Rice Husk Combustion for Energy Utilization: Perspective of Human Health Hazard, Environmental Impacts and Introducing Emission Control Systems

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Abstract

Rice husk is the main waste generated from the paddy milling process. It has low bulk density, making it difficult to be disposed properly. Its high calorific value makes it suitable for heat generation through combustion. Biomass combustion is the traditional method of energy utilization from biomass. However, it is one of the key sources of particulate matter (PM) and other pollutants. Research have been done to improve the combustion efficiency and energy optimization. However, exposure to PM emissions from biomass combustion poses health risk and contribute to air pollution and climate change effects. Research have linked respiratory problems to emissions from biomass combustion, necessitating a regional based field study of rice husk combustion in rice mill clusters in Nigeria.

Therefore, chapter 3 evaluated the effects of households' distance on exposure risk in rural rice milling communities. A questionnaire interview in collaboration with the local health department, was conducted to ascertain the level of risk. Strong correlation was found with symptoms such as chest pain (-0.949), itchy throat (-0.894), cough (-0.73) and eye irritation (-0.645). Therefore, the conservation of air quality and sustainability of biomass sources used principally in combustion requires comprehensive scientific investigation, focusing on real-world situations.

Hence, chapter 4 performed a comparative assessment of PM 10, 4.0, 2.5, and 1.0 size fractions, using a laboratory electric furnace attached with a fabricated heat exchanger, and a dust track II aerosol sampler to investigate the emission of the various PM size fractions under varied combustion temperatures (600 °C, 700 °C, 800 °C, 900 °C, 1000 °C). 1 g sample of rice husk was combusted for 3 minutes duration. An average from 5 test for each temperature category was carried out. Maximum PM_{10} mass concentration was recorded specifically at 600 °C and 1000 °C (150.0 mg/m^3 and 71.53 mg/m^3 respectively. The experimented parameters showed the significant effect of temperature on PM emissions.

Having identified temperature as one of the key factors affecting particulates emission, the experiments was extended as chapter 5, to investigate the effects of the rice husk physical properties (particle size, porosity), proximate composition, bran impurities and thermographic properties on PM emission trend. The combustion samples were prepared into 3 g each of Nerica rice husk of the African rice variety (NGR), Japonica husk of the Koshihikari variety (JPN) and its

husk briquette (RB). NGR had bran impurities and average particle size of 0.10 – 2.00 mm. JPN had no bran impurities, with average particle size of 4.00 – 5.50 mm. All the samples were combusted under similar conditions as in chapter 4. Testo 350 flue gas analyzer was added to the set up to measure the gaseous emissions. Higher $PM_{2.5}$ emission (32.4 mg/ g) was recorded for the combustion of RB at 700 °C compared to that of NGR husk (23.7 mg/ g) at 800 °C, and JPN (13.6 mg/ g) at 900 °C. That is because, RB had a lower surface area and pore volume, which affected its air-fuel mixing during the combustion phases. JPN emitted higher carbon monoxide (1592.4 ppmv) due to higher Sulphur content (0.2wt%db). That caused additional competition for oxygen in the oxidation process of Sulphur from SO_2 emission.

Oxygen availability and pore volume had significant influence on $PM_{2.5}$ at combustion temperature range from 600 – 700 °C. JPN had higher pore volume and emitted low $PM_{2.5}$ compared to NGR and RB. Increased combustion temperature from 800 – 1000 °C led to oxygen deficiency, causing low air-fuel mixing for JPN and NGR. However, RB had better performance because of its high volatile matter content. High Sulphur content created competition for oxygen needed for the oxidation of CO to CO_2 and emission of SO_2. JPN had higher Sulphur content and emitted higher CO than NGR and RB samples. Fuel properties such as surface area, pore volume and density greatly influenced the combustion phases.

Alternatively, catalytic exhaust component system for biomass combustion is viable for reducing emission. Unlike filters or electrostatic precipitators, catalyst can effectively reduce particulate matter (PM), CO and SO_2 emission. Chapter 6 investigated particulate matter, CO and SO_2 emissions from an exhaust system integrated with a metal honeycomb catalyst used for the combustion of rice husk. It compares emissions from a catalyzed combustion and a non-catalyzed rice husk combustion. The experimental set up comprises of a Yamato F100 fixed bed electric furnace attached with a detachable exhaust pipe housing the metal honeycomb catalyst. Non-catalytic combustion was performed by replacing the catalytic-exhaust pipe with a non-catalytic exhaust pipe. Rice husk (JPN) and rice husk briquette (RB) samples were selected as locally available feedstock and separately combusted in temperatures between 600°C – 1000 °C for 3 minutes duration.

A Dust Track II aerosol analyzer and a Testo 350 flue gas analyzer were mounted at the top of the exhaust pipe for PM and gaseous emission sampling. Results showed that the metal honeycomb catalyst significantly reduced CO, SO_2 and PM emission. Preheating treatment of the

catalyst had a huge positive impact on the oxidation of the flue gas as it significantly affected the emission rate. The CO conversion rate of the catalyst was 100% at a preheated temperature of 427.4 – 490.3 °C for JPN samples. Lowest SO_2 concentration was 78 ppm. For RB samples, the catalyst achieved 100% CO conversion. For SO_2, 100% conversion was obtained at 481.3 – 534.1 °C. SO_2 concentration was less oxidized by the catalyst compared to CO. The structural formation of the metal honeycomb catalyst made it more attracted to CO, meaning the sticking probability of CO to the catalyst surface is higher than that of SO_2 thus, leading to more CO conversion. The catalyst significantly decreased the PM emission especially after preheating treatment. Interestingly, $PM_{2.5}$ emission was reduced from its uncatalyzed value of 1169.9 mg/m^3 and 1572.2 mg/m^3 to its catalyzed value of 18.9 mg/m^3 and 170.1 mg/m^3, at the same combustion temperature of 600 °C and 700 °C, respectively. The application of this catalyzed exhaust system in small – medium scale biomass combustion system will greatly minimize indoor and air pollution.