the lignin. For "Alkali pre-treatment reactor" a 500ml capacity plastic jar is used. The detention period for alkali pre-treatment reactor is kept as one day. The lime [$Ca(OH)_2$] and soda[$Na_2CO_3$] treatment is used as alkali pre-treatment. The feed solution is prepared by adding the powdered OCHF with water. After thoroughly mixing, solution is kept for 24 hours for breakdown from lingo-cellulose state to carbohydrates. On next day the water is drained out and the material is washed with fresh water several times and allowed to dry out again for 24 hours. Then again the dried OCHF powder (80%) + fresh cow-dung (20%) is mixed with fresh water and the whole mixture was transferred to methane reactor and equal quantity of content from methane reactor is removed. This procedure is repeated every day for 55 days and gas yield is monitored and recorded daily.

Digestion Process in Reactor-II: The alkali pre-treated OCHF powder with lime and soda alone is used as feed material in Reactor-II. Same procedure as discussed for Reactor-I was repeated every day for 55 days and gas yield is monitored and recorded daily.

***Analysis of Content***

Following physico-chemical parameters were observed for both the reactors during course of study daily:

1. pH(pH meter)
2. Temperature(Thermometer)
3. Relative humidity(Hygrometer)
4. Gas yield(Calibrated glass Jar)

The bio-gas generated is checked for its methane ($CH_4$) and carbon-di-oxide ($CO_2$) percentage by Chimeto Gas-chromatograph. The sludge remaining after digestion is tested for its manurial value and compared with that of cow dung slurry obtained from biogas plant.

## 4. RESULTS AND DISCUSSION

After charging the digester, on very second day it started yielding biogas, however, depending on season, it took around 6 to 8 days for stabilization of the digestion process. Per day variation in gas production for the two reactors that uses different feed material is shown in Figure 3. A slight variation in the gas yield is observed in the two reactors. It is observed that Reactor-I with feed material OCHF and CD in the proportion 4:1 gives average yield of 35.03 lit/kg and maximum yield of 54 lit/kg of dried OCHF and CD combination; Reactor-II which uses 100% OCHF gives average gas yield of 34.35 lit/kg and maximum yield of 52 lit/kg of feed material. The slight increase in the average biogas yield in case of OCHF+CD mixture is due the increased number of fermentative microbes present in the CD. As stated by Patel and Chellapandi [20], mixed anaerobic consortia derived from fresh cattle dung and feed material increases anaerobic digestion potentials. It was also observed that there exist a definite correlation between the gas yield and the environmental condition.

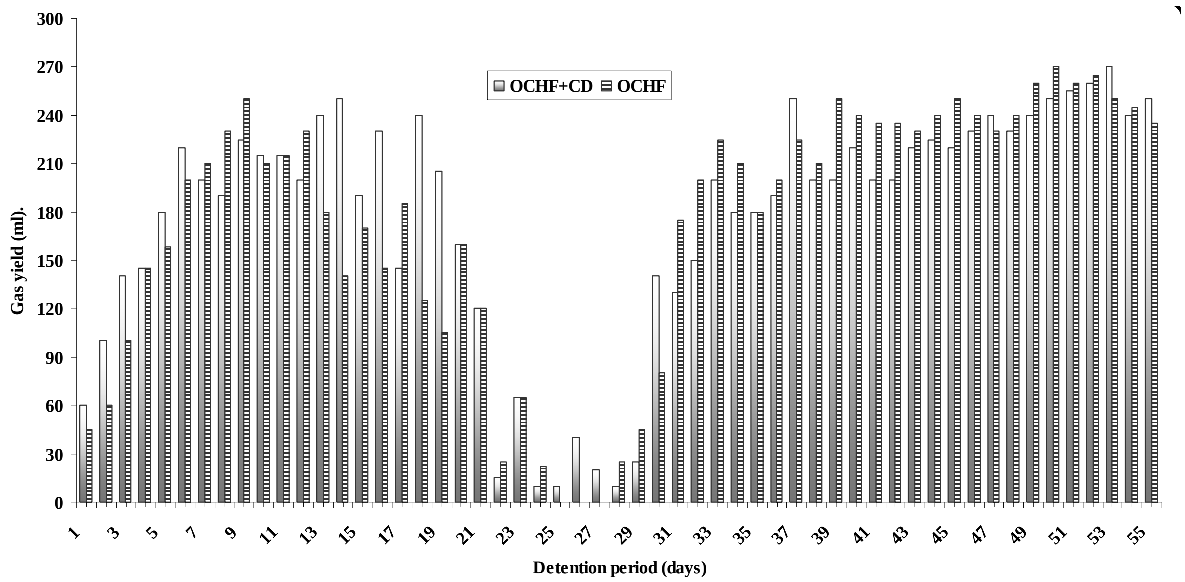



**Fig. 3. Gas yield in different reactors with different feed materials.**

From Figure 3, it can be seen that after reaching steady state condition, gas yield is somewhat constant for constant feeding rate. It is observed that on day 24, 25, 27, 28, and 29 from commissioning of the reactor, the gas yield recorded is either zero or negligible in both the reactors. This variation in gas yield can be explained with the help of Figures 4 and 5. From the Figure 4 it can be seen that the gas yield is the function of atmospheric temperature to some extent. Lower the temperature lower will be the gas yield. This is because of the fact that repeated and sudden changes in the atmospheric temperature reduce the counts of hydrogenotrophic methanogens. The fluctuation in climatic condition causes souring of the culture which affects the digestion process. The microbial conversion of biomass to methane by methanogenic bacteria suddenly reduced due to reduction in the count of methanogens bacteria who work better in steady condition. It was further observed that digestion process is accelerated beyond 30 $^0$C this means that the temperature range of 30 to 40 $^0$C is more suitable for bio-methanation of the non-cattle dung organic biomass. Ingole [21] examined the effect of temperature on bio gas yield from water hyacinth. The study reveals that at lower temperature the process of decay of the feed material is too slow. At a temperature of 35 $^0$C, the rate of decay is 3 to 4.5 times higher than that at 27 $^0$C, where as at 45 $^0$C, the rate of production of biogas is only 15-20% more than that of 35 $^0$C. The study concluded that, higher temperature yields large volume of gas in lesser detention time. Thus it can be said that the gas yield increases with ambient temperature for the same input of the feedstock.

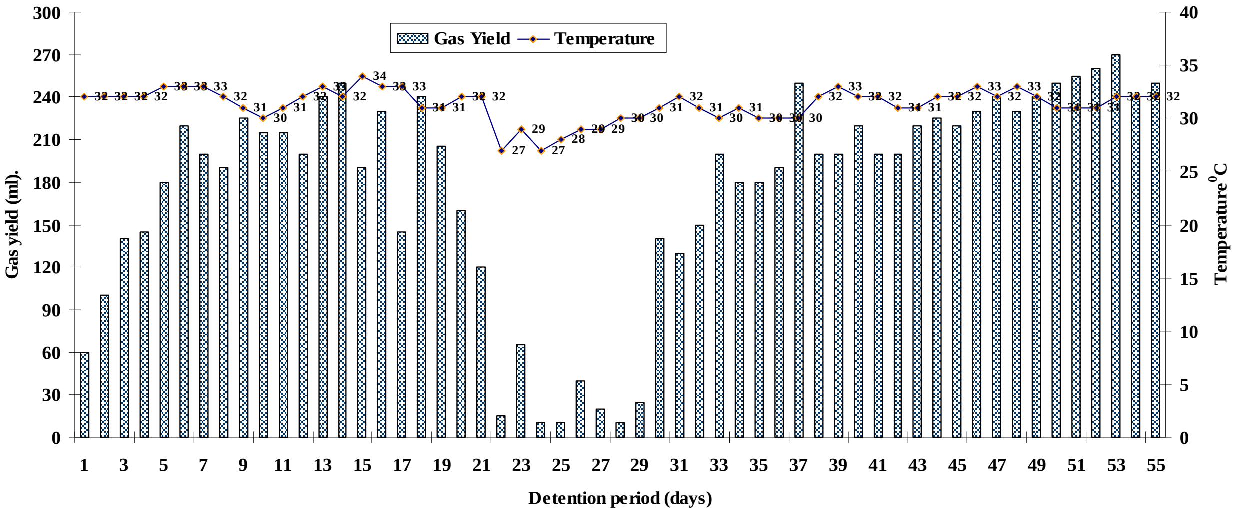



**Fig. 4. Relationship of gas yield, detention period and temperature in Reactor-I.**

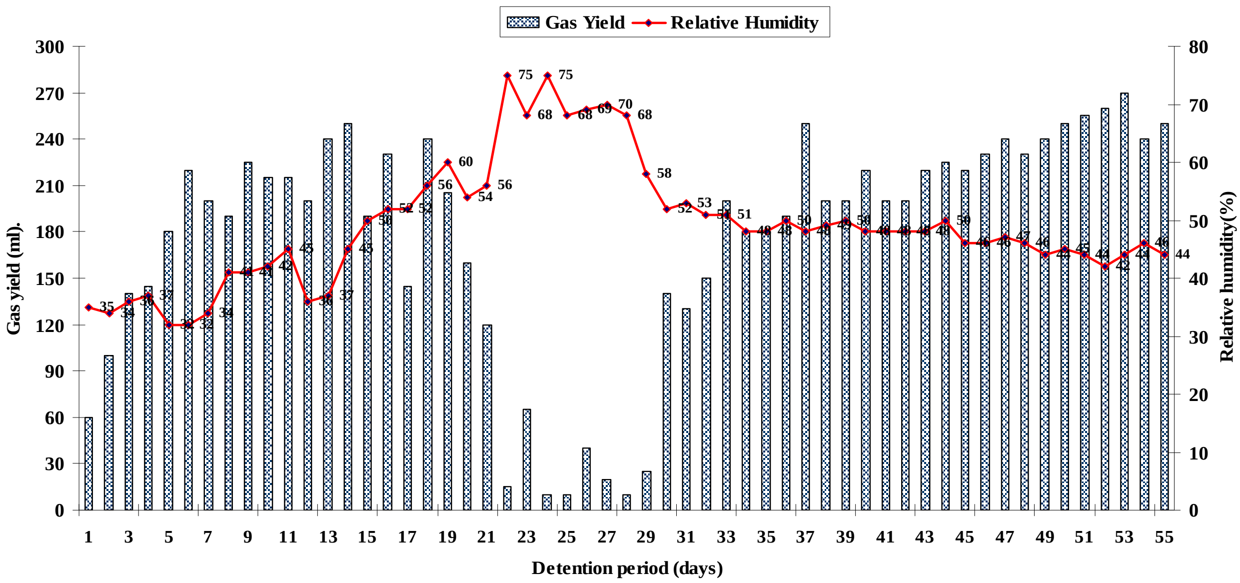



**Fig. 5. Relationship of gas yield, detention period and relative humidity in Reactor-I.**

The experimentation of biogas production is commenced in the month of August. It is also observed that during these days of August and September, whether changes suddenly from clear sunny day to cloudy or rainy day in central part of India. Impulsive increase in relative humidity is recorded during these days as shown in Figure 5.

This instability in humidity may be one of the reasons of lower gas yield. Hence the study reveals that the biogas production is function of temperature along with relative humidity. Both the reactors are charged on the same dates hence similar variation in the gas yield is observed in Reactor-II which can be seen from Figure 3.

Cumulative gas yield for the two reactors is given in Figure 6. From Figure 6 it is observed that for longer duration of operation the biogas yield from OCHF alone is same as that of OCHF+CD. This suggests that OCHF alone can be effectively used for biogas generation.

***The Methane/ Carbon Dioxide Proportion in the Biogas***

Except for first 3-5 days, which was the process stabilization period; the flame was dark blue and vigorous indicating higher percentage of Methane and higher calorific value. After process stabilization, average proportion of methane was found 62-65% in Reactor-I and 60-62% in Reactor-II and the amount of Carbon dioxide was 32-35%. On the other hand the amount of Carbon dioxide ($CO_2$) present in the biogas generated from cattle dung feed stock is as high as 40-50%. Similar results were recorded by other researchers while testing biogas obtained from cattle dung [13], [22]. Apart from $CH_4$ and $CO_2$ traces of hydrogen sulfide, hydrogen, and Nitrogen were also found. Thus, the biogas produced from pure OCHF and CD+OCHF has good fuel value, clean, smokeless and burns with blue flame as shown in Figure 7.

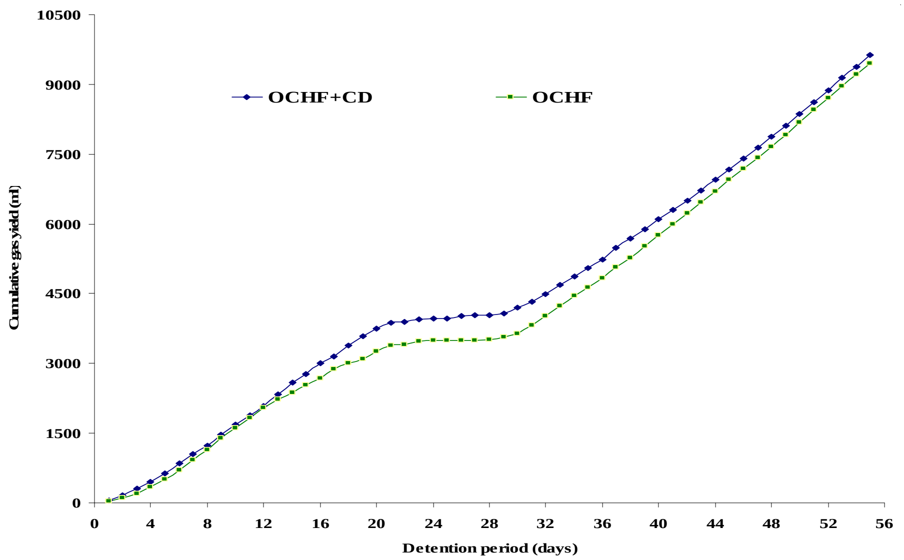



**Fig. 6. Comparison of collective gas production in Reactor-I and Reactor-II.**

***Manurial Value of the Slurry and Sludge after Decomposition***

One important reason behind the popularity of the biogas plants is the need for organic manure to sustain soil fertility [23]. The Nitrogen content, other primary, secondary and tertiary nutrients present in the OCHF sludge and slurry coming out from the reactor is determined by atomic absorption spectophoto meter and is shown in Table 1.

It can be noted from this analysis that the slurry and sludge is excellent manure, which can be used as fertilizer in farming operations. It may thus be noted that the percentage of these nutrient in OCHF is comparable with that in cattle dung manure. The digested OCHF is nitrogen rich organic biofertilizer.

***Biogas Potential of OCHF***

One hectare of hingan plantation has a potential to produce 50000kg of hingan fruit yielding more than 3500kg of hingan oil. At the same time OCHF in the range of 6000kg is also produced which otherwise was totally unutilized will yield minimum 2.8 million liters of biogas. The generated biogas can be used in rural households for cooking, agricultural and other heating purpose.

**Fig.7. Combustible biogas produced from OCHF.**

**Table 1. Nutrients present in decomposed OCHF.**

| Constituents | Decomposed OCHF (%) | Decomposed Cow dung (%) |
|---|---|---|
| Nitrogen (N) | 4.38 | 1.00 |
| Phosphorus (P) | 0.176 | 0.75 |
| Potassium (K) | 0.065 | 1.2 |

## 5. CONCLUSIONS

The utility of components of hingan fruit as source of triglycerides, feed material for gasification and as a steroidal saponine has been already proved. Present investigation of utilizing OCHF for biogas generation results in to following conclusions:

1. Anaerobic digestion of the OCHF is a good way of utilizing the byproduct of the vegetable oil yielding species. This can substantially reduce the production cost of biodiesel. The biomass residue of other non-edible oilseeds like Jatropha, Pongamia, karanj *etc.* can also be used in similar manner.
2. It gives superior quality renewable fuel. The quality of the gas produced is much better than of cattle dung.
3. Biogas generation potential of the waste biomass OCHF was found in the range of 40 to 50 liter/kg of feedstock in controlled climate condition.
4. The biogas generation rate depends on the ambient temperature and it is found highest in the temperature range of 30 to 40 $^0$C.
5. Based on the predicted quantity of hingan fruit yield per hector of land, it can be estimated that 2.8 million liters of biogas can be produced form OCHF/hector. This can cater the cooking energy requirement of 400 households. If this potential is fully tapped, the rural energy scenario of India will be revolutionized.
6. The manurial value of the digested slurry and the sludge is very high. This can serve as an excellent organic fertilizer.

Using better organic material as feedstock in place of cattle dung for anaerobic digestion process poses several advantages like; high gas yield, higher % of methane in biogas, compact design of the digester, low initial as well as operating cost, less hydraulic retention time and better adoptability. It can thus be concluded that the modification in the conventional design of the biogas plants so as to make it suitable for this type of feedstock will result in to a promising, sustainable energy conversion device for rural area of the developing countries like India. The study revealed that each and every component of hingan fruit is useful for potential energy generation making it a prominent biomass species. The systematic plantation will make this species a potential bio-resource for energy generation in rural area in India and elsewhere.

## REFERENCES

[1] Murphy, J.D. and McCarthy, K., 2005. The optimal production of biogas for use as a transport fuel in Ireland. *Renewable Energy* 30 (21): 11-27.

[2] Demirbas, A.H. and Demirbas, I., 2007. Importance of rural bioenergy for developing countries. *Energy Conversion and Management* 48: 2386‐2398.

[3] Meher, L.C., Vidyasagar, D. and Naik, S.N., 2006. Technical aspects of biodiesel production by transesterification-a review. *Renewable and Sustainable Energy Reviews* 10: 248-268.

[4] Francisco, V.T., Andre´s, M., Horrillo, A. and Dı´ez, A., 2006. Rosa method for predicting the performance of an internal combustion engine fuelled by producer gas and other low heating value gases. *Fuel Processing Technology* 87: 135-142.

[5] Sen, H.N. and Chatterjee, 1931. Gasification of water hyacinth. *Journal of Industrial Chemical Society* 8: 1-7.

[6] Anonymous. 1974. Water hyacinth can cure goitre. *Nagarjun*. 18 (2): 43-46.

[7] Government of India. Planning Commission. 2003. *Report of the Committee on Development of Biofuel*. New Delhi, India.

[8] Kapilakaran, K. and Peaugtong, A., 2007. A comparison of costs of biodiesel production from transesterification. *International Energy Journal* 8 (1): 1-6.

[9] Klass, D.A., 2006. *Biomass for Renewable Energy, Fuel and Chemicals*. USA: Elsevier Publication.

[10] Khandelwal, K.C., 1990. Biogas technology development and implementation strategies: Indian experience. In *International Conference on Biogas Technologies and Implementation Strategies*. 13-15 September, Pune India.

[11] Chanakya, H.N, Rajabapaiah, P. and Modak, J.M., 2004. Evolving biomass-based biogas plants: The ASTRA experience. *Current Science* 87 (7): 225-240.

[12] Jagadish, K.S., Chanakya, H.N., Rajabapaiah, P. and Anand, V., 1999. Plug flow digesters for biogas generation from leaf biomass. *Biomass Bioenergy*, 14: 165-170.

[13] Karve, A.D., Gandhali, K. and Karve, P., 2004. Design and field testing of a compact biogas plant. In *International Conference on Engineers in Technical and Humanitarian Opportunities of Service*, 31 Jan- 1Feb, Seattle, Washington.

[14] Haridasan, T.M., Maheswaran, K.G. and Sornathan K., 2004. Biogas production from jatropha oil cake in batch type digester. *Energy and Fuel User's Journal* 2:33-35.

[15] Deshmukh, S.J. and Bhuyar, L.B., 2009. Transesterified Hingan (Balanites) oil as a fuel for compression ignition engines. *Biomass and Bioenergy* 33: 108-112.

[16] Deshmukh, S.J., Bhuyar, L.B. and Thakre, S.B. 2008. Prospects of vegetable oil derivatives for rural agricultural energy in India. .J*ournal of Energy, ENERGIJA* 57 (6): 610-623.

[17] Deshmukh S.J., Bhuyar L.B. and Thakre S.B., 2008. Investigation on performance and emission characteristics of CI engine fuelled with producer

gas and esters of Hingan (Balanites) oil in dual fuel mode. *International Journal of Mechanical Systems Science and Engineering* 2 (3): 148-153.

[18] Wiesman, Z. and Chapagain, B.P., 2006. Larvicidal activity of saponin containing extracts and fractions of fruit mesocarp of Balanites aegyptiaca. *Fitoterapia* 77: 420–424.

[19] Singh, L., Maurya, M.S.; Rarnana, K.V. and Mam, S.I., 1995. Production of biogas from nightsoil at psychrophilic temperature. *Bioresource Technology* 53: 147-49.

[20] Patel, C.N. and Chellapandi, P., 2008. Anaerobic digestion of cotton seed cake using developed mixed consortia. *Electronic Journal of Environmental, Agricultural Food Chemistry* 7 (6): 3035-3046.

[21] Ingole, N.W., 2002. Utility of water hyacinth in the field of environmental engineering. Ph. D. Thesis,. SGB Amravati University, Amravati, India. Unpublished.

[22] Lingaiah, V. and Rajasekaran, P., 1986. Biodegradation of cow dung and organic wastes mixed with oil seed cake in relation to energy. *Journal of Agricultural Wastes* 17: 161-173.

[23] Bhat, P.R., Chanakya, H.N. and Ravindranath, N.H., 2001, Biogas plant dissemination: Success story of Sirsi, India. *Journal of Energy and Sustainable. Development* 5: 39–41.

## APPENDIX

The data observed during the specified period is given in Table A.

Table A. Day to day performance of Reactor-I (pre-treated OCHF + CD).

| Time (Days) | Temperature ($^0$C) | pH | Relative Humidity (%) | Gas Yield | Cumulative Gas Yield (ml) |
|---|---|---|---|---|---|
| 1 | 32 | 7 | 35 | 60 | 60 |
| 2 | 32 | 7 | 34 | 100 | 160 |
| 3 | 32 | 6.9 | 36 | 140 | 300 |
| 4 | 32 | 6.9 | 37 | 145 | 445 |
| 5 | 33 | 6.9 | 32 | 180 | 625 |
| 6 | 33 | 6.9 | 32 | 220 | 845 |
| 7 | 33 | 7 | 34 | 200 | 1045 |
| 8 | 32 | 7 | 41 | 190 | 1235 |
| 9 | 31 | 6.8 | 41 | 225 | 1460 |
| 10 | 30 | 6.8 | 42 | 215 | 1675 |
| 11 | 31 | 6.8 | 45 | 215 | 1890 |
| 12 | 32 | 6.9 | 36 | 200 | 2090 |
| 13 | 33 | 6.9 | 37 | 240 | 2330 |
| 14 | 32 | 7 | 45 | 250 | 2580 |
| 15 | 34 | 6.9 | 50 | 190 | 2770 |
| 16 | 33 | 7 | 52 | 230 | 3000 |
| 17 | 33 | 6.8 | 52 | 145 | 3145 |
| 18 | 31 | 6.9 | 56 | 240 | 3385 |
| 19 | 31 | 6.9 | 60 | 205 | 3590 |
| 20 | 32 | 6.9 | 54 | 160 | 3750 |
| 21 | 32 | 6.9 | 56 | 120 | 3870 |
| 22 | 27 | 7 | 75 | 15 | 3885 |
| 23 | 29 | 7 | 68 | 65 | 3950 |
| 24 | 27 | 6.8 | 75 | 10 | 3960 |
| 25 | 28 | 6.8 | 68 | 10 | 3970 |
| 26 | 29 | 7 | 69 | 40 | 4010 |
| 27 | 29 | 6.9 | 70 | 20 | 4030 |
| 28 | 30 | 6.8 | 68 | 10 | 4040 |
| 29 | 30 | 7 | 58 | 25 | 4065 |
| 30 | 31 | 6.9 | 52 | 140 | 4205 |
| 31 | 32 | 7 | 53 | 130 | 4335 |
| 32 | 31 | 7 | 51 | 150 | 4485 |
| 33 | 30 | 6.8 | 51 | 200 | 4685 |
| 34 | 31 | 6.9 | 48 | 180 | 4865 |
| 35 | 30 | 6.8 | 48 | 180 | 5045 |
| 36 | 30 | 7.1 | 50 | 190 | 5235 |
| 37 | 30 | 7 | 48 | 250 | 5485 |
| 38 | 32 | 7 | 49 | 200 | 5685 |
| 39 | 33 | 6.8 | 50 | 200 | 5885 |
| 40 | 32 | 6.9 | 48 | 220 | 6105 |
| 41 | 32 | 6.8 | 48 | 200 | 6305 |

Table A. Day to day performance of Reactor-I (pre-treated OCHF + CD).

| Time (Days) | Temperature ($^0$C) | pH | Relative Humidity (%) | Gas Yield | Cumulative Gas Yield (ml) |
|---|---|---|---|---|---|
| 42 | 31 | 6.9 | 48 | 200 | 6505 |
| 43 | 31 | 6.8 | 48 | 220 | 6725 |
| 44 | 32 | 7 | 50 | 225 | 6950 |
| 45 | 32 | 6.9 | 46 | 220 | 7170 |
| 46 | 33 | 6.8 | 46 | 230 | 7400 |
| 47 | 32 | 7 | 47 | 240 | 7640 |
| 48 | 33 | 6.8 | 46 | 230 | 7870 |
| 49 | 32 | 6.5 | 44 | 240 | 8110 |
| 50 | 31 | 6.8 | 45 | 250 | 8360 |
| 51 | 31 | 6.7 | 44 | 255 | 8615 |
| 52 | 31 | 7.1 | 42 | 260 | 8875 |
| 53 | 32 | 6.7 | 44 | 270 | 9145 |
| 54 | 32 | 6.8 | 46 | 240 | 9385 |
| 55 | 32 | 7 | 44 | 250 | 9635 |