Investigation of the Best-case Scenario of Rice Husk/Briquette Combustion for Lower Particulate Matter Emission

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Abstract
The combustion of biomass such as rice husk, remains the most popular and commercial method for its energy utilization. However, its combustion is an important source of particulate matter (PM) emissions, which forms a crucial part of air pollution. This study investigated the effects of particle size of rice husk and bran impurities on the emission trend of $PM_{2.5}$. Commercial rice husk was obtained from a Japanese rice husk company and was prepared into 3g as JPN samples. They have no bran impurities and consist of normal sized Japonica husk particles (4 – 5 mm). Rice husk sample was imported from Nigeria under permission. The imported rice husk was obtained from rural milling centers in Nigeria. They are smooth and consist of smaller rice husk particles (0.1 – 2 mm) and has bran impurities. Rice husk briquette was obtained from Tromso Co., Ltd, Japan and were prepared into 3g as RB samples. The three samples were combusted in temperatures between 600°C – 1000 °C for 5 minutes resident time. The experimental set up comprises of a Yamato F100 fixed bed electric furnace attached with a fabricated tubular heat exchanger, connected to a coolant, a Dust Track II aerosol analyzer. Interestingly, RB samples recorded the highest average $PM_{2.5}$ emission (57.9 mg/m^3) at a temperature of 750 °C compared to that of NGR husk (39.0 mg/m^3) at 750 °C, and JPN samples (27.8 mg/m^3) at 900 °C. Interparticle space, density and particle size were the crucial factors that had significant influence on the emission trend.

Keywords: particulate matter (PM), $PM_{2.5}$, combustion, emission, particle size, density, rice husk

Introduction

Bioenergy generation have been in an upward trajectory since 2015, contributing in meeting the rising demand for energy in many countries while contributing to environmental objectives. Though, the sector has encountered challenges such as low oil prices and the policy of uncertainty in some markets (. Renewables 2016). Heat energy utilization accounted for approximately half of total global energy consumption in 2015 (IEA 2015). Global heat energy consumption increased at a mean yearly rate of about 1% (IEA 2016). In 2015, bioenergy's share of final energy utilization for heating was 25%; of this amount, nearly all of it was from traditional biomass, mostly in developing countries (IEA 2015).

While biomass combustion remains a popular and commercial method for energy generation, its combustion is an important source of particulate matter (PM) emissions, which forms a key part of air pollution. Air pollution from biomass combustion is regarded as the third largest contributor to the global burden of disease (Klasen et al., 2015). Inefficient combustion of biomass fuels emits a complex mixture of carbon monoxide (CO), PM, and other harmful gases (Abah et al., 2018). The combustion of biomass with high silica ash content such as rice husk, could lead to the emission of fibrous PM and crystalline silica, which has the potential of causing significant health problems (Gilbe et al., 2008). Studies have shown that emissions from biomass combustion is heavily dependent on temperature (Abah et al., 2018), fuel properties and air-to-fuel ratio Nussbaumer 2003).

Knowledge of specific fuel properties and specific combustion system such as fixed bed or natural draught system is needed in developing measures for emission control since pollutant emission (CO, soot and PAH) occurs due to incomplete combustion. Natural draught systems such as open-air combustion or simplified brick combustion system and other similar fixed bed combustion systems are still being used extensively in developing countries, especially in rural areas. These systems are inefficient and serve as key cause of pollution. Assessment of these systems in terms of PM emission is therefore required in for mitigating air pollution.

Therefore, it is imperative to examine the best-case scenario of rice husk combustion that emits lower PM emissions. Similarly, to know how to control PM emissions if the biomass fuel is transformed during its formation process due to the use of a given technology. Therefore, this study evaluates $PM_{2.5}$ emissions from rice husk combustion in a fixed bed combustor for 3 minutes duration. This study is limited to particulate matter of size fraction 2.5 μm. The experiment was conducted in laboratory, using a small-scale fixed bed incinerator. Consequently, the size per sample was limited to 3g

Experimental methods

Three different groups of samples were used for the combustion experiment. The first group refers to commercial rice husk that was obtained from a Japanese rice husk company and was prepared into 3g as JPN samples. They have no bran impurities and consist of normal sized Japonica husk particles (3 – 4 mm). The second group refers to rice husk samples imported from Nigeria under permission. The rice husk was obtained from rural milling centers in Nigeria and was prepared into 3g as NGR samples. They are smooth and consist of smaller rice husk particles (0.1 – 2 mm) and has bran impurities. These peculiar properties were due to the type of rice milling technology used in the rural areas (single pass milling machines). Single pass milling involves the removal of husk and bran in a single operation. The machine comprises of steel rollers which removes the husk and the bran. These machines generate a mixture of rice husk dust and bran.

The third group of samples refers to rice husk briquette obtained from Tromso Co., Ltd, Japan and were prepared into 3g as RB samples. These rice husk briquettes were made without the use of a binding material. They were grinded and compressed at temperatures below 300 °C. The JPN, NGR and RB samples were then separately combusted in temperatures between 600°C – 1000 °C using a fixed bed combustor. The resident time for each combustion experiment was 5 minutes. The experiment was conducted on a laboratory scale. The experimental set up comprises of a Yamato F100 fixed bed electric furnace attached with a fabricated tubular heat exchanger, connected to a coolant, and a Dust Track II aerosol analyzer (**Fig. 1**). The dust track II aerosol analyzer is a real-time PM counter, with a standard air flow rate of 3 L/min and uses size selective cascade impactors. [5] The targeted emission measurement for this experiment is $PM_{2.5}$.

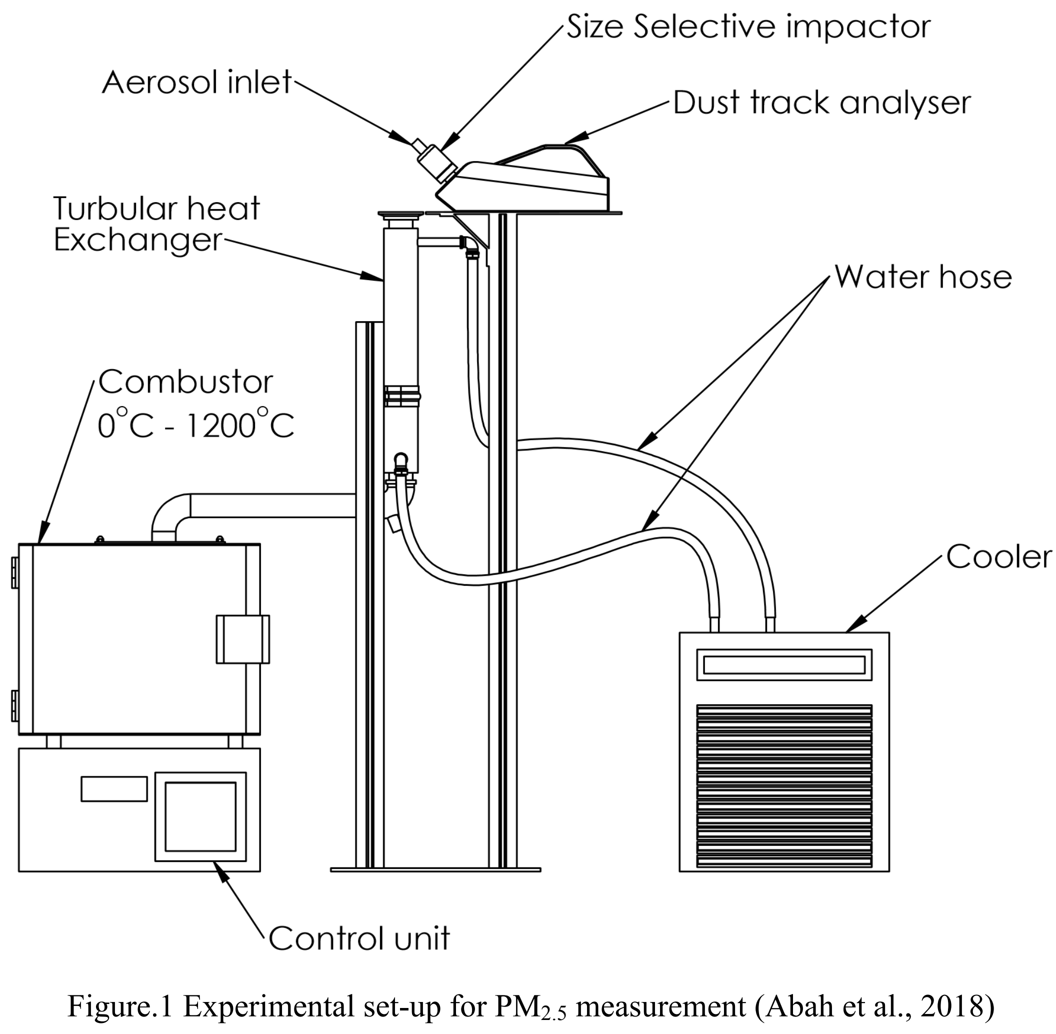

Figure.1 Experimental set-up for $PM_{2.5}$ measurement (Abah et al., 2018)

Results and discussion

The login interval for the data collection for the dust track II instrument was set at 10 secs. A total of 30 points data for 300 secs (5 minutes) was recorded by the instrument for each temperature category (600°C, 650°C, 700°C, 750°C, 800°C, 850°C, 900°C, 950°C, and 1000°C). The average $PM_{2.5}$ represent the average of the experimental result data recorded for each temperature category. **Fig. 2** presents the combined comparative result of $PM_{2.5}$ emission from the combustion of JPN, NGR and RB samples.

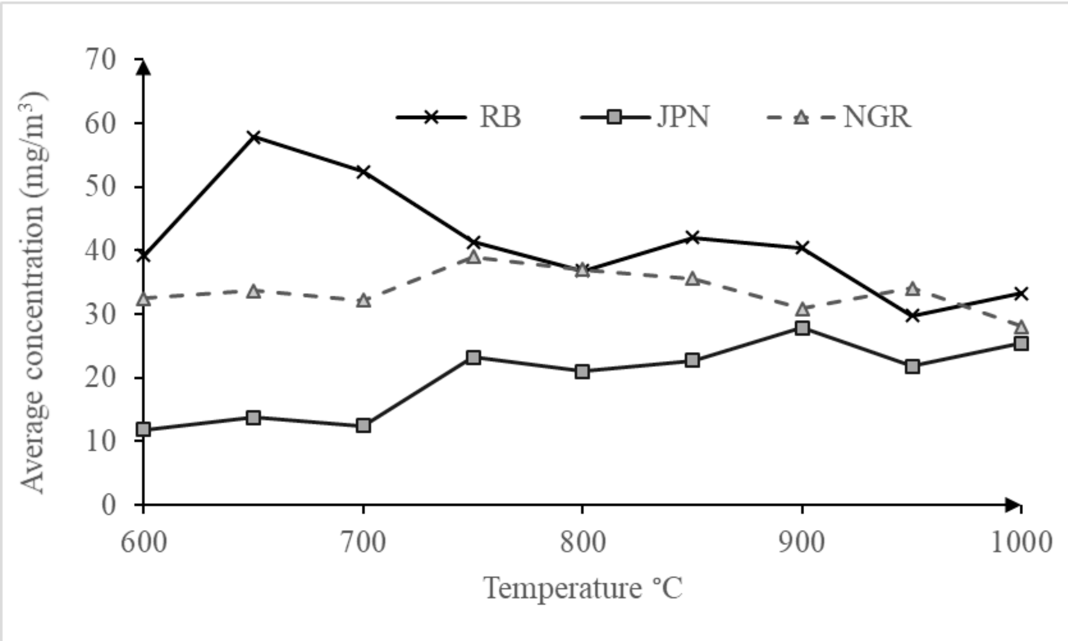

Figure 2. Comparative analysis of $PM_{2.5}$ emission from the combustion of JPN, NGR and RB samples.

$PM_{2.5}$ emission from the combustion of JPN husk increases from a minimum of 11.8 mg/m^3 at 600°C to its maximum of 27.8 mg/m^3 at 900°C. Emission from the NGR husk was notably higher due to its smaller size rice husk particles and bran impurities which increased the density. Therefore, the high $PM_{2.5}$ emission from the combustion of NGR husk was due to the higher density resulting in low interaction between the combustion air and the rice husk fuel particles. More so, the low pore spaces decrease the thorough mixing of the combustion air and the rice husk fuel, indicating the possibility of uneven combustion. As a result, the top portion of the sample is exposed to more combusted air and gets burnt faster than the bottom. This is common to fixed bed combustion system with no bottom air vent.

Porteiro reported in his study that, mean particle size, particle density, bed density and porosity are the key aspect of fuel morphology that influences fixed bed combustion systems as in terms of combustion efficiency (Porteiro et al., 2010). JPN husk sample has large interparticle spaces and ensures that the combustion air can mix better with the fuel, thereby leading to lower emission. This result agrees with previous studies that particle size, fuel density and porosity affect combustion rate, which in turn affects $PM_{2.5}$ emission (McKenzie et al., 1995, Launhardt et al., 1998, Bonjour et al., 2013,). Therefore, lower temperature (600 °C) of combustion of JPN and NGR rice husk, favors the lowest $PM_{2.5}$ emission in this study. This agrees with Abah, who reported low PM emission at 700 – 800 °C. For JPN and NGR, emission increases as the temperature increases (Abah et al., 2018). However, emission pattern from the combustion of the RB samples differs. In this case, emission decreases as temperature increases. This is because, the compression of rice husk into briquette increases its density and calorific value and are optimized when combusted at higher temperatures for longer time. This explains why RB combustion at 950 °C emitted lower $PM_{2.5}$ (29.8 mg/m^3) compared to its combustion at 650 °C.

The electric furnace has a constant supply of excess air to the combustion chamber. This could lower the temperature in the combustion chamber, especially for the RB combustion. Thus, leading to inefficient combustion and high $PM_{2.5}$ emission. Singh et al., reported that higher excess air in the combustion chamber, decreases the temperature of combustion, thus leading to a poor combustion (Singh and Kashyap 1985). Loosed rice husks (JPN and NGR) can be easily fluidized by air in the combustion chamber and thus, lesser $PM_{2.5}$ emission. RB due to its higher bulk density cannot be fluidized and burns in a fixed position therefore, lesser air-to-fuel mixing, consequently more $PM_{2.5}$ emission. Characteristically, briquettes (RB) is a high bulk density fuel and requires longer combustion time, which could lead to more emission. Urbanski reported that as the fuel bulk density increases, the combustion efficiency decreases and emission of CO, CH_4 and $PM_{2.5}$ increases (Urbanski et al., 2016).

Conclusion

This study investigated the effects of particle size of rice husk and bran impurities on the emission trend of $PM_{2.5}$. RB samples emitted the highest $PM_{2.5}$ followed by NGR and JPN samples respectively. The flaming phase of the combustion emits less $PM_{2.5}$ emission compared to the smoldering phase. The RB combustion predominantly occurred in the smoldering phase due to its compact nature and less interparticle space. The JPN combustion was predominantly flaming phase as a result of the better interaction of the fuel particles and air due to its larger interparticle space. This study has expanded the findings of other studies that particle size affects combustion efficiency and, particulate matter emission. The study showed that the combustion of briquette in fixed bed systems at low temperatures, emits higher particulates emission. This study recommends the combustion of briquette at higher temperatures to minimize the emission of particulate matter. Alternatively, adequate particulate matter removal systems should be installed to mitigate public health risk.

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