International Journal of Mechanical and Industrial Engineering

Volume 3 | Issue 4 Article 6

April 2014

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Recommended Citation
BISWAS, ARIJIT and Mahanta, Pinakeswar (2014) "DESIGN AND EXPERIMENTAL ANALYSIS OF FURNACE FOR THE PRODUCTION OF BAMBOO CHARCOAL," *International Journal of Mechanical and Industrial Engineering*: Vol. 3 : Iss. 4 , Article 6.
DOI: 10.47893/IJMIE.2014.1164
Available at: https://www.interscience.in/ijmie/vol3/iss4/6

DESIGN AND EXPERIMENTAL ANALYSIS OF FURNACE FOR THE PRODUCTION OF BAMBOO CHARCOAL

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Abstract- This paper presents the study of carbonization systems for the production of Bamboo Charcoal which is formed on dry distillation of raw bamboo. The paper mentions the drawbacks of the conventional practices of production of Bamboo Charcoal. Design of a new charcoal production unit is aimed at eliminating the identified drawbacks in the present methodology of production making the process of production faster and more efficient by minimizing heat loss during the production process. Designing is attempted with strong consideration for manufacture, operational cost and ease of operation of the furnace as the process finds application amongst rural people with little or no technical knowhow, making simplicity of design absolutely critical for implementation of the developed technology. Results of testing and experimentation presented in this paper describe the working prototype confirming qualitative and quantitative improvements in the bamboo charcoal being produced as compared to the conventional method of production.

Keywords- *Bamboo Charcoal, Pyrolysis, Furnace.*

I. INTRODUCTION

The production of charcoal from locally available raw material has been performed for centuries in the North East of India, China and many other parts of the world using traditional methods of production in earth pits or mud kiln [1-7]. Charcoal is formed by the pyrolysis of raw bio mass. The bio mass when heated in absence of air above a fixed temperature depending on the type of bio mass undergoing carbonization emits volatiles which are condensed to yield vinegar as a byproduct [8]. The solid residue remaining in the pyrolising chamber is called charcoal, has a porous microstructure and primarily comprises of carbon.

Even in modern times charcoal production with traditional methods is very popular amongst rural communities in developing countries [9-12] as it is used as a fuel for domestic purposes and generates income because the raw charcoal and its by product vinegar are the starting material for the manufacture of products which are in very high demand [13-14]. However the process of production is crude and inefficient, unscientific yielding poor quality of bamboo charcoal.

It takes only 3-4 years for Bamboo culms to reach adequate height and weight for commercial production of charcoal. Therefore the production of Charcoal with bamboo is very attractive as the time required to harvest the starting bio mass is lower compared to charcoal made from other sources. The process of production, usage and consumption for charcoal has a lower carbon footprint when compared to other sources of fuel and firewood [9-12]. Charcoal made from bamboo inherently has 1.5 times the calorific value as compared to wood charcoal and nearly 2-3 times the surface area of wood charcoal due to the porous microstructure of bamboo [13,18,19]. Bamboo has a number of other uses besides as a starting material in the production of charcoal, it is used in production of paper, furniture, finding usage in the handicrafts industry. Besides bamboo charcoal sticks or briquettes are used for fuel applications bamboo charcoal is used in the manufacture of activated carbon [13] which is used in clinical toxicology, manufacture of gas adsorbents, water and air filters, purification of drinking water, removal of heavy metal ions such as Lead and Cadmium, Mercury, chloramphenicol, nitrate nitrogen, air fresheners for eliminating organic impurities and smells [15-18]. Drinking water sterilized with chlorine can be treated with bamboo charcoal to remove residual chlorine and chlorides. These uses of charcoal especially bamboo charcoal is attributed to its porous microstructure and large surface area. Bamboo charcoal has the ability to act as humidifiers and as de humidifiers, it releases or absorbs moisture from the environment depending upon relative humidity therefore it is suitable for daily domestic household applications as well [18,19].

Bamboo charcoal is used in the manufacture of carbon based composites, nano rods, functional fabrics, Silicon Carbide, metal reduction and recycling.

Bamboo charcoal like bamboo vinegar has beneficial medicinal properties hence used as an anti bacterial, biological preservative [18]. It is used in making herbal and medicinal soap, bamboo charcoal is also known to show beneficial effects when added in minute quantities to the diet of poultry and farm animals [18]. Here in the North Eastern part of India and in places around the world bamboo charcoal is also used in making fertilizer by addition to manure and composts.

The potential for commercial exploitation of Bamboo Charcoal is immense. The work stated in this paper was to design an efficient, low cost, simple to operate pyrolysis unit for the production of quality bamboo charcoal capable of meeting market standards. Implementation of an improved process for production of bamboo charcoal would see increase in employment and entrepreneurship opportunities in the rural sector.

II. FIELD STUDY AND DATA COLLECTION ON TRADITIONAL PROCESS FOR BAMBOO CHARCOAL PRODUCTION AND IT'S IDENTIFIED DRAWBACKS

The majority of the production of bamboo charcoal in North East India is performed with usage of a metal oil drum as a carbonizing kiln. Raw Bamboo 3-4 years old is cut to approximately 80 cm in length and loaded into the oil drum. A large amount of earth is excavated to position the oil drum horizontally and it is covered with around 1 feet of soil as shown in Fig. 1a and Fig. 1b.

a b

Figure 1. Setting up of furnace in traditional method of production: (a) Raw Bamboo cut and loaded into tar drum in Tura. (b) Metal sheets cover opening, orifices provided for heated gas to enter into pyrolysing chamber.

The drum is loaded horizontally causing heating inside the oil drum to be non uniform, this is verified by temperature readings recorded with thermocouples inserted into the oil drum. The layer of soil provides insulation and minimizes heat loss which is crucial for carbonizing process as temperatures required for charcoal formation can be reached only with adequate insulation.

The loading end of the oil drum is closed by a metal sheet with 2 orifices. The orifices provide a passage for heated gases from combustion chamber into oil drum which is sealed with moist clay clay as shown in Fig. 1b. The combustion chamber is built by mud plastering bricks for ensuring an air tight seal as shown in Fig. 2a. The process of heating is not continuous, the unit is only fired during daylight hours as shown in Fig. 2b.

a b

Figure 2. Traditional method of producing bamboo charcoal: (a) Construction of combustion chamber with brick and mud plastering. (b) Firing of furnace during daylight hours in Tura

This extremely labour intensive process of preparing the unit manually is to be performed every time bamboo charcoal is to be produced making the process of production problematic. Also there is risk to the operator from open flames and high temperatures exposed on the outside surface of the production unit. Bamboo in the oil drum is heated convectively by burning of firewood, the process of production is carried on for 3 days.

The amount of firewood required in the process of production is high as a large fraction of the gases of combustion do not enter into the pyrolysis chamber but exit through the opening through which firewood is being provided. Poisonous gases are emitted during the production process is shown TABLE.1. Pyrolysis involves the partial combustion of bamboo, hence one of the major products of pyrolysis is Carbon Monoxide [19]. There is no provision for proper sealing or controlled flow of gas in closed ducts therefore posing a health risk to the unit operator.

The inspection of another similar type of bamboo charcoal production unit at a different location in North East India showed noticeable variation in the sizing of the combustion chamber which is built manually. The insulation on the oil drum in this scenario was at maximum around 6". This indicated the need for standardization of the process for production of bamboo charcoal.

TABLE I. GAS CONSTITUENTS AND COMPOSITION OF EMITTED VOLATILES

Time (hh:mm)	O_2 (%)	CO_2 (%)	CO (ppm)	C_XH_Y (ppm)	NO_X (ppm)	SO_2 (ppm)
2:00	19.22	3.48	3202	1370	57	0
4:00	7.33	10.20	2150	4600	176	103
6:00	5.28	11.61	Off limit	Off limit	7907	320
8:00	1.96	13.63	Off limit	Off limit	164	1401
11:00	6.07	11.02	Off limit	6000	195	202
12:00	5.53	11.42	5447	5910	171	488

III. BASIC CONCEPTUALIZATION AND CONSTRUCTIONAL FEATURES

The design of the pyrolysis unit was attempted by setting of the main pyrolysis chamber vertically instead of horizontally. The combustion chamber is placed below so that flue gases from combustion of firewood rise into the pyrolysis chamber. A draft/funnel arrangement is provided on top of the pyrolysis chamber as shown in Fig.3a. Insulation has been provided with rocks and a brick lining around the pyrolyis chamber.

A uniformly perforated plate separates the pyrolysis and combustion chamber as shown in Fig.3b and Fig. 4f ensures uniform flow and heating by gas from combustion chamber into pyrolysis chamber. The firewood is loaded on a grill arrangement 3" off the ground as shown in Fig.3c, the firewood is provided into the combustion chamber through 3 duct passageways.

The ducts for providing fresh firewood are covered with movable flaps to minimize heat loss by convection as shown in Fig.4a. Bamboo nodes are pierced to allow gases of combustion to heat the bamboo from inside as well as the outside, uniform distribution of gas is ensured by perforated distributor plate below. Grill arrangement prevents bamboo from coming in contact with the hot surface of the distributor plate as shown in Fig. 4c. The ducts have hollow passage way beneath the main opening through which firewood is loaded for entry of fresh oxygen from outside into the combustion chamber and ash formed on combustion of firewood to be pulled out from beneath as shown in Fig. 5a and Fig. 4b. The rocks are placed in the intermediate space between drum and brick lining, they serve to provide insulation as well as act as heat storage medium as shown in Fig.5b.

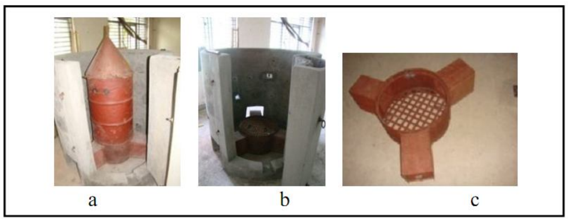

Figure 3. Features of the new furnace: (a) Setup of production unit after assembly. (b) Perforated plate separating pyrolysing chamber and combustion chamber. (c) Grill arrangement on which firewood is loaded.

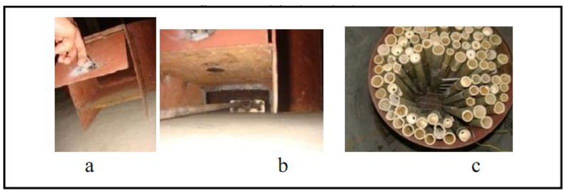

Figure 4. Feature of the new furnace which overcome the lacunas with the traditional method of Bamboo charcoal production: (a) Flaps covering entry point of combustion chamber, minimizes convective heat loss. (b) Duct passage way for entry of fresh oxygen and removal of ash from underneath the furnace. (c) Loading of the bamboo vertically in new developed production unit at IITG with perforated plate below

Figure 5. New furnace in opeation: (a) Flaps covering entry point of combustion chamber, ash formed on combustion of firewood pulled out from underneath (b) rock insulation and piping from furnace fed to condenser for bamboo vinegar production.

IV. ANALYTICAL CALCULATIONS FOR DESIGNING CHARCOAL PRODUCTION UNIT

The most critical aspect to the design of the carbonizing/pyrolysing furnace is the insulation. If the rate of heat loss from the pyrolysing chamber is high, adequate temperature required for carbonization to occur inside the chamber will not be achieved. The concept used is that the furnace is capable of providing insulation for a greater rate of heat generation than actually taking place in the production process.

The governing equating used for setting up the insulation thickness is

$Q = Q_1 + Q_2 =$ Net Rate of Heat Generation

For safe design of furnace

$Q = Q_1 + Q_2 = Q_{conduction} + Q_{convection}$

Where Q is the net heat generated per second, Q_1 is the heat generated per second by burning firewood and Q_2 is the heat liberated during carbonisation of the bamboo.

$Q_1 = CV_{firewood} \times M_{firewood}/(t \times 36000) = 17681.81$ Joule/Sec and

$Q_2 = CV_{bamboo} \times M_{bamboo}/(t \times 36000) = 9479.16$ Joule/Sec

Therefore net heat generated is evaluated to be

$Q_{net\ generated} = Q_1 + Q_2 = 27160.97$ Joule/Sec

Heat Transfer due to Conduction [41] is calculated to be $Q_{conduction} = (T_1 - T_2)/(R_1 + R_2 + R_3) = 5277.26$ Joule/Sec.

The concept of thermal resistance in a cylindrical shape is used where

$R_1 = \ln(r_2/r_1)/2\prod k_1$; $R_2 = \ln(r_3/r_2)/2\prod k_2$; $R_3 = \ln(r_4/r_3)/2\prod k_3$

R_1, R_2, R_3 are the thermal resistance of the three layers of insulation provided on the furnace. The configuration and the parameters used to evaluate heat loss by conduction are represented in Fig.6. The total thermal resistance is given as

$R_1 + R_2 + R_3 = R_{net} = 0.05969$

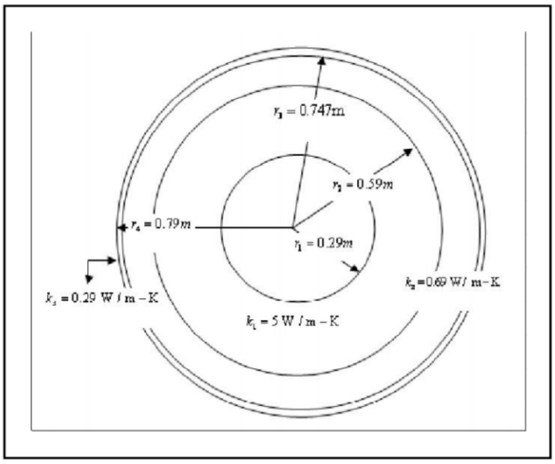

Figure 6. Schematic showing radius of insulation and thermal conductivities of various materials in furnace.

Heat Transfer due to Convection [20] is given by $Q_{convection} = \rho \times A_c \times v \times \Delta = 23030.14$ Joule/Sec

The safe criteria for design of furnace is satisfied as $Q_{convection} + C_{onduction} >= Q_{net\ generated}$

The funnel arrangement provided at the top of the tar drum to ensure uniform continuous flow of gas by creating suitable pressure difference. The pressure difference can be calculated by use of Continuity Equation and Bernoulli's Equation as the flow velocity is low and flow is incompressible. The Continuity Equation given as

$A_1 \times V_1 = A_2 \times V_2$

Where $A_1 = 0.264m^2$ and $A_2 = 0.00114m^2$ represent the inlet and exit cross sectional area of the funnel shown in Fig.2a. The exit velocity $v_1 = 0.2$m/sec therefore inlet velocity at the base of the cone represented by point 2 is calculated to be $v_2 = 46.34$m/sec using the Continuity equation and Bernoulli's Equation used for calculating pressure difference is given by

$P_1 + 0.5\rho v_1^2 + \rho g h_1 = P_2 + 0.5\rho v_2^2 + \rho g h_2$

The density can be approximated to be constant over the 1 feet of flow on which the calculations are being performed without affecting the results. The height difference between the two points is also negligible. Therefore the pressure difference P_1-P_2 between the top of the funnel represented by point 1 and base of the funnel represented by point 2 is evaluated as 1500.37 Pascal. The parameters used in evaluating the above equation are represented in TABLE II.

TABLE II. PARAMTERS USED TO EVALUATE CONVECTIVE HEAT LOSS

Symbol	Description/Meaning	Value
P	Density of flowing gas	1.4 kg/m3
A_c	Area of cross section of piping	0.246m2
V	Flow velocity under natural convection	0.2 m/sec
C_p	Thermal Heat Capacity of flowing fluid	1.006 X 103 Joule/kg-K
$\Delta = T_1 - T_2$	Difference between furnace interior and ambient temperature	315°C
T	Time taken for production process	11 hours
$CV_{firewood}$	Calorific Value of Firewood	18 MJ
CV_{bamboo}	Calorific Value of Bamboo	15 MJ
$M_{firewood}$	Mass of firewood	38.9 Kg
M_{bamboo}	Mass of bamboo	35 g

V. RESULTS AND DISCUSSIONS

The temperature distribution measured in the traditional process of production shown in Fig.7 shows large variations indicating non uniform heating of the bamboo charge inside the carbonization chamber. The standard deviation shows temperature deviation of more than 100^{o}C.

The non uniform heating results in poor conversion of the bamboo to charcoal, leaving brands of bamboo uncarbonized or partially converted, the extremely high temperature at the firing end causes burning of the bamboo in these regions adding to the net poor yield of the process.

The orientation of the oil drum vertically, with usage of a perforated plate and adequate sealing shows improvement in the thermal profile. Points apart from the centerline it is shown in as shown in Fig.8. and points along the centerline it is shown in Fig.9.

The standard deviation in temperature observed along the centerline is a maximum of 30^{o}C. The sealing is improved than before, majority of the gases now enter into the pyrolysis chamber.

The process of bamboo charcoal production with the traditional process is 3 days. The yield of Bamboo charcoal is 20-30 Kg form 75-90 Kg of raw bamboo. The cycle for production with new furnace is 12-14 hours. The yield is around 13.4 Kg of completely carbonized bamboo charcoal of calorific value equivalent to the above stated or more.

The amount of partially converted bamboo charcoal is around 2.8 Kg. The net yield in charcoal is around 16.2 Kg indicating conversion efficiency of 82.71%. The weight of Firewood consumed for the entire production process with the new prototype furnace is 26 Kg.

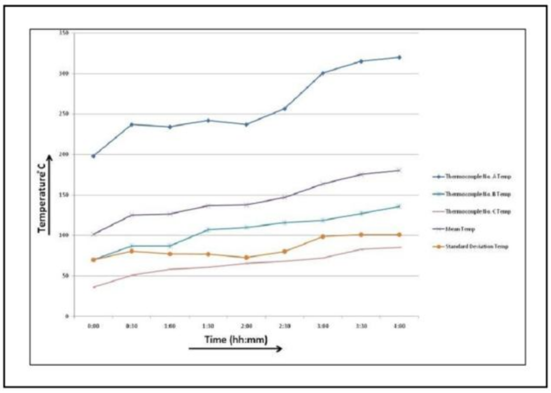

Figure 7. Thermal profile inside traditional furnace, non uniform heating with large deviations clearly indicated

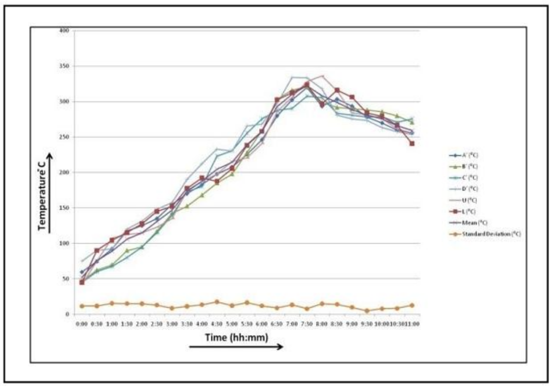

Figure 8. Thermal profile at points other than the centerline

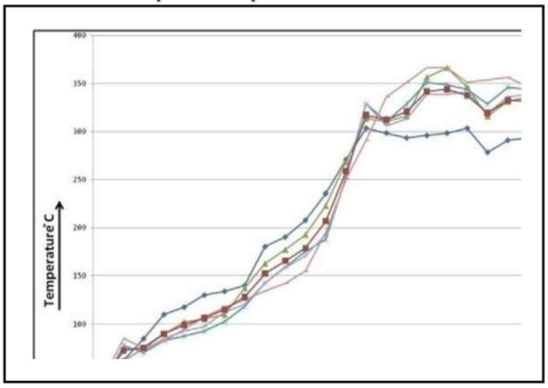

Figure 9. Thermal profile along centerline in new developed furnace

Temperature readings are taken with K-Type thermocouples oriented as shown in Fig.10 inside the pyrolyzing chamber.

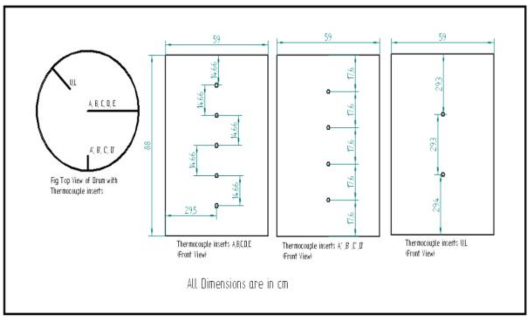

Figure 10. Arrangement of thermocouple inserts into pryolysing chamber

The calorific value of the bamboo charcoal produced with the traditional process is 6343 Kcal/Kg or lesser. The mass of firewood consumed in the traditional process is reported to be always greater than 40 Kg. The calorific value of the bamboo charcoal produced with the new method of production in Bomb Calorimeter revealed it to be 6944.23 Kcal/Kg for (Sample 1) and 6874.88 Kcal/Kg (Sample 2).

The developed process of production clearly features uniform heating, adequate insulation. The process of production of bamboo charcoal is much faster with higher conversion efficiency of raw bamboo to bamboo charcoal, The Heat loss is minimized and the process is more efficient in terms of consumption of firewood for firing. The calorific value testing of the produced bamboo charcoal clearly indicates qualitative improvements in the process of production besides the stated quantitative improvement. The temperatures recorded on the rocks used for thermal insulation show temperatures in excess of 100^0C; this represents a large amount of stored thermal energy that could be used for drying, cooking etc.

ACKNOWLEDGMENT

The project on design of a furnace for production of Bamboo Charcoal was performed with financial assistance from Rural Technology Action Group North East (RuTag NE). The study on Bamboo Charcoal production system was performed at the campus of Bethany Society an NGO in the North East of India.

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