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DESIGN OF AN IMPROVED BIOMASS TO HEAT COMBUSTER AND ITS EXPEREMENTAL VALIDATIONS

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ABSTRACT

Pulp and paper industry in Nigeria is heavily dependent on fossil fuels. Fossil-based fuel pollutes lower layer of the atmosphere, causes greenhouse gases (GHC) and other environmental worries. Renewable energy sources are clean and cost-effective nowadays. An innovative horizontal air staged inclined biomass combustion for drying purpose in the production of paper egg trays is developed and evaluation is performed with oil groundnut kernel shell and wood chip as the fuel. The development of the Biomass-to-Heat-Converter (B2HC) can serve as useful insight in the design and development a laboratory biomass combustion chamber. The influence of the air mixture ratio on the flue gas composition (combustible gases: carbon monoxide and hydrogen) and the B2HC converter (pyrolysis chamber, exhaust gas, surrounding) temperature profile is determined from the fuels. Temperature obtained for the pyrolysis chamber, exhaust gas and surroundings at the optimum condition were 304.41± 49.75^{0}C, 119.50± 26.84^{0}C and 32.14± 1.38^{0}C respectively. The average emission of carbon monoxide and hydrogen from the optimum condition were 274.71± 52.89^{0}C ppmv and 91.11± 33.66^{0}C ppmv respectively. The optimum average combustion efficiency determined is 62.47 %. The geometrical design in this B2HC shows that carbon monoxide is reduced compared to other works.

Keywords: Ambient , Biomass, Combustion, Temperature, Efficiency, Combustible Gases

1. INTRODUCTION

The role of design and development of biomass combustion system plays a significant role in the global energy crisis. Despite this, there has been relatively little attention paid to the design and material selection procedure of the biomass combustion. Nigeria is blessed with abundant renewable energy sources, especially biomass resource which is under-utilized. Table 1 summarized an estimation of the renewable potential in Nigeria [1].

Table 1: Estimation of Renewable Energy Sources in Nigeria [1]

Sources	Potentials (MW)
Small-hydro:	2,000
Solar PV	500
Biomass-Based Power	400
Wind	500

In principle, biomass combustion technologies can be grouped into three categories: (i) Fixed bed combustion (grate furnace or underfeed stoker), (ii) Fluidized bed combustion (stationary/bubbling or circulating) and (iii) Pulverized fuel (entrained flow/dust) combustion. Many literatures presented the state of the art of biomass combustion technology for fixed bed combustion [2]. One study [2] presented the fluidized bed combustion, bubbling fluidized bed combustion and circulating fluidized bed combustion research can be found in [3]. [6] Give some studied on pulverized fuel combustion also give an extensive detail for the classification and properties of the gas-solid reactors. To date, treatment technologies for drying pulp and paper industry in terms of cost-effectiveness, local availability and serviceability of materials and equipment that require low technical skills are not available [4].

A highly efficient and cost effective biomass-to-heat (B2HC) converter is deemed as an appropriate solution for drying in paper egg trays, pulp and paper industry,

especially in the developing countries. Hypothetically biomass combustion technology appears as a viable technology in the pulp and paper industry in Nigeria. In this research, an innovative horizontal air staged inclined biomass combustion for drying purpose in the production of paper egg trays is developed and evaluation is performed with oil groundnut kernel shell (OGKS) and wood chip as the fuel.
The development of the Biomass-to-Heat (B2H) converter can serve as useful insight in design and develop a laboratory biomass combustion chamber. The influence of the air mixture ratio on the flue gas composition (combustible gases: carbon monoxide and hydrogen) and the B2HC converter (pyrolysis chamber, exhaust gas, surrounding) temperature profile is determined from the fuels.

2. MATERIALS AND METHODS

2.1. Design of the B2HC Converter

The detail design such as dimension, refractory thickness, and refractory anchor of the B2HC converter (Figure 1) is based on [5]

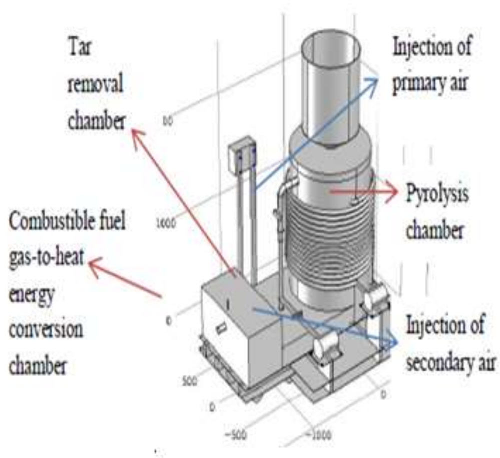

Figure 1: Conceptual design of B2HC converter

About 200 kg of fresh oil palm empty fruit bunch and oil palm kernel shell is collected from Gerawa Oil Mill LTD for the experiment. While the wood chips is collected from a furniture factory at the Aminu Kano way Kano State Nigeria. The collected sample is dried under the hot sun for about 7 days. A drying oven (Model: Binder) with natural convection is used to determine the moisture content of the selected fuel, according to the British Standard EN1477-2-2009 [6]. An anemometer (Model: Dwyer VT120) is used to determine the air flow rate from the B2HC exhaust. A flue gas analyzer (Model: TESTO 350XL) with thermo-chemical sensors is used to determine the emission of combustible gases from B2HC exhaust.

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3. RESULTS AND DISCUSSIONS

3.1. Development of the B2H converter

Parameters such as apparent residence time, stoichiometric ratio, refractory thickness, anchor of refractory were con-sidered to find out the dimension parameters of the B2HC converter. The calculated diameter of the pyrolysis chamber is 2.77m. Due to the available technology, this diameter is reduced to 575 mm as inner diameter with a height of 1600 mm. The inner dimension (width, length, height) for the rectangular tar converter chamber was about 724.1 mm, 1100 mm and 184.6 mm respectively. The dimension (width, length, height) of the combustible fuel gas-to-heat energy conversion chamber was about 775 mm, 500 mm and 500 mm respectively (Figure 2). This can serve as useful insight in design and develop a laboratory biomass combustion chamber.

3.2. Moisture Content of the Selected Biomass Sample

The moisture content of the selected biomass sample is shown in Table 2. Oil palm kernel shell recorded moisture content of 11.7 0.1 wt. %, while wood chip recorded moisture content of 16.2 1.1 wt. %.

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Table 2: Moisture Content of the Biomass

Sample	**Average, wt. %**	**Standard deviation**
Groundnut oil shell	11.7	0.1
Wood chip	16.2	1.1

3.3. B2HC Temparatures

3.3.1 Average Temperature of pyrolysis chamber

Generally, the average temperature of the pyrolysis chamber increased with AMR (pyrolysis time). This was in agreement with [7], this was due to the good mixing between fuel and air that promote the heat and mass transfer in the biomass combustion. Group A experiment gave the lowest average temperature range, that is from 205.41 ± 10.19^{0}C to 224.73 ± 39.20^{0}C . In group B, the average temperature range is 196.03 ± 30.78 to 303.41 ± 49.75^{0}C **.** Interestingly, group C experiments contributes the overall higher average temperature range among other groups that is 263.53 ± 21.46^{0}C to 336.80 ± 21.81^{0}C even the AMR is lower than Experiment ii, iii, v, and vi (Figure 2). In group C, Experiment viii give higher average temperature of pyrolysis might be due to the wood chips’s have wider effective surface area available for reaction compare to the OPKS. This factor was confirmed by [8]. The abnormally high average temperature of pyrolysis chamber in the Experiment v, was later found out was due to the burning fuel that spread over the thermocouple, which was quickly remove after about 18 minutes.

3.3.2 Exhaust Temperature

It can be observed that the average temperature of the exhaust consistently is decreased with the increased of AMR and or Excess air. This was attributed to the convective cooling effect of the secondary air, which became higher than the energy released by the exothermic reaction and also higher than the radiative heat transfer from the solid phase [9]. As the air flow rate is increased above the theoretical value, the B2HC input energy per kg of fuel gases is reduced and the exhaust gas temperature decreases. Previous study by [10]confirmed to these factors. Therefore, AMR is an important factor to achieve the desire temperature. According to Figure 2, generally group A recorded the highest average temperature of exhaust, follow by group B, and group C.

3.3.3 Surrounding Temperature

Generally, there is a very small difference changed of the B2HC surround temperature (Figure 2). This was due to the refractory used is of high heat capacity and low thermal conductivity to absorb the radiated energy for energy saving [8].

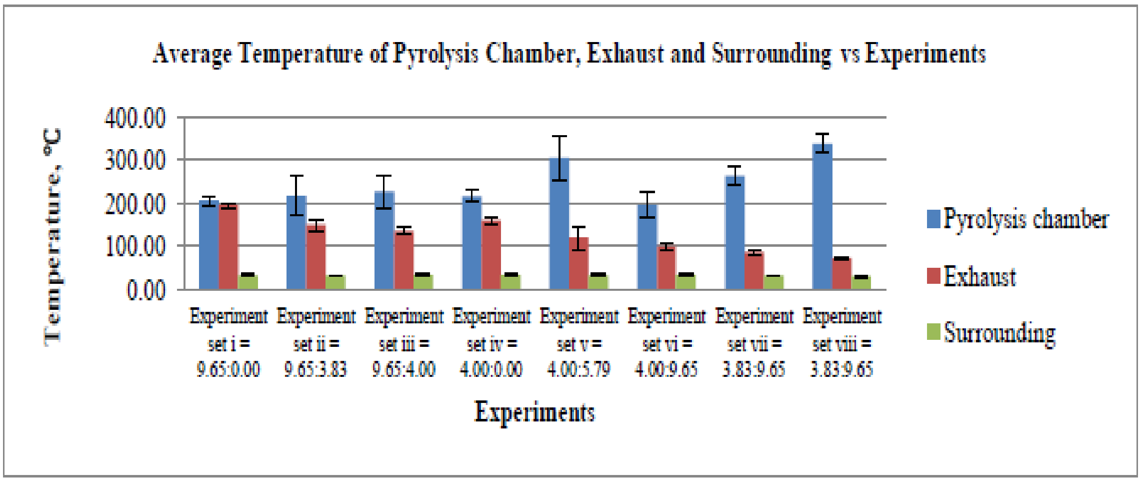

Figure 2: Average Temperature of Pyrolysis Chamber, Exhaust and Surrounding Versus Experiments

3.4. Combustible Gases

According to Figure 3, CO and H_2 concentration inversely proportion with the increased of AMR and or excess air. This was attributed to the air staging method applied in this experiment, fuel rich zone and fuel lean zone at pyrolysis chamber and tar removal chamber respectively. The work of [11] is in agreement with this result. There was CO emission reduction of 46.78 % and 81.28 % for the group A and B respectively. Experiment iv (non-air staging) in group B recorded the highest CO emission is attributed to deficient air combustion of 53.94 %. Follow by Experiment i (non-air staging) in group A as it only have 2.84 % excess air combustion. In group B, CO emission reduction of more than 80% was achieved by using air staging test (Experiment vi) compared to non-air staging test (Experiment iv). CO emission will be emitted from the combustion process attributed to the lack of sufficient oxygen to complete the reaction from CO to CO_2. When the secondary air is added into tar removal chamber to supply the oxygen to complete the combustion, the exhaust temperature will drop. In this particular experiment, the optimum condition of air staging method in B2HC is about 78.18% excess air combustion (AMR is 3.83:9.65). In group A, Experiment iii, the CO emission concentration is abnormally higher than Experiment ii, this might highly due to smoke detected in the exhaust during the initial combustion, subsequently caused the TESTO 350 XL analyser to malfunction [12]. This phenomenon mostly happened during the first 2 minutes. Where the fuel is just starting the combustion process with the limited oxygen supplied and residence time [12]. This phenomenon of high CO emission concentration mighty due to a few factors such as the location of the air staging [6], insufficient air supplied [13], ignition from the bottom [2] and or too short residence time of the combustion gases in the combustion zone [14]. According to Figure 4.x, the CO emission concentration from OPKS is lower compare to wood chip. According to [15], with about 75 % excess air combustion, the OPKS (collected from Perlis) emission recorded as about 680 ppmv by a Xentra 4904 B1 analyser. While in Experiment viii (OPKS as fuel), the CO_2 emission concentration measured as about 193.35 ± 9.17 ppmv. While the study by [16] showed that the CO emission by forest wood chips (spruce pellet) is about 822 ppmv under the excess air coefficient of about 210 excess air combustion. This was in agreement in this result, that the CO emission from wood chip is always higher than OPKS. The reason might attribute to the carbon content in OPKS (41.47% – 45.61%) [17]lower than wood chips (51.8 – 54.9 %) [18]. The H_2 emission concentration is direct proportion to the AMR and or excess air. This was due to a dilution effect caused by the increase of nitrogen content (introduce along the air). That explains these decreases of all percentages in Figure 3 (percentage volumetric). Besides, higher oxygen content is introduced will diminishes the reduction conditions. This was because the rate of oxidation reactions (exothermic burning) is opposite of the reforming reaction of H_2 [19].

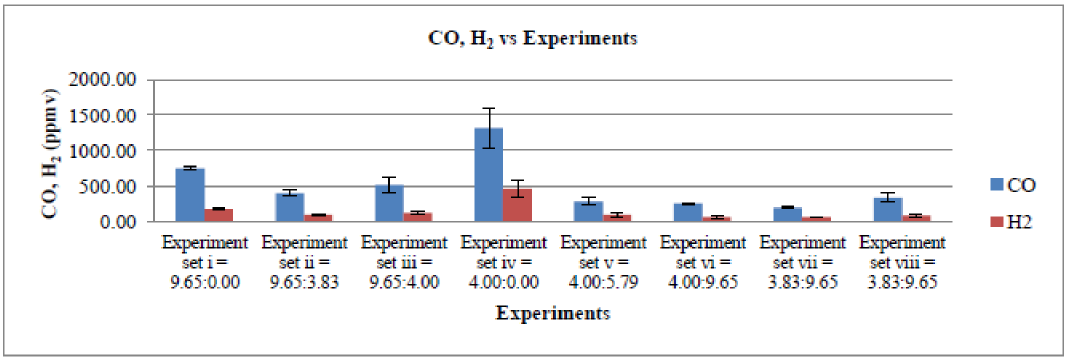

Figure 3: CO and H_2 versus experiments

3.5. Combustion Efficiency

Figure 4 shows that combustion efficiency detected is decreased with the increase of AMR and or excess air combustion. This was in agreement with [20] which stated that high excess air (more than about 50% excess air) can lead to reduction of combustion efficiency. The reason of this might due to the increase of the bed operating velocity, the hydrodynamic condition of the B2HC chamber changes. The increased of the exceedingly high bed operating velocity reduced the mean residence time of char particles in the chambers thus reduce the combustion efficiency [21] found out that the combustion efficiency of fluidized bed for OPKS is 63% with 40 % excess air and 20 % secondary air ratio. In a modified fluidized combustor, a maximum of 99.2 % of combustion efficiency is achieved at 65 % excess air combustion with sawdust [20] stated that normally, fluidized bed technology is reported to be the most efficient technology for converting agricultural waste into energy. [17] indicated that by the reduction of CO_2 does not make a significant improvement on the combustion efficiency. As according to [20], the loss of unburned carbon in the form of CO is in the range of 3 to 10 %.

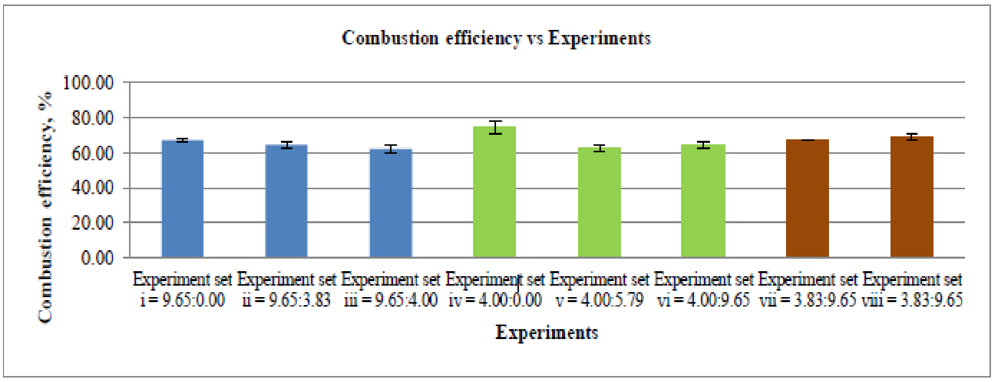

Figure 4: Combustion efficiency versus experiments

4. CONCLUSIONS

A newly B2HC converter is developed. Temperature obtained from the pyrolysis chamber, exhaust gas and surroundings at the optimum condition were 304.41±49.75^{0}C , 119.50±26.84^{0}C and 32.14±1.38^{0}C respectively. The average emission of carbon monoxide and hydrogen from the optimum condition were 274.71±52.89^{0}C ppmv and 91.11±33.66^{0}C ppmv respectively. The optimum average combustion efficiency determined is 62.47 %. The geometrical design in this B2HC shows that carbon monoxide is reduced compared to other works, such as direct combustion which is normally 54-62%. .

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