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EMISSION FACTOR OF DUSTFALL AND TSP FROM ANDISOL SOIL FOR AMBIENT AIR QUALITY CHANGE ASSESSMENT

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ABSTRACT

Dustfall (DF) and Total Suspended Particulate (TSP) are often used to characterize air quality near the source of the dust. These two important parameters that contribute to air quality deterioration are required to be measured in accordance with government regulation of the Republic of Indonesia (PP41/1999). The purposes of the study were to (1) measure the concentration of DF and TSP generated from Andisol soil, (2) determine the emission factors that were affected by wind speed, soil moisture content, land cover percentage, and (3) analyse distribution of DF size. The study was conducted in a laboratory scale tunnel where the surface was covered by Andisol soil originated from Tanggamus Municipality in Lampung Province. DF was determined by the gravimetric method (SNI 13-4703-1998) and the samples were collected with DF Canister. Measurement of TSP concentration in ambient air was carried out based on SNI 19-7119.3-2005 method and the instrument was High Volume Air Sampler (HVAS). Analysis of the size distribution of the dustfall was carried out by direct observation using a digital microscope. Based on the research results, concentration of DF and TSP generation was lower than the quality standard limit of PP 41/1999 and was positively correlated with wind speed, negatively correlated with soil moisture content and the percentage of land cover. Emission factor of DF and TSP generated by Andisol soil was affected by wind speed and soil moisture content. Dustfall size was dominated by fraction of 10-100 μm.

Keywords: andisol, dustfall generation, dustfall size distribution, emission factor, tanggamus, total suspended particulate (TSP).

1. INTRODUCTION

Ambient air quality is an important factor in the lives of human and other livings, but with increasing physical development of cities, urban centres and industrial centres, the concentration of pollutants in the air increased that deteriorated the air quality(Almuhanna 2015; Lu *et al*. 2015; Zhao and Shi 2012). According to Government Regulation No. 41/1999, air pollution is the introduction of substances, energy and/or other components into the ambient air by human activities so that the ambient air quality deteriorates to a certain level which causes the ambient air cannot fulfil its function. Dustfall (DF) and total suspended particles (TSP) are two important parameters in the ambient air quality. The existence and effect of both parameters in a single location is identical to the ambient air quality conditions at the site (Andrić*et al*. 2013; Hahnenberger and Nicoll 2014). Andisol soil derived from volcanic ash is characterized by a black or dark colour due to the high content of organic matter, loose, light and slippery. The soil has low bulk density, high water holding capacity, and high total porosity; it is also friable with less plastic consistency and not sticky. When wet the soil is greasy and smeary. These characteristics indicate that Andisol soil materials would easily distribute by water and air fluids (Shoji *et al*. 1993; Ranst*et al*. 2008; Kato and Kozai 2010; Wakindiki and Omondi 2012).

Estimated generation of DF and TSP from ten soils (Alluvial/Entisol/Inceptisol, Latosol/Oxisol, Ultisol/Red Yellow Podzolic, Andisol, and Grumusol/Vertisol) in Java has been studied by Amaliah*etal*. (2014), Rochimawati*et al*. (2014), and Yuwono*et al*. (2014). This research was conducted to obtain data generation and emission factors for DF and TSP parameters on the surface of Andisol soil from Tanggamus Municipality, Lampung Province. DF and TSP generation could be controlled effectively and efficiently if their generating factors such as wind speed, soil moisture content (Fecan *et al*. 1999; Wang *et al*. 2015) and land cover percentage have been known. Carvalho and Freitas (2011) stated that the air quality management strategy must consider relative contributions of various sources of air pollution, both of natural and anthropogenic sources.

The first objective of this study was to measure DF and TSP generation in ambient air laboratory scale at various levels of wind speed, soil moisture content, and percentage of land cover. The second objective was to develop emission factors of DF and TSP generation based on wind speed and soil moisture content. The third objective is to analyse particle size distribution of DF.

2. RESEARCH METHOD

2.1 Research framework

The steps in this research include initial data collection; DF and TSP concentration measurements in a laboratory scale and controlled wind speed, moisture content and percentage of land cover; particle size distribution measurement using a complete digital microscope with camera; and determination of emission factors. Measurements in the first two steps were followed by measurements of temperature and humidity in order to include influence of both factors on DF and TSP generation. Determination and analysis of emission factors were carried out with Excel and Minitab 16 software's. Flowchart of the research is presented in Figure-1.

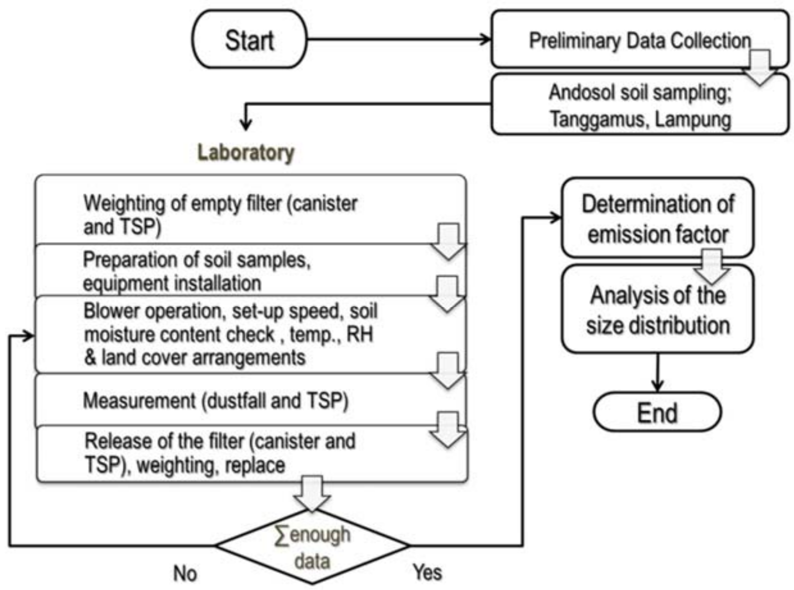

Figure-1. Research flowchart.

2.2 Measurement of dustfall and TSP

Schema of tools and tunnel test arrangement for generation and measurement of DF and TSP is presented in Figure-2. The tunnel dimension used for measuring the concentration of both DF and TSP in the laboratory was 7.6 m length, 0.76 m width and 2.4 m height. A layer of 3 cm depth Andisol soil was used to cover the surface of the tunnel. Three dustfall canisters [Model AS-2011-1] and High Volume Air Sampler [STAPLEX; TFIA-2] was set-up at one end of the tunnel, whereas a fan was set up at the other opposite end to generate artificial wind in the tunnel. Three levels of wind speed were controlled in the range of 2-5 [km/h] by adjusting the power level of the blower. Generation of DF was measured according to the national standard of SNI 13-4703-1998 about the determination of levels of dust in the air with DF canister. Generation of TSP was measured according to SNI 19-7119.3-2005 on test method for total suspended particles using high volume air sampler equipment (HVAS) with gravimetric method. Ambient air was inhaled using HVAS for an hour. The filtrate obtained was then stored in stabilization room in controlled-conditions of relative humidity and temperature prior to weighing. The concentration of particles suspended in ambient air in the tunnel was calculated by considering the exposure time, the volumetric rate of HVAS, and the mass difference between the filter and the filtrate. The role of soil moisture content (18-37 %) on concentration of dustfall and TSP was incorporated in the study. This was carried out by recording the soil moisture content three times per day which was used to develop correlation between soil moisture content and the generated of both parameters.

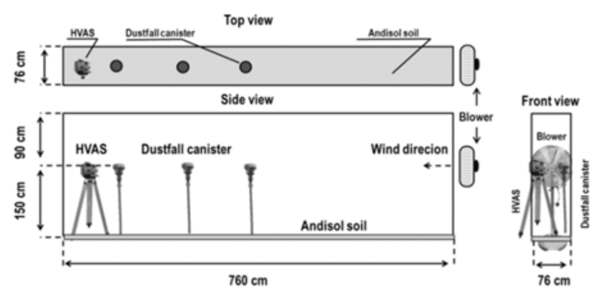

Figure-2. Schematic experimental generation and measurement of dustfall and TSP in the tunnel.

The percentage of land cover was simulated using rice plant with a high of about 15 cm that were placed on 4 trays each with dimensions of about 80 cm x 60 cm. The rice plant coverage on trays was 10, 20, 30 and 40%. Tools and materials used to measure the concentration of DF included DF Model AS-2011-1 canister, filter Whatman #41 (ø47mm), OHAUS analytical balance, and Universal Oven Memmert UNB 400.

2.3 Determination of emission factor

Referring to Amaliah*et al.* (2014) and Rochimawati*et al.* (2014), the technique of data analysis used in this study was the Pearson correlation technique. In addition, the model selection techniques for trend lines diagram were also used to help predict the direction of DF and TSP generation.

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Steps in determination of emission factors were (1) measurement of DF and TSP and collecting actual data of wind speed, soil moisture content and percentage of land cover; (2) correlation analysis between the measured DF and TSP with the data of wind speed, soil moisture content and percentage of land cover and presented the correlation in a diagram; (3) preparation of some alternative equations of trend line of DF and TSP in a chart correlation sheet; (4) selection of the best mathematical model according to the relative highest coefficient of determination (R^2) value; and (5) determination of emission factors based on the selected equation of the trend line (Mahowald*et al*. 2014; McTainsh and Strong 2007). Chen and Chu (2015) stated that the percentage relative contributions value can be considered in the process of preparing the emission factors.

2.4 Measurement of particle size distribution of DF

Measurement of particle size distribution of DF generation was conducted using a digital microscope MD 3000 Binocular models equipped with a digital camera. The observation was done by placing a sample on a glass DF specimen under a microscope lens. Observation was conducted after the right setting of magnification on the objective and ocular lens, and lighting arrangements on the condenser lens so that the shape and size of DF on the sample can be observed clearly. The view in the microscope projected onto a screen on the laptop monitor. Projected image was stored digitally as an image file. Particle size measurement was carried out onthe images that have been obtained using the software Corel Photo Paint. The dust particles are measured in units of µm. The particle size distribution can be defined by classifying the dust particles based on the same size

3. RESULTS AND DISCUSSIONS

Dustfall and Its Correlation with Wind Speed, Soil Moisture and Land Cover Percentage

Results of measurement on the generated DF are shown in Table-2. There is a strong correlation between the DF generation, wind speed and soil moisture content. Amaliah*et al*. (2014) stated that there were quadratic correlation between the generated DF, wind speed and soil moisture content in the measurements at surface of Andisol soil collected from Java Island. This quadratic relationship shows that decreasing soil moisture content and the increasing wind speeds at a certain limit will not significantly influence the reduction in generated DF (Kellogg and Griffin, 2006; Laurent *et al*. 2006; Hai*et al*. 2007; Feng*et al*. 2008). The wind speed of 2-5 km/h affecting 20% (R^2 = 45%), and soil moisture content 18-33% affecting 37% (R^2 = 83%) against the generated DF on the measurement at Andisol soil surface.

Table-1. Results of measurements of dustfall (DF) on the three levels of wind speed (W) and soil moisture content (S).

DF (ton/km^2.month)		**W** (km/h)		**S** (%)	
Result	Average	Result	Average	Result	Average
4	4.4	2	1.9	33	31.9
5		2		32	
5		2		31	
4	5.0	3	3.7	33	26.7
5		4		27	
6		4		21	
4	5.0	4	4.6	30	23.9
5		5		23	
6		5		18	
R^2 (%)		45	93	83	93
C (%)		20	-	37	-

Figure-3 shows the correlation between the generated DF, wind speed, soil moisture content, and the percentage of land cover with a P value obtained less than α (0.05). Pearson correlations were obtained showed that the generated DF was negatively correlated with soil moisture content (R = -0.93) and the percentage of land cover (R = -1.00), but positively correlated with wind speed (R = 0.67).

Table-1 showed also that the average for DF concentrations in ambient air from Andisol soil at 3 canisters, on the 3rd level wind speed is about 5 tons/ km^2.month. The highest concentration of DF was 6 tons/ km^2.month, whereas the lowest one was 4 ton/km^2.month. Generated DF of Andisol soil in this study was still far below the quality standard in PP 41/1999 i.e.10 tons/km^2.month for residential areas or 20 ton/km^2.month for industrial areas).

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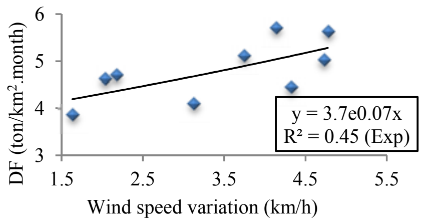
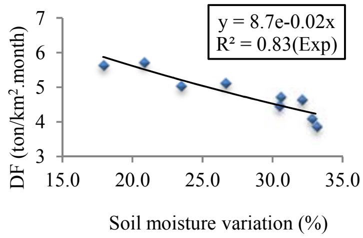


(a)



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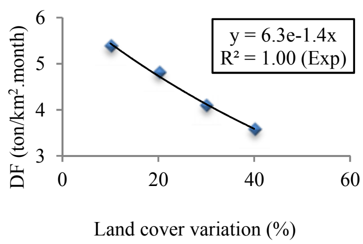


(c)

Figure-3. DF generation results in three variations (a) wind speed; (b) soil moisture; (c) land cover percentage.

TSP and Its Correlation with Wind Speed, Soil Moisture and Land Cover Percentage

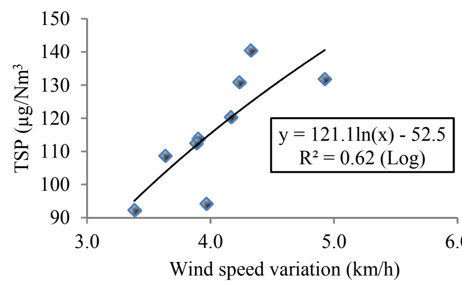
TSP measurement results in laboratory showed that the average concentration of TSP in ambient air from the Andisol soil surface at the three levels of wind speeds is around116 μg/Nm³. The highest TSP generation was resulted by the third wind speed level, with an average value of125 μg/Nm³. The lowest generation of TSP occurred at the first level of wind speed, with an average value of about105 μg/Nm³. Table-1, Figure-3 (a) and Figure-3 (b) showed that the wind speed and soil moisture content can affect the increase in generations of TSP of Andisol soil. All of TSP generation value in this study was still below the quality standard (230μg/Nm³ in PP 41/1999). Table-1 also showed that the wind speed about of 3-5 km/h affect the rate of 28% (R^2 = 62%), and soil moisture content 21- 44% affecting 26% (R^2 = 56%) of the TSP concentration from the Andisol soil surface.

Wakindiki and Omondi (2012) stated that the organic matter of soil properties affect the physics, chemistry and mineralogy. But there was little information on the relationship with the movement patterns of organic material and water storage in Andisol soil. Therefore, the provisional estimates are that the soil organic material content may also affect the release of generated TSP, which can lead to inconsistency value of R^2 in this study.

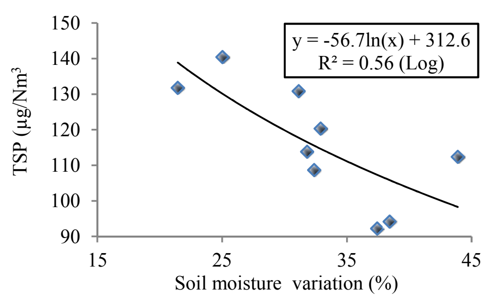
Table-2. TSP measurement results at three levels of wind speed (W) and soil moisture content (S).

TSP (μg/Nm³)		**W** (km/h)		**S** (%)	
Result	**Average**	**Result**	**Average**	**Result**	**Average**
92	105.0	3	3.6	37	33.9
109		4		32	
114		4		32	
94	118.4	4	4.2	38	32.1
120		4		33	
140		4		25	
112	125.1	4	4.3	44	32.2
131		4		31	
132		5		21	
R^2 (%)		62	99	56	88
C (%)		28	-	26	-

Fenget *al.* (2007) revealed that the average concentration of TSP spatially is higher in spring and winter, otherwise low in the summer. This statement can explain that the weak of the value of R^2 TSP (wind speed 62%, moisture content 56%) due to the air temperature relatively hot tropical regions.



(a)



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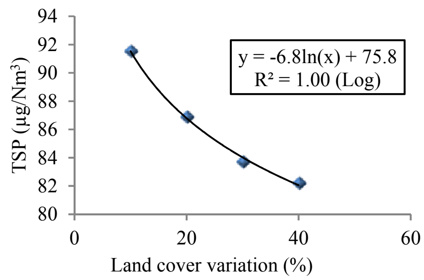

(c)

Figure-4. Results TSP generation in three variations (a) wind speed; (b) soil moisture; (c) land cover percentage.

Therefore, it is necessary to conduct further research to determine the relationship between levels of TSP and the air temperature in the tropics.

Figure-4 (c) showed the relationship between the generated TSP and the percentage of land cover measurements in the test tunnels. The calculation resulted in Pearson coefficient (R) -1.00 shows that there was decrease in TSP generation when the land cover percentage increased.

3.1 Estimation of dustfall and TSP generation

Table-3 shows the coefficient of determination (R^2) that the best trend line for the generated DF is exponential equations, while the best R^2 for the generated TSP is logarithmic equation. Thus, the mathematical models representing emission factor for the DF generation is exponential equation, whereas TSP is logarithmic equation.

Table-3. Coefficient of determination (R^2) in the relationship between DF and TSP generation at each wind speed (W), the soil water content (S) and vegetation cover (L).

Trend line Relation	DF (ton/km^2.month)			TSP (μg/Nm^3)		
	W (km/h)	S (%)	L (%)	W (km/h)	S (%)	L (%)
Exponential	0.449	0.831	0.996	0.590	0.514	0.957
Linear	0.447	0.858	0.996	0.600	0.538	0.952
Logarithmic	0.443	0.831	0.962	0.619	0.556	0.998
Power	0.448	0.799	0.941	0.611	0.530	0.998

Based on the relative contribution presented in Table-4 and the equation of the trend line is presented in Figure 3 and 4, the dust emission factor DF and TSP can be formulated in the equation:

$$e_{Ads\ DF} = (3.7e0.07W)*0.2 + (8.7e-0.02S)*0.4 + (6.3e-1.4L)*0.4 \quad (1)$$

$$e_{AdsTSP} = (121.1ln(W)-52.5)*0.28+(-56.7ln(S)+312.6)*0.26 + (-6.8ln(L)+75.8)*0.46 \quad (2)$$

Where e_{AdsTSP} is TSP emission factor (μg/Nm^3), e_{AdsDF} is DF emission factor in tons/km^2.month, W is the wind speed in km/h, S is the soil moisture in %, L is the land cover in %.

Table-4. Coefficient of determination (R^2) in the relationship between DF and TSP generation at each wind speed (W), the soil water content (S) and vegetation cover (L).

	DF (ton/km^2.month)				TSP (μg/Nm^3)		
	W (km/h)	S (%)	L (%)		W(km/h)	S (%)	L (%)
P	0.05	0.00	0.00	P	0.01	0.02	0.02
R	0.67	-0.93	-1.00	R	0.77	-0.73	-0.98
R^2	0.45	0.86	1.00	R^2	0.62	0.56	1.00
C	0.20	0.37	0.44	C	0.28	0.26	0.46

3.2 Distribution analysis of dustfall particle size

Andisol soil of Tanggamus Municipality, Lampung Province is dominated by DF size of 10–100 μm. There is no DF size 0-2.5μm that is potential as $PM_{2.5}$. The distribution of the size of the DF produced by Andisol soil presented in Figure-5. Based on the particle size distribution, the DF size <10 μm was more deposited in a canister 1 (farthest from the blower), while particles >10 μm at most deposited in the canister 3, closer to the blower. Figure-6 also shows that the PM_{10} is also deposited on all canister attached.

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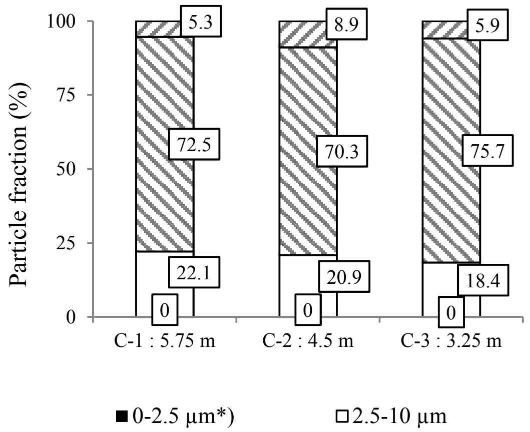

*) All canisters was no DF size 0-2.5 µm (0%)

Figure-5. Size distribution of DF on the Andisol soil surface at 3 canisters.

4. CONCLUSIONS

This study showed that the average concentration of DF about 5 tons/km^2.month. The highest concentration of DF was 6 tons/km^2.month, whereas the lowest one was 4 tons/km^2.month. Average TSP wasabout 116 µg/Nm^3. The highest TSP was about 125 µg /Nm^3, whereasthe lowest generated TSP was about 105 µg /Nm^3. Both of DF and TSP generated from Andisol soil in this study was still below the standard in PP 41 /1999. The rise of DF and TSP emissions from Andisol soil were influenced by wind speed, soil moisture and land cover.Emission factors of DF and TSP generation from Andisol soil were influenced by wind speed; soil moisture and land cover percentage. Emission factor of DF is e_{AdsDF} = (3.7e0.07W)*0.2 + (8.7e-0.02S)*0.4 + (6.3e-1.4L)*0.4 and TSP emission factor is e_{AdsTSP} = (121.1ln(W)-52.5)*0.28 + (-56.7ln(S)+312.6)*0.26 + (-6.8ln(L)+75.8)* 0.46. DF size distribution of Andisol soil was dominated by the fraction of 10-100 µm. Based on size distribution, DF particle size <10 µm was more deposited in canister 1 (farthest from the blower), particle size> 10 µm is at most deposited on canister closer to the blower.

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