KFRI Research Report No. 378 ISSN .....

Developing Appropriate Technology for Production of Bamboo Charcoal

(Final Report of Project KFRI 408/'03)

T. K. Dhamodaran
R. Gnanaharan
P. K. Thulasidas

Wood Science and Technology Division
Kerala Forest Research Institute
Peechi – 680 653
Kerala, India

August 2008

KFRI Research Report No. ....

ISSN .....

Developing Appropriate Technology for Production of Bamboo Charcoal

(Final Report of Project KFRI 408/'03)

T. K. Dhamodaran
R. Gnanaharan
P. K. Thulasidas

Wood Science and Technology Division
Kerala Forest Research Institute
Peechi – 680 653
Kerala, India

August 2008

CONTENTS

OUTLINE OF THE PROJECT PROPOSAL

1	Project Code	:	KFRI 408/'03
2	Title	:	Developing Appropriate Technology for Production of Bamboo Charcoal
3	Principal Investigator	:	Dr. T. K. Dhamodaran Scientist EII (Wood Science and Technology Division)
4	Associate Investigators	:	Dr. R. Gnanaharan and Dr. P. K. Thulasidas Scientists (Wood Science & Technology Division)
5	Objectives	:	Evolve appropriate technology for the production of charcoal and investigate the potential of activated carbon production from bamboo
6	Programme Outline	:	i. Investigate the different methods of production of charcoal from bamboo in order to identify an appropriate method suitable for local conditions ii. Assess the yield and quality of charcoal produced from bamboo iii. Investigate the potential of activated carbon production from bamboo employing the existing industrial pilot plant facilities.
7	Funding	:	KFRI Plan Funds
8	Budget Outlay	:	Rs. 5.4 Lakhs.
9	Duration	:	3 Years (April 2003-March 2006).

ACKNOWLEDGEMENTS

We sincerely acknowledge the technical support from M/s. Active Char Products Pvt. Ltd. (ACPL) and Indo German Carbons Ltd.(IGC), Binanipuram, Kochi, Kerala for permitting to use their pilot plant for charcoal production in this project. Special thanks are due to Mr. Raizin Rahman, Managing Director of ACPL and Engr. K. Kaladharan, General Manager, ACPL and Mr. M. M. Abdul Basheer, Managing Director, Indo German Carbons Ltd for the constant encouragements provided in terms of sharing their industrial experience and plant and laboratory facilities. The service of Mr. S. Babu, Senior Project Fellow, Wood Science and Technology Division of the Kerala Forest Research Institute (KFRI) is gratefully acknowledged. Acknowledgements are due to Dr. J. K. Sharma, Former Director and Dr. K. V. Sankaran Director, KFRI for their keen interest and encouragements. The financial assistance from the Plan Funds of KFRI is sincerely acknowledged without which this project could not have been taken up. Our sincere acknowledgements are due to Dr. S. Sankar, Dr. K. K. Seethalakshmi and Dr. K. V. Bhat, Scientists, Kerala Forest Research Institute for editorial scrutiny.

PREFACE

Bamboo, apart from being a versatile livelihood material for the poor, marginalized and socially weaker sections of the society as a raw material too for weaved mat products, handicrafts, etc., offers an excellent structural material for panel and board products, furniture and fixtures, housing, etc.. While the major bamboo consuming sectors, *viz*, the pulp and paper sector and the traditional mat and handicrafts utilize straight and mature bamboo culms, the crooked basal portion as well as the low diameter top portions of bamboo culms that are normally wasted can be effectively and economically utilized for the production of charcoal.

Eventhough the use of bamboo charcoal is very much established in bamboo rich countries like China, it is not so in India, especially in Kerala. If economically viable, the potential of utilizing bamboo species inferior for structural applications could also be thought for conversion into charcoal. As appropriate technologies for bamboo charcoal production have never been tested in Kerala, the present study was undertaken for evaluating different methods of production of bamboo charcoal and to assess the yield and quality of charcoal obtained for developing most appropriate bamboo carbonization system suitable to local conditions. We welcome entrepreneurs for further interactions for commercial scale bamboo charcoal production utilizing the know-how developed by the Kerala Forest Research Institute.

Dr. K. V. Sankaran
Director
Kerala Forest Research Institute

ABSTRACT

Even though India, especially Kerala, has a rich resource of bamboo after China, unlike in China, people here are neither making nor familiar with bamboo charcoal. In order to assess the potential of utilizing the crooked basal portion, the low diameter top portions of bamboo culms that are normally wasted, and full bamboo stems of species that are unsuitable for structural applications, a study was undertaken to evaluate the yield and quality of bamboo charcoal produced by different methods in order to develop appropriate methods of production.

The traditional earth-pit method and portable drum method normally employed for the production of charcoal from wood and coconut shell were evaluated for the production of bamboo charcoal. An indigenous earthen pot method, traditionally used for the production of teak wood distillate where charcoal is a by-product, was also evaluated. The yield and quality of bamboo charcoal were found to differ significantly between the methods. The self-firing pit and drum methods gave higher yield (33-36%, on oven dry basis) of charcoal with lower quality, whereas the externally heated earthen pot method gave a lower yield but higher quality. Bamboo charcoal had high ash content (7.5%) and was alkaline in nature (pH 8.9-9.7). Charcoal with high volatile content (12.3-24.3%) and low fixed carbon content (70.5-78.3%), suitable for domestic uses, was obtained from the self-firing earth-pit and drum methods and with low yield (26.4%), low volatile content (9%) and high fixed carbon content (83.9%), suitable for industrial uses, from the earthen pot method where indirect heating was employed. In general, bamboo charcoal was found to be brittle, with poor hardness.

External heating method was evaluated for the production of bamboo charcoal from *Bambusa bambos* employing metal drum retort having facility for recovering the pyroligninous vapour for burning purpose. Bamboo charcoal with low volatile (11.8%) and high fixed carbon (81.6%) was obtained. When the design of the retort was improved for recovering the distillate by condensation, bamboo charcoal with still higher quality (volatile content 9.0%, fixed carbon 84.2%) was achieved. Charcoal yield (on oven dry basis) was from 31.1 - 33.1%. The product was alkaline with a mean pH of 9.7 and mean iodine value of 256 mg/g. The study indicated that external heating system employing metal drum retort with facility for condensing the pyroligninous vapour and separating it could achieve above 30 per cent yield

with desirable qualities of low volatile content (around 9%) and high fixed carbon content (84%, rounded) required for industrial uses. The average ash content of bamboo charcoal produced was found 6.7 per cent. As far as the effect of carbonization temperature on the yield and quality of charcoal produced were concerned, an inverse effect was observed. Low carbonization temperature resulted in high yield with high volatile content and low fixed carbon content.

Trial production of bamboo charcoal in an industrial pilot carbonizing plant (refractory brick insulated stationary self-firing type carbonizing furnace of 1.3 m diameter, 1.5m height, capable of maintaining a draft of 20 mm water column) available with M/s. Indo German Carbons, Kochi, Kerala gave 30.8% yield on moisture free basis. Using this plant, 0.4 tonne of the crooked high-density basal portion of air-dry *Bambusa bambos* half-splits of 150-300 mm size was carbonized by employing self-firing method; maintaining a temperature of around 850^{0} C for 2 hrs with regulated air (35^{0} C) flow at atmospheric pressure, within a total carbonization time of about three hours. The resultant charcoal had a volatile content of 15.2%, ash 7.8%, and fixed carbon around 77%, pH 9.8 and iodine number 309 mg/g.

Trial production of bamboo charcoal was conducted in an improved pollution-free vertical carbonization plant developed by the Kerala Forest Research Institute (KFRI) for the community level production of coconut shell charcoal (with an input capacity of 3 tonne shell per day which can produce about 0.9 tonne charcoal per day), utilizing a charge of 2.5 tonnes of air dry *Bambusa bambos* which gave 29.2% yield (oven dry basis) with 12.0% volatile content.

As the traditional methods (earth-pit and drum methods) being polluting (due to ground level smoke spread), the need to go for pollution free carbonizing plants for the production of charcoal of desired quality for industrial use is well justified by the comparatively moderate yield (31.1 to 33.1% from retorts and 29.2-30.8% from industrial pilot plants tested) and quality (low volatile content in the tune of 9.0-15.2%).

Investigation on the potential of bamboo activated carbon production employing the existing industrial pilot plants designed and optimized for activated granular coconut shell carbon gave low yield and poor quality product. Considering the inherent poor hardness of bamboo charcoal, the trial indicated the need for further in-depth studies for developing appropriate technology and improved design for industrial plants for commercial scale production of bamboo charcoal and activated carbon for industrial use.

Key words: Bamboo charcoal; bamboo activated carbon; *Bambusa bambos*; charcoal yield and quality.

INTRODUCTION

Charcoal has many advantages as a domestic fuel over firewood in terms of energy and economy. Further, it is the raw material for producing activated carbon, an important industrial product. While the pulp and paper sector and the traditional mat and handicrafts sector utilize bamboo culms, the crooked basal portion as well as the low diameter top portions of bamboo culms that are normally wasted can be effectively and economically utilized for the production of charcoal. Bamboo charcoal is reported to have an average calorific value of 7800 kcal/kg (Park *et al.*, 1998); greater density, ash and volatile contents than the charcoal from *Eucalyptus urophylla* wood (Brito *et al.*, 1987). The activated carbon from bamboo charcoal is reported to be economically promising for the removal of dyes and phenol, in comparison to other commercial adsorbents (Wu *et al.*, 1999).

Traditionally in Kerala, charcoal is produced from coconut shell and only a minor quantity is produced from wood. Charcoal production from bamboo is not popular in Kerala. In this context, a study was carried out to produce charcoal from bamboo by the traditional methods (earth-pit method and portable drum method) which are used for the production of charcoal from coconut shell and wood employing direct or self-firing methods as well as employing drum retorts using indirect heating (with facility for recovering the pyrolignious vapour for burning in the burner or condensing it into wood tar), and also to evaluate the quality of charcoal thus produced. Attempts were also planned for conducting trial runs in available industrial pilot plants for shell charcoal production for investigating the scope of such plants for bamboo charcoal production.

Bamboo activated carbon is also not familiar to India and especially to Kerala. As a step towards value addition, a preliminary attempt was planned for activating the bamboo charcoal produced employing the industrial pilot scale plant available, and to assess the yield and quality of the product, the granular bamboo activated carbon.

REVIEW OF LITERATURE

Even though only a yield of 13-20 per cent is achievable from the existing industrial plants in Japan, higher yield up to 25.3 per cent was reported by Hosokawa and others (n. d) under experimental conditions. Bamboo charcoal had a high level of porosity and large surface area in the tune of 200-300 m^2 g^{-1}. Because of its excellent adsorption property, bamboo charcoal is suggested for deodorants and moisture adsorbents. It is also used for barbeque fuel, water purification, rice cooking, soil improvement, humidity control, etc. in bamboo rich Southeast Asian countries. The low specific gravity of bamboo charcoal makes it a very light electromagnetic wave shielding material (electric resistance value under 10^7 Ohms) beyond the reach of metals or polymers. As electromagnetic wave shielding materials using charcoal offer heat and fire resistance, oxidation resistance, chemical stability, anti-degradation, high dimensional stability and biological affinity at the same time, their applications are not confined to the bodies of electronic equipments but include building materials (bamboo carbonized formed boards) and components for automobiles, trains, spacecrafts and ships (Sugiura, 1992).

The by-product of bamboo charcoal production, the condensed pyroligneous liquor, consists of more than 95 per cent water, and more than twenty trace organic materials including vinegar, acetone and furfural. It is a powerful deodorizer and useful as a preservative and bactericide. It is reported to have applications in food additives (to improve flavour and to prevent spoilage) and medicine (to fight skin infections, and as a natural antibiotic) (Uchiyama, 1998).

An overview of the current methods of carbonization of bamboo and the types of kilns employed in Japan is detailed by Hosokawa and others (n. d). This consists of the mud earthenware kiln, iron kilns, fixed stainless steel kilns, etc. The Schwartz type earth mound kilns capable of achieving higher carbonization temperature and reasonable yield (carbonization time of around 240 hours for a 4 m^3kiln) are widely adopted by the Japanese bamboo charcoal makers (Huang *et al.*, 2000 and 2004). Bamboo with a moisture content of around 15-20 per cent (on oven dry basis) is reported to be better in yield and quality. Different temperatures are used to make different types of charcoal suited for various purposes. Charring temperature greatly affect the structure of charcoal. In charcoal prepared up to 400 °C, most of the morphological characteristics remained relatively unchanged with the exception of the cell-wall layering (Kim and Hanna, 2006). The surface area of bamboo charcoal is also reported to be varying depending upon the carbonizing temperature employed. Variations in the tune of 98 to 255 m^2/g are reported for products from different temperatures. INBAR (2003) states that 1 g of bamboo charcoal has an adsorbing area of over 350 m^2. Industrial kilns are reported to employ a maximum temperature up to 800 °C. The volatile content is reported to be inversely related with carbonization temperature. Takashi *and others* (2002) reported the effect of carbonizing temperature (400, 700 and 1000 °C) of bamboo charcoal on its removal capability of harmful gases and odorants, and the use of bamboo charcoal as a countermeasure deodorant for "sick building syndrome" or "chemical sensitivity". The effect was tested for formaldehyde, toluene and benzene that are known to cause sick building syndrome, and for ammonia, indole, skatole, and nonenal as odorants. They concluded that the effective carbonizing temperature is different for each chemical, and charcoal must be specifically selected for use as an adsorbent or deodorant. The electric resistance of bamboo charcoal is found to decrease as the carbonization temperature increases. The BET surface area and total pore volume increased as the carbonization temperature of the bamboo charcoal increased (Takashi *et al.*, 2006). They also detailed the excellent ammonia adsorption capacity of bamboo charcoal. The Forest Products Research and Development Institute (FPRDI) of Philippines developed a 90 kg capacity bamboo charcoal kiln which can produce high quality charcoal and pyroligneous liquor or raw industrial vinegar that is in great demand in Japan (FPRDI, n. d.). The bamboo charcoal is found as good as activated carbon in purifying water, removing odour, keeping food fresh and maintaining soil alkalinity; it is used in electronics and battery manufacture. The by-product of bamboo charcoal production, bamboo vinegar, is in great demand in Japan, to treat allergies and sore throat; it acts as an antiseptic, skin and hair conditioner, air cleaner, bathroom deodorizer, and prolongs the vase-life of fresh flowers and plants. FPRDI also has reported a technology for bamboo charcoal briquetting with starch.

As far quality is concerned, unfortunately, even in international scenario, there is not yet an agreed quality standard for bamboo charcoal (Hosokawa, n. d.); whatever systems followed for bamboo charcoal quality assessment in Southeast Asian countries and China are arbitrary and are not internationally accepted.

The Indian Institute of Technology (IIT), Mumbai has developed a batch type bamboo charcoal production facility (drum type) with an input capacity of 100 kg/batch. The system took a carbonization time of 2.5 hours/batch yielding 25% bamboo charcoal of calorific value 28 MJ/kg from bamboo with moisture content not greater than 30%. The limitation of the system is that the size of bamboo material to be fed to the unit for charcoal production is to the tune 1-3.5 inches dimension (Anuradha *et al.*, n. d.). Anuradha (2003) details the design of the drum carbonization unit developed and reports that a temperature of 500 ^{0}C is desired to produce commercial quality charcoal from bamboo. The pyrolignious vapour condensate predominantly contains phenols and substituted phenols, a good source for resin manufacture. Anuradha (2003) also introduced the conceptual design of a bamboo gasifier. The National Mission on Bamboo Applications (NMBA) has developed specially designed batch type brick kilns of input capacity of 2.5 - 3.5 tonnes to produce bamboo charcoal of high yield and quality (yield 25%; ash 4.5-6.5%; moisture 6-9%; carbon 80-85%; calorific value 6,900 – 7,000 kcal/kg). A kiln of the above type takes a production cycle time of 5 days on an average. A battery of 5 NMBA brick kilns is reported to be the minimum size of a commercially viable bamboo charcoal unit (NMBA, n. d.).

The International Network for Bamboo and Rattan (INBAR) reports that bamboo charcoal has much higher adsorbtivity than wood charcoal and hence can be used for a wide range of applications such as drinking water purifiers, air filters, gas masks, mattresses and pillows, as deodoriser and in certain industrial purification uses. The by-product of the manufacturing process, bamboo vinegar, is used as an ingredient in health products. INBAR reported an export potential of about 7000 tonnes of bamboo charcoal to Japan and South Korea during 2001 and China took the advantage (INBAR, 2007). INBAR has published a transfer of technology model for bamboo charcoal (INBAR, 2003).

Innovative application of bamboo charcoal in textile, building, food, medicine, gardening, and animal farming sectors are detailed by Sakada and others (1993), Hosokawa and others (1991), Minamide and others (1992), and Abe and others (2001). Metal ion (Cu^{2+}, Ni^{2+} and Fe^{2+}) removal capability of bamboo charcoal is reported to be very high (98.0-99.9%) (Joshi, *et al.*, 2003).

MATERIALS AND METHODS

Crooked basal portions of *Bambusa bambos* which are usually rejects for commercial uses such as slivers for mat weaving and poles for structural applications, were collected from bamboo depots of Palakkad District of Kerala, India. They were air dried, cross cut into 25-50 cm long pieces and used for charcoal production. Wherever round bamboo could not be accommodated, half-splits were used. Moisture content of bamboo was determined by oven drying.

Earth pit method

The traditional earth pit method employed by the local communities in Kerala for the production of coconut shell charcoal was tested for its suitability for producing bamboo charcoal. A weighed quantity of bamboo of known moisture content was piled in a pit of 30 cm depth, 100 cm width and 100 cm length, in a heap form with a provision for air inlet and lighting the fire. The heap was slowly built up to the full and covered with leaves, over which a mud plaster was given with a hole at the top for venting the smoke (Fig. 1). The bamboo charge was lighted and allowed to burn slowly. After three hours, the vent was closed to restrict air entry (to prevent further burning of charcoal) and the charge was allowed to cool overnight. The heap was opened the following day morning and charcoal was collected and weighed after cooling. The moisture content was determined by oven drying and yield was calculated on moisture-free basis.

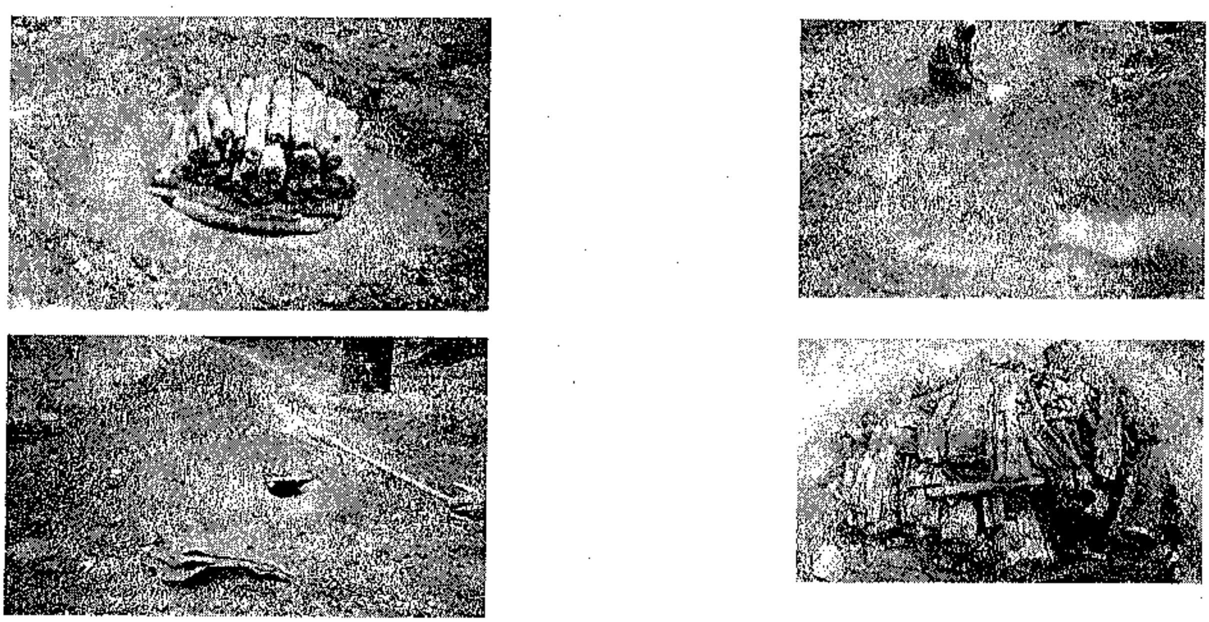

Fig. 1. Traditional earth pit method of charcoal production - various stages.

Drum methods

Vertical drum method

A portable oil drum (cylindrical, 200 l capacity, top opened) of dimension 90 cm height and 55 cm diameter, was held vertically and partially filled with weighed quantity of air-dry round bamboo billets of known moisture content. It was lighted and once the fire stabilized, the entire drum was slowly filled with bamboo billets. After filling and once the fire got distributed evenly, the drum was closed with a lid and the edges were sealed with mud plaster to limit the air supply. The set up was allowed to remain overnight (Fig. 2). Charcoal was collected on the next morning by opening the drum; weighed after cooling.

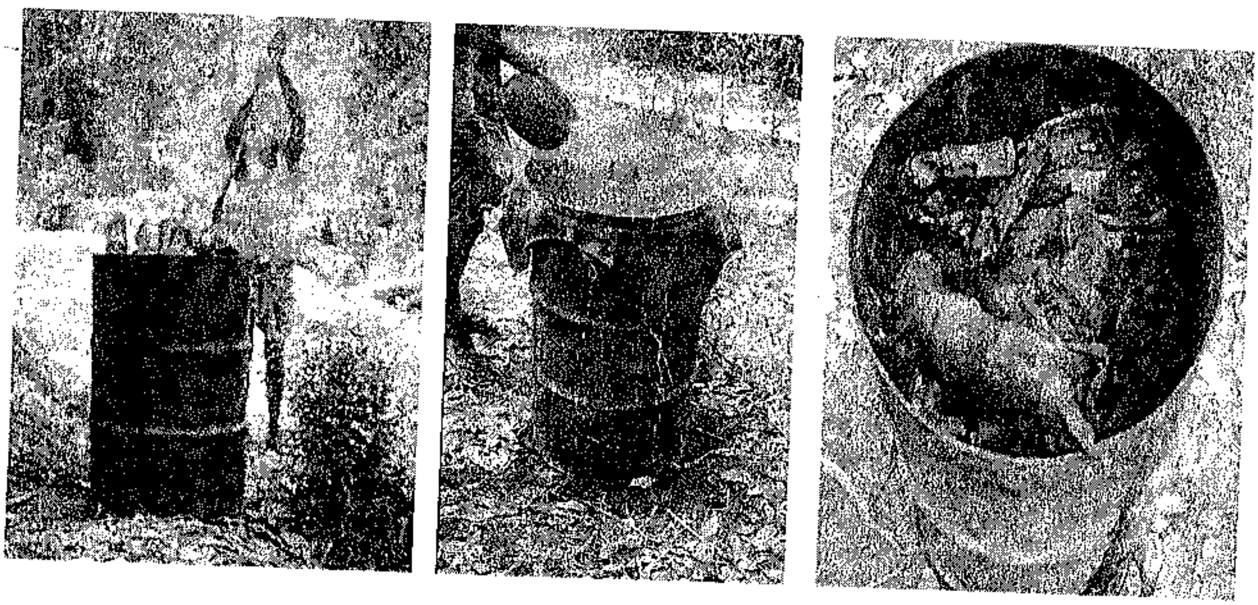

Fig. 2. Portable vertical drum method of charcoal production - various stages.

Tongan drum method

In this method (*see* Gnanaharan *et al.*, 1988) a drum of dimensions as above, but with a lateral opening of 20 cm width and 80 cm length, was placed horizontally. The drum was loaded partially (one-fourth) with weighed quantity of air dried bamboo billets of known moisture content, and the material was ignited (Fig. 3). Once the fire got spread evenly, the drum was gradually filled with bamboo billets and finally the opening was closed and sealed with mud plaster and allowed to remain overnight. Charcoal was collected the next morning, weighed after cooling and the yield was determined.

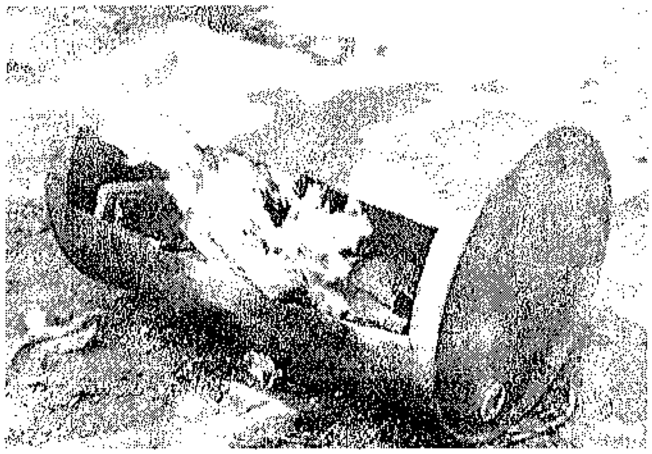

Fig. 3. Tongan drum method of charcoal production.

Indigenous earthen pot method

There is an indigenous method to produce teak wood distillate in which charcoal is a by- product (*see* Dhamodaran, 2003). In this method, an earthen pot of 100 l capacity was used. The bamboo was split, cross cut into 25 cm long pieces and stacked inside the vessel carefully. The filled up pot was turned upside down and another small mud pot was connected at the mouth to collect the distillate; made air-tight by sealing with cloth soaked in clay and cow dung. The pot was kept in a small pit. An air dried reed (reed bamboo) of about one m length was connected to the small mud-pot and the joint was sealed airtight with mud plaster, cow dung and cloth. At the open end of the reed pipe, a small mud pot was placed for collecting the condensed distillate liquor. The pit was covered and made airtight by using clay and cow dung. Later, firewood was placed over the earthen pot and ignited (Fig. 4). After some time, the black liquor oozing as a result of the destructive distillation was collected in the receiver pot. After about an hour, when the flow of black liquor ceased, heating was discontinued, and the assembly was allowed to cool for an hour. The system was then carefully dismantled. Bamboo charcoal from the distillation vessel was allowed to cool, weighed and yield was determined. The distillate (bamboo tar) was collected from the receiver pot and volume of the liquor measured.

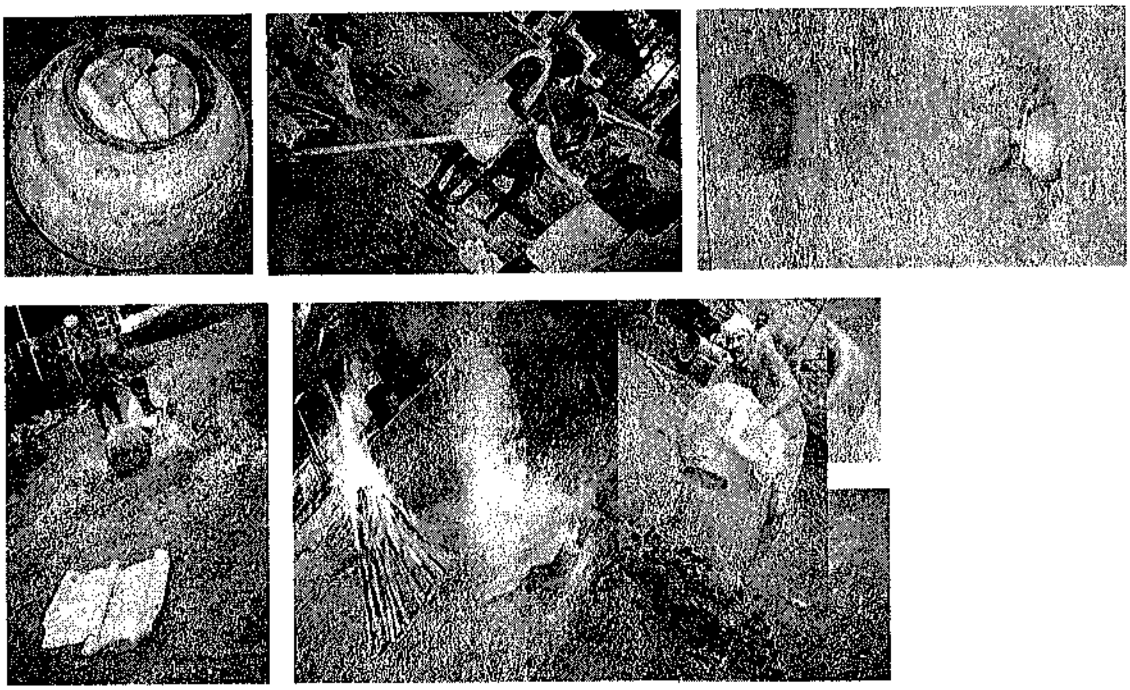

Fig. 4. Externally heated, indigenous earthen pot method of charcoal production yielding distillate – various stages.

Double drum retort method

A double drum retort fabricated from two empty cylindrical oil drums (each of 200 l capacity) of dimensions 90 cm height and 55 cm diameter, made as per the guidelines of American Fireworks News (Anonymous, 2002) was employed in the preliminary trial for producing bamboo charcoal by indirect heating system. Digital pyrometers were connected to the drums for observing the temperature raise, for better control over the heating duration. This system (Fig. 5) was not permitting the recovery of distillate liquor; instead, the pyrolignious gas produced was recovered for combustion in the fireplace. Both the drums were fully loaded with weighed quantity of bamboo of known moisture content and the system was closed air-tight by using the lid of the drums and metal ring clips. The edges of both the drums were sealed with mud plaster to avoid any further air entry. A fire was lighted in the fireplace below the drums. Temperature rise inside the carbonizing chambers was noted in regular time intervals. The external heating was regulated in such a way that the temperature inside the retort stabilized at 600^{0} C. When the temperature inside the drums got stabilized at 600^{0} C, external heating was stopped. Once more the edges of the drum and the lid were given an additional sealing with mud plaster to secure the system from air entry while cooling. The double drum retort was allowed to cool overnight. On the next morning, the system was opened, charcoal was unloaded, cooled and weighed to determine the yield.

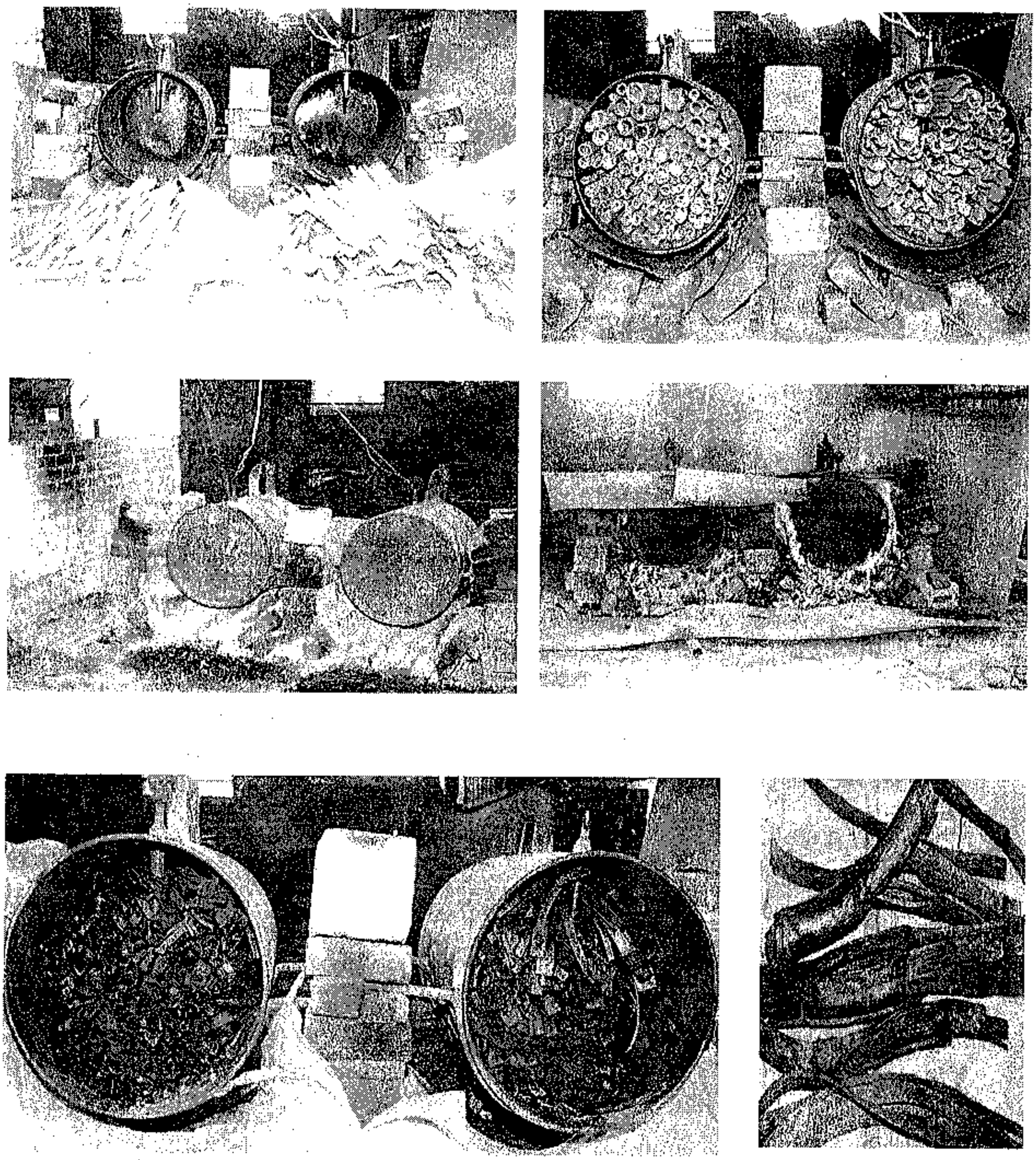

Fig. 5. Double drum retort for bamboo charcoal production employing external heating using firewood – various stages.

Improved drum retort method

An improved single drum retort was designed and fabricated for facilitating the recovery of the distillate liquor. A pipe starting from the upper side of the horizontally laid drum retort was attached to multiple condensing pipes enclosed in a cover pipe with facility for water cooling the upcoming vapour. The distillate was collected in a mud pot placed below the condenser tap. This system (Fig.6) was connected with a digital pyrometer to observe the temperature changes inside the retort. As mentioned earlier, the drum retort was fully loaded with weighed quantity of bamboo of known moisture content and the system was closed air-tight with its lid and the metallic ring clip; the edges of the drum were sealed with mud plaster to avoid any further air entry. External heating was made with firewood in the fire-place. When the temperature inside the drum reached 600ºC, heating was discontinued; the edges of the drum were given an additional sealing with mud plaster and the system was allowed to cool overnight. On the next morning, the system was opened, charcoal unloaded, cooled and weighed for yield determination.

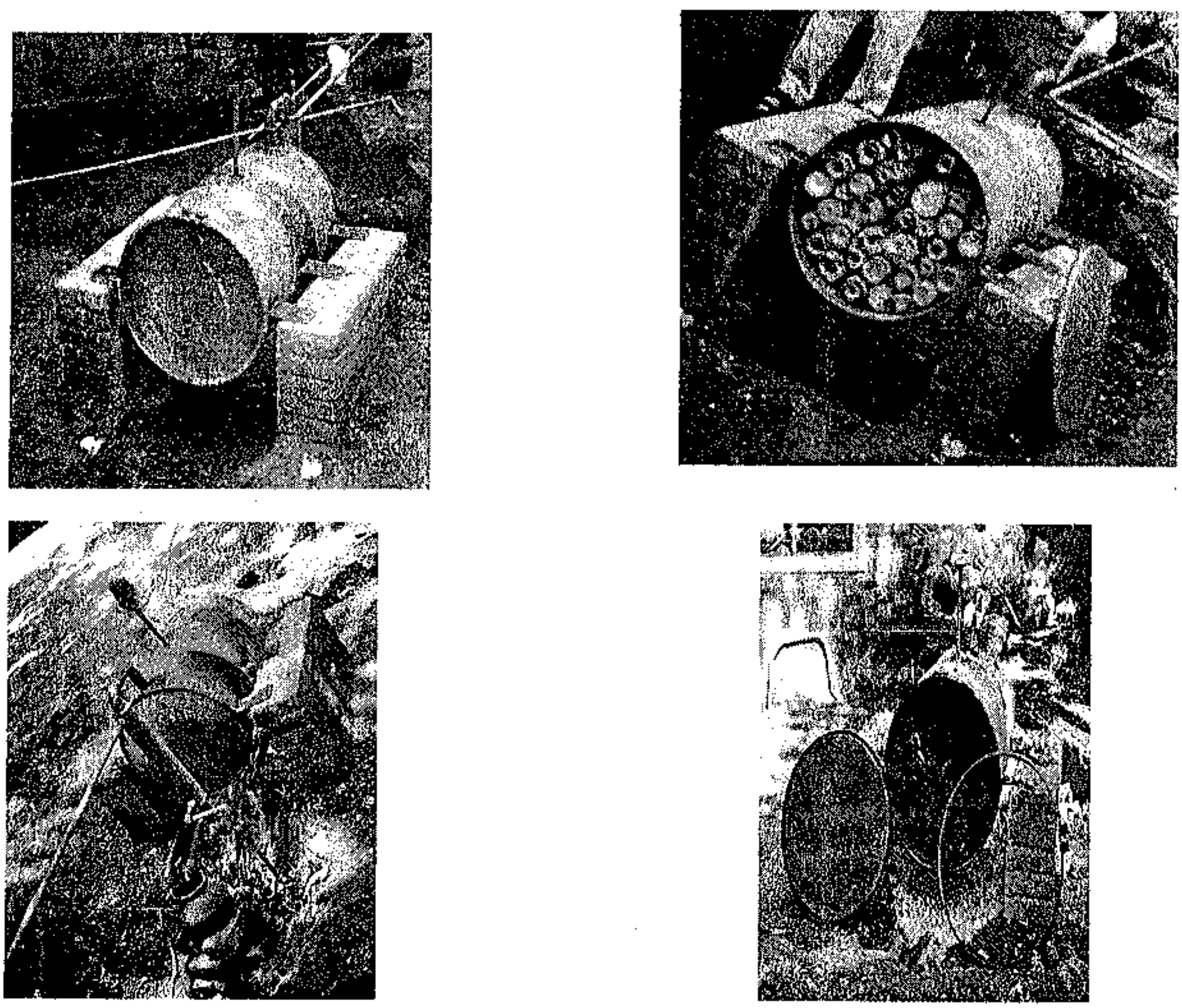

Fig. 6. Improved drum retort with facility for collection of distillate for bamboo charcoal – various stages.

Effect of carbonizing temperature on charcoal quality

The effect of carbonizing temperature on charcoal quality was investigated by employing a cylindrical electrically heating oven. Air dry bamboo samples were subjected to different carbonizing temperatures (400, 300, and 200^0 C) for different duration (2.8 hrs, 1.5 hrs and 8.0 hours respectively). Yield and quality of charcoal was evaluated as usual.

Industrial pilot plant trial run for bamboo charcoal production

A pilot plant optimized for the production of coconut shell charcoal, available with M/s. Indo German Carbons, Binanipuram, Aluva, Kerala was used for the trial production of bamboo charcoal. The plant was an insulated refractory brick lined furnace with a diameter of 1.25 m and height 1.5 m, capable of maintaining a draft of 20 mm water column (Fig 7). High-density basal portions (waste residue of about 1 m length) *Bambusa bambos*, 4 years of age were procured, converted to half-split sizes of about 150 – 300 mm length (assorted sizes) and used for the trial. The material had a mean moisture content of around 22%. The furnace was filled with weighed assorted sizes of bamboo. Some fired red-hot coconut shells were fed for initiating self firing. A maximum temperature of 850^0 C was maintained for two hours. Regulating or varying air (at 35^0 C, atmospheric pressure) quantity into the furnace maintained uniform temperature during the operation. The product, charcoal was unloaded and weighed after cooling into room temperature; the yield and quality were estimated.

Another trial production of bamboo charcoal was attempted in a vertical continuous carbonizing plant developed and optimized by the Kerala Forest Research Institute (Dhamodaran and Gnanaharan, 2010a) (Fig. 8). The vertical carbonizing plant designed for community-level production of coconut shell charcoal and installed at the "SUBICSHA" project site at Perambra, Kozhikkode, Kerala was used. This was a pollution free system with 3 tonne input capacity per day. The detailed drawings of the plant and operation are described in Dhamodaran and Gnanaharan (2010 b). The yield and quality of bamboo charcoal produced was determined.

Investigation into the feasibility of activated bamboo charcoal

A weighed quantity of bamboo was carbonized in the industrial pilot plant of M/s. Indo German Carbons (Fig. 7) and the charge was directly activated in the same plant using the available waste steam with a pressure of 0.5 kg/m^2 (from their main steam line) at 250° C for one hour. The activated carbon was removed when the temperature reached 250° C, permitting for a cooling time of another 20 minutes in the plant. The product was weighed after cooling to room temperature. Yield and quality were determined by the same techniques employed for charcoal.

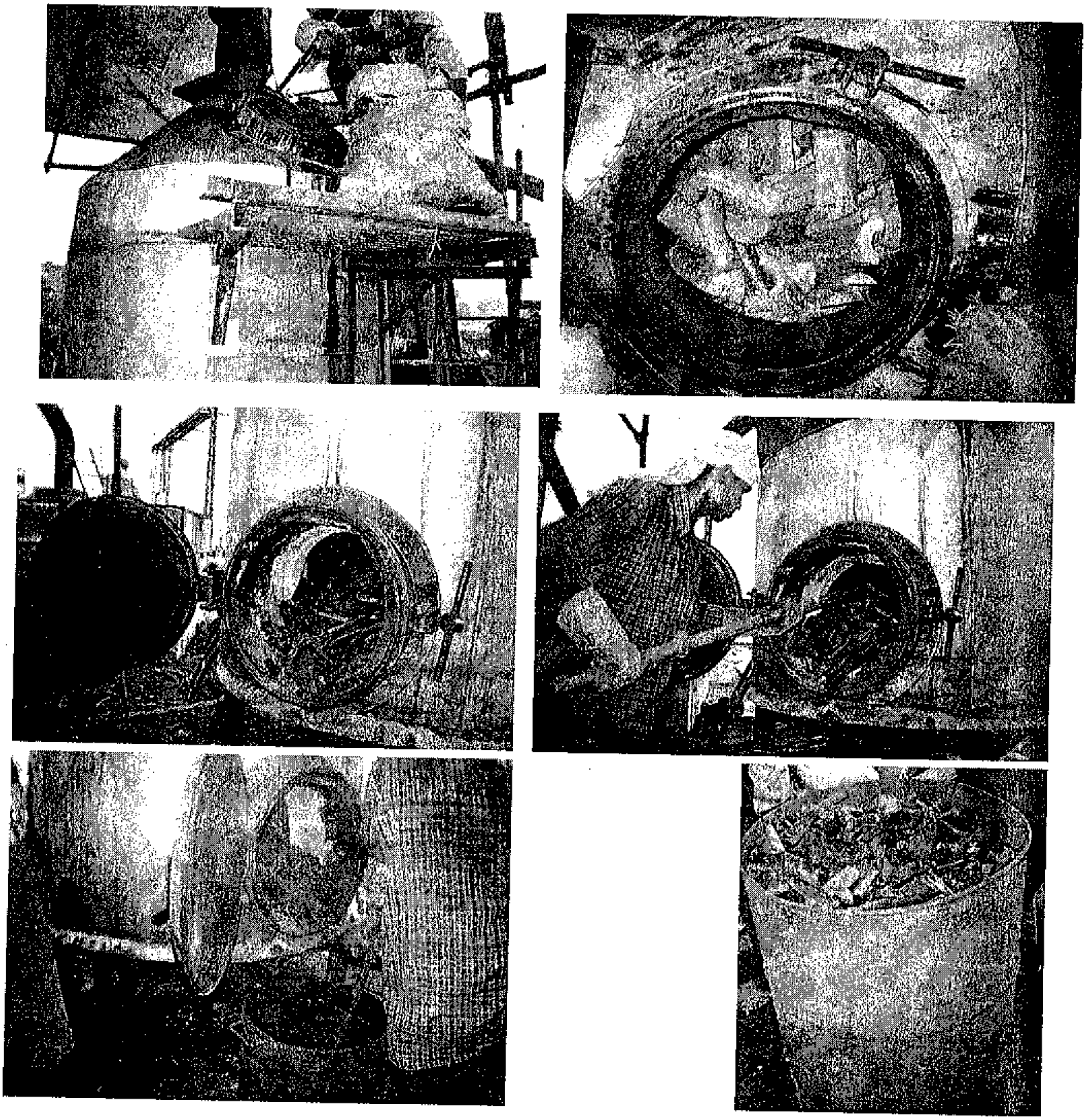

Fig. 7. Bamboo charcoal production in the industrial pilot plant of M/s. Indo German Carbons – Various stages.

Analysis

Eight replicates of charcoal samples from each method were analyzed for moisture, volatiles, ash and fixed carbon content by ASTM methods (ASTM, 1981). Volatiles and ash contents were corrected to moisture-free basis and accordingly fixed carbon content was determined. The pH was determined from the extract of 10 g charcoal dust in 100 ml distilled water. Iodine number of the charcoal was determined as per the procedure of the Indian Standards (BIS, 1995). Quality of activated bamboo carbon (volatile content, ash content, fixed carbon content, pH, iodine number, methylene blue value - MBV, and carbon tetrachloride - CTC value) was tested as per Indian Standards (BIS, 2002).

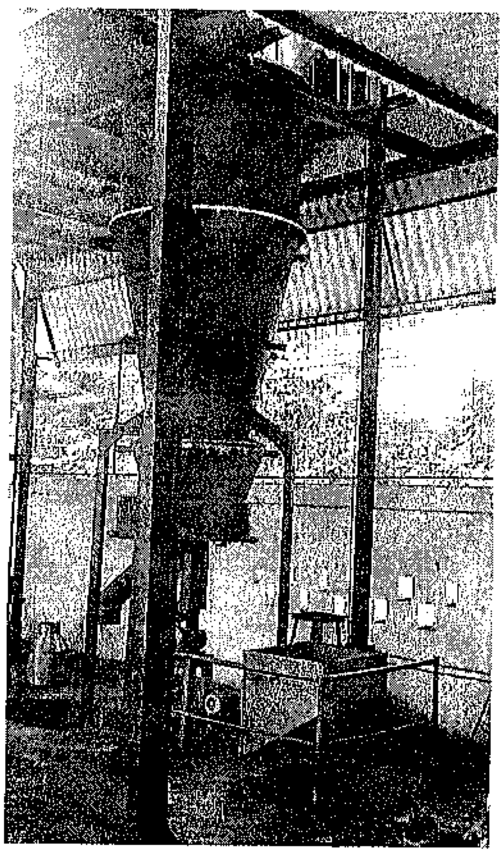

Fig. 8. The pollution-free industrial charcoal kiln developed by KFRI.

RESULTS AND DISCUSSION

Traditional and Indigenous methods

The air-dry bamboo used for charcoal making had a mean density of 600 kg/m^3 and a moisture content of 15%. The details on yield and quality of charcoal produced by the traditional self-firing methods such as the earth-pit and drum methods and the indirectly heated earthen pot method are given in Table 1. Although the yield was highest (36%) in the vertical drum method, the difference in yield among the earth pit method and the vertical and Tongan drum method was not appreciably high. The indigenous earthen pot method produced the lowest yield (26.4%) along with 5.2 per cent (v/wt) distillate (as this method is originally designed for producing distillate from teak wood).

Table 1. Yield and quality of bamboo charcoal obtained by different methods (range of values within brackets; CV% values in italics).

Sl. No.	Method of production	Yield (%) (on moisture free basis)	Quality*			
			Mean Volatile Content (%)	Mean Ash Content (%)	Mean Fixed Carbon Content (%)	pH
1	Earth-pit method	33.7	18.7 (16.4-24.3) *14.2*	5.8 (4.5-10.1) *30.5*	75.5 (70.5-78.3) *40.9*	9.6
2	Vertical drum method	36.0	14.2 (12.3-15.6) *9.7*	10.8 (9.6-11.2) *5.5*	75.1 (73.5-77.1) *1.8*	9.2
3	Tongan drum method	33.0	19.8 (19.4-20.8) *3.3*	6.1 (5.6-6.9) *6.5*	74.2 (73.0-75.5) *1.1*	8.9
4	Earthen pot (Indigenous) method	26.4*	9.0 (7.7-10.6) *13.5*	7.1 (6.8-7.6) *4.8*	83.9 (82.5-85.4) *1.4*	9.7

n = 8; * Yield of distillate = 5.2% (v/wt)

The ash content of bamboo charcoal was found to differ substantially depending on the method of production and it varied widely from 4.5 to 11.2 per cent with an average of 7.5 per cent. Thus, the method of production is important in producing charcoal with less ash content. In general, the ash content of bamboo charcoal is comparatively higher than that of wood and coconut shell charcoal.

The fixed carbon content of charcoal from pit and drum (vertical and Tongan) methods was found to be comparable (around 75%), whereas the indigenous earthen pot method gave a product with high fixed carbon content (around 84%). The volatile content of charcoal from the earth pit and drum methods was high (12.3 – 24.3%); whereas it was significantly low for the product from the externally heated indigenous (earthen pot) method (average 9%). Charcoal from the indigenous earthen pot method was found to possess a mean iodine value of 265 mg/g. This indicates the superiority of product from the externally heated indigenous earthen pot method. Further, it showed that the indirect heating for carbonization yielded better quality charcoal, though the yield was slightly low. Good quality charcoal should contain at least 75 per cent fixed carbon. Charcoal with a volatile content of around 20 per cent is suitable for domestic use, especially for barbeque (Gnanaharan *et al.*, 1988). Bamboo charcoal obtained from the earth pit and drum methods is suitable for domestic purpose as it falls under this category. Even though volatile content and fixed carbon content are found to depend on the method of production, they are comparable with that of the charcoal from other sources. Bamboo charcoal is found to be alkaline in nature; the pH values of water extract ranged from 8.9 to 9.7. In general, the charcoal produced by all the different methods was found to be very brittle (with poor hardness).

Drum retorts

Providing external heat to carbonize bamboo inside the kiln has reported to possess the potential of achieving the theoretical fixed carbon yield (Antal *et al.*, 2000). Slow carbonization at comparatively low temperature is known to yield better quality charcoal. Due to this reason, while employing retorts, the rise in carbonizing temperature inside the retort was controlled by regulating external heating. As seen from the record of the temperature rise inside the retort at regular time intervals (Fig. 9), the external heating was controlled in such a way that the targeted carbonizing temperature of 600^0 C was attained within a time span of about 1.75 hours after starting the external heating. At this stage the external heating was discontinued and the system was allowed to cool overnight.

The yield and quality of product, on oven-dry basis, from both the trials (double drum retort with facility for recovering the pyrolignous vapour for burning in the burner, and the improved single drum retort with facility for condensing the recovered vapour as tar) are given in Table 2. In general, drum retorts employing external heating yield an average moisture-free charcoal yield of 31.1-33.1 per cent.

Charcoal with comparatively high fixed carbon (around 83%) and low volatile content (9-12%, rounded) desired for industrial uses was obtained by the use of drum retorts. The average ash content of bamboo charcoal produced from retorts was found to be 6.7 per cent.

A better product with low volatile content (9%) and high fixed carbon (about 84%) was obtained from the improved drum retort where facility for the recovery of the condensed volatile distillate was incorporated; this indicated the design advantage of the improved drum retort where the volatiles are separated by condensation to tar, thereby avoiding the percolation of the pyrolignous vapour with the charcoal, in producing high quality product required for industrial uses. Comparing the bamboo charcoal produced by self-fired traditional methods which yielded products with high volatile (14-20%, rounded) and low fixed carbon contents (74-75%, rounded), the use of externally heated retorts, especially the one with facility to separate the condensable volatiles, was found to have better quality in terms of low volatile and high fixed carbon content. Bamboo charcoal produced by both the retorts was alkaline; pH of products from both the trials did not vary much (mean pH 9.7), indicating the need of mild acid washing to produce neutral product. The iodine number of the products from both the trials did not vary significantly (mean iodine value of 256), indicating the adsorption capability of bamboo charcoal. The yield of distillate from retorts was found to be 3.4% volume/weight.

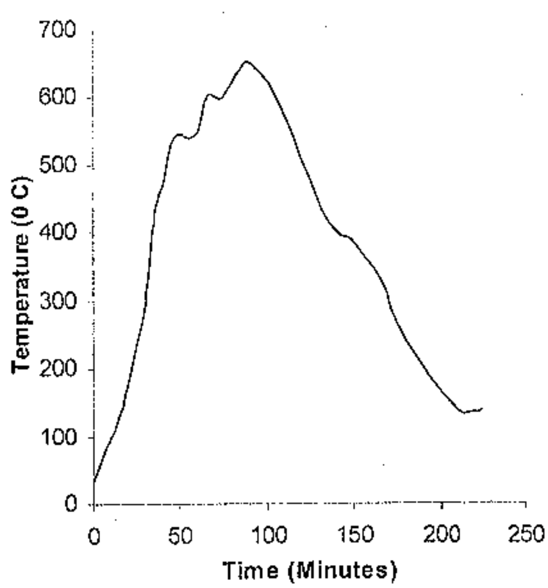

Fig. 9. Temperature rise inside the retort during bamboo charcoal production by external heating.

Table 2. Yield and quality of charcoal from bamboo (*Bambusa bambos*) by the different drum retort methods (*CV values are given in parenthesis)*

Method of production	Charcoal Yield (%) (Moisture free basis)	Charcoal quality *				
		Mean Volatile content (%)	Mean Ash content (%)	Mean Fixed Carbon content (%)	pH	Iodine Number (mg/g)
Double drum retort with facility for recovering the pyroligninous vapour for burning purpose	31.1	11.8 *(8.6)*	6.6 *(2.9)*	81.6 *(1.3)*	9.8	254 *(3.8)*
Improved single drum retort with facility for recovering the condensed distillate liquor	33.1	9.0 *(12.1)*	6.8 *(7.0)*	84.2 *(0.9)*	9.6	258 (4.6)
Pooled Mean CV (%)	32.1 *(4.4)*	10.4 *(3.6)*	6.7 *(2.1)*	82.9 *(2.2)*	9.7 *(1.5)*	256 *(1.1)*

* *n = 8; Yield of distillate = 3.4% v/wt*

Table 3 shows the effect of various carbonizing temperatures on the yield and quality of bamboo charcoal obtained while employing an electrically heated carbonizing furnace. It was found that low carbonizing temperature produced charcoal with high volatile content and low fixed carbon content.

Table 3. Charcoal making by using an electrically heated carbonizing furnace - effect of temperature on charcoal quality

Carbonizing Temperature (^{0} C)	Duration (Hrs.)	Yield (%)	Volatiles (%)	Ash (%)	Fixed Carbon content (%)
400	2.8	41.5	20.6	4.6	74.8
300	1.5	42.5	27.1	5.5	67.4
200	8.0	59.4	28.0	5.4	66.6

Trial run in industrial pilot plants

A yield of 30.8 per cent bamboo charcoal was obtained in the trial production while employing the industrial plant optimized for coconut shell charcoal production, available with M/s. Indo German Carbons (Table 4). Comparatively higher iodine value of bamboo charcoal obtained from the industrial pilot plants (309-315 mg/g) than from the indirectly heated earthen pot method (265.2) showed that the product from the self-fired industrial pilot plants is in no way inferior. Similar were the results for the other quality parameters (volatile content, ash content and fixed carbon content) of the product from the industrial pilot plants optimized for shell charcoal production (Table 4). As the plant developed by KFRI (Dhamodaran and Gnanaharan, 2010a) had the facility for employing various carbonizing temperatures, products of desired volatile and fixed carbon content could be produced from it. This shows the potential of employing the pollution-free carbonizing plant developed and optimized by KFRI for community level production of shell charcoal for the production of bamboo charcoal too. Improvement of the design of the KFRI plant and optimizing production parameters for appropriating it for the commercial scale production of bamboo charcoal needs to be further looked into in-depth.

Table 4. Yield and quality of charcoal from *Bambusa bambos*) employing industrial pilot plants optimized for coconut shell charcoal production (*CV values are given in parenthesis)*

Method of production	Charcoal Yield (%) (Moisture free basis)	Charcoal quality *				
		Mean Volatile content (%)	Mean Ash content (%)	Mean Fixed Carbon content (%)	pH	Iodine Number (mg/g)
Industrial pilot plant optimized for coconut shell charcoal production available with M/s. Indo German Carbons.	30.8	15.2 *(6.1)*	7.8 *(3.1)*	77.0 *(1.4)*	9.8 *(1.5)*	309.0 *(14.9)*
Pollution free industrial pilot plant developed by KFRI, optimized for the community level production of shell charcoal.	29.2	12.0 *(7.8)*	7.0 *(4.2)*	81.0 *(2.1)*	9.5 *(1.7)*	315 *(15.0)*

* *n = 8*

Trial run for activating bamboo charcoal in an industrial pilot plant

Table 5. Yield and quality of bamboo activated charcoal produced by employing the industrial pilot plant available with M/s. Indo German Carbons.

Yield (%) (moisture free basis)	Quality*						
	Mean Volatile content (%)	Mean Ash content (%)	Mean Fixed Carbon content (%)	pH	Iodine Number (mg/g)	Methylene Blue Value (MBV, mg/g)	Carbon Tetra Chloride (CTC) Value (%)
11.0	0.0 (0.0)	9.1 (2.2)	90.9 (0.2)	9.91	512 (6.7)	41.5 (5.5)	9.6 (22.9)

* n = 8

The quality of bamboo activated carbon produced (pH, iodine number, MBV, CTC value, etc), as is evident from Table 5, was found inferior to that of coconut shell activated carbon produced in almost similar conditions (pH 9.95, iodine value 850, MBV 44.5, CTC value 50). Other quality parameters such as volatile content, ash content, fixed carbon content, etc. being species- and process- dependant, were non-comparable. Comparing with commercially available laboratory grade BDH powder activated carbon with MBV of 51.0 mg/g, bamboo activated carbon produced had an MBV of 41.5 mg/g.

The poor hardness of bamboo charcoal, the raw material for producing bamboo activated carbon, could be one reason for the poor quality of the bamboo active carbon produced. Further, the plant employed for producing bamboo activated carbon was the one optimized for the production of coconut shell granular active carbon. This could be another reason for the poor quality of bamboo active carbon produced. Further, it was observed that due to the poor hardness of bamboo charcoal, it was difficult or rather impossible to employ pulverizer for the size reduction of bamboo charcoal. Almost the entire quantity of bamboo charcoal was getting powdered into irregular sizes and getting wasted, instead of getting specified sizes of granular charcoal desired for activation. Possibility of employing bamboo charcoal for powder activated carbon is out of question with the physical (steam) activation system employed; as chemical activation is the widely accepted method for the commercial or industrial scale production of powder active carbon. Further, the starting raw material for powder active carbon is saw dust. It was felt that it is unlikely to be economical (on energy requirement grounds) to powder bamboo and activate it chemically. In this situation, further work on the preparation of granular bamboo activated carbon was dropped.

Experience on the trial production of granular activated carbon from bamboo indicated the following for optimizing the yield:

i. Ideal size of the raw material should be less than 10 cm for uniform heating and activation
ii. Higher activity can be achieved if superheated steam at higher pressure is used
iii. Bamboo should be of even thickness as far as possible and moisture content preferably less than 15%.

CONCLUSION

The yield of charcoal from bamboo differs between the methods employed. A moisture-free yield of 33-36 per cent was obtained from pit and drum methods, whereas the yield from retorts was slightly low (31-33%). Except from the vertical drum method, the average ash content of bamboo charcoal was found to fall between 5.8 to 6.8 per cent. The product from the self-firing vertical drum method was found to possess the highest ash content (10.8%); product from the indirect heating earthen pot method was with an ash content of 7.1 per cent.

The volatile content and fixed carbon content were also found to vary depending on the method of production; high volatile (14.2 – 19.8%) and low fixed carbon content (74.2 – 75.5%) for the charcoal from pit and drum methods and low volatile (9-11.8%) and high fixed carbon content (81.6-84.2%) for the charcoal from the indirect heating systems such as the indigenous earthen pot method and drum retort methods. Since, charcoal with high quality (low volatile and ash contents, high fixed carbon) is required for industrial uses and the indirect heating system is found producing charcoal of better quality, indirect heating system may be more promising on product quality point of view for industrial uses. The earth pit and drum methods can produce charcoal suitable for domestic purpose.

As bamboo charcoal from all the different methods employed is found brittle in nature (poor hardness), it may be more suitable for powder charcoal applications as far as its industrial use is concerned. Bamboo charcoal is found to be alkaline in nature (pH 8.9 - 9.8), indicating the need for mild acid washing for making it neutral for chemical applications where neutral charcoal is desired.

External heating system with facility for condensing and separating the pyroligninous vapour formed while carbonizing was found producing high quality bamboo charcoal (low volatile content up to the level of 9% and high fixed carbon up to 84%, rounded) suitable for industrial uses.

Retort with improved design facilitating the collection of distillate liquor was found producing better quality bamboo charcoal than the retort where the volatile gases were recovered just for burning. The general indication is that for high quality bamboo charcoal production, the design of the carbonizing retort should be in such a way that the percolation of the volatile pyrolignious gases formed with the charcoal already inside the retort needs to be avoided by incorporating condensation and separation facility of the volatiles formed.

Investigations on the possibility of employing industrial pilot plants optimized for coconut shell charcoal production revealed the possibility of utilizing the same for the production of bamboo charcoal of desired quality. However, due design and process parameters optimization needs to be further undertaken for utilizing the basic designs of such plants for commercial scale production of bamboo charcoal cost effectively.

Trial production of granular bamboo activated carbon showed that it required further inputs for developing appropriate technology and design of the activation plant for the production of desired quality bamboo activated carbon. The inherent quality of the bamboo charcoal raw material as well as the product, activated granular bamboo carbon, i. e., its poor hardness, was found to be the primary bottle-neck in employing the already existing technology of coconut shell activated carbon for producing granular activated carbon from bamboo.

REFERENCES

Abe, I., Fukuhara, T., Maruyama, J. and Tatsumoto, H. 2001. Preparation of carbonaceous adsorbents for removal of chloroform from drinking water. *Carbon* 39: 1069-1073.

American Society for Testing and Materials (ASTM). 1981. Standard Method for Chemical Analysis of Wood Charcoal. ASTM D 1762-64 (Re-approved 1977). Annual Book of ASM Standards. Part 22, Philadelphia. Pa.

Anonymous. 2002. A Handbook on Charcoal Making. American Fireworks News. 52 p.

Antal. M., Allen, S., Dai, X., Shimizu, B., Tam, M. and Gronlin, M. 2000. Attainment of the theoretical yield of carbon from biomass. *Industrial Engineering Chemical Research* 39: 4024-4031.

Anuradha Ganesh. 2003. Bamboo characterization for thermochemical conversion and feasibility study of bamboo-based gasification and charcoal making. Final Report of a project supported by TIFAC, DST, Government of India. Energy Systems Engineering Department, Indian Institute of Technology, Mumbai, India. 28 p.

Anuradha Ganesh., Patil, N. D., Lal, R. and Venkatesh, R. (n. d). Bamboo Charcoal Unit. Pamphlet by Energy Systems Engineering Department, Indian Institute of Technology (IIT), Mumbai. 8 p.

Brito, J. O., Tomazello, F. M. and Salgado, A. L. 1987. Production and characterization of charcoal of species and varieties of bamboo. IPEF, Instituto de Pesquisas e Estudos Florestias 36: 13-17.

Bureau of Indian Standards (BIS). 1995. Activated Carbons, Granular – Specification. IS 2752. Bureau of Indian Standards, New Delhi, India.

Bureau of Indian Standards (BIS). 2002. Activated Carbons: Powdered and Granular – Methods of Sampling and Test. Indian Standard IS: 877-1989 (Reaffirmed 1999). Bureau of Indian Standards, New Delhi, India. 7 p.

Dhamodaran, T. K. 2003. The science behind "Chandattam" – Teak wood distillate: A wood preservative. *Evergreen*. KFRI Newsletter No. 50. p4. Kerala Forest Research Institute. Peechi – 680 653, Kerala, India.

Dhamodaran, T. K. and Gnanaharan, R. 2010 a. Developing appropriate technology for community level production of charcoal and activated carbon from coconut shell and stem wood for industrial use. KFRI Research Report

No. 347. Kerala Forest Research Institute, Peechi – 680 653, Kerala, India. 61 p. (*In press*).

Dhamodaran, T. K. and Gnanaharan, R. 2010 b. Transfer of appropriate technology for small scale production of charcoal and activated carbon. KFRI Handbook. Kerala Forest Research Institute, Peechi – 680 653, Kerala, India. 31 p. (*Unpublished Technology Document*).

Forest Products Research and Development Institute (FPRDI) (n. d.). Selected FPRDI Technologies – Pamphlet. FPRDI, Laguna, 4031 Philippines. 8 p.

Gnanaharan, R., Dhamodaran, T. K. and Thulasidas, P. K. 1988. Yield and quality of charcoal from coconut stem wood. *Biomass* 16: 251-256.

Hosokawa, K., Minamide, T and Kanai, H. 1991. The application of bamboo active carbon for keeping bamboo shoots freshness. *Bamboo Journal* 9: 27-32.

Hosokawa Kenji, Subansenee Wanida, Panyathanya Winai and Kuhakanchana Chirapong (n. d). Bamboo Charcoal. Technical Report No. 3. http://www.forest.go.th.bamboo

Huang, G., Yu, H. and Toba, A. 2004. Effects of carbonization temperatures in an earthen kiln on the tree density and electric resistivity of Makino bamboo charcoal. *Taiwan Journal of Forest Science* 19: 237-245.

Huang, C., Yang, T. and Wang, S. 2000. Study on basic physical properties of bamboo charcoal: Charcoal yield, shrinkage and specific gravity. *Journal of Experimental Forestry* 14: 11-20.

International Network for Bamboo and Rattan (INBAR) 2003. Bamboo charcoal: A modern technology for poverty reduction. INBAR Technology Pages – Bamboo Charcoal. INBAR, Beijing, China.2 Pp.

International Network for Bamboo and Rattan (INBAR) 2007. Bamboo charcoal Transfer of Technology Model. http://www.inbar.int/totem/totemmain.asp.

Joshi, M., Chaudhari, A., Gour, K. and Modak, J. P. 2003. Confirmation of feasibility of bamboo charcoal as a low cost adsorbent. Unpublished personal communication. Priyadarshini College of Engineering and Architecture, Nagpur, Maharastra, India. 3 Pp.

Kim, N. H. and Hanna, R. B. 2006. Morphological characteristics of *Quercus variabilis* charcoal prepared at different temperatures. *Wood Science and Technology* 40: 392-401.

Minamide, T., Hosokawa, K. and Hada, A. 1992. Effect of bamboo active carbon on quality of cooked rice under warming with electronic rice cooker. *Bamboo Journal* 10: 75-82.