The effect of rice husk mass on temperature and characteristics of its ash using a pyrolysis equipment organic-inorganic waste

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Abstract. Carbon-containing residues are produced from rice husks when used in gasifiers and boilers. To understand the problem of incomplete carbon conversion, a study of combustion, pyrolysis, and gasification of rice husks is needed. Thermogravimetric experiments were carried out using rice-plastic husk pyrolysis equipment in the air atmosphere with a single airflow of 25 m s⁻¹ under different temperature conditions and mass of rice husk (8, 9 and 10 kg). The results showed that at temperatures higher than 700°C there was an incomplete conversion, whereas at low temperatures a complete conversion occurred. The mass of the white and grey colour of rice husk ash increased with increase the rice husk mass while the black colour decreased. According to statistical analysis shows that the yield of ash with white colour has significant effect (P<0.05) while the grey and black colour was no significant effect. On the other hand, the amount of rice husk on the ash recovery of rice husk was no significant effect. Kinetics of combustion, pyrolysis, and gasification are also very sensitive to the rate of heating.

1. Introduction

Rice husk and rice husk ash are very high utilization values. There are many studies that have reported the use of rice use husks and rice husk ash. Rice husk can be used as fuel for furnace [1-2], raw materials of bioethanol [3-5] and sodium silicate production [6], toxic metal removals in waste water [7], xylitol, furfural, acetic acid [8] and also as cleaning and polishing agents for metals and machinery industries [9-10], animal feed [11-12], organic fertilizers [13-14]. On the other hand, the utilization of rice husk ash is also not inferior compared to rice husk such as silica synthesis[15-16], activated carbon, silica xerogels [17], porous carbon, zeolites, silica carbide, silica nitride, manufacturing of silicon chip and light weight construction materials insulations, catalysts, cordierite, ingredients for lithium ion batteries, graphene, capacitor (energy storage), carboncapture, manufacture of soluble silicate, silicones and its alloy, silicon based chemicals, reinforcing filler in natural, synthetic rubber, processing of refractory industry [18-27]. There are various factors which affects the ash properties such as, incinerating conditions (temperature and duration), rate of heating, burning technique [28-29].

The boiler's efficiency found the same as using of coal (68%) with the rice husk calorific value 15,217. 20 kJ/kg that means rice husk is cheaper fuel than coal [2, 30]. Heat energy is produced by direct combustion and gasification of rice husk, it can be used for several processing such as generation of steam in parboiling of rice [30, 31-32]. Addition, rice husk is potentially used for the electricity generation which is required 1 tone rice husk to produce 1 MWH electricity. It is also used as alternative fuel for household energy [33]. Therefore, in this study rice husk was used as a resource heat for pyrolysis of plastic waste which produced the fuel oil from plastic waste while rice husk ash and liquid smoke from rice husk. This study was focused to analysis temperature, energy and characteristic of rice husk ash as a product of rice husk during combustion using pyrolysis equipment organic-inorganic waste.
2. Materials and methods
Rice husk with moisture content (% w.b) 7.94±0.86 from North Sumatera, Indonesia was used. The study was conducted using various mass 8, 9 and 10 kg per batch by nine repetitions. The main components and the details of the arrangement of pyrolysis equipment organic-inorganic (Figure 1) had been reported by Sigalingging et al. [34]. The position of eleventh thermocouples was placed in such a way with T1 (75 cm), T2 (21 cm), T3 (60 cm), T4 (16 cm), T5 (93 cm), T6 (42 cm), T7 (54 cm), T8 (12 cm) and T9 (107 cm) from base of reactor as shown in Figure 2 whereas T10 and T11 were placed at surrounding.

![Figure 1. Design view of pyrolysis equipment](image)

The yield or conversion efficiency of rice husk ash, $Y_{ash}$ (wt %, Eq. 1), waste reduction efficiency, $WR_e$ (wt %, Eq. 2), ash recovery, $A_{rec}$ (kg of ash kg$^{-1}$ of rice husk, Eq. 3) were determined by the following formula.

$$Y_{ash} = \frac{\text{Mass of rice husk ash converted (kg)}}{\text{Mass of rice husk (kg)}} \times 100\%$$

$$WR_e = \frac{\text{Mass of sample rice husk (kg)} - \text{Mass of ash (kg)}}{\text{Mass of rice husk (kg)}} \times 100\%$$

$$A_{rec} = \frac{\text{Volume of rice husk ash converted (kg)}}{\text{Mass of rice husk (kg)}}$$
3. Results and discussion

The value of ash yield or conversion efficiency, waste reduction efficiency and ash recovery of rice husk under different temperature condition and the mass of rice husk are displayed in Table 1 while for the maximum temperature is showed in Table 2.

Table 1. The values of mass of ash (g), ash yield ($Y_{ash}$, %), waste reduction efficiency ($WR_e$, %) and Ash recovery of rice husk ($A_{rec}$, kg ash/kg rice husk)

| Mass of rice husk (kg) | Mass of ash | $Y_{ash}$ (%) | $WR_e$ (%) | $A_{rec}$ (kg ash/kg rice husk) |
|-----------------------|-------------|---------------|------------|--------------------------------|
|                       | white       | grey          | black      | white       | grey          | black      | white       | grey          | black      | white       | grey          | black      |
| 8                     | 243.00a     | 1656.11b      | 108.67c    | 3.04a       | 20.70b       | 1.36c       | 96.96a      | 79.30b       | 98.64c     | 0.03a       | 0.21b        | 0.01c        |
| 9                     | 289.09d     | 1781.56e      | 71.21f     | 3.21d       | 19.80e       | 0.79f       | 96.79d      | 80.20f       | 99.21e     | 0.03d       | 0.20f        | 0.01f        |
| 10                    | 299.39g     | 1993.33h      | 57.13i     | 2.99g       | 19.93h       | 0.57i       | 97.01g      | 80.07h       | 99.43i     | 0.03g       | 0.20h        | 0.01i        |

Based on Table 1 shows that the total mass of rice husk ash yield and the waste reduction efficiency in different colour were affected by the amount of the initial mass of rice husk. The mass of the white and grey colour of rice husk ash increased with increase the rice husk mass while the black colour decreased. According to statistical analysis shows that the yield of ash with white colour has a significant effect ($P<0.05$) while the grey and black colour were no significant effect. On the other hand, the amount of rice husk on the ash recovery of rice husk was no a significant effect.

Table 2 shows that T2, T4 and T8 were greater than T1, T3, T5, T6 and T7 because the airflow is higher at T2, and T8 position than at T1, T3, T5, T6 and T7 position. This position is closer to the tube of the blower (with initial airflow 25 m s$^{-1}$). This condition affected to flow rate of the combustion of rice husk whereby the husk ash conversion can complete by increasing temperature. At this moment the hot spot develops by following partial combustion of rice husk. Ganesh at el. [35] reported that the husk ash becomes subject to change at a temperature above 900°C. White husk ash is the result of burning rice husks with controlled high temperatures of 600 - 900°C. The lower combustion temperature, the longer
it takes to produce white rice husk ash. This is because combustion at low temperatures has a low combustion rate [36].

Table 2. The maximum of temperature with position of each thermocouple measured from rice husk reactor’s base

| Mass of Rice husk (kg) | T1  | T2  | T3  | T4  | T5  | T6  | T7  | T8  | T9  | T10 |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 8                     | 225.3 | 873.6 | 134.3 | 707.2 | 129.3 | 154.7 | 126.3 | 507.1 | 117.3 | 41.3 |
| 9                     | 171.2 | 903.4 | 161.6 | 678.4 | 168.8 | 381.9 | 164.8 | 514.4 | 153.3 | 44.9 |
| 10                    | 176.3 | 903.4 | 190.8 | 709.5 | 170.2 | 371.1 | 177.9 | 541.5 | 129.0 | 42.2 |

Figure 3a shows the outer surface characteristics of the rice husk ash pyrolysed at 8 kg under different temperature condition T2 and T8 (white colour); T4 (grey colour) and T6 (black colour); Figure 3c shows the outer surface characteristics of the rice husk ash pyrolysed at 9 kg under different temperature condition T4 and T8 (white colour); T2 (grey colour); T6 and T7 (black colour) while Figure 3b shows the outer surface characteristics of the rice husk ash pyrolysed at 10 kg under different temperature condition T4 and T8 (white colour); T2 (grey colour); T6 and T7 (black colour) respectively.

Figure 3. The relationship between temperature and time during the pyrolysis process in the different mass of rice of husk to produce: (a) white ash, (b) black ash, and (c) grey ash
The relationship between temperature and time during the pyrolysis process in the different mass of rice of husk to produce grey ash is shown in Figure 3c. According to Figure 3c shows that increasing the mass of rice husk with increase the temperature rapidly in the short time then goes down meaning that to achieve grey colour of ash the pattern of temperature should be increased in the short time.

The carbon-oxygen (air) reaction is highly exothermic and relatively very fast which causes an increase in localized temperature (Figure 3a to 3c), thus accelerating structural changes and the tendency of the chemical combination of carbon with silica residue in rice husk char. This process will produce a large amount of carbon residue during burning of rice husks. According to Jagustyn et al., [37] and Rosendahl [38] that the temperature at the ash starts to flow and eventually melt as called melting point leading to slag formation on the grade and in the bed increases by magnesium and calcium while potassium and sodium decreases. This ash-forming elements and ash melting point is depended on the type of biomass. The major ash-forming elements as very important in combustion characteristics are namely silicon, calcium, magnesium, sodium and potassium.

Table 3. Relationship between time and maximum temperature for different mass of rice husk during pyrolysis process

|     | 8 kg | 9 kg | 10 kg |
|-----|------|------|-------|
|     | Temperature | Temperature | Temperature |
| Time (minutes) | °C | Time (minutes) | °C | Time (minutes) | °C |
| T1  | 353.0 | 225.3 | 201.3 | 171.2 | 291.7 | 176.3 |
| T2  | 67.0 | 873.6 | 35.7 | 903.4 | 49.0 | 903.4 |
| T3  | 262.0 | 134.3 | 251.3 | 161.6 | 319.3 | 190.8 |
| T4  | 216.7 | 707.2 | 91.0 | 678.4 | 106.7 | 709.5 |
| T5  | 311.7 | 129.3 | 223.7 | 168.8 | 401.3 | 170.2 |
| T6  | 298.0 | 159.7 | 194.7 | 381.9 | 240.3 | 371.0 |
| T7  | 338.7 | 126.3 | 278.7 | 164.8 | 303.7 | 177.9 |
| T8  | 131.3 | 507.1 | 101.3 | 514.4 | 130.3 | 541.5 |
| T9  | 297.3 | 117.3 | 212.0 | 153.3 | 287.3 | 129.0 |
| T10 | 293.7 | 41.3 | 270.0 | 44.9 | 249.3 | 42.2 |

4. Conclusions
At temperatures higher than 700°C there was an incomplete conversion, whereas at low temperatures a complete conversion occurred. The mass of the white and grey colour of rice husk ash increased with increase the rice husk mass while the black colour decreased. According to statistical analysis shows that the yield of ash with white colour has significant effect (P<0.05) while the grey and black colour was no significant effect. On the other hand, the amount of rice husk on the ash recovery of rice husk was no significant effect. Kinetics of combustion, pyrolysis, and gasification are also very sensitive to the rate of heating.

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