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HEAT TRANSFER AND PERFORMANCE ANALYSIS OF A FABRICATED BIOMASS-FIRED OVEN

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ABSTRACT

This study is based on the heat transfer and performance analysis of a biomass fired oven which was fabricated using design specification, conceptual design and heat exchanger calculations. Sawdust was used as a biomass fuel due to its availability at little or no cost. Heat transfer analysis showed that 3 kg of sawdust was required for combustion in the oven in other to raise the temperature of air from 37 ^oC to 130 ^oC while the quantity of heat was 7.62 kW. For the performance analysis of the oven, two tests were carried out, which include cake baking and fish drying. From the results, it took 1hour 30 minutes to bake a 2 kg cake and 1hour 45 minutes to dry fish at 130 ^oC using the same quantity of sawdust (3 kg). Considering the cost of sawdust as compared to the cost of obtaining wood, kerosene, cooking gas and electricity units, the results show that the sawdust fired oven is more economical for use compared to other traditional cooking ovens, which use wood and kerosene, and the modern ovens, which uses either gas or electricity.

1. INTRODUCTION

Human beings have harnessed biomass derived energy since the time when people began burning of wood to make fire. Biomass is the plant and animal matter used either to generate heat or electricity via direct combustion, gasifier or steam turbine. This replaces fossil fuels for generating electricity or heat (Justin, 2013). Families can replace smoky kerosene, electric kitchen oven, microwaves with biomass just as small-scale businesses can extend their working hours and new businesses can start up (Justin, 2013). The use of biomass is common in Asia especially in the area of gasification, where many companies in India and China have added gasifier to their product list (Bridgewater and Evans, 1993). Research has shown that biomass (sawdust, pellets, briquettes) are much better for the environment because they emit up to 90% less greenhouse gases than fossil fuel (oil, coal, natural gas) (Gaspard, 2013).

Biomass includes husk, wood (including sawdust), leaves, pellet and generally, every non-fossilized and biodegradable organic material originating from plants, animals and microorganisms. This also includes products, by- products, residues and waste from agriculture, forestry and related industries. Biomass has high variable moisture content and is made up of carbon, hydrogen, oxygen, nitrogen, sulphur and inorganic elements. The utilization of biomass is a very important source of energy in many parts of the world, especially for remote areas where there is no high quality fossil fuels (Yang *et al*., 2004). There is need to replace or reduce our dependence on fossil fuels by using a more local and renewable energy source such as biomass. We would therefore significantly be reducing our carbon footprint and increasing energy efficiency when considering the life cycle of the fuel.

In the history of biomass oven technology, different stoves/ovens have been developed and used in different parts of the world. Stoves and ovens using biomass is one of the main sources of the energy in rural areas. Wood stove is a simple stove type, which utilize energy for heating and cooking with burning of the wood (Klass, 1998). Sawdust stove has a similar running system as wood stove and sawdust obtained from cutting trees is used as the feedstock. Sawdust or wood dust is a by-product of cutting, grinding, drilling, sanding, or otherwise pulverizing wood or any other material with a saw or other tool; it is composed of fine particles of woods biomass production (Green and Harvey 2006).

Sawdust is flammable and can be compressed into a block by a briquette press (Frederick, 2012). As the sawdust is compressed, the lignin in the wood acts as a natural glue and binds the briquette together. There are no additives and that makes briquettes a natural and green product. Sawdust is cheap to get and renewable, hence it was chosen as the source of fuel for the fabricated oven. Sawdust has averagely good combustion efficiency. This of course, is the reason for its consideration for use as fuel in the oven. Heat transfer analysis of the sawdust was conducted in other to evaluate the performance of the oven.

The essence of this study is to develop a baking/drying system that can eliminate some of the negative effects encountered in using wood as fuel source in a traditional cooking system and the use of fossil fuels like kerosene, gas etc. as a source of fuel in ovens and high cost of using electric ovens.

2. MATERIALS AND METHOD

Biomass from wood (sawdust) was collected from the saw mill at Uselu market in Benin City, Nigeria. The sawdust fired oven components were locally sourced.

2.1. Fabricated Biomass Fired-Oven

Figure 1 show the biomass fired oven fabricated using locally sourced materials.

2.2. Heat Transfer Analysis

2.2.1. Heat delivered by sawdust

The calorific value is the quantity of heat that one kg of sawdust can deliver. According to Yank et al. (2016), the calorific value of sawdust with a moisture content of 20% is 16000kJ/kg. The mass of the sawdust measured into the combustion chamber is 3kg.

$$\text{Quantity of heat given off by sawdust, } Q = Mcv \qquad (2)$$

Where:

m =charging rate of saw dust in kg/s; CV = Calorific value of sawdust in kJ/kg

Time taken for 3kg of sawdust to be burnt to release the required quantity of heat according to tested result was 105 minutes i.e. 6300secs

$$m = \frac{\text{Mass of sawdust}}{\text{Time taken}} \tag{3}$$

$$m = \frac{3}{6300} = 0.0004762\text{kg/s}$$

Therefore, the amount of heat delivered by fuel (sawdust) was:

$$Q = mCV = 0.0004762 \times 16000 = 7.62\text{kW}$$

Figure 1: Fabricated biomass fired-oven

2.2.2. Heat required to raise the temperature of air

According to Rajput (2007), the heat required to raise the temperature of air is:

$$Q_R = mC_p\Delta T \tag{4}$$

Where m is mass flow rate of air that occupies the baking chamber
C_p=specific heat capacity of air at constant pressure
ρ = Density of air

Note that the air temperature is raised from 37ºC to130ºC, therefore the mean temperature T_m is:

$$T_m = \frac{37+130}{2} = 83.5^{o}\text{C}$$

From thermodynamic Tables, the properties of air at 83.5ºC are shown in Table 1.

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Table 1: Properties of air at 83.5°C (Rogers and Mayhew, 2005)

Parameters	Values
Specific heat capacity (C_p)	1.009kJ/kgK
Density (ρ)	0.9751kg/m^3
Kinematic velocity (V)	2.192m^2/s
Prandtl number (Nr)	0.0695

According to Lienhard (2013), the volume flow rate of air at 83.5°C = 0.066m^3/s. Thus, mass flow rate of air = density x volume flow rate of air:

m = 0.9751 x 0.066 = 0.06435kg/s

Hence, the rate at which temperature of air is raised is:

$Q_R = mCp\Delta T = 0.06435 \times 1.009 \times 93 = 6.4$kW

It is assumed that the system is perfectly insulated and there are no losses due to conduction in the system, hence the oven is capable of building up large heat value, but with proper ventilation and sawdust loading losses occur to reduce it to a safe and lower value for proper drying.

2.2.3. Heat loss due to conduction

The heat loss due to conduction is:

$$Q_L = \frac{kA\Delta T}{\Delta x} \quad (6)$$

Where thermal conductivity of sawdust insulation, k = 0.08W/mK (Joshua, 2008)

Δx = Thickness

Area of surface of baking chamber that undergo heat loss, A = Surface area of baking chamber - Area of bottom surface of baking chamber

But the Surface area of baking chamber is given as:

$$A_{hl} = A_{bc} - (\text{length x breadth}) \quad (7)$$

$$\text{but } A_{bc} = 2(lb + lh + bh) \quad (8)$$

Height of baking chamber, h = 40cm

$A_{bc} = 2[(35.5 \times 35.5) + (35.5 \times 40) + (35.5 \times 40)] = 0.82m^2$

Therefore, $A_{hl} = 0.82 - (0.355 \times 0.355) = 0.694m^2$

Hence the heat loss due to conduction is given as:

$Q_L = \frac{0.08 \times 0.694 \times 93}{0.05} = 0.103$kW

Thus, the total heat delivered or supplied to baking chamber, Q_T is equal to heat required to raise the temperature of air in the baking chamber plus losses in the baking chamber as expressed in Equation (9).

$$Q_T = Q_R + Q_L \tag{9}$$

$$Q_T = 6.4 + 0.103 = 6.503\text{kW}$$

2.2.4. Energy losses

Energy loss Q_{loss} is equal to quantity of heat delivered by sawdust minus heat received from baking chamber as expressed in Equation (10).

$$Q_{loss} = Q - Q_T \tag{10}$$

$$Q_{loss} = 7.62 – 6.503 = 1.117 \text{ kW}$$

3. RESULTS AND DISCUSSION

The result from the design shows that 3 kg of sawdust was needed for the combustion process in the burner to raise the temperature from 37°C to 130°C. In the cake baking test, it took 105 minutes for the cake to be completely baked. It was also observed that a steady temperature of 130°C was maintained after 70 minutes of heating the cooking chamber which was sufficient to bake the cake. This is shown in Figures 1. In the fish baking test as shown in Figure 2, the temperature increased steadily with time and later a constant temperature value of 122^{0}C was maintained for a period of 50 minutes and 60 minutes respectively. The results obtained from the charts are in correlation with results obtained from electrical and gas ovens.

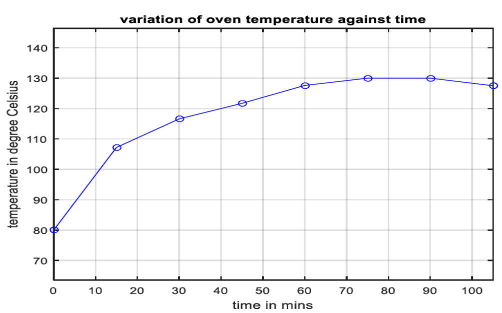

Figure 1: Variation of oven temperature against time using cake baking

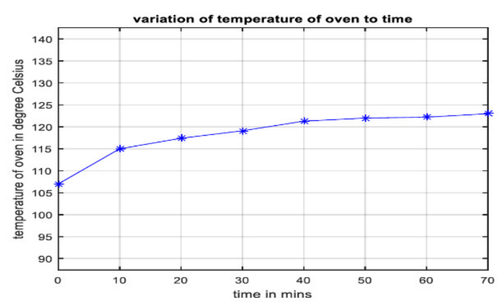

Figure 2: Variation of temperature of oven to time using fish drying

4. CONCLUSION

Renewable energy is a very important source of fuel in an environment where there is limited supply of other sources of energy required for our daily cooking and heating. In this work, biomass energy as a renewable energy was considered. Developed countries harness this energy to supplement power production, while developing nations like Nigeria are yet to fully harness the potential of this technology. From the results, it was observed that a steady temperature of 130 °C was maintained after 70 minutes of heating the cooking chamber which was sufficient to bake the cake while 122 ^{o}C was sufficient for the drying of fish. The results obtained from the charts are in correlation with results obtained from electrical ovens and gas ovens. Therefore, the heat transfer and performance analysis show that the biomass oven is viable and should be looked into seriously as it would reduce the usage of fossil fuel energy required for heating and drying purposes.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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