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Design and Testing of Biochar Stoves

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Abstract

Biochar is a solid material obtained from the carbonization of biomass. Biochar is used on agricultural lands as a soil amendment to improve the fertility of the soils. Currently the most common method of producing biochar is through biochar stoves. There are two basic stove operations in the production of biochar. The first type of stove produces biochar by direct combustion of biomass. Here biomass is burnt inside a chamber in an oxygen limited environment. The resulting residue is the bio-char. The second type involves burning the biomass in one chamber and housing the biomass to be charred in the annular portion of an outer chamber. Heat is transferred from the burning fuel on the inner chamber to the material to be charred in the outer chamber. While the process of biochar production in these stoves is known, the basic principles of the stove design are not readily available. The design methodology for both the types was developed from first principles. Prototypes of both types were constructed based on the design developed and tested. The paper lists the basic principles in the design of biochar stoves and the test results.

Keywords

Biochar, Stove Types, Design Principles, Test Results

1. Introduction

Biochar is a solid material obtained from the carbonization of biomass. Biochar is added to improve the soil. Biochar can increase the soil fertility, increase agricultural productivity, and provide protection against some foliar and soil-borne diseases [1]. The technique of using charcoal as biochar was first developed in the Amazon basin over 2500 years ago as a means to improve soil fertility in the areas in which the indigenous inhabitants used to cultivate their crops. Biochar also has the potential to help mitigate climate change via carbon sequestration.

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mass. The second type involves burning the biomass in one chamber and housing the biomass to be charred in the annular portion of an outer chamber. Heat is transferred from the burning fuel on the inner chamber to the material to be charred in the outer chamber.

Constructional details of both types are given in literature [2]-[4].

The rest of this paper is organized as follows: Section 2 provides a brief description of the basic processes of producing biochar; Section 3 gives a review of the popular direct combustion stove called Top Lit Upwards draft (TLUD) gasifier; and Section 4 gives an indirect combustion of the Rocket stove with design basics. Test results are given in Section 5 and conclusion in Section 6. The results conclude that the biochar produced is of good quality thereby validating the design procedure.

2. Basic Process

The basic process of producing bio char is by thermo chemical conversion. This includes the processes of gasification and pyrolysis. In pyrolysis, biomass is decomposed by secondarily heating it with controlled oxygen to support the combustion process of the biomass.

In the combustion of biomass, there are various stages and steps that take place before and after the burning. To evaporate the moisture content present in the biomass, it is heated up to approximately 100˚C. In the range between 0˚C - 100˚C, no heat is generated from the burning of the biomass. The solids that are present in the biomass start to breakdown and convert to fuel gases as the temperature approaches 300˚C. The main energy present in the fuel is released when the fuel vapours containing up to 60% of the energy burn at temperatures between 300˚C - 600˚C. After all the fuel vapours have been combusted biochar is left behind.

3. Direct Combustion Stove (TLUD)

Here biomass is burnt inside a cylinder in an oxygen limited environment. The biomass goes through a gasification cycle where most of the volatile components are released and flared. The resulting residue is the bio-char. Top lit up draught gasifier [TLUD] is a popular version of this type. Prototype of the TLUD was built based on the basic principles of an inner cylinder forming the combustion chamber within an outer cylinder for regulating primary and secondary air flows [2].

The TLUD (Top Lit Upward Draft) gasifier was originally designed by Paal Wendelbo which he took to Africa in 1988. Since then, the design has been adapted and distributed around the world. A prototype of the design amended by Anderson has been produced and tested in Cambodia. A model was also adapted by ARTI in India [3].

Design Basis

The basic sizing calculations involve determining the stove diameter and height for a desired biochar burning rate. The chemical composition of the biochar is required based on which the stoichiometric air and resulting flue gas flow rate can be calculated.

Sizing calculations are made based on basic thermodynamics and chimney stack draught flow principles. The required air flow for pyrolysis is kept just below stoichiometric air requirement. The total air flow is divided into primary and secondary air flows in the ratio of 9:1.

The diameter of the stove (D) is fixed to give a maximum gas velocity 1 m/s. The calculations for stack height are made to achieve the natural draught to drive the process of pyrolysis (**Figure 1**).

The height of the stove is determined based on the rate of natural draught by the stack height and is decided by the relation given in Equation (1).

$$q = CA\sqrt{2gH\frac{T_i - T_e}{T_e}} \tag{1}$$

where: q = flue gas flow rate (m^3/s), A = cross sectional area (m^2), C = discharge coefficient, g = gravitational acceleration (m/s^2), H = height of chimney (m), T_i = average temperature inside chamber (K), T_e = external temperature (K).

The discharge coefficient is based on the discharge coefficient for subsonic flow through a round orifice (0.6 to 0.65). The average temperature inside the chamber is the average temperature of flue gas during combustion.

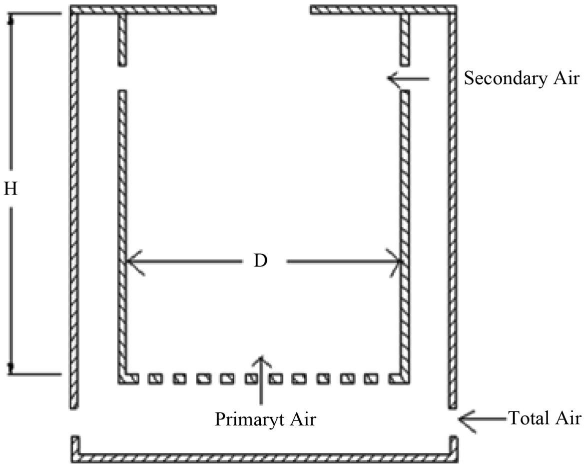

Figure 1. Stove sizing.

A large stack height will give maximum draught but this would make lighting, filling and using it difficult. Thus balance should be stuck between the natural draught effect and practicality. The stove is provided with a grate and other peripherals (**Figure 2**).

4. Indirect Combustion (Rocket Stove)

Here the biomass is burned in the inner chamber and the biomass to be charred is housed in the annular portion between the inner chamber and outer chamber.

Heat is transferred from the burning fuel on the inner cylinder to the material to be charred in the outer cylinder. Airflow can be based on natural draught or through a separate fan [4].

The stove under discussion is provided with a fan. The rocket stove is developed by Larry Winiskari. It is simple in design. The rocket stove is very efficient in that it is clean and produces no smoke. It allows for the heat to be concentrated in thermal mass.

Heat can be directed to a central point as with the other biochar stoves, and allows for the smoke produced by pyrolysis and gasification to be burned, thus eliminating the exhaust of smoke fumes from the stove (**Figure 3**).

Design Basis

The heat required to dry the biomass in the retort and turn it to biochar is given by Equation (2).

$$Q_{bio} = \left(2.5 \times m_{bio} \times M\right) + \left(2.5 \times m_{bio} \times \left(9H_2\right)\right) \tag{2}$$

m_{bio} = mass of biomass to be charred, M = moisture equation in biomass/kg, H_2 = hydrogen in biomass/kg, 2.5 = heat required to evaporate moisture in MJ/kg.

The heat obtained by burning of the biomass is given by Equation (3).

$$Q = m_f \times HV \tag{3}$$

The heat obtained by burning of the biomass should be sufficient to dry the biomass in the retort and turn it to biochar. This determines the mass of biomass to be burned. The heat obtained by burning the biomass is transferred to the biomass to be charred through the wall of the inner chamber by conduction. This fact is used in determining the dimensions of the stove like height and diameter.

Heat transferred by conduction through the wall = Q_{cond} and is given by Equation (4).

$$Q_{cond} = Q_{bio}$$

$$Q_{cond} = \frac{2\pi kH\left(T_i - T_o\right)}{\ln\left(\frac{r_0}{r_i}\right)} \tag{4}$$

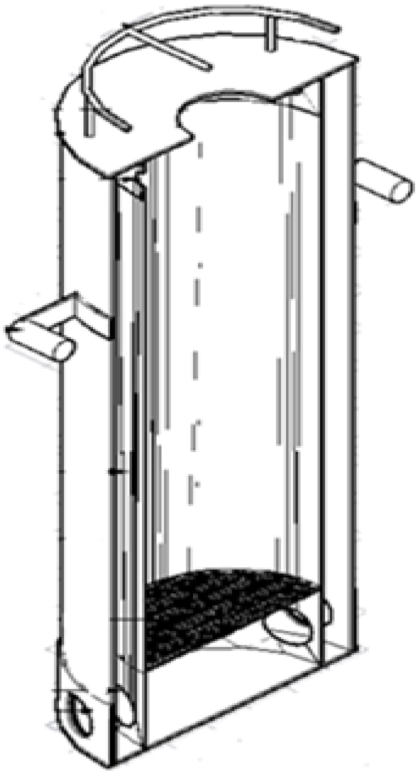

Figure 2. Isometric view.

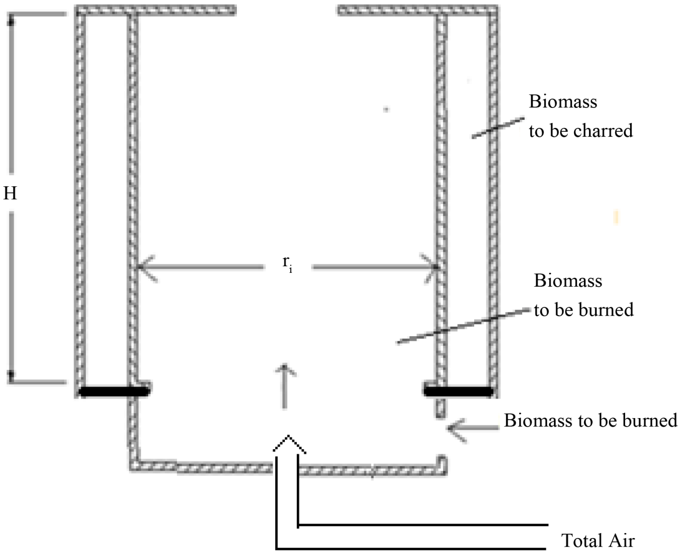

Figure 3. Rocket stove.

where k = thermal conductivity of material of stove, H = height of stove, r_0 = outer radius of inner chamber, r_i = inner radius of inner chamber, T_i = inside temperature = combustion temperature, T_o = outside temperature = charring temperature.

T_i can be taken as 1800˚C and T_o can be taken as 500˚C as a rough approximation [5].

The required air flow through inner chamber is kept just above stoichiometric air requirement. The diameter of the inner chamber is fixed to give a maximum velocity 1 m/s as in the case of TULD stove. This fixes the inner radius of the inner chamber. The outer radius is fixed based on the thickness chosen.

Using the heat transferred by conduction, the height of the stove can be fixed once the inner and outer radius of the inner chamber is fixed.

5. Test Results

The two types of biochar stoves were designed based on the above simplified procedure. These were manufactured as part of student projects and tested [6]-[8] to verify the deign premises.

5.1. Tlud Stove

Tests were done on the stove to assess the water boiling and the char quality (**Figure 4**). The fuel efficiency and water boiling tests were done. The stove boiled three litres of water in 6 minutes and the fuel efficiency was 64%. After the water boiling test was completed, the biomass turned into biochar. The pyrolysis rate was 0.1006 kg/min.

The char was tested and found to be rich in carbon with a pH of 5 - 7. The results conclude that the biochar produced is of good quality used for an alkaline soil.

5.2. Rocket Stove

Tests were done on the stove to assess the water boiling and the char quality (**Figure 5**). The fuel efficiency and water boiling tests were done. The stove boiled five litres of water in 9 minutes and the fuel efficiency was 62%. After the water boiling test was completed, the biomass turned into biochar.

The pyrolysis rate was 0.0475 kg/min. The char was tested and found to be rich in carbon with a Ph of 8. The results conclude that the biochar produced is of good quality and it was burnt at very high temperature (**Figure 6**).

Figure 4. TLUD stove.

Figure 5. Rocket stove.

Figure 6. Biochar.

The pH results mean the biochar is ideal for an acidic soil. Before the biochar is used for an alkaline soil, the soil has to be fermented.

6. Conclusion

Basic principles in the design of bio char stoves of both direct combustion types and indirect type have been identified and a design methodology has been developed from the first principles. The stoves designed as per these procedures are found to work well. The biochar produced from both the stoves are found to be suitable as soil amendment. The Rocket stove was found to char the biomass at a higher temperature and the biochar produced has a higher pH, making it more suitable for alkaline soils. The simple design methodology developed is found to be adequate.

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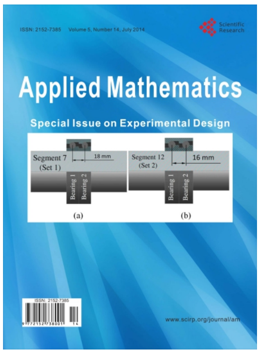
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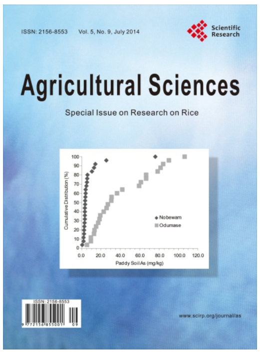
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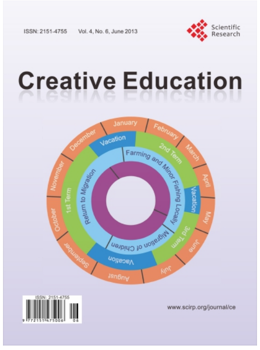
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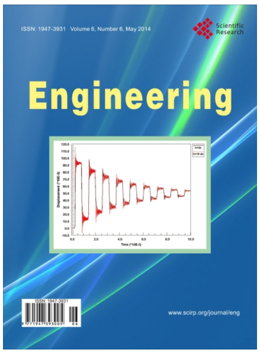
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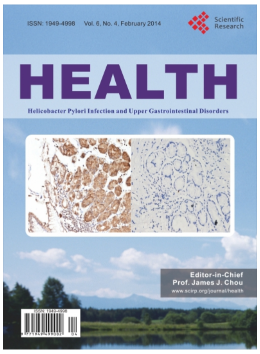
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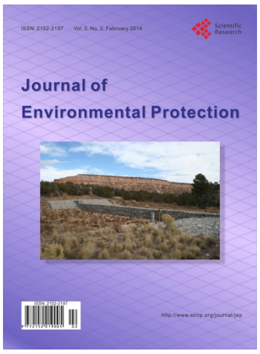
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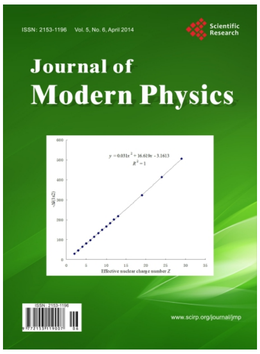
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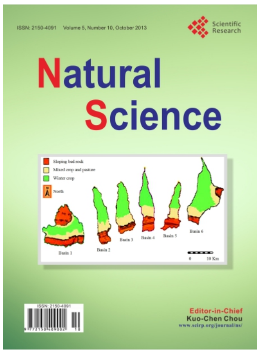
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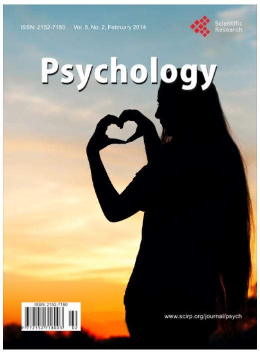
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