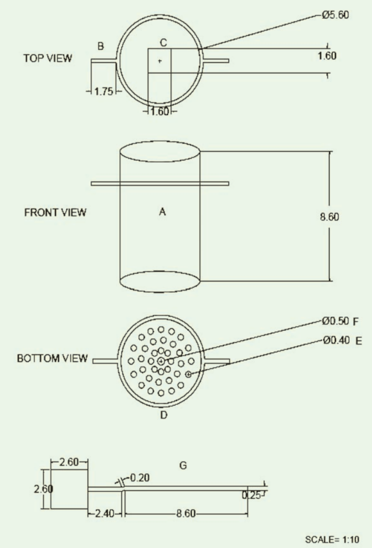
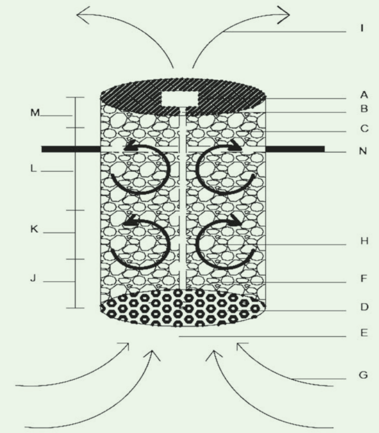


Schematic diagram of biochar kiln
A, cylindrical chamber; B, metal handle; C, top feed and exhaust vent; D, bottom vents in three concentric rings at equidistant from the rim; E, staggered vents in three concentric circles; F, central vent; and G, metal lid

- Locally available dry twigs can be used as combustible source at firing point of the kiln base vents to raise the temperature for spontaneous ignition under open atmospheric conditions
- Exposed bio-residues at concentric base vents are flamed for 3-4 min for partial direct combustion to develop sufficient exothermic temperature to trigger thermal bio-carbonization in the remaining bio-residues
- Primary airflow through the concentric staggered base ports is used as carrier medium for rapid heat development through partial oxidation and flow of hot volatiles toward cooler fragments for uniform thermal exchange in kiln chamber and subsequently for upward thermal buoyancy of the released water vapor and volatiles
- The target end stage of bio-carbonization is indicated by distinctive thin blue hot gases with puff of flame
- At this stage, the kiln is ready to be sealed with clay and sand sealing mixture to restrict the flow of carrier medium through the kiln for significant yield realization
- The metal lid is placed over the top vent to block the upward movement of hot gases
- The kiln is then transferred to a leveled surface to ensure that no significant primary air ingression occurs in order to cutoff totally the partial combustion process
- A sealing mixture of clay can be used to seal the circumferential edges of the drum and also along the edges of the metal lid used for covering the top hole for development of gas pressure in the enclosed space of kiln
- During the cooling cycle, it should be ensured that no volatiles escape from the kiln by sealing all possible air-entry points
- Biochar samples in the kiln should be left for cooling for 3-4 h by heat loss through natural convection and radiation
- After cooling, the sealed mixture is removed thoroughly and the biochar is taken out



Schematic diagram of the kiln operational process
A. top feed and exhaust vent, B. central continuous vent from bottom to top, C. sun dried bio-residues, D. bottom vents for air flow, E. initial firing point, F. ignited bio-residues, G. primary air flow, H. heat transfer process between hot gases and bio-residues, I. hot gas exhaust, J. combustion zone, K. drying zone, L. reduction and M. bio-carbonization zone

Biochar yield

The CRIDA biochar kiln was used to produce biochar from maize, cotton, castor and pigeonpea stalks on a small scale and the operational (process) parameters viz. loading rate, holding time and maximum conversion efficiencies were standardized for four bio-residues. The biochar conversion efficiency of the kiln ranges from 24.4% for castor stalk to 35% for pigeonpea stalk.

Bio-residue	Loading rate (kg/kiln)	Holding time (min)	Biochar yield (%)
Maize	8.7	15	29.3
Cotton	10.8	11	26.9
Castor	15.0	17	24.2
Pigeonpea	18.0	16	35.0

Loading of bio-residue


Central Vent

Bio-carbonization end stage
Top and bottom sealing

Field operational process in biochar production

Cotton, pigeonpea, castor and maize stalk biochar produced using CRIDA biochar kiln

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Low-Cost Portable Kiln for Biochar Production

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Low Cost Portable Kiln for Biochar Production

Availability of bio-residues

Crop bio-residues, a renewable resource, are an important component in ecosystem stability of the agricultural land. A huge quantity of bio-residue wastes are produced in agricultural, agro-industrial, and forestry operations and are becoming an issue of importance due to lack of bio-residue management practices. The major crop residues produced in India are straws of paddy, wheat, millet, sorghum, pulses (pigeonpea), oilseed crops (castor, mustard), maize stover and cobs, cotton and jute sticks, sugarcane trash, leaves, fibrous materials, roots, branches and twigs of varying sizes, shapes, forms and densities. In India, the total dry bio-residues generated are estimated at 217, 239 and 253 Mt in 1994, 2005 and 2010, respectively. Some of these bio-residues are recycled back into soil as compost or manure for soil rejuvenation, used as fodder for domestic animals, fuel source for household etc. while large amounts remain unused and are eventually burned on the field.

Burning of agricultural bio-residues in the fields is a common practice in India. Studies sponsored by the Ministry of New and Renewable Energy (MNRE), Govt. of India have estimated surplus biomass availability at about 120–150 million tons/annum. Of this, about 93 million tons of crop residues are burned in each year. Farmers opt for field burning of crop bio-residue primarily to clear remaining straw and stubbles after harvest and to prepare the field for the next cropping cycle. Other reasons for intentional burning include clearing of fields, fertility enhancement, and pest and pasture management. It also provides a fast way of controlling weeds, insects and diseases, by both eliminating them directly or by altering their natural habitat. However, in addition to loss of valuable bio-residue and nutrients, bio-residue burning leads to loss of soil microbial populations, and release of toxic gases including GHGs. About three-fourths of greenhouse gas (GHG) emissions from agro-residues burning were CH_4 and the remaining one-fourth was N_2O. Burning of wheat and paddy straws alone contributes to about 42% of GHGs.

Need for recycling of bio-residues in agriculture

- Improve soil health through efficient use of bio-residues as a source of soil amendment/nutrients
- Sequestration of carbon in the soils
- Improve soil physical properties viz. bulk density, porosity, water holding capacity, drainage etc.
- Soil and water conservation by using the bio-residues as a surface mulch
- Minimize dependence on external inputs and to ensure sustainable crop production
- Mitigation of greenhouse gas emissions by avoiding bio-residue burning

Constraints in recycling of bio-residues

- Unavailability of farm labour, higher wage rates, and collection and processing of bio-residues is time consuming and laborious
- Lack of appropriate farm machines for on-farm recycling of bio-residues
- Reliance on readily available fossil fuel based energy for both domestic and agricultural activities
- Inadequate policy support/incentives for bio-residue recycling

Biochar production – A novel strategy for efficient recycling of bio-residues

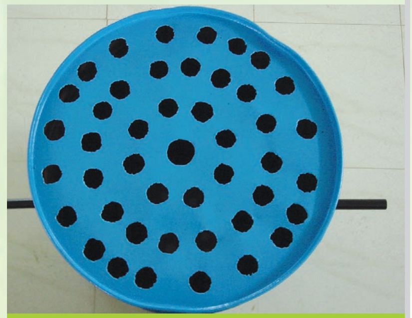
Biochar is a fine-grained, carbon-rich, porous product remaining after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperatures (~350–600^{0}C) in an environment with little or no oxygen. Biochar production from a variety of high-molecular lignocellulosic bio-residues is a carbon-neutral process. Unlike charcoal, which is produced for various industrial purposes, bio-residue derived biochar is produced specifically as a soil amendment. Biochar is capable to increase the rate of soil carbon sequestration and improves the soil fertility and crop yield.

There are different ways to make biochar, but all of them involve heating bio-residues with little or no oxygen to drive off volatile gasses, leaving carbon behind. This simple process is called thermal decomposition usually achieved from pyrolysis or gasification. Biochar can be produced at scales ranging from large industrial facilities down to the individual farm and even at the domestic level, making it applicable to a variety of socioeconomic situations. Worldwide, various pyrolysis technologies are commercially available that yield different proportions of biochar and bio-energy products, such as bio-oil and syngas.

However, biochar production protocols are yet to be standardized in India. Furthermore, to make biochar technology popular among the farmers, it is imperative to develop low cost biochar kiln at community level or low cost biochar stove at individual farmer's family level. Hence, a low cost biochar kiln was fabricated at CRIDA, Hyderabad.

Fabrication details of biochar kiln

A low cost portable kiln unit was developed to match the needs of the small and marginal farmers. The cost of one unit of the kiln is ₹ 1200 (approx.) including cost of metal drum, vent making charges and side fittings. A brief description of the kiln is given below:


Bottom view of the kiln

- Kiln design functions with direct up-draft principle with bottom ignition
- The cylindrical metal drum kiln of about 212 L capacity is based on a single barrel design of vertical structure with perforated base
- The gross volume of the kiln is about 0.21 m^3
- The cabinet is circular in cross section and consists of an intact bottom and top section
- The kiln is about 28 cm in radius and 86 cm tall with one square shaped hole of 16 cm x 16 cm cut at the kiln top, for loading bio-residues, which can be closed at the end of conversion by a metal lid (about 26 cm in length and 26 cm in width) with a handle (110 cm)
- For making of vents, three concentric circles at equidistant interval of approximately 9 cm are marked from the center of kiln base to border of the kiln

General view of biochar kiln

- A total of 40 circular vents (each about 2 cm in radius) are cut in such a way that 16, 16 and 8 vents are in first, second and third circle from the rim
- Staggered arrangement is maintained by alternating the vents in all the three circles to avoid row arrangement
- In addition, a central vent of about 2.5 cm radius is made in the centre of the kiln base to hold wooden pole of about 110 cm height and 2 cm radius
- Under open atmospheric conditions, the central and concentric staggered vents at the kiln base hasten hot gas movement through the bio-residues for uniform heat transfer by primary air movement while the kiln's top hole vents out the released water vapours and hot gases
- A strip of metal is welded around at 3/4th height of kiln, to which two metal rods of about 1.3 cm in radius and 17 cm in length are welded on opposite sides to serve as lifting jack

Process: Thermo-chemical conversion of bio-residues to biochar

The steps involved in preparation of biochar from different bio-residues by using the biochar kiln are as under:

- Prior to loading, a wooden pole (110 cm height and 2.0 cm radius) is inserted through top hole and fixed to central bottom vent of the kiln to create a central vent through the packed bio-residues
- Pre-configured and Sun dried bio-residues are loaded through kiln top vent into the combustion chamber
- Depending upon the bio-residue load, stalk fragments are manually packed and arranged parallel to bottom in as many voids as possible in the kiln chamber by gentle shaking
- The loaded kiln is lifted and placed over hearth of three flat stones (minimum of about 20 cm height) on level surface to facilitate primary air flow through the bottom vents
- Before initiating the conversion process, the wooden pole is carefully removed leaving a central vent through the loaded bio-residues to ensure efficient flow of hot gases from bottom to top for continuous heat transfer through the bio-residues.