

TORREFACTION OF BAMBOO

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ABSTRACT: Bamboo is a fast growing fibrous plant grown in abundance in India. As a consequence to bamboo flowering, it becomes imperative to find additional ways and means of using bamboo within a short span of time. If not put to immediate use the one other way is to extend the shelf life of the bamboo. The current practices of bamboo usage can only consume a part of the excess bamboo generated thereby opening possibility for other usages. Torrefaction of bamboo is seen as one such possibility that apart from energy densification makes the product resistant to fungal attack. Under one of funded project, torrefaction of bamboo has been successfully attempted on a kiln of 1 ton/day input capacity. Prior to conceiving the design of the kiln, basic studies have been conducted between 180 and 350 °C temperature. Furthermore torrefied bamboo has been characterized for calorific value and elemental balance. Based on the analysis it is found that there is an enhancement in energy density by 20% against raw bamboo between torrefaction temperatures of 250 and 260 °C. This 1 Ton/hour kiln has completed successful trials at the laboratory is expected to be located in an industry.

Keywords: Torrefaction, bamboo, grey charcoal, hydrophobic

1 INTRODUCTION

Bamboo is a fast growing fibrous plant grown in abundance in India. It is a versatile material finding usage in structural, construction, wood substitute, composite and energy production. In India, one particular species of bamboo namely 'Melocanna baccifera', estimated to represent over a sixth of the country's growing stock of bamboo, is facing the threat of gregariously flowering between 2004 – 2008 [1]. The flowering of Melocanna baccifera is an event of great significance wherein large tracts of land are affected, as bamboo forests burst into bloom and then die. This sudden death of bamboo in huge quantity is expected to significantly increase the bamboo availability and therefore there is an urgent need to identify ways and means by which several tons of bamboo could be put to effective use in short span of time. So there is definite need to immediately use or preserve or extend the shelf life of the bamboo. The current practices of bamboo usage can only consume a part of the excess bamboo generated on account of this gregarious flowering thereby opening possibility for other usages. Torrefaction of bamboo is seen as one such possibility that apart from energy densification makes the product resistant to fungal attack.

Literature survey does not seem to contain information on bamboo torrefaction per se, nevertheless there is large amount of basic research conducted on biomass torrefaction. Research as early as in 1930 is reported in France, but there does not seem to be any publications available. Research work on torrefaction at a fundamental level has been reported by Mark J Prins [2] in his PhD thesis entitled "Thermodynamic analysis of biomass gasification and torrefaction", however it does not contain details of industrial torrefaction process technology. Literature reports that in the 1980's, a commercial plant with a capacity of 14,000 ton/year was operated in France for the production of barbecue fuel [3], but the plant is no more in operation. Similarly Bourgois and Doat [4] have published torrefaction work

using two tropical wood samples. This research is reported to have resulted in the building of a continuous wood torrefaction plant in 1987, the torrefied wood was used as a reducer in the production of silicon metal. Similarly Bergman et al [5] reports the benefits of torrefaction process in terms of reduced electricity requirement for size reduction and production technology for the production of pellets. Similarly Pach et al [6] discusses the torrefaction process performed in a laboratory unit using two species of wood, birch, pine and sugar cane bagasse.

The above compiled literature study clearly reveals the work done at the fundamental level but there is no information about technology packaging and industrializing the process. Even though commercial plants are reported to be operational in France a few years ago there is no further information available on it. Therefore the work that is reported here was undertaken in the background of not much information on the technology package of torrefaction. Since the mandate of the current project involved developing a technology package, the work conducted was limited to designing of a pilot scale plant and establishing of operational parameters.

2 TORREFACTION PROCESS

Torrefaction involves mild treatment of biomass between 200 to 300 °C in an inert atmosphere. Untreated biomass particularly agricultural waste has low energy density, high moisture content. These features make transport relatively expensive. Just drying would be insufficient as the biomass can regain moisture and rot during storage. Increasing the energy density such as torrefaction process can be seen as an attractive proposition. The product of torrefaction process is a solid product, which is torrefied biomass, has attractive properties such as improved heating value, low moisture content and ease of size reduction. The properties of torrefied biomass are as follows:

- Lower moisture content and therefore higher heating value compared to biomass, Due to lower moisture content, it is cheaper to transport the torrefied biomass
- Hydrophobic nature: the material does not gain humidity in storage and therefore unlike charcoal and biomass, it is stable and is resistant to fungal attack.
- Easy burning and less smoke formation when burnt
- Suitable for various application such as for cooking fuel, residential heating, raw material for manufacturer of fuel pellets, reducer in smelters - steel industry, manufacture of charcoal or activated carbon, gasification, co-firing with other fuels in boilers etc.

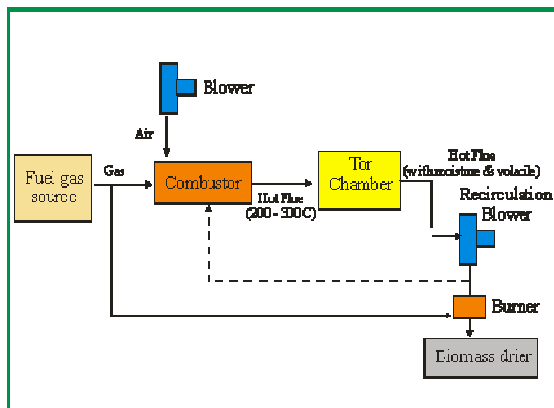


Figure 1: Torrefaction Process

2.1 Process Description

A laboratory scale plant with an input feed capacity of 50 kg/hr (batch type) was built for the initial trials. The plant consists of a torrefaction chamber for holding the charge, a heat source that can generate hot products with minimum excess oxygen content in the flue gases, a re-circulating blower to enhance the efficiency of the process. The heat source for torrefaction was obtained by combusting producer gas + air mixture in the combustor. The producer gas was in turn generated in a gasifier system [7] using waste wood as the feedstock. The hot gas temperature at the entry to the torrefaction chamber was maintained at varying temperatures between 200 and 350 °C. The combustor and the torrefaction chamber were fitted with thermocouples to record the bed temperature in the chamber. To enhance the efficiency of the torrefaction process the hot flue gas was re-circulated. The combustor, torrefaction chamber, blower and all connecting ducts were insulated to reduce heat loss. The schematic of the torrefaction process is shown in Fig. 1.

One of the most important parameters that were to be established in the above process was the residence time. The only sure way of determining this was through experimental trials. Therefore experimental trials were conducted using cut green bamboo of 0.6 m length (50 – 60 mm diameter) with an initial moisture content between 9 and 47 % (on wet basis). Two types of bamboo, namely thin and thick bamboo were tried for experiments. Most of the trials were conducted using thin bamboo (Bamboosa-Bamboosa species). It took about 2 to 3 trials to establish the operational procedure. During these exploratory trials the combustor was operated at power level of about 20 – 25 kWth. The hot gas entry to

the torrefaction chamber was maintained at about 200 to 225 °C. First set of experiments were conducted in non-recirculation mode and the dryer efficiency was found to be about 7%. This was followed by experiments in part-recirculation mode wherein the operation was carried for about 3.5 hours, the efficiency of system turned out to be about 14%. The process was further optimized wherein the flue gas recirculation rate was increased such that there is no flame quenching in the combustor, this resulted in an efficiency of about 30 - 35%.

Further trials were conducted between temperatures of 200 and 350 °C and at varying residence times (1- 3 hours). Other than maintaining of flue gas temperature at the entry to the torrefaction chamber, roughly inert conditions (oxygen < 2- 3%) were maintained at all times in order to prevent combustion of volatiles/biomass in the torrefaction chamber. The temperature during the torrefaction process was continuously monitored by recording the bamboo temperature at three/four tiers. In each of the tier, one bamboo had a provision for thermocouple insertion. Thermocouples were inserted to measure the surface, pulp and core on each of the identified bamboo. During the initial process there was large variation observed in temperature at various levels and also temperature within the bamboo. With time the non-uniformity used to reduce and by the time of completion of the trial the temperature was more or less uniform (variation by about 25 °C). Upon achieving of the desired temperature by the top tier bamboo, the trial was stopped.

It is evident from this figure that the heating rate is between 0.5 to 1.0 °C/min. The temperature throughout the cross section of a given bamboo is more or less uniform at any point of time through the process. This uniformity in temperature ensures generation of uniform and consistent product. Fig. 2 shows the temperature profile at the exit of the combustor and the entry of the torrefaction chamber – grate entry. The temperature of the flue gas is maintained between 220 and 250 °C right through the process. The flue gas exit temperature slowly increases from ambient to about 230 °C by the completion of the process. Similarly Fig. 3 shows the temperature profile measured at three locations within a given bamboo – surface, inner and hollow. It is evident from this figure that the heating rate is between 0.5 to 1.0 °C/min. The temperature throughout the cross section of a given bamboo is more or less uniform at any point of time through the process. This uniformity in temperature ensures generation of uniform and consistent product.

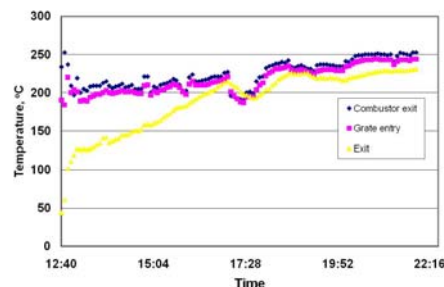


Figure 2: Temperature at various locations in the chamber

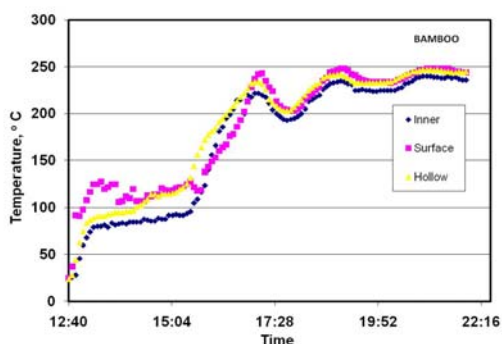


Figure 3: Temperature in the bamboo during the Process

On the whole more than thirty trials were conducted these results show that as the operating temperature is increased the loss of volatile matter is higher and consecutively the yield of solid matter is lower. The dependency on temperature appears to be much stronger than the residence time. In the temperature range of 180 to 220 °C, the yield of solid matter is about 83% and as the temperature is increased to 350 °C, the yield comes down to about 45%. The solid yield at varying torrefaction temperature is summarized in Table 1. The residence time at higher temperature is lower in some case because of initial moisture content being low in the raw bamboo. Lower initial moisture content would therefore need lower residence time.

Table -1: Solid Yield at varying torrefaction temperature

Temperature, °C	Residence Time, hour	Solid yield, %
180 - 220	5.0 - 6.5	81 - 83
225 - 250	6.0 - 7.0	70 - 78
250 - 280	6.0	66 - 72 (55 - 79)
280 - 300	4.0	55 - 63 (50 - 66)
300 - 350	5.0 - 6.0	43 - 45

2.2 Product Description

The torrefied bamboo or grey charcoal was further characterized in terms of its composition and calorific value. Both proximate and ultimate analysis was conducted. Proximate analysis was conducted to determine the fraction of volatile and fixed carbon content. The results of the proximate analysis on moisture and ash free basis are shown in Fig. 4, wherein it is evident that increasing the temperature reduces the volatile fraction and increases the fixed carbon. The raw bamboo has about 85% volatiles and 10% fixed carbon is transformed to contain about 73% volatiles and 27% fixed carbon after subjecting to a torrefaction process at 250 – 275 °C. The process when carried at 350 °C results in higher fixed carbon content up to 64%. Further the samples were subjected to ultimate analysis where the elemental constituents like hydrogen, carbon, oxygen and ash were determined. Fig. 5 shows the elemental analysis wherein there is a reduction in oxygen element and correspondingly increase in the hydrogen and carbon content with the increase in temperature. Therefore torrefaction process results in reduction in O/C ratio,

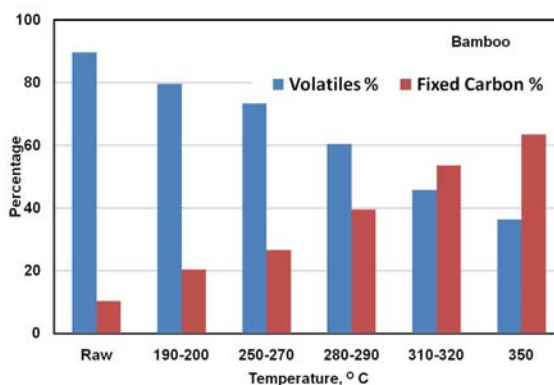


Figure 4: Proximate Analysis (on ash and moisture free basis) of the Torrefied Bamboo at Varying Temperatures.

which essentially contributes to increase in the calorific value. The ash content in the raw bamboo is about 2.5% and increases to about 5.5% with grey charcoal at 350 °C.

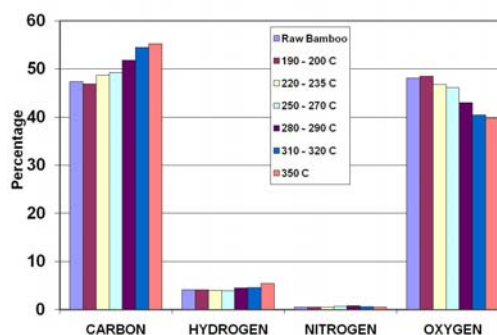


Figure 5: Ultimate Analysis of Torrefied Bamboo

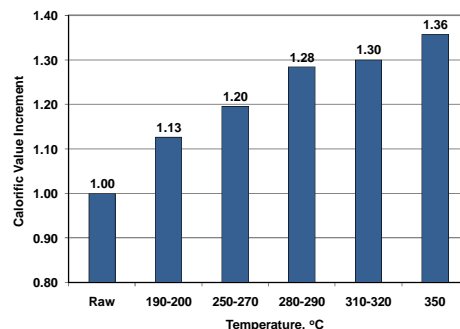


Figure 6: Energy Density of the Torrefied Bamboo at Varying Temperatures. The reference measurement is the Gross Calorific Value of raw bamboo which is 17.6 MJ/kg on dry basis.

A very important property is the increase in energy density of the torrefied bamboo compared to raw/untreated bamboo as shown in Fig. 6. The gross heating value of torrefied bamboo was found to increase with temperature: a 20% increase was observed at 250-260 °C (from 17.6 to 21.1 MJ/kg on dry basis). Apart from energy densification, torrefaction process makes the material hydrophobic, the moisture absorption over a

long duration of observation is found to be between 3 and 5% against 10 and 12% with sun dried bamboo. The product from the process of torrefaction is referred as 'Grey Charcoal'

2.3 Pilot Plant

The pilot plant of 1 Ton/day, an extension of the batch type lab scale system is shown in Plate -1. The pilot plant is designed for continuous operation and meant for production of torrefied bamboo. The test plant comprises of six identical chambers (each measuring 1 x 0.55 x 0.85 m) juxtaposed to each other with adequate thermal insulation. Each of the chambers has provision for hot flue gas entry at the bottom and exit at the top. The entry part of all the chambers are connected to one common manifold whose other end forms the exit of the combustion chamber. Similarly exit of all the chambers are connected to another common manifold whose other end is connected to a recirculation blower. There is isolation valves provided on the entry and exit side of each of the chambers.



Plate 1: The pilot Plant of 1 Ton/day

The heat source for torrefaction is obtained by combusting producer gas + air mixture in the combustor. The producer gas was generated in a gasifier system using waste wood as the feedstock. A 30 kg/hr capacity gasifier would suffice the requirement. The air for combustion was supplied by a separate blower, which had provision for supply of air either from the ambient or hot air (recuperated heat) sucked through the chambers undergoing cooling process. In order to achieve this, provision was made for fresh air entry to each of the chambers to facilitate heat recovery. The complete system including the blowers were insulated and cladded to reduce heat loss and improve the overall efficiency of the system. The connected electrical load of the two blowers was about 4 – 5kWe. Each of the torrefaction chambers is provided with thermocouple (see Plate 10) for temperature measurement and display. Similarly is the case with the combustion chamber. The temperature data was acquired on to a PC during lab trials and this would not be required for field trials since a temperature display is supplied along with the equipment. Also, the system is equipped to measure the gas flow rate, recirculation rate etc.

A long duration trial of 76 hour duration was conducted wherein bamboo with 42% initial moisture was used. The heating time was about 7 hours and cooling time was reduced to about 4.5 hours. The cooling process was shortened by adapting a two step cooling strategy wherein initial cooling for about 3 hours was done by allowing the chambers to cool out naturally and once the

temperature reached below 160 – 170 °C, cold air was sucked through the bed. This reduced the cooling time from 6 hours to about 4.5 hours. The quality of the product has been found to be satisfactory. Further the pilot plant is expected to be relocated in an industry where the torrefied bamboo production would be under taken to explore if this could be a substitute for normal charcoal for metallurgical purpose.

3 CONCLUSIONS

Torrefaction of bamboo has been successfully demonstrated and grey charcoal generated with an increment of calorific value by 20% corresponding to a torrefaction temperature of 250 °C. A temperature of 250 °C is identified as the torrefaction temperature for bamboosa-bambos species bamboo. The grey charcoal as a result of torrefaction is also found to be hydrophobic, the maximum moisture absorption of about 6% against 12% with raw bamboo. Also, a pilot plant has been successfully tested for a throughput of 1 ton/day (based on input raw bamboo). Further the pilot plant is expected to be located in an industry where the torrefied bamboo production would be under taken to explore if this could be a substitute for normal charcoal for metallurgical purpose.

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