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# Production of charcoal from woods and bamboo in a small natural draft carbonizer

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**Abstract**
There is a strong domestic market for charcoal in Thailand and many developing countries. Charcoal is usually made from biomass materials in small scale, simple kilns. Traditional charcoal making kilns adopts a process that is very inefficient, and damaging to the environment. In this work, an alternative charcoal reactor based on natural draft, pyrolysis gas burning concept was proposed and demonstrated. Tests with longan woods and bamboo showed that good quality charcoal can be produced in shorter time with lower pollution emissions, compared with traditional kilns. The proposed carbonizer proved to be suitable for small scale, charcoal production in rural area.


**Keywords:** Appropriate technology, Biomass, Charcoal, Pyrolysis, Renewable energy.

## 1. Introduction

Energy is central to current concerns over sustainable development, accumulation of greenhouse gases in the atmosphere, climate change, and its dramatic consequences to the planet, humans and other living organisms. Renewable energy has been the primary source of energy throughout the history of human race, long before the recent episode of fossil fuel addiction. Interest in harnessing this energy resource has been overwhelmed due largely to rapid escalation in petroleum oil prices. Renewable alternatives have been a main focus, especially in developing countries. It has been realized that producing renewable energy locally can offer a viable alternative, and facilitate socio-economic development in communities. Bioenergy is a promising strategic resource in the effort to fulfil these goals. Biomass production represents about 14% of the World's primary energy supply. About 75% of its usage is in developing countries [1]. Virtually all South and Southeast Asian countries are major biomass energy producers, as well as consumers. In countries like India, Bangladesh, Myanmar, Cambodia and Laos, biomass fuels are the most significant indigenous source of energy [2, 3].

Biomass combustion provides the basic energy requirement for cooking and heating of households, and process heat for local industries. However, biomass combustion is rather inconvenient, and tends to produce high emissions due to extensive smoke formation, compared to burning of charcoal. Solid biofuel in form of charcoal is usually preferred due to the ease of transport and low smoke emissions. Decomposition of biomass materials, in the absence of oxygen, by the action of heat is known as pyrolysis. Pyrolysis products can be classified into a volatile fraction consisting of gases, vapors and tar components, and a carbon rich solid residue. Slow pyrolysis may be alternately referred to as carbonization [4]. Production of charcoal by carbonization is one of the oldest methods of biomass conversion. When biomass is subject to intense heating, its volatile components are released, converting

into char. These volatiles in turn are burned for further supply of heat for the process. Pyrolysis and combustion of biomass have been subjected to many detailed investigations. Good reviews are given by Antal and Gronli [5], Strezov et al. [6], Goyal et al. [7], Demirbas [8] and Werther et al. [9]. Charcoal is a premium fuel, acceptable and readily used in villages and modern households. Commercial charcoal contains about 75% carbon, 20% volatile, and about 5% ash, depending on raw material types and conditions produced. It is normally produced from wood through the use of charcoal piles, earth kilns, or pit kilns. These traditional kilns do not have good insulation. Large heat loss occurs during long period of operation. Major fraction of biomass is used as fuel for burning to sustain the pyrolysis process. It is generally known that current practice of charcoal production, especially by local entrepreneurs, is inefficient and entails large energy loss. Long process time, poor process control, low char yield and environmental pollution problems due to the release of pyrolysis gases into the atmosphere are the major drawbacks. Development for new designs to improve performance of charcoal kilns have been introduced [10-13]. Efficiency and emissions of charcoal making systems can be improved by installing proper insulation, improving process control and burning pyrolysis gases inside the reactor to provide process heat.

The aim of this work was to develop a charcoal making system suitable for domestic use. The system should be simple and easily handled by rural people, and must not require electricity or mechanical power to operate. The system should perform better in terms of energy efficiency and environmental acceptability. In this study, a practical method to produce charcoal was demonstrated using an in-house, natural draft carbonization reactor. The capacity was 50 kg per batch. Two different biomass materials were used. The carbonizer was evaluated for its performance in terms of reaction temperatures attained, overall process time, char yield and char properties.

## 2. Experimental

### *2.1 Biomass composition analysis*

Locally available biomass materials that are usually used to produce charcoal are woods from longan or mango trees. Bamboo is also in abundant. These biomass samples collected in Chiang Mai, Thailand were used. For chemical analysis, the samples were cleaned and air dried naturally in a dry store room at ambient condition. The dried samples were later ground in a high speed rotary mill, screen sieved and used for further analysis. ASTM standard methods were followed to carry out proximate and ultimate analyses for the samples. The carbon, hydrogen and nitrogen contents were determined using a CHN Elemental Analyzer. The oxygen content was calculated by difference. The heating value of the dried samples was determined using a Parr bomb calorimeter. It is reported as a gross heat of combustion at constant volume. Results obtained are shown in Table 1.

Table 1. Chemical analysis of biomass samples

| Property | Unit | Woods | Bamboo |
|---|---|---|---|
| Moisture | [%] | 3.5 | 5.7 |
| Volatile | [%] | 77.4 | 74.7 |
| Fixed carbon | [%] | 16.6 | 14.1 |
| Ash | [%] | 2.5 | 5.5 |
| C | [%] | 48.8 | 45.7 |
| H | [%] | 5.2 | 4.3 |
| O | [%] | 44.6 | 49.7 |
| N | [%] | 1.4 | 0.3 |
| Higher heating value (HHV) | [MJ/kg] | 17.8 | 16.8 |

### *2.2 Carbonization*

Experimental runs on carbonization of the biomass material were performed in a batch carbonizer, as shown in Figure 1. The carbonization reactor was cylindrical shaped with 1.2 m high and inside diameter of 0.6 m. It was made of a used oil drum, surrounded on the inside by thick insulating wool and a 3 mm thick steel sheet. It had a centrally located pyrolysis gas burner inside the cylinder. The burner tube had six radial fins attached to it to provide large heat transfer surface. Two tangential air ports were connected to the bottom end of the gas burner. There was a fixed grate near the bottom with other two air ports connected underneath the combustion chamber. The samples were cut into size range of 30 – 50

mm in diameter and about 1 m long. Prior to the test, pre-weighed batches of biomass materials were loaded into the reactor. About 5 kg of biomass in small pieces was loaded first to be utilized as combustion bed. Long sticks biomass materials were then loaded. The cover was put in place, checking that the reactor was air tight. Figure 2 shows schematically operation step of the carbonization system. Initially, air was supplied and regulated such that oxidation zone at the bottom of the reactor can be established and the chamber got heated. Exhaust gas from combustion and released moisture from biomass was vented through a twin temporary exhaust pipe (Figure 2a). When the pyrolysis temperature of biomass was reached (about 250$^{o}$C), gaseous products produced from the biomass became combustible. The twin pipe was shut, hence the combustible gas was forced to enter the pyrolysis gas burner through perforated wall. Meanwhile, the bottom air was shut down to stop the combustion at the bottom and the burner air ports were opened. Air was drafted into the burner tube. Mixture of pyrolysis gases and air was ignited to establish a flaming combustion inside the burner tube (Figure 2b). This way, pyrolysis gases was oxidized and process heat was continually supplied to the carbonization chamber (Figure 2c).

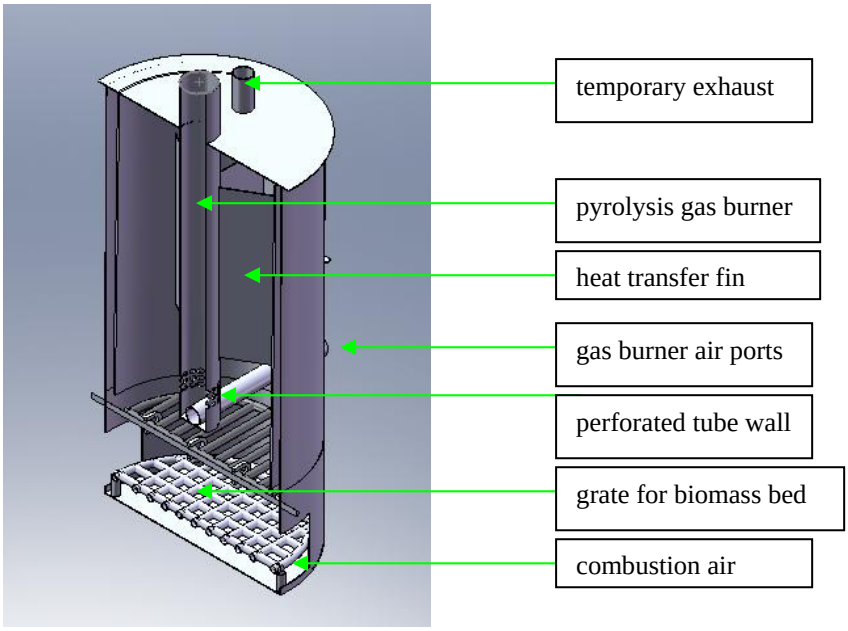
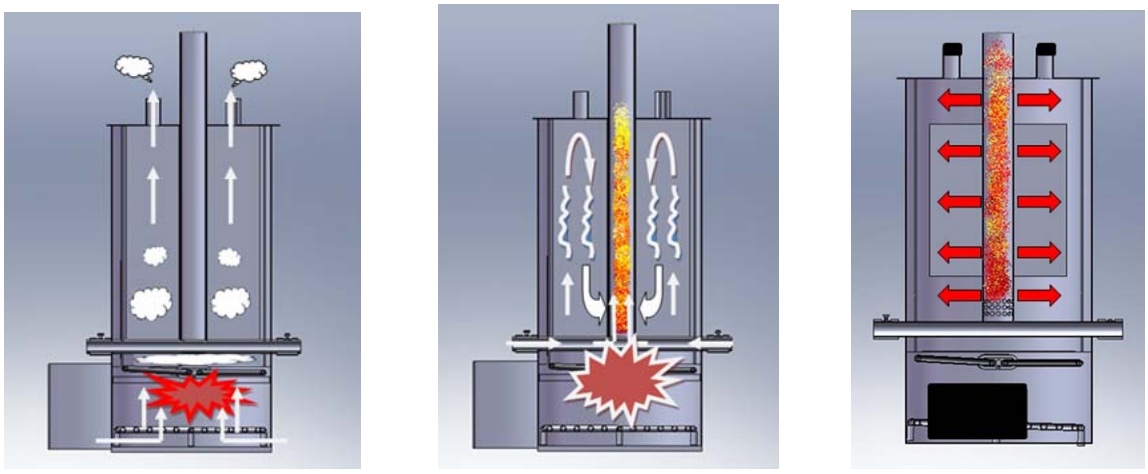



Figure 1. Schematic drawing of the natural draft, carbonizer system



(a) (b) (c)

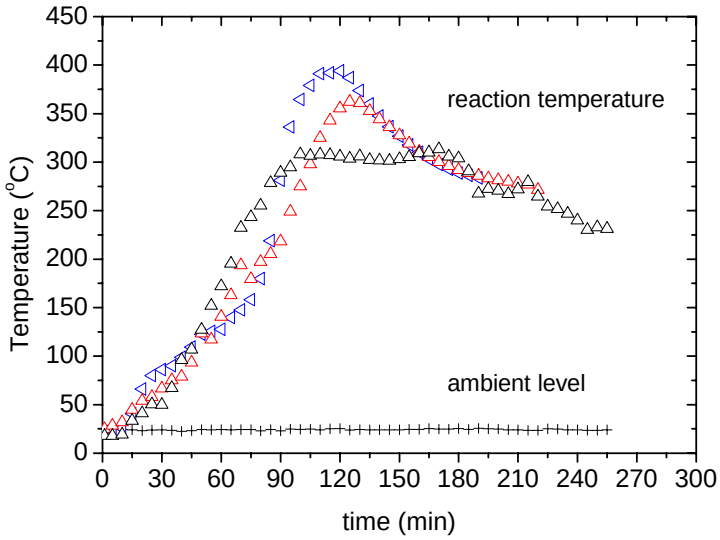
Figure 2. Operation of the carbonizer system (a) initial heating up and moisture release, (b) ignition of pyrolysis gas, (c) heat transfer during carbonization process

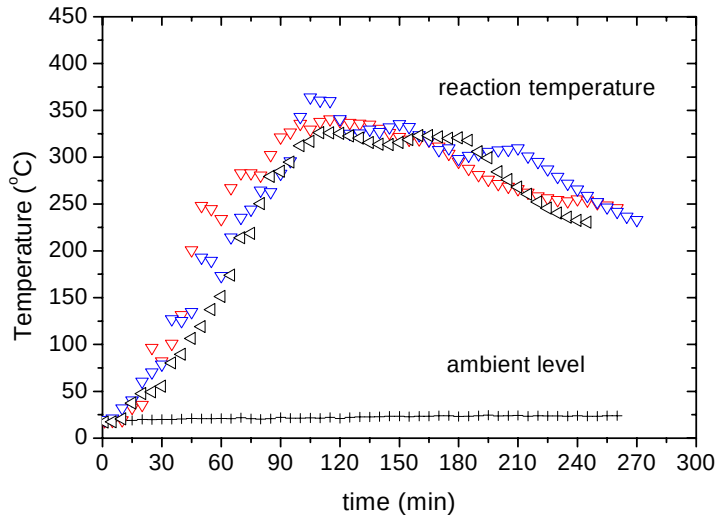
Reaction temperatures were measured by thermocouples inserted thru its body at two locations along the height of the carbonization chamber. The temperatures were automatically recorded by means of a data logger. Temperatures obtained from thermocouple readings inside the reactor were represented as pyrolysis temperature. Limited number of the gaseous products was collected at the exit of the dry filter in a 0.10 $dm^3$ sampling bag. The volatiles were immediately sent for composition analysis. A Shimadzu Gas Chromatography model GC-8A was used to analyze CO, $CO_2$, $H_2$, HCs, $O_2$ and $N_2$. The end of operation for certain condition was determined by checking that flame was no longer sustained, no combustible gas was released and reaction temperature was dropped below 250$^o$C. At the end of every experiment, the solid char residues were collected and weighed to determine mass balance. They were then sent for analysis.

## 3. Results and discussion

Performance of the carbonizer system has been defined in terms of reactor temperature profile, charcoal yield, and characteristics of charcoal obtained. Figure 3 shows evolution of temperature profiles inside the carbonization chamber, for bamboo and woods, respectively. It can be seen that reaction temperature was increased from room temperature to about 250$^o$C in about 90 and 75 min for bamboo and woods, as a result of heat transfer from combustion of fuel bed at the bottom of the carbonizer.




(a) bamboo




(b) woods

Figure 3. Evolution of reaction temperature inside the carbonization chamber

Table 2. Yield and characteristics of charcoal obtained

| | Charcoal yield [%] | | | Fixed carbon | Volatile | Ash | HHV |
|---|---|---|---|---|---|---|---|
| | min | max | mean | [%] | [%] | [%] | [MJ/kg] |
| Woods | 35.1 | 38.4 | 36.8 | 53.5 – 60.0 | 21.6 – 32.2 | 5.8 – 9.7 | 22.5 |
| Bamboo | 32.7 | 34.6 | 33.9 | 55.9 – 59.0 | 25.7 – 28.4 | 7.0 – 9.8 | 23.1 |

Table 3. Comparison with traditional charcoal system

| | Traditional system | This work |
|---|---|---|
| Process time [hour] | 72 – 84 | 3 – 4 |
| Saleable charcoal yield [%] | 23 – 27 | 28 – 33 |
| Powdery and partially charred fraction [%] | 10 – 20 | 4 – 7 |
| Charcoal composition | | |
| Fixed carbon [%] | 50 – 87 | 54 – 60 |
| Volatile matter [%] | 10 – 46 | 22 – 32 |
| Pyrolysis gas utilization | emitted directly to atmosphere | combusted inside the carbonizer |
| Visible smoke during operation | high | very low |

Once a pyrolysis gas flame was established, heat transfer from the central tube burner led to a high reactor chamber temperature in a range between 250-400$^{o}$C where main components of biomass materials were thermally degraded [14, 15]. Charring process was observed to complete in about 4 hours. Charcoal yields were found to be in the range of 35.1-38.4% and 32.7-34.6% by dry weight for woods and bamboo, respectively (Table 2). They were average values from three repeated runs for each biomass material. Most charcoals obtained were in saleable form while less than 15% of the carbonization product was either in powdery or partially charred forms. From the proximate analyses of charcoal obtained, it was shown that both biomass materials gave high fixed carbon content of almost 60%. It should be noted that volatile matter content was also relatively high. The fixed carbon content was somewhat lower than those reported in literature [10, 13]. Table 3 compares performance of the present carbonizer with the traditional system. It was apparent that the present system produced slightly higher saleable charcoal yield, but at much faster process time. The fixed carbon contents between the two were of similar quality. The present system was found to offer better environmental acceptability, than the traditional charcoal making system.

It should be pointed out here that the experimental runs were undertaken by research engineers who were familiar with the traditional system. With further training and practice, an experienced worker or a local entrepreneur will be able to operate the reactor system satisfactorily well so that better yields and quality of charcoal can be obtained. There may be a promising prospect that this system will be accepted. Adoption of this system in place of traditional ones should be encouraged. From a preliminary cost estimate, it is financially viable for potential individuals to invest in the system. Nonetheless, governmental incentives in terms of subsidies may be made available to those interested to help speed up this development.

## 4. Conclusion

A natural draft, carbonization reactor with no need for electricity or mechanical power input was successfully developed and operated. Charcoal yields of 33 – 38% were obtained. It can produce good quality charcoal from locally available biomass materials, similar to those produced from traditional charcoal kilns, but the process takes no more than 4 hours, compared to 72 – 84 hours for traditional charcoal kilns. The system proved to perform very well and it may be adopted in place of traditional kilns.

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