Particulate Matters from Rice Straw Burning with Kaolin

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Abstract

For over a decade, Thai government has been combating the air pollution problem, especially Particulate Matter (PM), which impacts on environmental and health risks. PM emissions are known to mostly come from transportation, construction, industry, and agricultural sectors. Statistics data shows that during dry season, the elevated PM emissions, primarily attributed to the burning of agricultural residues, comes from rice straw, a crop most harvested in the central part of Thailand. Even though Thailand has legislated laws controlling burning residues in an open area, there is still burning in many areas without authorization. Past literatures showed that one of the methods of reducing PM emissions for solid biofuels in the coal burn industry is by adding additives such as aluminum silicate-based additives (kaolin), sulfur-based additives, calcium-based additives, and phosphorus-based additives. For this reason, this research mainly focused on using kaolin for reducing PM emissions from rice straw burning. The experiment is conducted in an open area. Rice straw with various amounts and sources of kaolin, produced in Thailand, are burned in a sample container. PM concentrations were measured by DustTrak™ DRX Aerosol Monitor 8533 downstream. In addition, the sizes of PM are classified into PM1, 2.5 and 10, which are particles less than 1, 2.5, and 10 micrometers in diameter respectively. The results show that PM concentration reductions depend not only on the amounts, but also on the chemical compositions of kaolin.

Keyword: Particulate Matter (PM), Rice Straw Burning, Kaolin

1 Introduction

Air pollution, particularly PM2.5, has become a significant problem in Thailand over the past several years [1, 2]. Overall, PM2.5 concentrations in Thailand were estimated using a developed model with the data from satellites from 2011 to 2022. The findings indicated that the highest PM2.5 concentrations occurred in November to March every year [3]. These months are in a dry season in Thailand, and several studies identified biomass burning practices in the northern Thailand as the major source of PM2.5 during this period, especially in Chiang Mai, Chiang Rai, and Mae Hong Son provinces [1, 4, 5], as well as in the Bangkok metropolitan region [6, 7]. In this study, which focuses on biomass burning in Bangkok, located in central part of

Thailand, the biomass burning in the central region was primarily from agricultural burning (52%), followed by forest fire (32%), and grassland burning (16%) [8]. In addition, the most common food crop planted in the area was rice [9], which is consistent with [10] showing that the burned areas in the central part of country were paddy fields, based on satellite data. There are many methods for utilization of rice straw such as feed for ruminants and solid biofuel [11-14]. To reduce PM from burning biomass fuel, methods like modified cookstove [15-17], furnace [18], and pellets for boiler [19] are employed. However, burning residues still happen because this practice consumes less time and budget [20, 21] to prepare the next crop harvest.

Thus, one approach that may be used to minimize PM in open burning is by adding additives to rice straw, similar to those used in solid biofuel or pellets. The additive used in this research is kaolin, with known chemical properties. Moreover, some studies also applied kaolin on rice planting [22] and reduce damage from aphid in wheat [23], so kaolin might not adverse effect for crops field after burning.

2 Literature Review

Biomass is a renewable energy, which comes from numerous sources: wood, agricultural crops (wheat, rice, and so on), animal waste, algae, sewage sludge, and industrial residues [24]. From [25, 26] identified biomass in three classification:

1. Biomass characterized by ash mainly rich in Si and K, but low in Ca, contributing in low ash fusion temperatures. This group typically includes herbaceous and agricultural biomass.
2. Biomass characterized by ash rich in Ca, but low in Si and K, contributing in high ash fusion temperatures. This group typically includes wood and woody biomass.
3. Biomass characterized by ash rich in Ca, and notable amounts of P is found in animal waste biomass.

There are several applications and methods to convert biomass into energy such as biomass solid fuels (briquettes and pellets) [27] via the combustion process. These types of fuels are also added some additive substances to reduce emissions. The additives can be classified into four groups: [28]

1. Aluminum silicate-based additives (kaolin)
2. Sulphur-based additives
3. Calcium-based additives
4. Phosphorus-based additives

In biomass combustion, there are concerns regarding to the ash formation and emissions composing from K, Cl, and S combinations, for example, potassium chloride, KCl. The assumption of reduction PM emissions by using kaolin could be used to capture these volatile alkali compounds as shown in chemical reaction equation (1) and (2) [29, 30]. In addition, aluminum silicate-based additives are the most effective substance for capturing K from combustion of biomass [31].

$$Al_2O_3{\bullet}2\ SiO_2 + 2\ KCl(g) + H_2O(g) \rightarrow 2\ KAlSiO_4 + 2\ HCl(g) \quad (1)$$

$$Al_2O_3{\bullet}2\ SiO_2 + K_2SO_4(g) \rightarrow 2\ KAlSiO_4 + SO_3(g) \quad (2)$$

This study [32] indicated that added kaolinite reduced the inorganic part of PM (K, Na, and Ca) from combustion process of biomasses by bounded with K-Al-silicates in additive as shown in equation (1) to (4) [33-37]. At high temperatures, K is accumulated in the stable compound as $KAlSiO_4$ in the ash.

$$Al_2O_3 \bullet 2\ SiO_2 + 2\ KCl + 4\ SiO_2 + H_2O \rightarrow 2\ KAlSi_3O_8 + 2\ HCl \quad (3)$$

$$Al_2O_3 \bullet 2\ SiO_2 + K_2CO_3 \rightarrow 2\ KAlSiO_4 + CO_2 \quad (4)$$

3 Experimental Setup

In the current study, rice straw burnings were tested with kaolin in open area by using DustTrak™ DRX Aerosol Monitor 8533 for measuring PM1, PM2.5, and PM10. The portable fan was adjusted to set the wind speed and measured by a hygro-thermo-anemometer. Distances among sample points were approximated by the distance of rice field and pavement (the width of pavement is 1 to 3 meters [38]). The experimental setup is shown in Figure 1. All tests were conducted under the wind speed of 1 m/s, which is in the range of the average wind speed in the central part of Thailand [39]. The amount of rice straw is initially 50 g burning with two different sources of kaolin, referred to as K1 and K2. The amounts of kaolin vary from 1%, 5%, to 10% by weight of rice straw. Chemical properties of K1 and K2 are shown in Table 1. In addition, before testing, rice straw and kaolin were dried in the oven at 70˚C and 105 ˚C, respectively, until their weight stopped changing.

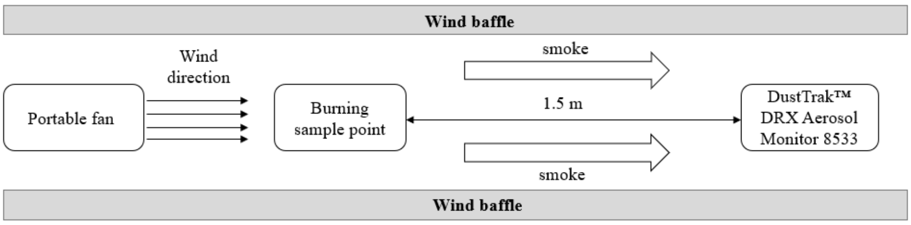

Fig. 1. Schematic diagram of open area burning tests.

Table 1 Compositions of kaolin sources analyzed by XRD, SEM, and BET.

Kaolin source	Phases (wt%) analyzed by XRD				SEM	BET
	Kaolinite ($Al_2(Si_2O_5)(OH)_4$)	Quartz (SiO_2)	Zeolite (SiO_2)	Illite ($KAl_2(Si_3Al)O_{10}(OH)_2$)	Average size (micron)	Surface area (m^2/g)
K1	100	-	-	-	2.7 ± 0.7	18.4
K2	-	66	1	33	7.2 ± 1.9	9.9

4 Results and Discussions

PM concentrations from rice straw burning without kaolin are shown in Fig. 2(a). Comparisons of PM concentrations with kaolin, K1 and K2 at 1% are shown in Figure 2(b) and 2(c), respectively. It is clearly seen that adding kaolin reduces PM emissions drastically when compared to pure rice straw burning.

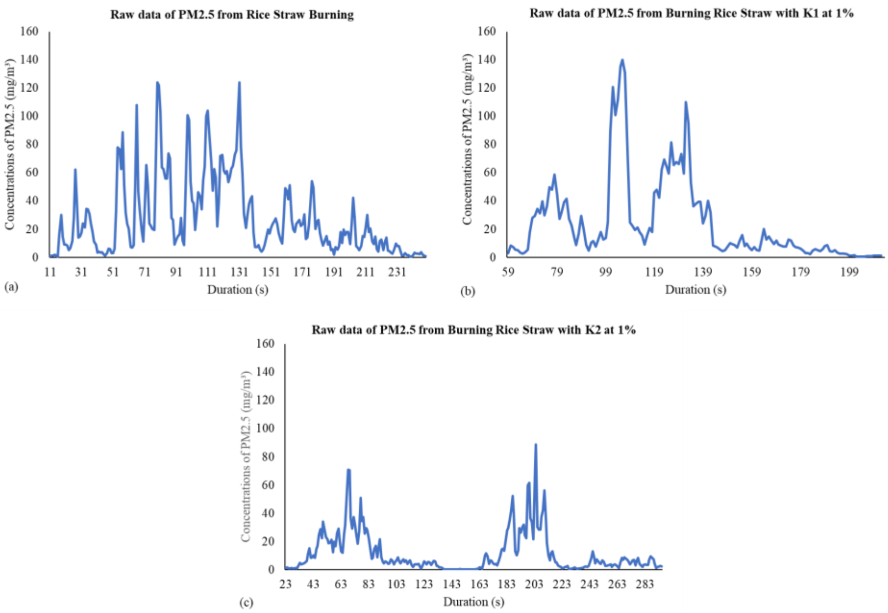

Fig. 2 Raw data of peak interval of PM2.5 from burning (a) rice straw (b) rice straw with K1 added 1% and (c) rice straw with K2 added 1%.

Referring to the burning time and ash-fuel ratio (bar charts and line seen in Fig. 3, respectively), the graph illustrates that the more percentages of added kaolin weights, the more ash-fuel ratio regardless of kaolin sources. The amount of ash-fuel ratio can be as high as 30%. When comparing to RS. The burning time (including ignition and smoldering duration) for RS+K1 shows decrease from 5% to 40% and slightly increase for RS+K2, which can be up to 16% in RS+K2 10% case.

Overall, the results indicate that the addition of kaolin decreases PM emissions (seen in Fig. 4). Adding K2 at 1% wt. shows the most reduction in PM emissions up to 60%. In addition, as the ratio increases, the lower PM emissions abate. For 5% and 10% blends, PM emissions decrease approximately 25% and 14%, respectively. Moreover, it shows a similar trend when K1 is added, with PM emissions dropping around 40% in all ratios. However, it is clearly seen that the reduction of PM emissions from rice straw burning depends on not only amounts of kaolin added, but also chemical compositions. PM emissions could be reduced by Kaolinite and Illite capture K in rice straw and the result suggests that the increase in ash, when kaolin is added, could be due to the unburned kaolin remaining in the ash. Besides, these studies [40-42] found that applying kaolin as a fire retardant could lead to longer burning times, depending on the types of materials and amounts of kaolin blended.

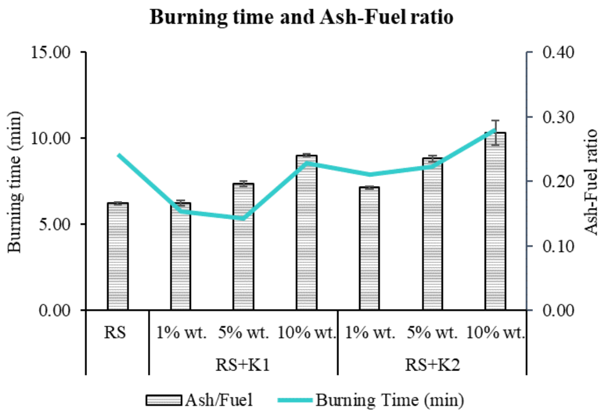

Fig. 3. Burning time and ash-fuel ratio from burning rice straw (RS) with and without kaolin added conditions.

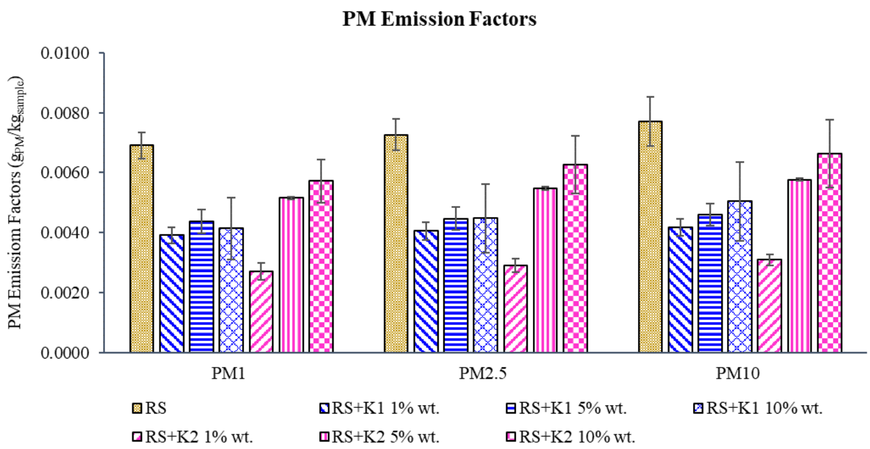

Fig. 4. PM emission factors from burning rice straw (RS) with and without kaolin at varied proportions.

5 Conclusion

The current study is conducted on a rice straw burning in an open area condition under a wind speed of 1 m/s, a typical average wind speed condition in Thailand. Rice straw is burnt with varying sources (K1 and K2) and amounts (1%, 5%, and 10% weight of rice straw) of kaolin. The findings from this experiment indicate that both sources of kaolin may lower PM emissions. Furthermore, it can clearly be seen that the addition of K1 at 1% wt. may be the most effective PM emissions reduction when compared to other amounts as well as another source. Nevertheless, the proportion of kaolin directly affects an increase in the duration of burning and amounts of ash. Adding kaolin as an additive for the open burning of rice straw shows possible solution of diminishing PM emissions.

6 Acknowledgement

The Faculty of Engineering, Kasetsart University, Bangkok, Thailand provided financial support under a Graduate Research Scholarship Contract No. 65/13/ME/D.ENG. Special thanks go to Prof. Kanapol Jutamanee for providing kaolin samples and Prof. Orathai Jongprateep for kaolin chemical analysis.

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