Comparative Study on Utilization of Charcoal, Sawdust and Rice Husk in Biomass Furnace-Dryer

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ABSTRACT

Three biofuels: charcoal, sawdust and rice husk were burned in a biomass furnace-dryer and their thermal powers were measured. Air is supplied into the furnace of the dryer by natural convection through air ducts. The drying chamber is lagged (insulated) by a 25.4 mm air space between inner wall and the outer casing to prevent heat loss. Three tests were replicated on each fuel and the mean values used to evaluate heat flow by conduction, radiation and the thermal efficiency of the biomass furnace-dryer. The performance characteristics of the biomass furnace-dryer, including overall efficiency, and thermal capacities of each fuel were evaluated.

The results indicated that charcoal exhibit the highest thermal power expressed by temperature increase, 4.08 kW. Burning of sawdust was slower, and the thermal power lower, 3.56 kW. Rice husk has the least thermal power of 2.93kW as a result of low differential temperature (difference between the highest and lowest temperatures) and its combustion was followed by emissions with dark exhaust gases. The overall thermal efficiency of the biomass furnace-dryer for all fuel is 59%.

Observed temperature rises and characteristic temperature curves in the drying chamber indicated that charcoal attained very high drying temperatures and increase within a short period than other fuels, while sawdust and rice husk have much lower heat buildup and longer temperature rise response time. By these results, charcoal are suitable for short time heat processes such as baking and roasting, rice husk could be suitable for milk and fruit juice pasteurization, which require heat processing conditions of between 63-85° C for about 15 to 30 minutes. Sawdust can be used in sterilization of meat, fish, soup etc. Charcoal is more environmental-friendly than the other products because of the smokeless burning process thus suitable for indoor cooking.

Keywords: Biomass furnace-dryer, thermal efficiency, charcoal, sawdust, rice husk

1. INTRODUCTION

The decreasing availability of fuel like wood, coupled with the ever-rising prices of kerosene and cooking gas in Nigeria, has drawn attention to the need to consider alternative sources of energy for domestic and cottage level industrial use in the country (Lucas and Akinoso, 2001). As rightly noted by Stout and Best (2001), a transition to a sustainable energy system is urgently needed in the developing countries such as Nigeria. Traditionally, wood in form of fuel wood, twigs and charcoal has been the major source of renewable energy in Nigeria, accounting for about 51% of the total annual energy consumption (Olorunnisola, 2007).

Utilization of rice husk, sawdust and charcoal as alternative sources for fuel in drying have made these products more valuable rather than considering them as agricultural wastes. There are three main biomass byproducts from rice, viz. straw, husk and bran. Rice straw and rice bran are used as feed for cattle, poultry, fish etc. and the rice husk is used for energetic purposes. Rice husk offers much potential for energy generation and biomass-to-energy projects could create sustainable enterprises, protect the environment, and reduce poverty and improve the quality of life for the rural poor (Ahiduzzaman, 2007). About 70% of rice husk energy is consumed by the rice parboiling system in Bangladesh (Ahiduzzaman, 2007). Jain (2006) reported that rice husk fired gasifier performed well and showed the gasification efficiency around 65% in the capacity range of 3 to 30 kW. According to Rajvir *et al.* (1980) rice husk is quantitatively the largest by-product of rice milling industry and constitutes one fifth of paddy on a dry weight basis.

Appropriate combustion properties of fuel materials are essential during drying, blanching and storage operation and are equally necessary in the design and analysis of the numerous machines and processes involving heat treatment. Many food crops when harvested cannot be consumed directly, but must pass through several stages of processing as well as cooking in order to be palatable and digestible. Raw meats, uncooked grains, vegetables and even fruits required preparation and heating to enhance their flavour, rendering their components edible and digestible. The processing and cooking stages reduce harmful organisms and parasites, which might pose health hazards. Poorly handled and stored food can become spoiled and contaminated.

In order to explore the potentials of these materials for energy production, an biomass furnace-dryer was developed and constructed at National Root Crops Research Institute, (NRCRI) Umudike which was used to study the thermal properties of charcoal, sawdust and rice husk and their performance when used as fuel in the dryer.

2. MATERIALS AND METHODS

2.1 Experimental Unit

The biomass furnace-dryer used in this study, shown in Figure 1 is rectangular in shape and has three functional sections: the heating chamber, drying chamber (with three compartments) and the chimney. The heating chamber has rectangular shape (520 x 410 x 200 mm) and air supply to by conventional air flow through pipes. The fuel compartment is within the combustion chamber, constructed of mild steel and has a weight of 11 kg. The total measured weight of the biomass furnace-dryer including the fuel compartment and the grills is 35.3 kg. Combustion chamber is connected to the chimney located at the back of the biomass furnace-dryer to allow burnt gasses passed out. The heating chamber is separated from the drying chamber by a metal plate through which absorbed heat from the heating chamber is transferred to the drying chamber, (700 x 580 x 600 mm) by conduction. The drying chamber is constructed of mild steel plate and partitioned into three layers. The first layer has a rectangular mild steel tray while the other layers have drying grills for roasting and drying (Figure 1).

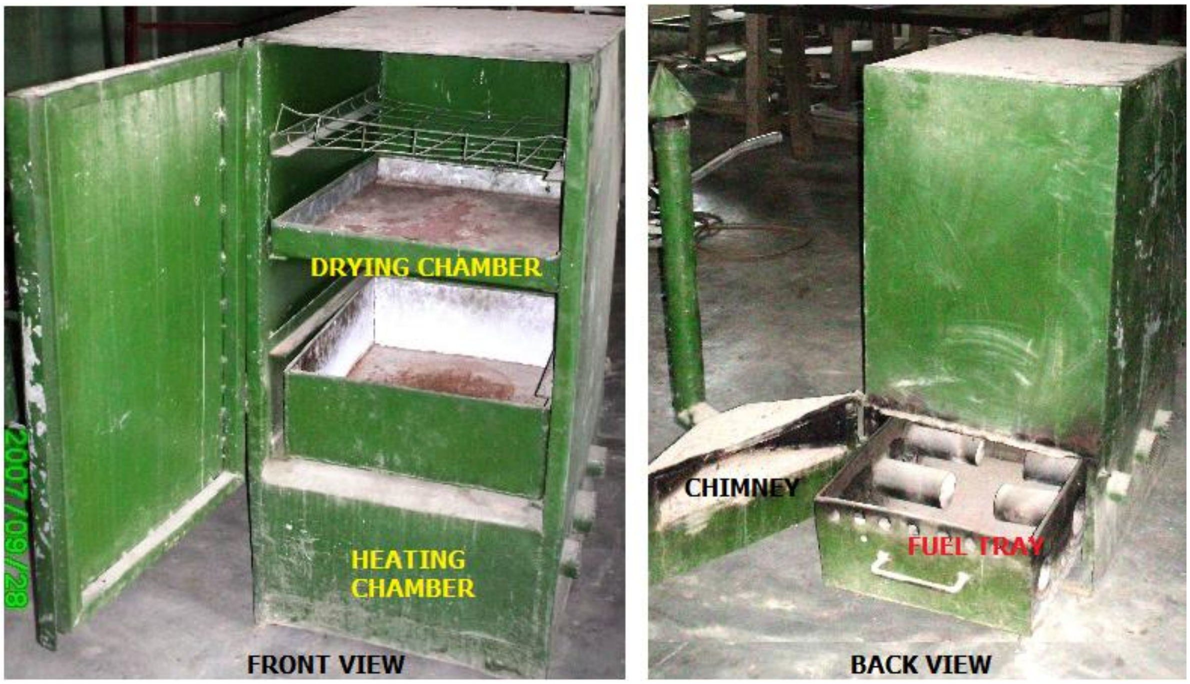


Figure 1. The biomass furnace-dryer: drying chamber and the fuel compartment.

2.2 Experimental Setup

Samples of charcoal, sawdust and rice husk were locally sourced and sundried adequately to reduce moisture content to about 12% dry basis. Then 10 kg of each sample was measured on a Salter scale model 250, (50 kg ± 0.02 kg) and compressed to volume made up to 0.01 m^3 in the fuel compartment. The measured fuel (i.e. the test samples) is introduced in turn into the heating chamber and fired until all the material in the furnace completely burn out. Air supply to support combustion in the furnace is by natural convection by orienting the air inlet and outlet ducts in the direction of air flow. Heat transfer from the heating compartment to the drying chamber is by conduction and radiation. Convective heat transfer within the combustion chamber is minimal and has no significant practical effect on heat transfer, thus it is assumed negligible. The drying chamber is lagged (insulated) by a 25.4 mm air space in between inner wall and the outer casing to prevent heat loss. Three trial replication tests were performed for each fuel and the average recorded. The time taken for each material to burn out completely was recorded against temperature rise in the drying chamber.

2.3 Performance Evaluation Procedures

The performance characteristics of the experimental unit including overall efficiency, drying chamber efficiency and thermal capacities (Oloko and L. Agbetoye, 2006) of each fuel were evaluated based on heat flow by conduction, radiation with an assumption of negligible convective heat flow. The thermal efficiency of the biomass furnace-dryer was calculated from the given thermal relationship.

Conduction heat flow: Heat transferred from the furnace through the metal of the drying chamber by conduction is evaluated by heat flow equation given by Kirk and Holmes (1975):

$$Q_{con} = KA\,(T_1 - T_2)\,/\,L \qquad (1)$$

where:

Q_{con} = Conduction heat flow (W m^{-2} K^{-1}),
K = Thermal conductivity of material (steel = 54 W m^{-1} K^{-1}),
A = Heating chamber surface area (m^2),
T_1-T_2 = Drying chamber temperature difference at time interval t. (°C),
L = Distance between drying chambers.

Radiation Heat Flow: Resulting temperature gradient experienced in the drying chamber as a result of radiation from heat conducted to metal surface according to (Duffie and Beckman 1991) is given by:

$$Q_{Rad} = \varepsilon\,\sigma\,(\Delta T)^4 \qquad (2)$$

where:

Q_{Rad} = Heat radiated in drying chamber (kW),
ε = Emissivity factor for material (metal plate=0.14-0.38)
σ = Boltzman's constant (5.72*10^{-5}) kW m^{-2} K,
ΔT = Temperature gradient in the chamber (K).

Furnace efficiency: Furnace efficiency is related to the sensible heat generated and the calorific value of 1kg of fired sampled materials and it is represented and used in evaluation of furnace efficiency according to (Rajviv *et al.*, 1980) as Furnace Efficiency = Sensible heat in drying chamber per kg of fuel fired x 100%

$$\eta_F = \frac{Q}{MxNHV} \cdot 100 \text{ in } \% \qquad (3)$$

where:

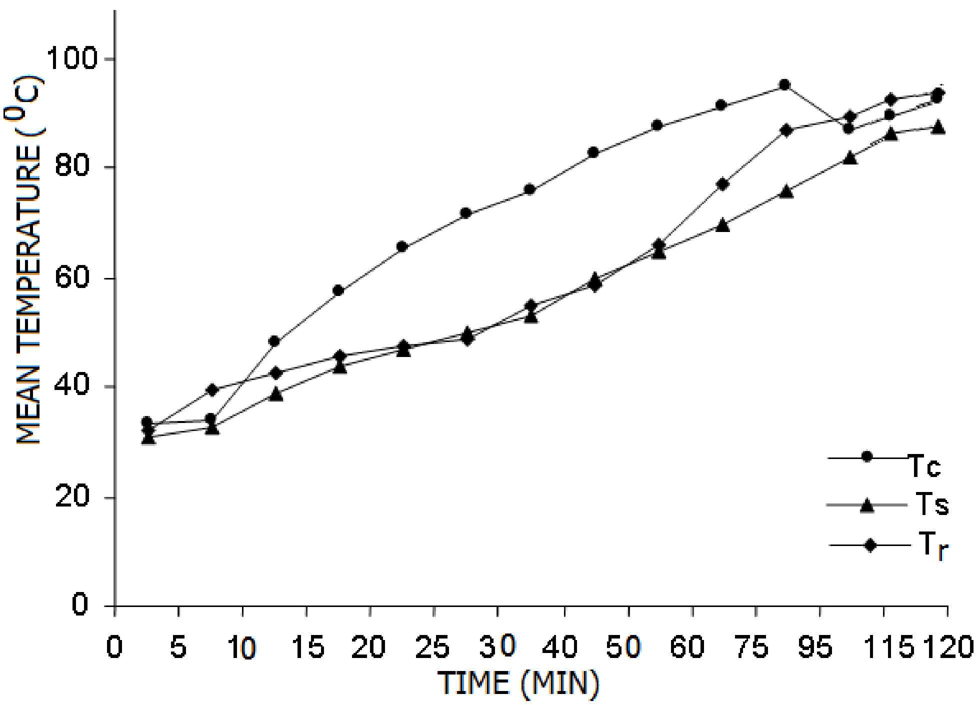
Q = Sensible heat flow (MJ)
NHV = Net Heating Value in (MJ/kg),
M = Mass of fuel fired (kg).

Drying Chamber Efficiency: This is measured as the rate of heat transfer from the combustion chamber to the drying chamber. The amount of heat reaching the drying chamber is that conducted by the metal plate from the combustion chamber, hence the efficiency of the system is the rate at which the heat conducted is related to the drying chamber by radiation (Rajviv *et al.*, 1980):

$$\eta_D = \frac{Q_{Rad}}{Q_{con}} \cdot 100 \text{ in } \% \qquad (4)$$

3. RESULTS AND DISCUSSION

Temperature readings in each of the three drying layers were recorded after a time interval of 5 minutes for 120 minutes and a chart plot of mean temperature rise for each fuel is shown in Figure 2. Charcoal burns more rapidly than sawdust and rice husk and hence heated up the drying chamber faster due to the passage of conventional airflow within the loosely packed materials in the combustion chamber. Rice husk is more or less a bulk material and has a higher density and less pore spaces than saw dust and charcoal. The rate of combustion of rice bran and sawdust are generally slow and produces a lot of smoke because of inadequate air for complete combustion and the presence of some bio-chemical constituents present in agricultural materials such as fiber.



T_c = Charcoal mean temp. T_s = Sawdust mean temp. T_r = Rice husk mean temp.

Figure 2. The mean temperature at intervals for each fuel in the drying chamber.

The plot of mean temperature rise versus time interval showed a rapid increase in temperature response for charcoal fuel but temperature rise in rice husk and sawdust are gradual and over a longer time to reach the peak. Charcoal has a higher differential temperature within the drying chamber (Figure 2) and generating 4.08 kW of energy. Sawdust generated 3.56 kW of energy and burn for a longer time. Rice husk emits greater exhaust gasses and produced the least energy; 2.93kw as a result of low differential temperature defined by the difference between the highest and lowest temperatures (Figure 3). Rice husk and sawdust has less thermal power but generate more heat after some interval of heating.

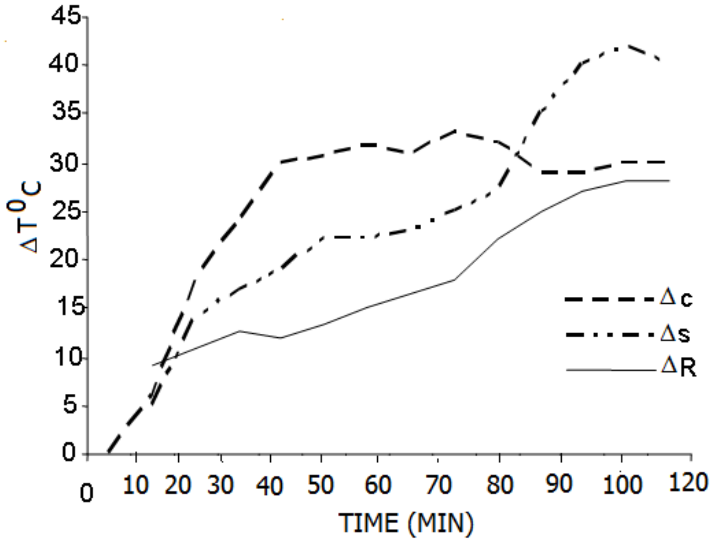


Figure 3. Differential temperature in the drying chamber.

Heat produced in the combustion chamber is transferred to the lower layer by conduction, while the upper chambers experienced radiation from the lower part. There is a general reduction in heat conducted, Q_{con} and as the temperature increases there is a simultaneous increase in radiated heat Q_{rad} to the upper chamber. This is as a result of temperature equilibration within the system. Heat transfer by the fuels through conduction gradually increased in the biomass furnace-dryer for a period of time, 15 to 20 minutes (Figure 4) and then dropped.

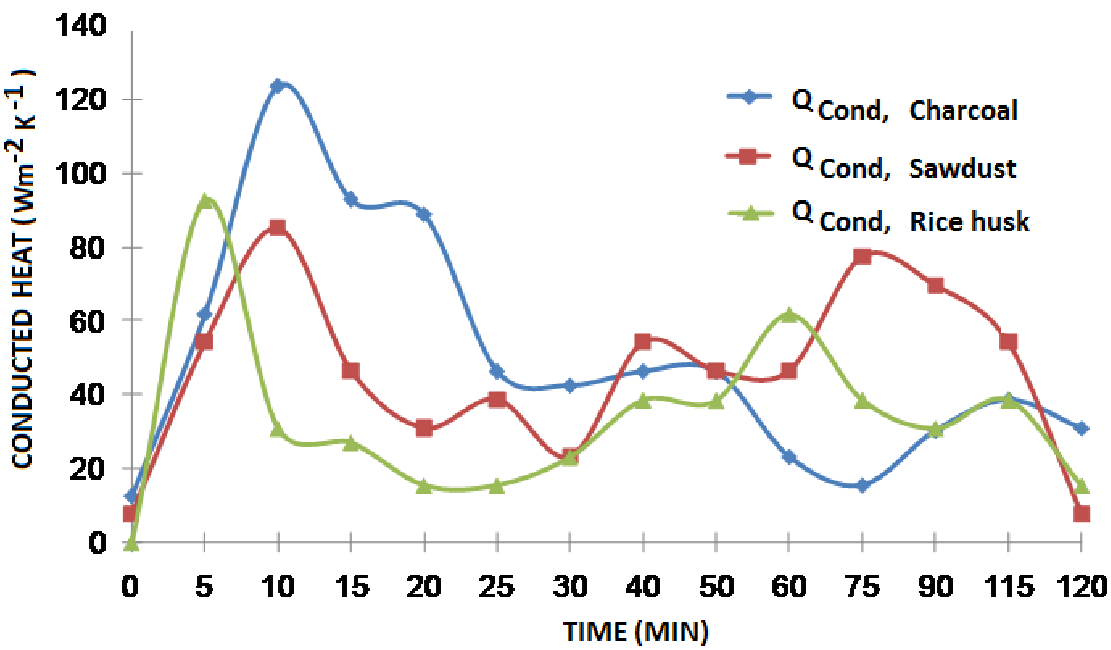


Figure 4. Heat conducted to the drying chamber by each fuel per unit time.

The conducted heat is transferred to the three upper chambers by radiation in order to equilibrate the temperature gradient within the system. The total energy/heat transfer by conduction per hour for charcoal is the highest 1.47 kW per hour while rice husk is the least with 0.98 kW per hour, though rice husk retains its heat over a long period of time. It was observed that charcoal completely burn away at shorter durations than sawdust and rice husk.

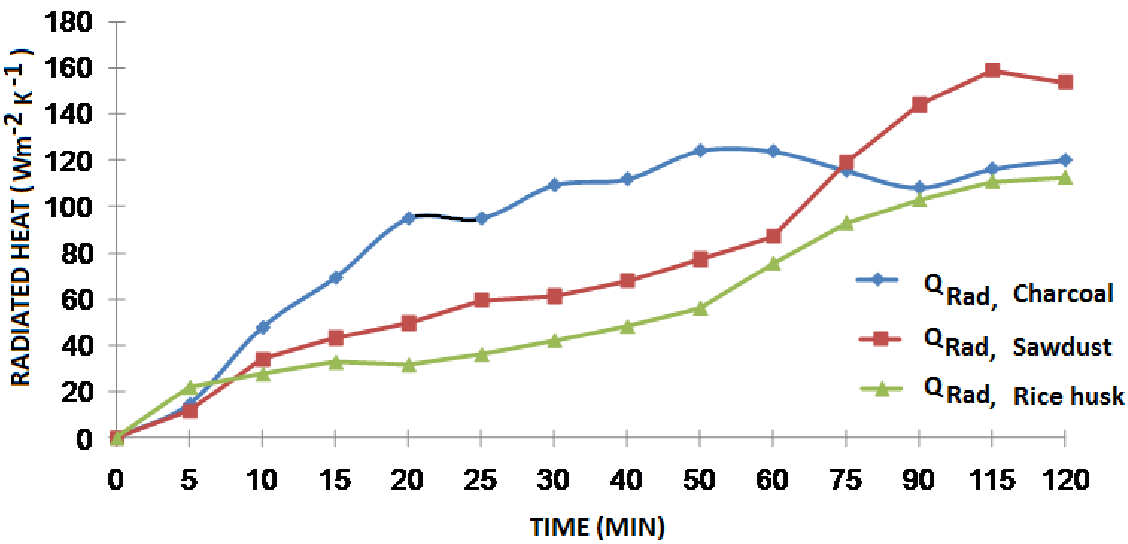


Figure 4: Heat radiated to the drying chamber per unit time.

Thermal efficiency measured as a ratio of heat conducted in the drying chamber to the radiated heat measured in the biomass furnace-dryer for all gases is evaluated to be approximately 59%.

4. CONCLUSIONS

Charcoal has a higher differential temperature within the drying chamber and generating 4.08 kW of energy by radiation in the drying chamber without smoke. Sawdust generated 3.56 kW of energy and burn for a longer time. Rice husk emits greater exhaust gases and produced the least energy, 2.93 kW as a result of low differential temperature. Thus charcoal is more environmental friendly and could be suitable for indoor heating. Rice husk and sawdust have less thermal capacity, but longer combustion period, which could make them more suitable for long process operations.

The biomass furnace-dryer has an average thermal efficiency of 59%. This efficiency can be further increased if the heat loss to the environment as conduction and radiation losses through the top cover and outer casing is prevented. It was observed during the heating the top cover of the biomass furnace-dryer is extremely hot which an indication of heat loss.

From the utilization point of view, rice husk can be used for heat process operations, which requires heat-processing condition between 63-85° C for about 15 to 30 minutes such as pasteurization of milk, fruit juice, and boiling of eggs. Because of the characteristic temperature curve observed in the chamber, the sawdust can be used for sterilization of meat, fish, soup etc. Charcoal has higher thermal values for short duration of burning and hence could be used for domestic cooking and boiling.

The three materials tested are potential fuels capable of using in household/domestic cooking if chimney is properly designed and the air entering the furnace is aspirated (forced convection by introducing fan) to increase rate of air flow to support complete combustion.

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