Comparative study on utilization of charcoal, sawdust and rice husk in heating oven

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Abstract: Three biofuels, charcoal, sawdust and rice husk were used in furnace and their thermal capacities and efficiency were measured. 0.01 m^3 of each fuel used in the tests were measured to and fired in the heating chamber until all the material completely burn out. Air is supplied into the furnace by natural convection through air ducts. The drying chamber was 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 were used to evaluate heat flow by conduction, radiation and the thermal efficiency of the oven. The performance characteristics of the machine, including overall efficiency, drying chamber efficiency and thermal capacities of each fuel were evaluated. The results indicated that charcoal exhibit the highest combustion properties producing 2.54 kJ of energy per hour, sawdust produced 2.68 kJ while rice husk produced the least energy of 1.96 kJ per kg of burnt the products per hour. The overall furnace efficiency of the oven was 75%, and drying chamber efficiency was 62%. Characteristic temperature curves observed in the drying chamber indicated that charcoal attained very high thermal value within a short period than other fuels, while saw dust and rice husk had much lower heat buildup and longer temperature rise response time. By these results, charcoal is 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 between 63–85℃ for about 15 to 30 minutes. Sawdust can be used in sterilization of meat, fish; soup etc. Charcoal is more environmentally friendly than the other products because of the smokeless burning process thus suitable for indoor cooking.

Keywords: Thermal capacity, heat process, thermal efficiency, differential, temperature

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1 Introduction

Appropriate combustion properties of fuel materials are essential during drying /dehydration, 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.

Food preservation usually requires the application of heat to destroy microbiological agents such as bacteria, yeast and mould. Pasteurization causes the inactivation of spoilage enzymes and reduction of bacteria at temperatures around 80 to 90℃. Heat sterilization can use atmospheric steam at 100℃ for high acid- foods, and pressurized steam at around 120℃ for low acid foods (Abubakar and Umar, 2006). Other techniques include dehydration to reduce moisture content, smoking to reduce microbial activity, fermentation, salting and

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freezing. Food transformation activities are generally less energy intensive and release less carbon dioxide than most other industrial activities per unit of the product. In all parts of the world today the demand for energy is increasing almost on daily basis. In Nigeria, energy and in particular oil, has continued to contribute over 70% of federated revenue (CBN, 1999). National developmental programmes and security depend on energy. It is also true that all activities for the production of goods and services in the nation's major sectors of the economy (industries, transport, agriculture, health, politics, education, etc) have energy as an indispensable input.

There is a gradual focus on the need for more energy-related research to reduce costs through energy conservation with a view of preventing possible folding up of the industry due to reduced availability of energy resources (Bamgboye and Jekayinfa, 2006). The decreasing availability of fuel wood, coupled with the ever-rising prices of kerosene and cooking gas in Nigeria, draw attention to the need to consider alternative sources of energy for domestic and cottage level industrial use in the country Lucas and Akinoso (2001). Such energy sources should be renewable and should be accessible to poor. 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 alternatives for fuel in drying process made them valuable rather than regarding them as agricultural wastes. There are three main biomass byproducts from rice viz, rice straw, rice husk and rice bran. Rice straw and rice bran are used as feed for cattle, poultry, fish etc. and the rice husk is used as energy. 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 as 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.

In order to explore the potentials of these materials for energy production, an oven 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 oven.

2 Materials and methods

2.1 Machine description

The oven used in this study (Figure 1) was rectangular in shape and had three functional sections known as, the heating chamber, drying chamber (with three compartments) and the chimney. The heating chamber had rectangular shape, (520×410×200) mm in size and air supply to support combustion was by conventional air flow through pipes. The fuel compartment was within the combustion chamber, constructed of mild steel and had a weight of 11 kg. The total measured weight of the oven including the fuel compartment and the grills was 35.3 kg. Combustion chamber was connected to the chimney located at the back of the oven to allow burnt gasses passed out. The heating chamber was separated from the drying chamber by a metal plate, through which absorbed heat from the

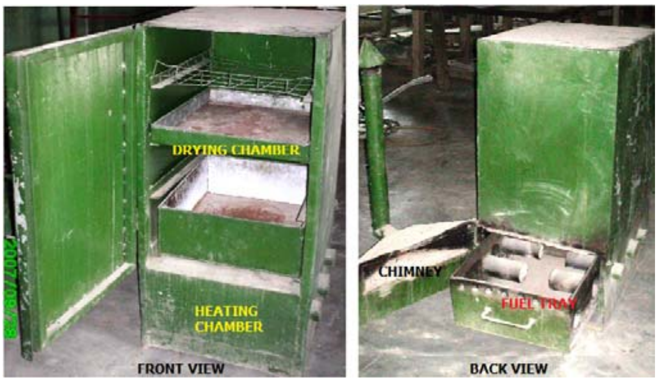


Figure 1 The Oven, showing the Drying Chamber and the fuel compartment

heating chamber was transferred to the drying chamber, (700×580×600) mm by conduction. The drying chamber was constructed of mild steel plate and partitioned into three layers. The first layer had a rectangular mild steel tray while the other layers had drying grills for roasting and drying (Figure 1).

2.2 Experimental setup

Samples of charcoal, sawdust and rice husk were locally sourced and sundried adequately to remove moisture. Then 10 kg of each sample was measured on a Salter scale model 250, (50 kg ± 0.02 g) and compressed to volume made up to 0.01 m^3 in the fuel compartment. The measured fuel (i.e. the test samples) was 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 was 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 was by conduction and radiation. Convective heat transfer within the combustion chamber was minimal and had no significant practical effect on heat transfer, thus it was assumed negligible. The drying chamber was 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 machine, 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 oven was calculated from the given thermal relationship.

Conduction heat flow: Heat transferred from the furnace through the metal to 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/($m^2\cdot$K); K = Thermal conductivity of material (steel = 54 W/(m·K); A = Heating chamber surface area, m^2; ΔT = Drying chamber differential temperature at time interval t, ℃.

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; σ = Boltzman's constant (5.72×10^{-8}) W/($m^{-2}\cdot$°K); ΔT = Temperature gradient in the chamber, °K.

Furnace efficiency: Furnace efficiency is related to the sensible heat generated and the calorific value of sampled materials and it is represented and used in evaluation according to (Rajviv et al., 1980) as

Sensible heat in drying chamber per kg of fuel fired×100% (3)

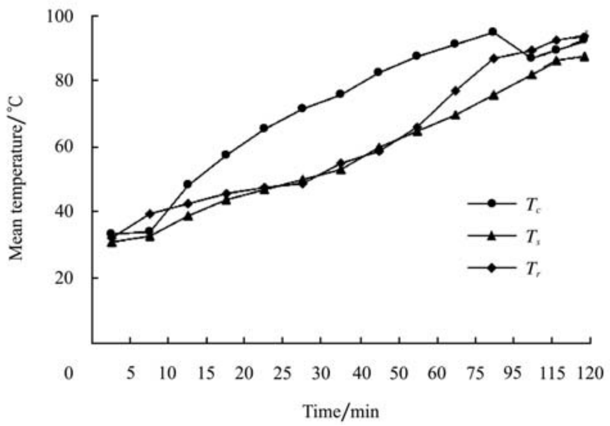
Calorific value of 1kg of fuel fired.

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).

$$\text{Drying Chamber Efficiency} = \frac{\text{Total } Q_{Rad}\text{, within the chamber/h}}{\text{Total } Q_{con}\text{, in the drying chamber per hour}}\times 100\% \qquad (4)$$

3 Results and discussion

Temperature readings in each of the three drying layers were recorded after a time interval of 5minutes for 120 minutes and a chart plot of mean temperature rise for each fuel is shown in Figure 2. Charcoal burns more rapidly than saw dust 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 saw dust 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.



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

Figure 2 Mean temperature in the drying chamber for each fuel at intervals 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 were gradual and over a longer time to reach the peak (Figure 3). Charcoal had a higher differential temperature within the drying chamber (Figure 2) and generating 4.08 kJ of energy per hour. Sawdust generated 3.56 kJ of energy per hour and burn for a longer time. Rice husk emit greater smokes and produced the least energy as a result of low differential temperature (Figure 3). Rice husk and sawdust had less thermal capacities but generate more heat after some interval of heating.

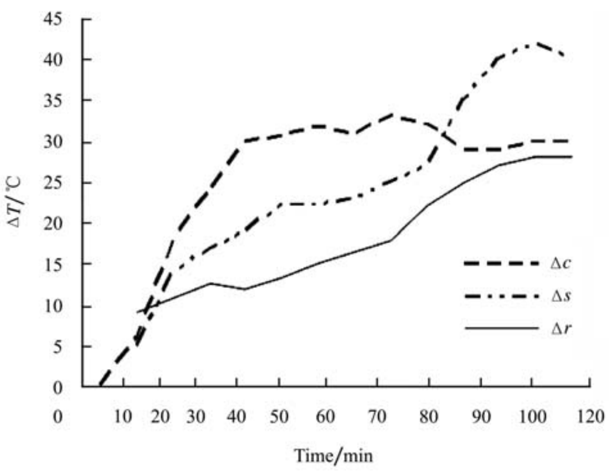


Figure 3 Differential temperature in the drying chamber

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

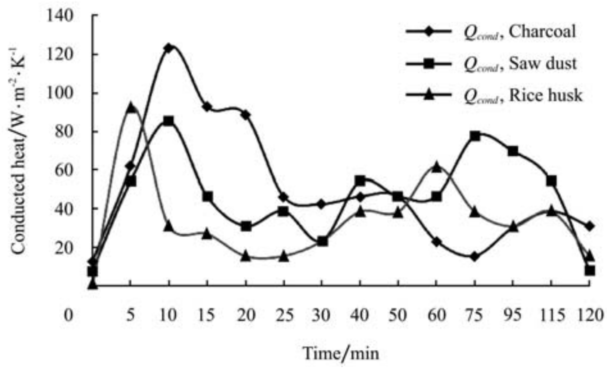


Figure 4 Heat conducted to the drying chamber by each fuel per unit time

The conducted heat was 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 was the highest with 1.47 kJ per hour while rice husk was the least with 0.98 kJ per hour, though rice husk retained its heat oven for a long period of time.

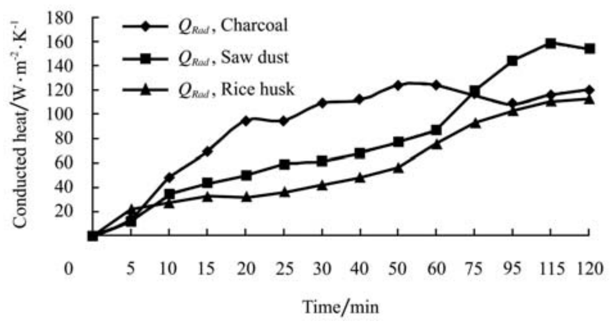


Figure 5 Heat transfer to the drying chamber per unit time

Thermal efficiency measured, as a ratio of heat conducted in the drying chamber to the radiated heat was the highest for saw dust 59.30%. However, on the average, the thermal efficiency of the oven was evaluated to be 58.97%.

4 Conclusions

Charcoal had the best combustion characteristics generating 1.47 kJ per hour of energy by conduction and 2.62 kJ per hour of energy by radiation in the drying chamber without smoke. Thus it is environmental friendly and suitable for indoor heating. Rice husk and sawdust had less thermal capacity but longer combustion period thus making available energy for long process operations.

The oven had an average thermal efficiency of 58.9%. 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 oven was extremely hot which an indication of heat loss.

Rice husk can be used for heat process operations, which requires heat-processing condition between 63–85℃ for about 15 to 30 minutes such as pasteurization of milk, fruit juice, and boiling of eggs. The wastes of rice husk energy can be reduced by replacing the conventional heating systems with improved system and the surplus rice husk could be converted to rice husk briquette fuel which is used for cooking in small restaurant and poor household sector (Ahiduzzaman, 2007). Because of the characteristic temperature curve observed in the chamber saw dust 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. Saw dust and rice husk can be extruded or pelleted to reduce bulkiness and thus increase air circulation by convention which supports burning and reduce excessive smoke.

The three materials tested are potential fuels capable of used 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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