Appropriate Rural Technologies: Agricultural Waste to Charcoal and Strategies for Biogas Production from Organic Garbage

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Anand D. Karve

Abstract

Abstract for Sect. 6.1

Agricultural Waste to Charcoal: Two cottage scale processes have been described for pyrolysing agricultural waste into charcoal. One of the processes uses a kiln working on the "oven and retort" principle, and the other one uses the "top-lit, updraft" principle. Because charred agricultural waste is powdery in nature, it is mixed with a binder and extruded into briquettes. Currently, more than 100 organizations in India and abroad are making charcoal by using these processes. A team of four persons can produce daily about 70–80 kg briquettes. Working for about 200 days in a year, in the post-monsoon period, this team can make about 15 tons of char briquettes having a market value of about Rs.400,000, but the process can be easily scaled up without increasing the manpower component. Sugarcane trash was found to be ideal for continuous supply of raw material, but one can also use leaf litter from roadside trees, plantations and forests. The charcoal briquettes made by this method can be used as cooking fuel, as industrial fuel or also to replace metallurgical grade coke. The charcoal can also be applied to the soil for raising soil fertility. Efforts are on at the author's organization to convert the charcoal into value-added products like active charcoal and water gas.

Abstract for Sect. 6.7

A Strategy for Biogas Production from Organic Garbage: In spite of new knowledge gained since the advent of the twenty-first century, the biogas researchers still use some of the older concepts. The new concepts pointed out in this article are:

A.D. Karve (✉)
Appropriate Rural Technology Institute, Narhe Road, Dhayari, Pune 411043, India

Samuchit Enviro Tech P. Ltd., Law College Road, Pune 411004, India
e-mail: adkarve@gmail.com

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1. Because the biogas-producing microbes reside in the intestines of animals, they eat what the animals eat.
2. Breeding super-methanogens can be achieved, but their use in a biogas plant would not be practical, as it would be impossible to maintain them in an open system like a biogas plant.
3. All animals represent living biogas plants. The faecal matter of animals is therefore effluent slurry of a biogas plant. The biogas-producing microbes occur in the faecal matter of animals because they exit the animal body along with dung.
4. The anaerobic microbes extract the chemically bound oxygen from their feedstock and use it in their metabolism. Therefore, feedstock of a biogas plant must have oxygen in its chemical makeup. Since animals represent living biogas plants, the same is also true of food eaten by animals.
5. The value called % volatile solids actually represents the % digestibility of the concerned substance.
6. The digestibility of the feedstock is more important than the C/N ratio of a feedstock.
7. In the case of material which is difficult to be digested under anaerobic conditions, use is made of biphasic digestion, in which the feedstock is first treated aerobically and then subjected to anaerobic digestion. This is wrong, because most of the organic carbon, which would have yielded methane in the anaerobic phase, gets oxidized in the aerobic phase itself, leading to drastic reduction in the methane yield.

Keywords

Keywords for Sect. 6.1

Char briquettes • Pyrolysis • Use of char

Keywords for Sect. 6.7

Biphasic digestion • C/N ratio • V.s.%

6.1 Introduction

India generates annually about 800 million tons of agricultural waste, having more or less the same energy as an equivalent quantity of wood. It cannot be used directly as fuel, because of its low density. Currently, this waste is compressed into briquettes, which are sold as boiler fuel at Rs.10,000 per ton. Although commonly called "white coal", these briquettes resemble wood in their physico-chemical properties. There is good demand for biomass briquettes in the industrial belt of Western Maharashtra. As boiler fuel, 3 kg briquettes, worth Rs.30, can replace a litre of fuel oil costing about Rs.60. It is logical to expect farmers who have agricultural waste to convert it into briquettes, but the high capital cost of the briquetting machinery and the requirement of a three-phase, 50 kW electricity connection prevent farmers from doing so.

6.2 Charring and Torrefaction of Agro-Waste

Industry also needs mineral coal, and charcoal can substitute it. Scientists of the Appropriate Rural Technology Institute (ARTI) developed in the year 1996 a cottage scale process for converting agricultural waste into charcoal. In this process, biomass filled into metallic barrels is pyrolysed by heating the barrels from outside. At a temperature >300 °C, biomass undergoes a process called pyrolysis, whereby about 70% of it decomposes into a volatile fraction called pyrolysis gas, leaving behind 30% as a solid fraction, called charcoal. In the process developed at ARTI, it was possible to control the degree of pyrolysis by controlling the period of time over which the barrels are heated (Karve et al. 2001). The practice of terminating pyrolysis prematurely is called torrefaction. Torrefaction yields more charcoal than complete pyrolysis, but torrefied charcoal is of an inferior quality because it still retains some of the volatiles. Because agricultural waste is light, its charcoal too is powdery and light. Using starch paste as a binder, the char is densified into briquettes, by means of an extruder. Although extruders of industrial scale are available in the market, ARTI developed a small one which uses a 1 h.p. motor, running on a 220 volt single-phase domestic electrical connection. The kiln for charring the biomass and a small briquette extruder together cost only about Rs.25,000. At this cost, charring agricultural waste and briquetting the char become a viable business for a rural family. Two persons in the family, operating two kilns in tandem, and two other persons operating the extruder can produce daily about 75–80 kg charcoal briquettes. Excluding 4 months of the rainy season, it is possible to conduct this operation for about 200 days in a year, to produce about 15 tons of char briquettes, saleable at about Rs.400,000. Availability of agricultural waste in sufficient quantity can be a limiting factor in some areas, but at least in the sugar belt of Maharashtra, sugarcane trash is plentifully available in the sugarcane harvesting season. Leaf litter from roadside trees, plantations, and forests is also a potential source of raw material for this business (Figs. 6.1, 6.2, 6.3, 6.4, 6.5, and 6.6).

Fig. 6.1 An "oven and retort"-type kiln for charring agricultural waste

Fig. 6.2 Kiln working on TLUD principle (Photograph courtesy of Samuchit Enviro Tech, Pune, India)

Fig. 6.3 A briquette extruder in operation

6.3 The TLUD Process of Making Charcoal

In 2006, a new type of wood burning stove was personally demonstrated to the staff members of ARTI by Prof. Paul Anderson from the United States of America. The fuel chamber of the stove is filled with wood chips, and the pile is ignited at the top. Air required for burning the wood is provided through holes at the bottom of the combustion chamber. The heat generated by the burning wood pyrolyses the wood chips, and the pyrolysis gas produced by the wood is provided with additional fresh air to burn it as fuel in the same stove. The charcoal that is produced due to pyrolysis

Fig. 6.4 Sarai cooker system for using char briquettes as fuel (Photograph courtesy of Samuchit Enviro Tech, Pune, India)

Fig. 6.5 Individual components of Sarai cooker system (Photograph courtesy of Samuchit Enviro Tech, Pune, India)

Fig. 6.6 An urban domestic biogas plant (Photograph courtesy of Samuchit Enviro Tech, Pune, India)

is left behind in the fuel chamber. Because of good mixing of air with the pyrolysis gas, this stove gives a surprisingly clean fire, without any smoke at all. This stove gives a charcoal yield of about 30% of the weight of the wood chips. Because the wood chips are ignited at the top of the heap, and because air is supplied from the bottom, this stove is called top-lit updraft stove, or TLUD stove. Based on this principle, ARTI developed a stove named Sampada (wealth), which uses waste woody biomass as fuel (e.g. coconut shells, coconut fronds, corn cobs, mango kernels, hulls of legume pods, twigs, seeds, bark of trees, etc.). While cooking the food, the stove simultaneously generates charcoal, a high-value fuel. The disadvantage of Sampada is that the fire intensity cannot be easily controlled. It is therefore primarily used for heating bath water.

In the year 2013, the author developed a charring kiln based on this principle. Its fuel chamber has a capacity of 100 liter. If filled with wood, it takes about 45 min to char it, whereas light biomass like leaf litter, sugarcane trash, twigs, hulls of legumes, etc. is pyrolysed in just about 15 min. A clear and smokeless flame emerges from this kiln, so that one can also use the kiln as a stove for cooking a meal. A video showing the operation of this kiln can be seen by activating the YouTube link provided in the website, www.samuchit.com. More than 100 kilns of this type are currently in operation in India and abroad.

6.4 Using Briquetted Charcoal as Cooking Fuel

Charcoal burns very cleanly, without producing any smoke or soot. It is therefore valued as cooking fuel. Along with the kiln and the extruder, ARTI also developed a non-pressurized steam cooker, which uses just 100–150 g charcoal for cooking a complete meal consisting of rice, dal, vegetables, meat, etc. for a family of five. The cooker became an instant success, because once the cooker has been placed on its built-in charcoal stove, the housewife can do any other chore, or even leave the house for an hour or two, because once the charcoal in the stove has burned itself out, the fire gets extinguished. This cooker comes in 4 models, small for 2 persons, medium for 4–5 persons, large for 8–10 persons and Jumbo for 25 persons.

In the year 2002, Appropriate Rural Technology Institute received the Ashden Award for Renewable Energy, for developing the technologies described above, namely, charring kiln, briquette extruder and the steam cooker.

6.5 Other Uses

The fully pyrolysed charcoal produced by either of these methods is devoid of volatiles, and it burns very cleanly, without any smoke or soot. Being free from volatiles, it is equivalent to metallurgical grade coke, which costs about Rs.35 per kg in Pune. The industries using coke require it in relatively large quantities. The present process of charring and making char briquettes has been designed for operation on a small scale. The reason for opting for the small size of the kilns was to make them portable. It was assumed that the kilns would be taken to the sites where agricultural waste would be available. With larger kilns, one has to transport the biomass to the site where the kilns are situated. But the example of white coal has shown that if farmers get a remunerative price, they are willing to transport their agricultural waste to the processing factory at their own cost. The white coal manufacturers currently pay farmers Rs.2000–2500 per ton for the biomass delivered at the factory gate. With the present price of Rs.35,000 per ton of the metallurgical grade coke, one can very well afford to have large kilns and to pay farmers for the waste biomass delivered at the factory gate.

In the Himalayan Region, our process is being used for making charcoal briquettes from pine needles. These briquettes are used in special stoves, which burn day and night during winter, for room heating. In the forested areas of Eastern Maharashtra, attempts are being made under the aegis of the Department of Forests to use our process for charring fallen leaves of teak and to sell this char to manufacturers of *agarbatti* (incense sticks). Several of our kilns have been exported to Germany, where people use them for charring leaf litter, which is applied to the soil for increasing soil fertility.

If the charring process can be conducted at a higher temperature of about 800 °C, the resultant char can serve as active charcoal. Efforts are on at the author's organization to develop commercially viable methods of producing activated charcoal.

6.6 Future Prospects

Charcoal consists of molecular carbon and some of the minerals found in the original biomass. Before the modern process of iron smelting was introduced to India, iron was extracted from iron ore by heating powdered iron ore together with powdered charcoal, whereby the oxygen in the iron oxide combined with carbon in the charcoal to release metallic iron. Iron smelting was conducted on a cottage industry scale. Today, we export iron ore from Peninsular India, because of paucity of mineral coal in this region. However, with the availability of the technology of making charcoal from agricultural waste, we can reintroduce iron smelting as a cottage industry in India.

Char briquettes are currently sold primarily as cooking fuel, but by scaling the process up, the briquettes can also be sold to industries to supplement mineral coal, of which very little is available in Maharashtra. Maharashtra has 100,000 ha of sugarcane. Assuming that each ha produces 10 tons of trash, Maharashtra can supply 1 million tons of trash for making char briquettes. It should be noted that sugarcane trash is normally burned *in situ* by the farmers. By using our process, one can produce about 300,000 tons of charcoal from sugarcane trash alone. Our process can also be used for converting combustible urban solid waste into charcoal. One unit in Pune City uses our process to produce charcoal briquettes from empty hulls of green coconuts left behind after people have drunk the coconut water. The author was told that Pune City generates daily 30 tons of this material. In addition, the city also generates shells of mature coconuts in all households, restaurants and temples. There are many other sources of combustible dry waste such as seeds and kernels of various fruits, bamboo and furniture waste from respective artisanal workshops, sugarcane bagasse from sugarcane juice vendors, corn cobs and husk from vendors of roasted cobs, leaf litter and pods from avenue trees, etc. They can all be used for making charcoal.

If steam is passed through charcoal heated to about 700 °C, it yields a combustible gas called water gas, which consists of a mixture of carbon monoxide and hydrogen. It can be used as fuel in internal combustion engines. If this process is properly developed, we can completely stop using petroleum-based fuels in transport.

6.7 Introduction

It had always intrigued the author as to why cattle dung is used as feedstock in biogas production. Other industrial fermentations (e.g. antibiotics, citric acid, as well as alcohol) use sugar. Trials in the year 2003, in which sugar was used as feedstock, showed that while one needed 40 kg cattle dung and 40 days time to produce 1 kg (about 800 l) biogas, just a kilogramme of sugar was enough to produce a kilogramme of biogas and that the microbes completed this reaction within just 24 h. Assuming the dry weight of dung to be 20 kg, my biogas system turned out to be 800 times as efficient as the traditional dung-based biogas system. Also starch, cellulose, powdered milk, vinegar, flour of cereals, flour of legumes, oilcake, etc. yielded 1 kg biogas per kg dry weight. I could thus show that anything that served as food for humans or animals proved to be a highly efficient feedstock for biogas production. Since my biogas plant did not use dung, I had a system which could be used as an urban domestic biogas plant which would yield biogas by consuming food waste. Dung was applied only once, at the beginning, as an inoculum. During the years 2003 and 2004, we installed about 40 biogas plants in and around the city of Pune. At that time, the traditional biogas scientists believed that anything that goes into a biogas plant must be accompanied by dung and therefore nobody believed in my results. Therefore, I could not publish my findings in any formal journal but wrote popular articles and gave talks on my concepts. Unfortunately, nobody in India paid heed to me, but my ideas found an echo abroad. In the year 2005, our Institute (Appropriate Rural Technology Institute) received, for this work, an award from the US Environmental Protection Agency, and in the year 2006, the Ashden Award for Renewable Energy. Later, Yale University (USA) invited me to interact with its final year MBA students who wanted to commercialize the urban domestic biogas plant. Invitations were also received by me to give lectures in Sri Lanka, South Africa, East Africa and Nepal.

6.8 Why Everybody Used Dung

Because microorganisms producing biogas are found universally in the dung of animals, it was assumed in the past that dung was the food of these organisms. But it is now known that being residents of the intestines of animals, these microbes eat what the animals eat. They are found in dung because they exit the animal body along with the dung. While most of the bacteria in the guts of animals are facultative anaerobes, the methanogens are obligate anaerobes. The latter belong to a very ancient group of unicellular microbes called *Archaea*, which appeared on the earth about 4 billion (4×10^9) years ago, when there was no oxygen in our atmosphere. The photosynthetic organisms that evolved about half a billion years (5×10^8 years) later started to produce oxygen in its gaseous (or molecular) form, which proved to be toxic to the *Archaea*. The latter then retreated to sites having no free molecular oxygen. Guts of animals was one of the locations where these organisms found a safe refuge.

6.9 Utility of Super-Methanogens

It is quite common in the fermentation industry to develop highly productive microbes by using mutation breeding. Similar efforts are being made also in the case of methanogens, and many strains of so-called super-methanogens have been developed and patented. Such organisms are offered commercially by their respective developers as super-methanogens. This concept works in the case of antibiotics, because the antibiotics are produced under strictly sterile conditions. But it does not work in the case of biogas, because a biogas plant is not operated under sterile conditions. One cannot afford to spend money every day on sterilizing the garbage that goes into the biogas plant. As a result, the super-methanogens have to compete with the local microbes, which would soon outnumber and eliminate the super-microbes because nature does not care whether an organism produces more methane or less. It favours those organisms which have a high rate of multiplication.

6.10 Anaerobes Too Need Oxygen

Although a biogas plant represents an anaerobic system, the biogas-producing organisms do need oxygen like all living organisms. However, instead of obtaining it from air or from the oxygen dissolved in water, they obtain oxygen from their feedstock itself. Thus, by removing oxygen from carbohydrates, a biogas plant gives back to us methane, which is a hydrocarbon. A corollary of this statement is that a substance devoid of oxygen in its chemical makeup cannot serve as feedstock of a biogas plant. Since it was shown by us that the biogas-producing organisms eat what the animals eat, the rule of oxygen in the food is applicable even to animal food. That is why hydrocarbons and plastics cannot be digested either by a biogas plant or by an animal. The oxygen extracted from the feedstock is used by the methanogens in their own metabolism, resulting in the formation of carbon dioxide, which combines with water to form carbonic acid (H_2CO_3). Methanogens are so hungry for oxygen that they remove oxygen not only from a part of the H_2CO_3 but also from the nitrate and sulphate in the feedstock to convert them into their reduced forms, namely, ammonia (NH_3) and hydrogen sulphide (H_2S), both of which contribute to the foul odour of faecal matter. Ammonia and hydrogen sulphide are also present in biogas, but when biogas burns, the malodorous substances get oxidized, and the foul odour vanishes.

6.11 Methanogens Are in Contact with Other Bacteria

The methanogens, being very primitive organisms, can digest only small organic molecules having just two atoms of carbon. The non-methanogenic organisms in the intestine degrade relatively complex organic substances which ultimately end up as acetic acid (CH_3COOH), having only two carbon atoms. In the presence of oxygen, these organisms would convert acetic acid into carbon dioxide and water, but in the absence of oxygen, this reaction stops at the stage of acetic acid. Methanogens generally attach themselves like parasites to the cells of the intestinal microflora and, taking up the acetic acid directly from the cells of the hosts, convert it into one molecule each of carbon dioxide and methane.

6.12 Animals Represent Living Biogas Plants

All animals act as living biogas plants, and their faecal matter represents their effluent slurry. It had always intrigued me why rural householders smear dung paste on the flooring, walls and even on their stoves. The rural householders assured me that dung plaster repelled flies. The fact however is that dung, being the end product of the process of digestion, has nothing in it that would serve as food to attract flies. This also explains why dung of ruminants is inefficient as feedstock for producing biogas, because there is practically nothing left in it to digest. 1 kg dung (dry weight) produces only about 50 g biogas, having an energy content of only about 200 kcal, whereas the same quantity of dry dung, if burned directly, would yield about 4000 kcal energy. One thus recovers only 5% of the original energy from dung, if it is transformed into biogas. Dung cakes, having a calorific value of about 4000 kcal per kg, are saleable as fuel in India. A family-sized biogas plant requires daily about 40 kg dung. In the form of dung cakes, it would fetch a daily income of Rs.70. Thus, only a fool would use dung as feedstock in his biogas plant. This explains why, out of an estimated 168 million rural households in India, only 2 million, or less than 2%, have working biogas plants.

6.13 Percent Volatile Solids Means Percent Digestibility

The percectage of biogas that can be obtained from any substance is denoted as its "volatile solids percentage" (v.s.%). It changes from feedstock to feedstock. Sugar, starch, cellulose, digestible proteins, fats, vegetable waxes and mucilage get completely converted into biogas, giving a v.s.% of 100%. Green leaves, on the other hand, have 80% moisture, and out of the moisture free dry matter, only 50% is digestible. Therefore, they exhibit v.s.% of only 10% on the basis of fresh weight.

These examples show that the v.s.% of a feedstock depends on the % digestibility of the feedstock. Laboratory methods are now available for estimating the in vitro dry matter digestibility (IVDMD) of any substance. The figures representing IVDMD match those of v.s. %.

Energy lost in the process of conversion from feedstock to biogas is relatively low in the case of substances having a high degree of digestibility. Thus a kg of sugar, having a calorific value of 4000 kcal/kg, yields 370 g methane, also having a calorific value of 4000 kcal. Dung, having low digestibility, would yield per kg dry weight only 18.5 g methane, having only 200-kcal energy. Therefore, a rule of thumb for selecting a feedstock for biogas generation is to verify if an animal would be able to digest that substance. If the answer is "yes", one can use that material as feedstock in a biogas plant. The "animal" in this case can even be an insect.

6.14 How Important Is C/N Ratio

Textbooks lay a lot of emphasis on a value called carbon/nitrogen (C/N) ratio of the feedstock. The textbooks state 25 to be the ideal C/N ratio. This is the C/N ratio of dung, but it is a relic of the past when dung was universally considered to be the ideal feedstock. It has already been discussed how dung, representing the effluent slurry of a living biogas plant, can hardly be considered to be the ideal feedstock. Sugars, starches, cellulose, fats and digestible proteins show 100% digestibility. Of these substances, sugars, starches, cellulose and fats have $C/N = \infty$, whereas the C/N ratio of proteins is just 4 or 5. And yet, all of them show the v.s.% value of 100. One should realize that as a living system, a biogas plant requires all the inorganic components that a living cell needs and that it is illogical to take only the nitrogen content of the system into consideration.

6.15 Biphasic Systems

The realization that some of the substances in the feedstock are digested only under aerobic conditions has given rise to using the so-called biphasic digestion. This system has two digesters, one aerobic and the other anaerobic. The biomass is first introduced into the aerobic digester, from where it is led into the anaerobic digester. It is argued that the material that does not get degraded under anaerobic conditions is degraded in the aerobic part of the system, reducing thereby the indigestible ballast that would unnecessarily enter the anaerobic digester. Experience however shows that the carbon, which would normally have yielded methane, gets converted into carbon dioxide in the aerobic digester, resulting in drastic reduction in biogas yield. Thus, if at all one has to use a biphasic digester, it is advisable that both the phases should be anaerobic.

The account given above covers mainly some traditional beliefs and practices with which the author does not entirely agree. The author feels that the biogas researchers take into consideration the new knowledge that has been gained since the year 2000 and discard some of the misconceptions that are still being carried over from the last century.

6.16 Conclusions

Present paper tries to clear some misunderstandings about the biogas production in order to drive forward the movement initiated by Khadi and Village Industries Corporation in the last century. New concepts and clear understanding of biogas plants using organic garbage mentioned here are likely to solve many problems like disposal of urban biodegradable garbage, clean energy from biomass, etc.

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Reference

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