The effect of airflow distribution on temperature, liquid smoke, rice husk ash and plastic oil yield using prototype systems of pyrolysis equipment organic-inorganic waste

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Abstract. Airflow influences the pyrolysis process. This study was carried out on air distribution flow in the integrated pyrolysis tool of plastic waste and rice husks with added pipeline inside the rice husk's reactor furnace and without added it. A total of 10 kg of rice husk, 3 kilograms of plastic burlap, and 25 m s⁻¹ initial air velocity from the blower were used. The results showed that the addition of 1-inch diameter pipelines with 18 holes with a 2.5 mm diameter affected the yield of rice husk oil, husk ash colour (white, grey and black) and the temperature at T4 (16 cm from the base) and T7 (54 cm from the base). In contrast, the other temperature was not a significant effect. Also, the yield of plastic oil produced was not impacted considerably. The yield of ash and rice husk oil (RHO) without using an airflow pipe was higher than using an airflow pipe, but the resulting plastic oil (PO) was lower.

1. Introduction
Pyrolysis of polymer is thermally degrading long-chain polymer molecules into smaller and more complex molecules through heat and pressure. This process requires intense heat with a shorter duration and no oxygen. While pyrolysis of biomass is a series of physical and chemical processes during the pyrolysis process, starting slowly at less than 350°C and occurs rapidly when the temperature is more than 800°C. In this zone, three types of products are produced: syngas (H₂, CO, CO₂, H₂O, and CH₄), tar, and charcoal [1].

The pyrolysis process is influenced by various factors such as water content of raw materials, particle size, type of raw material, heating rate, temperature and catalyst. The high-water content of raw materials requires higher energy than materials with low water content because it takes more energy to evaporate water before the pyrolysis process. On the other hand, the larger the particle size will result in increased solids while decreasing the volatiles and gases due to a decrease in the material's surface area in contact with hot temperatures. Byproducts in the form of volatiles and gases obtained will increase to a specific temperature and then decrease according to the increase in particle size [2]. Temperature is one of the essential factors in the pyrolysis process, at high temperatures, it will produce more gas while the solids obtained tend to decrease, on the other hand, low temperatures will result in decreased gas while solid production will increase [3]. Different raw materials will produce products with different contents depending on the composition of the ingredients used. The more the amount of material will increase the yield of gas and solids obtained [4].
The pyrolysis tool's heat distribution process needs to be known to determine the areas where thermal cracking occurs, which significantly affects the pyrolysis results. The addition of airflow has a contribution to combustion in the reactor because the greater the rate of air given; the sufficient air available for discharge. Consequently, the quality of fuel consumption that occurs will also be greater, and the time required will be shorter for a more efficient combustion process. The addition of combustion air in the reactor will cause the fuel to burn faster and turn into burning ash. In that case, the high process temperature tends to decrease the concentration of the results obtained, because the higher the airflow rate is given, the higher the concentration of CO, H₂, and CH₄ produced. However, the large airflow rate but not proportional to the raw material being fed will cause the fuel used to run out more quickly, so that the resulting profile of CO, H₂, and CH₄ concentrations tends to decrease over time [5,6]. This study was conducted to observe the effect of pipe addition and without pipe addition for air distribution in the combustion chamber of the rice husk’s reactor at the same feed air velocity using a prototype of pyrolysis equipment organic-inorganic waste.

2. Materials and methods
The equipment used was the integration pyrolysis of an organic-inorganic waste device equipped with a temperature measuring device directly connected to a computer with the different position from rice husk reactor’s base of each thermocouple of 75 cm (T1), 21 cm (T2), 60 cm (T3), 16 cm (T4), 93 cm (T5), 42 cm (T6), 54 cm (T7), 12 cm (T8) and 107 cm (T9), as explained by Sigalingging [5,6]. The raw materials used were rice husk (10 kg per batch with moisture content (% w.b) 7.94±0.86 from North Sumatera, Indonesia), and gunny sack (3 kg per batch). The airflow feed from the blower was 25 m s⁻¹. To understand the effect of airflow distribution was placed spiral pipe by 1-inch diameter with 18 holes with a 2.5 mm diameter (Figure 1), and the measurement was repeated three times. The data were analysed statistically by using One Way ANOVA analysis with a significance level α=0.05.

![Figure 1. Design view of pyrolysis equipment with (a) with pipeline airflow distribution (P), (b) without pipeline airflow distribution.](image)

3. Results and discussion
The result shows that without using an air distribution pipe with air feed velocity from the blower 25 m s⁻¹, the combustion temperature was obtained by various thermocouples for 6 hours of combustion, which the temperature measured every 30 minutes from the start until the end of combustion (Table 1).
Figure 2 shows that the average temperature on Thermocouple 2 (T2) and T8 has a highly significant increase, but this increase only lasts up to 1 hour of burning; after that, it decreased. In comparison, the other thermocouple points’ temperature is much lower than the T2 temperature, which increases slowly but continues to increase from the beginning to the end of combustion. On the other hand, without an additional pipeline for airflow distribution, the air comes out only focuses on the bottom of the combustion chamber (T2 and T8) as points that are close to the air outlet. As a result, the fire feeder makes the perfect combustion reaction due to sufficient air availability due to the air–fuel ratio being proportional. Meanwhile, resulting of the air that comes out only from the bottom causes less air to be supplied to other points because it was blocked by rice husks, which causes a low air-fuel ratio in the middle and top of the combustion chamber, making the combustion reaction incomplete.

Table 1. The average temperature distribution every 30 minutes on the reactor and statistical analysis result using One way ANOVA analysis

| Time (hour) | T1  | T2  | T3  | T4  | T5  |
|------------|-----|-----|-----|-----|-----|
|            | NP  | P   | NP  | P   | NP  | P   | NP  | P   | NP  | P   | NP  | P   | NP  | P   | NP  | P   |
| 0.0        | 33.2| 29.2| 74.0| 30.0| 34.7| 28.6| 34.8| 29.5| 39.3| 32.2|
| 0.5        | 47.6| 32.8| 523.7| 466.8| 40.3| 28.8| 85.9| 51.5| 39.2| 35.3|
| 1.0        | 64.4| 41.3| 564.6| 432.2| 68.3| 31.7| 391.6| 186.2| 50.0| 42.1|
| 1.5        | 66.9| 58.6| 607.2| 454.6| 76.6| 44.6| 448.0| 243.1| 74.9| 52.7|
| 2.0        | 69.6| 78.4| 638.1| 430.7| 70.8| 60.7| 549.0| 241.2| 76.0| 70.1|
| 2.5        | 94.6| 100.6| 653.7| 449.8| 68.6| 102.0| 588.7| 217.7| 96.1| 94.8|
| 3.0        | 118.4| 133.0| 600.6| 440.6| 75.3| 108.1| 530.2| 273.5| 109.0| 119.5|
| 3.5        | 143.6| 167.8| 478.6| 426.4| 89.6| 159.0| 455.7| 273.1| 123.4| 144.7|
| 4.0        | 159.0| 175.6| 399.5| 462.0| 85.9| 180.5| 411.9| 292.5| 132.4| 158.9|
| 4.5        | 173.2| 189.0| 313.8| 380.1| 93.3| 209.5| 383.0| 333.6| 140.0| 162.4|
| 5.0        | 171.1| 189.5| 249.0| 308.1| 144.6| 206.0| 349.9| 324.6| 141.3| 160.1|
| 5.5        | 178.5| 180.5| 249.3| 280.0| 161.2| 200.3| 355.7| 365.5| 126.3| 158.3|
| 6.0        | 178.4| 167.6| 203.5| 246.2| 164.9| 177.1| 296.1| 372.2| 144.4| 142.8|
| P-value     | <0.05| <0.05| <0.05| <0.05| <0.05| <0.05| <0.05| <0.05| <0.05| <0.05|

| Time (hour) | T6  | T7  | T8  | T9  |
|------------|-----|-----|-----|-----|
|            | NP  | P   | NP  | P   | NP  | P   | NP  | P   | NP  | P   | NP  | P   |
| 0.0        | 32.9| 30.1| 33.5| 33.0| 37.2| 30.7| 35.2| 35.0|
| 0.5        | 58.8| 31.9| 37.7| 37.9| 172.7| 35.3| 34.5| 35.0|
| 1.0        | 76.5| 36.5| 59.8| 53.0| 280.6| 136.6| 42.5| 41.7|
| 1.5        | 75.2| 68.8| 73.0| 91.8| 423.4| 202.5| 105.0| 64.3|
| 2.0        | 109.2| 138.4| 69.9| 139.5| 493.9| 230.7| 89.8| 107.5|
| 2.5        | 146.5| 263.1| 74.8| 163.3| 528.7| 296.2| 103.0| 152.1|
| 3.0        | 173.2| 358.9| 78.5| 236.4| 531.2| 369.2| 108.9| 149.0|
| 3.5        | 188.7| 394.6| 90.8| 310.8| 403.4| 427.1| 130.5| 167.8|
| 4.0        | 220.4| 315.2| 112.4| 258.2| 303.6| 417.8| 147.9| 168.2|
| 4.5        | 237.2| 254.6| 121.6| 234.5| 233.2| 454.0| 159.6| 148.9|
| 5.0        | 312.9| 232.7| 124.1| 213.0| 190.6| 390.4| 151.6| 137.9|
| 5.5        | 270.8| 219.0| 137.0| 203.2| 207.7| 437.4| 106.4| 127.0|
| 6.0        | 246.3| 195.6| 147.1| 180.5| 183.4| 359.4| 133.3| 106.3|

P: with pipeline distribution; NP: No Pipeline distribution; P-value, * < 0.05 has a significant effect, and >0.05 has no significant effect.
The pyrolysis temperature using the addition of air distribution pipes compared to the combustion temperature of the appliance without air distribution pipes shows that the maximum temperature (Figure 4) in the tools without air distribution pipes in T2 and T4 appears to be higher than the average temperature. The average temperature of the thermocouple in combustion process by using the addition of an airflow pipe dominates the thermocouple whose temperature is higher at T1, T3, T5, T6, T7 when compared to without pipeline air distribution where the thermocouple temperature is only higher T2 and T8. In addition, the temperature of the thermocouple (T9) on the top plastic pyrolysis’ reactor was higher by using pipeline air distribution (235.3 °C), while without pipeline air distribution, the maximum temperature was only 129 °C. This occurs because the air can be distributed to all points so that the air-fuel ratio (air-fuel ratio) in all parts of the combustion chamber can be optimized. In contrast to the without an addition pipeline airflow distribution, the air enters only through one hole located at the bottom of the combustion chamber points T2 and T4, so that at that point, the air-fuel ratio is optimal, which results in a high flammable gas content reaction. However, the air-fuel ratio at other points becomes low so that the temperature is achieved at the lower. However, the statistical analysis (Table 1) shows that only points T4 and T7 affected by the addition of air distribution pipes, while the temperature at other thermocouple points did not have a significant effect.

![Figure 2](image2.png) **Figure 2.** The average temperature of the integration pyrolysis of an organic-inorganic waste without an airflow pipe (P)

![Figure 3](image3.png) **Figure 3.** The average temperature of the integration pyrolysis of an organic-inorganic waste without an airflow pipe (NP)
Figure 4. Graph of the maximum temperature on the combustion thermocouple with an air distribution pipe (P) and without an air distribution pipe (NP)

Table 2 shows that statistically, the yield of ash and rice husk oil (RHO) or liquid smoke has a significantly affected by airflow pipes use. The yield of ash and rice husk oil (RHO) without using an airflow pipe was higher than using an airflow pipe, but the resulting plastic oil (PO) was lower due to the temperature distribution's influence in the reactor chamber [1, 4-6].

Table 2. The yield average and statistical analysis of Rice Husk Ash (RHA), Rice Husk Oil (RHO), and Plastic Oil (PO)

| RHA Colour | RHA Yield (%) | P-value |
|------------|---------------|---------|
| NP         | P             |         |
| White*     | 2.68±0.13     | 1.43±0.23| <0.05   |
| Gray*      | 23.30±0.79    | 18.40±2.85| <0.05   |
| Black*     | 0.50±0.10     | 0.21±0.08| <0.05   |

| NP         | P             |         |
| RHO Yield (%)* | 3.30±0.29   | 0.61±0.02| <0.05   |
| PO Yield (%)   | 7.07±3.04    | 12.10±1.64| >0.05   |

P: with pipeline distribution; NP: No Pipeline distribution; P-value, * < 0.05 has a significant effect, and >0.05 has no significant effect.

4. Conclusions
The addition of 1-inch diameter pipelines with 18 holes with a 2.5 mm diameter affected the yield of rice husk oil and the resulting husk ash colour and the temperature at T4 (16 cm from the base) and T7 (54 cm from the base) at the same feed air velocity (25 m s⁻¹). In contrast, the other thermocouple temperature were not significantly affected. Also, the yield of plastic oil produced was not considerably impacted. On the other hand, the yield of ash and rice husk oil (RHO) without using an airflow pipe was higher than using an airflow pipe, but the resulting plastic oil (PO) yield was lower.
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