Investigation of burning rate on particulate matter emission factor of rice straw burning
(case study in lombok island, indonesia)

K A Hadi¹, A Y P Wardoyo¹, A Naba¹, U P Juswono¹, and A Budianto¹

¹Physics Department, Laboratory of Air Quality and Astro Imaging, Physics Department, Brawijaya University, Jl. Veteran, Malang, 65145, East Java, Indonesia

*Corresponding author’s email address : kasnawi_alhadi@student.ub.ac.id

Abstract. This study investigates the emission factor arising from the agriculture waste burning especially rice straw burning. This research is a preliminary study to look further about the health impacts that occur due to the biomass burning that often occurs in Lombok island. The Laboratory study has been conducted to quantify the emission factor that looks into different burning rate related to the real condition in the field to estimate the health impact. The burning rates were varied into three different burning conditions, namely fast burning (13 m/s), medium burning (9 m/s) and slow burning (4 m/s). The concentration of the particle emissions (PM₁₀ and PM₂.₅) were measured using a Handheld Air Tester (Hinaway, model CW-HAT200S) and a Digital Dust Monitor (Kanomax, model 3443). The emission factor is quantified by the total particle concentration divided by the burned fuel. The result shows that the burning rate determines the particle emission factor. The fast burning produces the particles the lowest PM₁₀ and highest PM₂.₅ emission factor otherwise the slow burning results in the particle particles the highest PM₁₀ and lowest PM₂.₅ emission factor.

1. Introduction

Biomass burning is a significant source of air pollution, with global, regional and local impacts on air quality, public health and climate. Around the world studies have been carried out on almost all aspects of biomass burning, including specific types, on the quantification of emissions and on the assessment of their various impacts [1]. Biomass open burning generally causes a significant impact on the economy, health and safety of humans, with significant and severe consequences when compared to other natural risks [2]. Biomass open burning usually occurs in tropical areas due to burning of vegetation to clear crop residues and for land change purposes [3].

One example of biomass burning is the burning of biomass in the form of rice straw which can emit a large amount of pollution in the atmosphere. Effects of water content of rice straw (5%, 10%, and 20%) on carbon dioxide (CO₂) emissions and on organic and inorganic constituents of loose particulate matter (PM): dioxins, heavy metals, and polycyclic aromatic hydrocarbons (PAHs) [4]. The burning of rice straw can emit large amounts of atmospheric pollutants, especially carbon dioxide (CO₂) and particles (PM). Other pollutants are also emitted during straw burning: carbon monoxide (CO), methane (CH₄), nitrogen oxides (NOx), sulfur oxides (SOx), non-methane hydrocarbons (NMHC), and some organic and inorganic compounds such as heavy metals, ions, volatile organic compounds (VOCs), dioxins (polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD / Fs)), and polycyclic aromatic hydrocarbons (PAHs), which are emitted in the gas phase or as constituents of PM [5-8]
PM in the air is not only produced from direct emission in the form of particulates, but also from the emission of certain gases that condense and form particulates, so that there are primary and secondary particulates. Primary particulates are particles that are emitted directly in the form of particulates, while secondary particles are particles that are formed in the atmosphere. Air pollution is a world public health problem. PM, a mixture of solid and liquid particles in air, is of increasing concern in China's social and economic development. Exposure to air pollution produces a large number of adverse effects on human lung disease. The impact of PM2.5 depends on the components and sources. In turn, PM2.5 produces a specific type of damage which varies with time and region. PM2.5 which is caused by a burden on the health care system plays an increasingly negative role in social and economic development in China [9]. PM triggers a range of biological processes including inflammation of innate immunity, oxidative stress, apoptosis and autophagy, all of which are associated with pathological changes in respiratory disease [10].

Postharvest burning is still a common practice for removing cereal straw in many countries [11]. The burning of rice straw has a marked contribution to the damage of local air pollution, which causes severe impacts on human health. Every harvest season arrives, a periodic cycle of biomass burning occurs [12]. On a global scale, fire emissions are dominated by biomass burning in tropical areas [13-14].

The open burning of biomass from agricultural waste in the form of rice straw that occurs on Lombok Island takes place every year in the post-harvest period, in every district and even in the city of Mataram itself. This, of course, has a real impact on the health of the surrounding community, especially in relation to the amount of PM emission that results from the biomass combustion. This periodic event in every year, it is possible to obtain data on emission factors from each burning of rice straw carried out by the community, which is related to the impact of exposure to fine particle (PM$_{2.5}$) and coarse particle (PM$_{10}$).

This study investigates the emission factor arising from the agriculture waste burning especially rice straw burning. This research is a preliminary study to look further about the health impacts that occur due to the biomass burning that often occurs in Lombok island. The Laboratory study has been conducted to quantify the emission factor that looks into different burning rate related to the real condition in the field to estimate the health impact.

2. Materials and Method

2.1. Biomass Samples

Biomass samples were rice straw obtained from Lombok Island, West Nusa Tenggara Province, Indonesia. All samples were naturally air-dried with the moisture content below 12%. These samples were waste products of the agricultural process. Burnt rice straw samples according to field conditions on the island of Lombok.

2.2. Particle Concentration Measurements

Fine particle (PM$_{2.5}$) dan coarse particle (PM$_{10}$) concentrations ($C$) emitted from biomass burning was measured using a Handheld Air Tester (Hinaway, model CW-HAT200S) and a Digital Dust Monitor (Kanomax, model 3443) The measurements were conducted continuously to determine the fine particle and coarse particle concentration by determining the mass of biomass to be burnt ($m$) by varying the speed value ($v$). Each speed variation was repeated three times. The emission from the combustion process was introduced to a chamber using a blower with these speed variations, $v_1$ (4 m/s) (slow burning), $v_2$ (9 m/s) (medium burning), $v_3$ (13 m/s) (fast burning). The time needed to suck the emission ($t$) was collected. For the step control, the temperature of the emission was measured using a thermocouple. The used samples were tested with a constant mass $m$ (5 grams) for each measurement in an exposure chamber with the volume of 40 x 40 x 25 cm$^3$. After burning the biomass, the mass of the burnt biomass was measured ($m_b$). These treatments were conducted for all variations. For more details about the experimental scheme carried out on a laboratory scale, it can be shown as in Figure 1.
2.3. Emission Factor

Emission factors (EF) was calculated by measuring the mass of the detected fine and coarse particles \( (m_a) \) divided by \( m_b \). EF is a value that represents the relationship between the amount of pollutants released into the atmosphere with the activities associated with the release of pollutants. The PM\(_{2.5}\) and PM\(_{10}\) emission factors were calculated as follow: [15]

\[
m_a = \int_0^t A \cdot v \cdot C \, dt \tag{1}
\]

\[
EF = \frac{m_a}{m_b} \tag{2}
\]

2.4. Statistical Analysis

A one-way ANOVA test was used to investigate the average value of emission factors obtained from the burned samples (\( p < 0.5 \) was determined as significantly different). All measurements were repeated three times, while the values were interpreted as the mean ± SEM (Standard Error of the Mean).

3. Results And Discussion

3.1. Particle Concentration

3.1.1 Particle Concentration of PM\(_{2.5}\)

Particle Concentration of the PM\(_{2.5}\) can be shown in the following table (Table 1).

| Data | Concentration PM\(_{2.5}\) (mg/m\(^3\)) |
|------|----------------------------------|
|      | \( v_1 \) (4 m/s) | \( v_2 \) (9 m/s) | \( v_3 \) (13 m/s) |
| 1    | 14.737            | 6.891            | 5.191            |
| 2    | 10.456            | 6.971            | 5.181            |
| 3    | 11.121            | 5.561            | 6.651            |

Table 1 above shows the average fine particle concentration (PM\(_{2.5}\)) of the combustion of rice straw biomass with different burning speeds. It can be seen from the table that the faster the combustion is, the smaller the particle concentration obtained. This shows that the concentration of particles in PM\(_{2.5}\) at the rate of combustion of rice straw biomass has an effect on the value of the particle concentration.

3.1.2 Particle Concentration of PM\(_{10}\)
Particle Concentration of the PM can be shown in the following table (Table 2).

### Table 2. Particle concentration at different combustion rates in PM$_{10}$

| Data | Concentration PM$_{10}$ (ug/m$^3$) |
|------|----------------------------------|
|      | $v_1$ (4 m/s) | $v_2$ (9 m/s) | $v_3$ (13 m/s) |
| 1    | 77872          | 52270          | 82298          |
| 2    | 73858          | 89909          | 78177          |
| 3    | 91498          | 91773          | 80908          |

Table 2 above shows the average concentration of coarse particles (PM$_{10}$) from the combustion of rice straw biomass with different burning speeds. It can be seen from the table above that the amount of particle concentration at each different $v$ shows results that are not much different. This shows that the particle concentration at PM$_{10}$ at the rate of combustion of rice straw biomass does not significantly influence the value of the particle concentration.

### 3.2 Emission Factor

#### 3.2.1 Emission Factor of PM$_{2.5}$

Emission factor of the fine particle can be shown in the following figure (Fig.2).

![Figure 2. Fine particle emission factors for the burning process of the rice straw](image)

The figure 2 above shows a graph of the relationship between the value of the PM$_{2.5}$ emission factor and the burning speed of rice straw biomass. From the graph above, it can be seen that the magnitude of the emission factor depends on the rate of biomass combustion. The faster the combustion, the greater the emission factor value you get. For more details, see table 3 below:

### Table 3. Emission factor for PM$_{2.5}$

| Data | Emission factor PM$_{2.5}$ (mg/g) |
|------|----------------------------------|
|      | $v_1$ (4 m/s) | $v_2$ (9 m/s) | $v_3$ (13 m/s) |
| 1    | 0,8377        | 0,9657        | 0,9097         |
| 2    | 0,5801        | 0,9570        | 1,0189         |
| 3    | 0,6983        | 0,8937        | 1,3080         |
| Average | 0,7054        | 0,9388        | 1,0789         |

It can be seen from the table above that at the speed of $v_1$ (4 m / s), the emission factor value is 0.7054 mg / g, for the speed of $v_2$ (9 m / s), the emission factor value is 0.9388 mg / g and at the velocity $v_3$ (13 m / s) obtained an emission factor value of 1.0789 mg / g.
3.2.2. Emission Factor of PM$_{10}$

Emission factor of the coarse particle can be shown in the following figure (Fig.3).

![Emission Factor of PM$_{10}$](image)

**Figure 3.** Coarse particle emission factors for the burning process of the rice straw

Figure 3 above shows a graph of the relationship between the value of the PM$_{10}$ emission factor and the rate of burning rice straw biomass. From the graph above, it can be seen that the magnitude of the emission factor depends on the rate of biomass combustion. The faster the combustion, the greater the value of the emission factor [16]. For more details, see Table 4 below:

| Data | Emission factor PM$_{2.5}$ (ug/g) |
|------|----------------------------------|
|      | $v_1$ (4 m/s) | $v_2$ (9 m/s) | $v_3$ (13 m/s) |
| 1    | 6886          | 11394         | 22435          |
| 2    | 6374          | 19201         | 23916          |
| 3    | 8937          | 22943         | 24752          |
| **Average** | **7399** | **17846** | **23701** |

It can be seen from the table above that at the speed of $v_1$ (4 m/s), the emission factor value is 7399 ug/g, for the speed of $v_2$ (9 m/s), the emission factor value is 17846 ug/g and at the speed of $v_3$ (13 m/s) the emission factor value is 23701 ug/g.

4. Conclusion

The result shows that the burning rate determines the particle emission factor. The fast burning produces the particles the lowest PM$_{10}$ and highest PM$_{2.5}$ emission factor otherwise the slow burning results in the particle particles the highest PM$_{10}$ and lowest PM$_{2.5}$ emission factor.

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