# Design of a Pyrolysis Reactor for Smokeless Biomass Carbonization

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## Abstract

Biomass carbonization, particularly (charcoal making), serves as a source of livelihood in rural areas, especially in developing countries. Charcoal is also used as a reducing agent during the pyro-metallurgical extraction of iron from its ores. In the conventional method of biomass carbonization; the release of lots of smoke that contains harmful gases such as carbon monoxide is not environmentally friendly. Globally, Scientists are making efforts to reduce the bad effects of climate change mostly caused by harmful gases emitted during numerous anthropologic activities. This paper presents a design for the smokeless carbonization of biomass. In most conventional methods of carbonization, the reactor stands upwards, leading to the emission of lots of harmful smoke. However, the design being presented provides smokeless biomass carbonization. In this design, the reactor is positioned upside down to allow a downdraught of emissions from the pyrolysis of biomass in the reactor. Thus, smoke and other emissions from the reactor have a longer travel distance within the furnace and are therefore combusted before emerging into the atmosphere. The efficiency of the designed smokeless reactor was compared with that of a conventional method during the carbonization of selected biomass such as palm kernel shells, coconut husks, and paper. The results of the investigations showed that in the conventional reactor method, lots of smoke was produced as compared to the smokeless reactor method. The yields of char from each method were compared. The upright method for producing biochar from the palm kernel shells, coconut husks, and paper produced yields of 43.72%, 37.16%, and 9% respectively. Carbonization was possibly incomplete. In the smokeless method, the yields of char from the palm kernel shells, coconut husks, and paper were 31.6%, 22.20%, and 7.8 % respectively and this process, more importantly, was smokeless.

**Keywords:** Pyrolysis, Design, Smokeless, Carbonization, Biomass

## 1 Introduction

Policymakers and engineers have only recently recognized the enormous relevance of biomass, particularly wood and other agricultural leftovers, in developing countries energy systems (Zaror and Plye, 1982; Buah and Kuma, 2016). Biomass is all organic matter produced by plants or any conversion process involving life. Despite the world's vast array of energy sources, such as oil, gas, coal, uranium, and hydropower, Ghana, a country on Africa's west coast, had electricity shortages as the new millennium began. This is due to the country's lack of infrastructure and ability to utilize commercial energy sources. Ghana lost around 1.8 percent of its GDP growth between 2006 and 2007 as a result of the country's avoidable power crisis; this is according to a report by World Bank in 2013 (Obeng-Darko, 2019). Biomass, including firewood and other agricultural leftovers such as palm kernel shells and coal (64 percent), petroleum (27 percent), and electricity (9 percent), are Ghana's primary energy sources (Duku *et al.*, 2011).

Pyrolysis, which involves a process termed carbonization, is used to produce biochar. For example, the production of charcoal is often done in a very simple earthen kiln (Monela *et al*., 1993; Arnold and Jongma, 1977), but the need for a small investment and operating skills, as well as the fact that charcoal can be transported economically over relatively long distances, have all contributed to increased commercialization and usage of it (Zaror and Plye, 1982; Sepp, 2008). The pyrolysis process produces a lot of smoke when biomass is carbonized. The smoke contains hazardous chemicals such as carbon monoxide, which are not only destructive to the environment but also to human health.

According to WHO figures, air pollution caused by biomass burning, particularly wood used for cooking in rural households, kills over 500000 Indian women and children each year (Gebresas *et al.*, 2015). However, in Ghana, the production and sale of wood fuel serve as a source of income for most rural people, as well as an increasing number of city dwellers involved in the coal fuelwood trade (Anang *et al.*, 2011; Alhassan *et al.*, 2022). Traditional economies can simply be classified as biomass economies, according to (Gelder *et al.*, 1995). Rural livelihoods are inextricably related to the natural environment, making carbonization by biomass pyrolysis a complex subject that cannot be easily stopped despite its pollution to the environment.

In the University of Mimes and Technology (UMaT) for instance, research on various metallurgical processes is on the increase. Mostly the conventional method of producing a lot of smoke is used. Clearly, there is a need to have an effective diffusion of a new technology that will help reduce the effect of the harmful gases being produced. Hence the need for a smokeless reactor, which is environmentally friendly and less detrimental to human health.

# 2 Materials and Methods Used

## 2.1 Materials

Palm kernel shells were collected from a local oil palm processing company in Tarkwa in the Western Region of Ghana. Coconut husks were obtained from coconut vendors whereas the papers were obtained from the Minerals Engineering laboratory, UMaT. A custom-made smokeless reactor which can also perform the conventional method of charring was utilized during the carbonization process, while the jaw crusher, roll crusher, electronic balance, thermometer, and other relevant materials were obtained from the Minerals Engineering, UMaT.

## 2.2 Design of Pyrolysis Reactor Assemblage

The reactor is made up of three main components as shown in Figure 2.1 and 2.2. These are namely; an elongated cylindrical external furnace, mini cylindrical inner reactor and liquefied petroleum gas (LPG) storage unit.

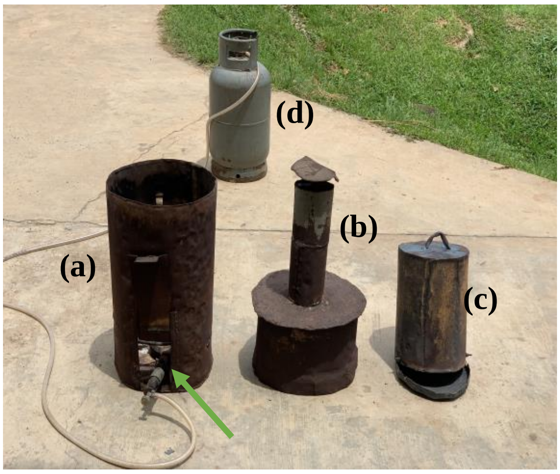


**Figure 2.1 Disassembled Pyrolysis Reactor showing the External Furnace (a), Inverted Funnel-shaped Cover (b), Mini Inner Reactor and Cover (c) and LPG Storage Unit (d).**

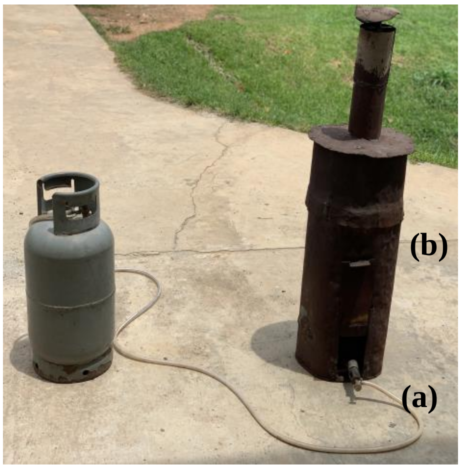


**Figure 2.2 Assembled Pyrolysis Reactor**

### 2.2.1 External Furnace

The external furnace was made up of a steel plate. The furnace has a cylindrical base with the LPG inlet attached (Figure 2.1a) and an inverted funnel-shaped top covering (Figure 2.1b). Underneath the cylindrical base is a heating chamber that supplies heat to the furnace from the combustion of LPG.

### 2.2.2 Inner Reactor

The inner reactor was also made up of steel plate and it is clearly displayed in Figure 2.3. It is made up of a cylindrical container with a cover. Attached to the cover is a small screw to keep it in position and finally a small handle at the top to aid in handling the reactor. The inner reactor can be placed upright or upside down. The upright position offers the conventional method of carbonization, where the smoke emerges from the top of the reactor. The smoke thus has a shorter residence time in the furnace and is not fully combusted before reaching the environment. The upside-down positioning of the inner reactor allows a downdraught of the emissions from the pyrolysis of biomass in the reactor. Thus, smoke and other emissions from the reactor have a longer travel distance within the furnace and therefore combusted before emerging into the atmosphere. This design, therefore, provides smokeless carbonization of biomass.


**Figure 2.3 Inner Reactor**

### 2.2.3 LPG Storage Unit

A 45 kg cylinder was used to store the LPG, which was used as fuel for heating the reactor furnace as shown in Figure 2.1d.

## 2.3 Carbonization

The crushed palm kernel shells, coconut husks and shredded papers of 500 g each were fed into the reactor and heated to a final temperature of 500 ℃ for a period of 30 minutes each to produce char. This was done in the reactor for both the smokeless method and the conventional methods with Liquefied Petroleum Gas (LPG) as a fuel source. In the conventional/upright method, after the samples were kept in the inner reactor and covered, the container was placed in the furnace with the covered part facing upwards. This was kept in the external furnace without it inverted funnel-shaped cover and heated. This method produced lots of smoke as seen in Figure 3.3. However, in the smokeless process, the inner reactor container was positioned with the cover facing downwards. It was then placed in the external furnace and further covered with the inverted funnel-shaped cover of the external furnace and heated. This method makes the smoke and other emissions from the reactor have a longer travel distance and residence time within the furnace and therefore combusted before emerging into the atmosphere, hence rendering it smokeless.

### 2.3.1 Yield Analysis

The yields of char (Y) produced from the charring process for both methods were calculated in percentage:

$$Y (\%) = (m/M) * 100$$

Where m is the mass of material after the charring process; M is the mass of material before the charring process and Y is the yield in percentage.

### 2.3.2 Safety Precautions

All safety protocols required in the processes were adhered to: safety goggles and nose mask were worn to protect the eyes and nostrils respectively from fine and dust particles during crushing and grinding.

Pyrolysis was performed in an open space and also at high temperatures. Hence, heat resistance gloves were worn for protection against the heat from the reactor. Also, the product from carbonization (char) was allowed to cool before storing to prevent self-ignition and any potential fire outbreak.

# 3 Results and Discussions

## 3.1 The Reactor Design

Figure 3.1 shows a cross-sectional diagram of the covered external reactor whereas the plan view detailing the heating compartment at the base is displayed in Figure 3.2.

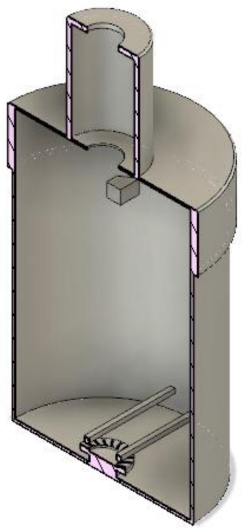

**Figure 3.1 Sectional View of the Covered External Reactor**

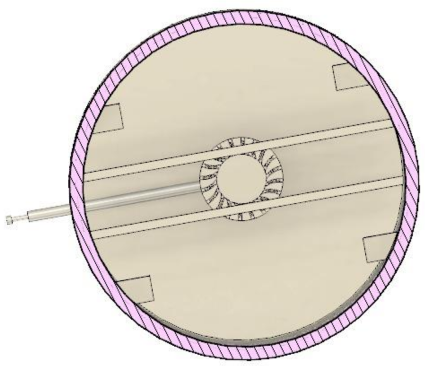

**Figure 3.2 Plan View of the External Reactor without the Cover**

The reactor was designed and fabricated at UMaT Minerals Engineering Laboratory. It is made up of a stainless-steel plate of 5 mm thickness. The external cylindrical furnace reactor has a rectangular opening at the bottom part, which allows a sufficient supply of air for the combustion of the LPG to heat the furnace. The inner reactor is also cylindrical with a cover or lid and can be placed in the furnace with the lid upward or downward. The upright position of the inner reactor offers the conventional carbonization method, where lots of smoke is produced. The upside-down position of the inner reactor provides smokeless carbonization. It allows a downdraught of emissions from the pyrolysis of biomass during carbonization. The external furnace has an inverted funnel-shaped top covering which allows smoke and other emissions from the inner reactor to have a longer travel distance within the furnace and are therefore combusted before emerging into the atmosphere. The simplicity of the design and the ease of feeding and unloading the reactor are some of the unique advantages compared to other pyrolysis reactors. To load the reactor, the inner reactor cover is opened to receive the required amount of biomass feed and cover. The cover is kept in position with a screw to tighten it. With the aid of the handle at the top, it is then put into the external finance with the covered part at the bottom. At this point, the inverted funnel-shaped cover of the external reactor is used to cover it for the pyrolysis process to begin. Discharging of carbonaceous product is done after allowing the reactor to cool less than 150 ℃. The inverted funnel-shaped cover is removed first and the inner reactor is also removed with the aid of its handle. The covered part is unscrewed to discharge the product. The reactor is then ready to receive the next batch of biomass material. The reactor system, excluding the gas source, cost roughly GHC 5000.00 to build in Ghana. The reactor can be used for small-scale production in its current state. The design, on the other hand, using the down draught smokeless carbonization concept, permits scale-up to accommodate large-scale smokeless carbonization.

## 3.2 Carbonization and Yield Percentages

At the end of the charring process for all the samples, the upright method for producing biochar from palm kernel shells, coconut husks, and paper produced yields of 43.7%, 47.16%, and 9% respectively. A lot of smoke was emitted during this carbonization process. This process of conventional carbonization of biomass is not environmentally friendly and can be poisonous to human health. Figure 3.3 shows the emission of smoke using the conventional method

**Figure 3.3 Conventional Method of Carbonization Showing Smoke Emission**

On the other hand, when the reactor was positioned in the furnace with the cover facing downwards, the yields of the char from the palm kernel shells, coconut husks, and paper were 31.6%, 22.2%, and 7.8% respectively. This process was indeed smokeless. This is so because of the design of the reactor. The smoke coming from the base of the reactor was burnt before coming out, hence rendering the process totally smokeless during carbonization. Figure 3.4 shows the charring for the smokeless methods.

**Figure 3.4 Smokeless Charring in the Down Draught Pyrolysis Reactor**

## 4 Conclusions and Recommendation

The conventional method of carbonization, where the reactor is placed upright in the furnace leads to the release of smoke from the reactor into the atmosphere. The proposed design where the inner reactor is placed upside-down causes emissions/smoke emerging at the bottom of the reactor to have a longer residence time in the furnace and get combusted before coming out into the atmosphere.

It is highly recommended that the smokeless reactor be produced on a larger scale for the carbonization of biomass because it is environmentally friendly and very efficient.

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