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ESTIMATING DUSTFALL GENERATION AFFECTED BY WIND SPEED, SOIL MOISTURE CONTENT AND LAND COVER

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ABSTRACT

There is a lack of quantitative approach to estimate the amount of natural and anthropogenic dustfall generation during an environmental impact assessment in Indonesia. Dustfall is an obligatory parameter of Indonesian ambient air quality standard. The final objective of the research was to formulate a simple mathematical expression used to estimate the ambient dustfall generation as affected by wind speed, soil moisture content and land cover, during an environmental impact assessment. The experiment was carried out in a laboratory scale tunnel with a land model consisted of soil layer originated from Java Island, Indonesia, i.e. Complex Mediteran Red Yellow Grumusol (RYG) and Regosol (REG). Three speed levels of artificial blowing wind were applied in the tunnel to assess the impact of wind speed on the dustfall generation. Soil moisture content was kept in the range of 35-40%. Paddy plant (15 cm high) was used to serve as land cover to simulate the impact of cover crop on the generated dustfall. Analysis on the resulted dustfall was carried out according to national standard (SNI 13-4703-1998). The revealed experiment result showed that the average generated dustfall over RYG soil type was 14 ton/km^2.month, whereas for Regosol was 4 ton/km^2.month. Mathematical expression of the dustfall generation was successfully formulated. It indicated that dustfall generation was strongly affected by wind speed, soil moisture content and land cover. The mathematical expression can be used to estimate the amount of dustfall generation by simply inputting the three affecting parameters (soil moisture content, wind speed and land cover).

Keywords: ambient air, dustfall, land cover, soil moisture content, wind speed.

INTRODUCTION

Dustfall is defined as ultrafine particles larger than 10 µm (SNI 13-4703-1998) and has ability to settle down after a temporary suspension in the air. According to Lue *et al*. [1], the size of dustfall over the occurrence of dust storms varied ranging from 2.5 µm up to greater than 60 µm. Dust can move thousands of kilometres as far as caused by the wind at high speed on the surface of land [2, 3], mechanical turbulence, and frontal lifting [4]. Research shows a strong dust storm that happened in the Gobi Desert caused the displacement of dust and sand into East Asia, Korea, and Japan. This displacement is caused by high wind speed and low moisture soil in Gobi Desert [5].

The most harmful impacts of dustfall generation are caused by contamination of heavy metals on dustfall. One of the largest atmospheric pollution is caused by heavy metals [6]. The content can cause disease, especially in the respiratory organs when the environment was exposed [7] and also eyes irritation [8]. In addition, dust particles can damage not only ecological [9] and atmosphere by blocking solar radiation, but also earth radiation at visible wave spectrum (VS) and infrared (IR) by means of scatter and absorb radiation [10].

Research to determine dustfall generation on soil types of Andisol and Entisol found in Java Island has been carried out by Amaliah *et al*. [11] and Yuwono *et al*. [12]. More researches on dustfall generation and the correlation between the main soil types existing in Java Island, i.e. Complex Mediteran Red Yellow Grumusol (RYG) as well as Regosol (REG) and other influencing factors need to be addressed. The final objectives of this research focused (1) to measure dustfall generation as affected by wind speed, soil moisture content, and land cover by vegetation from the REG and RYG soil types; (2) to formulate a simple mathematical expression that can be used as a quantitative estimation of dustfall generation in the ambient air during an environmental impact assessment in Indonesia.

MATERIALS AND METHODS

Instruments and materials used in the research were dustfall canister [Model AS-2011-1; Ø = 9 cm], blower [Hercules; Ø = 24"; 220 V; 50 Hz; 170 W], digital anemometer [Lutron AM-4201], digital grain moisture tester [OGA Model TA-5], tunnel [L = 7.8 m; W = 0.76 m; H = 2.5 m], analytical balance [OHAUS; Adventurer Pro], Petri dishes [Ø = 80 mm], 10 µm filter paper [Whatman # 41], universal oven [UNB 400], stopwatch, distilled water, soil samples [Regosol and Red-Yellow Podzolic], and a dustfall calculation program (spreadsheet) [© Arief Sabdo Yuwono 2012].

Measurement of dustfall generation lasted for ± 11 hours on each test. Generation of dustfall on ambient air associated with wind speed was carried out in the laboratory scale tunnel. The generated dustfall was then accumulated and stuck on the applied filter paper in

the dustfall canister. After ±11 hours campaign, the blowing wind was stopped. The paper filter was then withdrawn from the canister and kept in a desiccator to stabilize its humidity and temperatures.

Data obtained from the experiment included wind speed, soil moisture content, land cover percentage, and amount of the dustfall generation. Research steps are schematically illustrated in Figure-1. The equation used to calculate the generation of dustfall which refers to the national standard namely SNI 13-4703-1998 is presented in Equation (1). Illustration of the experiment tunnel, position of the dustfall canisters as well as the blower in the tunnel is shown in Figure-2.

$$C = \frac{W}{A} x \frac{30}{T} \quad (1)$$

Where "C" is dustfall generation in the ambient air [ton/km^2.month], "W" is dustfall mass accumulated on the filter [ton], "A" is surface area of dustfall canister [km^2], and "T" is measurement elapse time [day].

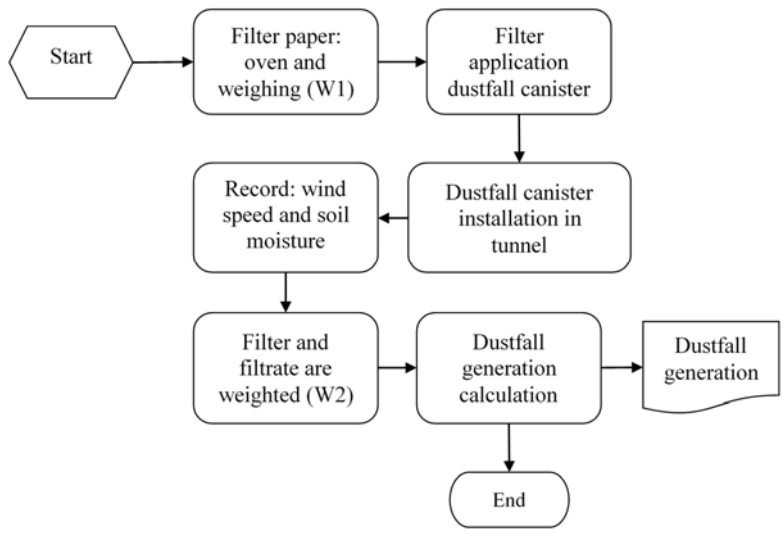

Figure-1. Flowchart of the research steps.

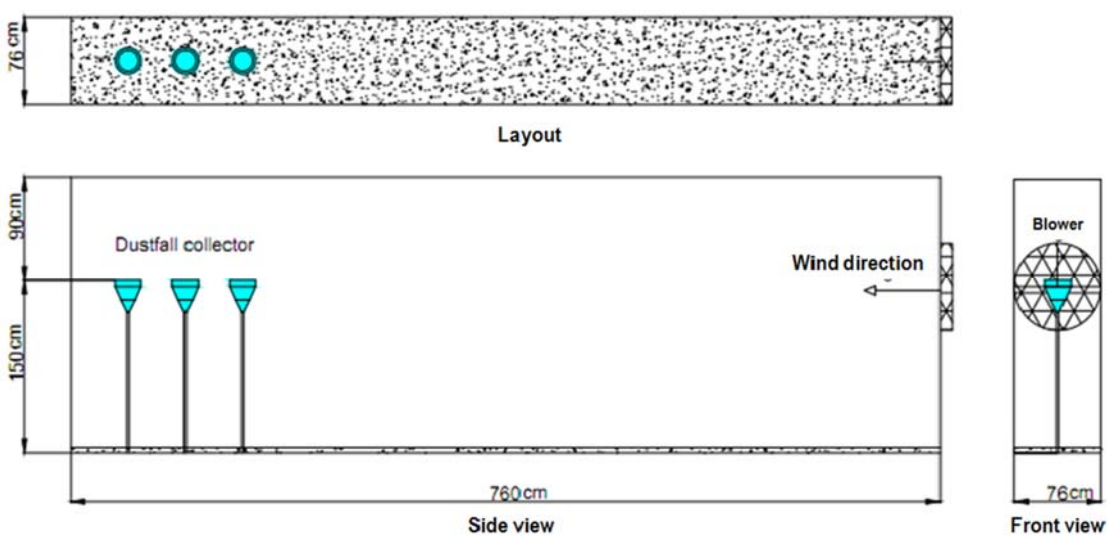

Figure-2. Layout, side view, and front view of the tunnel with the dustfall canisters and blower.

RESULT AND DISCUSSIONS

Complex Mediteran Red Yellow Grumusol (RYG) soil is a type of soil that is characterized by red and yellow colour and has low permeability [13]. Soil moisture content and wind speed are the factors that influence each other. An exponential equation can be a model that relates dustfall generation, soil moisture content, and wind speed as illustrated in Figure-3.

Result of the experiment shows that there is high positive correlation between dustfall generation and wind speed whereas high negative correlation was found between dustfall generation and soil moisture content. The R-Sq value illustrates the level of influence of the wind speed and soil moisture content on dustfall generation.

The modelling can also be contributed by factors of vegetation cover. Vegetation has been suggested to play an important role in trapping dust because it can produce surface roughness that reduces wind speed near the soil surface and thus reduces re-suspension of deposited dust [14]. In this research, paddy plants as high as 15 cm was used as land cover and applied in the tunnel as much as 10%, 20%, 30%, and 40% of tunnel surface area, respectively. Dustfall generation modelling with the vegetation cover is illustrated in Figure-4. The influence of vegetation cover shows that vegetation cover has high negative correlation with dustfall generation, meaning that the higher covering area, the lower dustfall generation.

Regosol (REG) soil can be divided into Regosol volcanic ash and sand dunes. Regosol soil used in this study originated from deposition sedimentation of alluvium material as a result of the volcano eruption which formed the limestone mountain (Exploratory Soil Map of Java and Madura 1960). Forms of distribution territory cover from hilly to mountainous areas. REG soil is lush naturally; soil texture is usually rough; and sensitive to erosion. Field conditions on REG soil sample area is a relatively flat land and include plantation area. REG soil is widely available in every island that has a volcano, either active or inactive. If the generation of dustfall was tested on the field, the results obtained may differ from the laboratory one due to the influence of non-uniform vegetation type, meteorological factors, C-organic content of the soil, unstable soil moisture content, and wind speed. The correlation between dustfall generation, wind speed, and soil moisture content (volume basis) as a result of this laboratory scale experiment are showed in Figure-5.

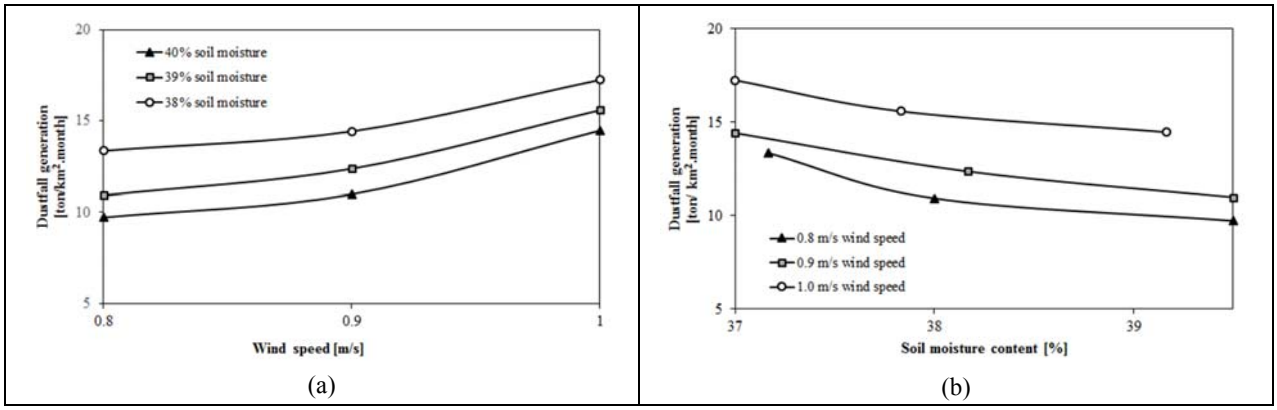

Figure-3. Correlation between dustfall generation vs. wind speed (a) and dustfall generation vs. soil moisture content (b) on RYG soil.

Figures 4 and 5 show that dustfall generation exceeds the threshold limit for residential areas according to Government Regulation (PP No. 41/1999), with the highest the number of dustfall generation was 26 tons/km^2. month for Regosol soil and 18 tons/km^2.month for RYG soil. Based on Figure-5, generation of dustfall shows a high positive correlation with the wind speed. It is in accordance with the research carried out by Zakey *et al*. [15], Du *et al.* [16], Bian *et al*. [17] as well as Amaliah *et al*. [11] and Yuwono *et al.* [12] that the increment of wind speed will increase the number of particles in the air significantly. In addition, based on Figure-5, it is clear that soil moisture content (volume basis) has high negative correlation with dustfall generation. According to Amaliah *et al.* [11] and Yuwono *et al*. [12], the increase in soil water content will decrease the number of dustfall generation. It is in line with the results of research carried out by Jinyuan *et al*. [18] conducted in the North China dust where a major component of aerosols in the atmosphere was largely caused by the soil surface that has low soil moisture content (dry land) and high wind speeds during the spring.

Figure-5 shows that at certain wind speed and soil moisture content, RYG and REG resulted in different dustfall generation, where the higher dustfall generation was obtained by REG soil. This was caused by the soil texture of the soil, as it is known that soil texture is an important factor influencing the erodibility soil because soil since texture affects the consistency of cohesion and mobility [19]. RYG is a sticky and dense soil type, so

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that at the time of testing soil texture using the hydrometer method, sodium silicate solution, and hydrogen peroxide were required to separate the bonding between soil particles. This was due to high cohesive strength of the soil particles during the wet state. Therefore, generation of dustfall on RYG was lower than REG soil one. In addition, another influencing factor causing this phenomenon is allegedly by C-organic content of the RYG soil which was higher than REG soil that tend to have a better and more stable structure.

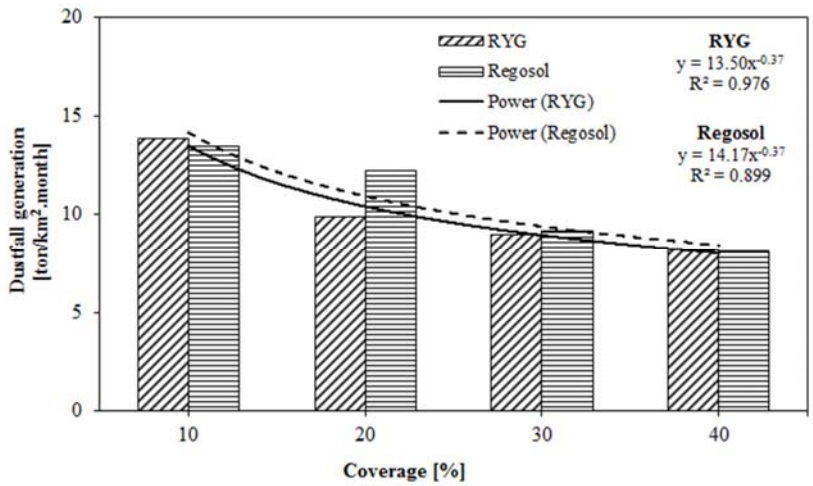

Figure-4. Correlation between dustfall generation and land cover crop on RYG and Regosol soils.

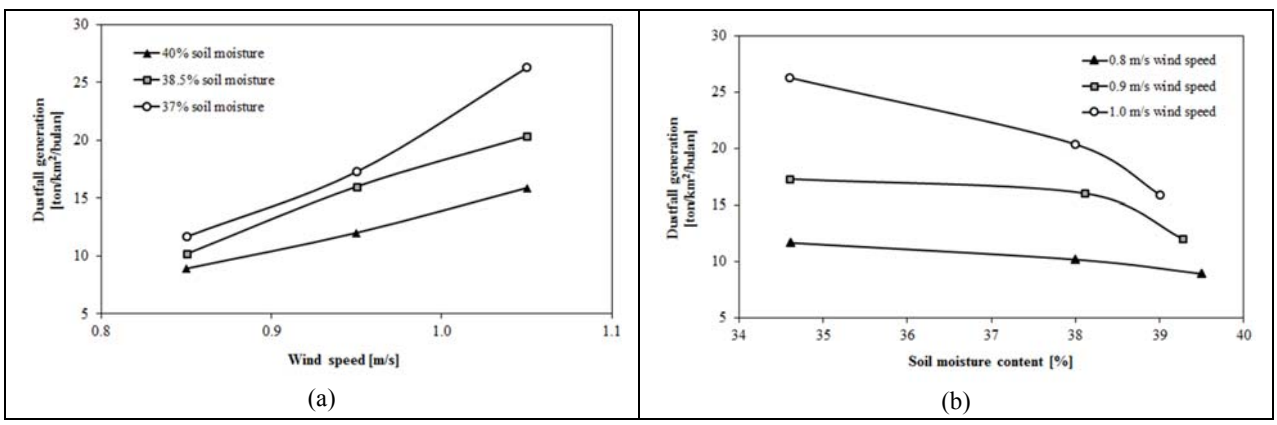

Figure-5. Dustfall generation vs. wind speed (a) and soil moisture content (b) on Regosol soil.

The emission factor is a form of simplification expression to obtain the amount of dustfall generation in the real condition. However, in fact, there are other factors that cause difference between amount of the dustfall generation in the field and laboratory scale one. The amount of dustfall generation in the real condition could be different due to soil moisture content and unstable wind speed, wind direction, local circumstances such as high buildings, industries producing the dustfall, vegetation, topography (valleys and mountains), and meteorological factors or local weather. Dustfall emission factors on Regosol (REG) and Complex Mediteran Red Yellow Grumusol (RYG) soils are presented in Equation (2) and (3).

$$E_{REG} = (896.1e^{-0.10A})x0.35 + (0.45e^{4.06U})x0.32 + (16.5e^{-1.8L})x0.33 \quad (2)$$

$$E_{RYP} = (24843e^{-0.12A})x0.35 + (8.14e^{0.12U})x0.35 + (8.3e^{-1.02L})x0.30 \quad (3)$$

Variable "A" represents soil moisture content of the REG and RYG soil [%], "U" is the wind speed [m/sec], and "L" is the percentage of land cover [%]. The emission factor is expressed as E_{REG} for dustfall from REG soil [ton/km^2.month] and E_{RYG} for dustfall from RYG soil [ton/km^2.month].

The above mentioned mathematical expressions are ready to be an estimation of the dustfall generation originated from soil surface of the both soil types as affected by wind speed, soil moisture content, and vegetation cover. According to Li *et al*. [20], the deposition of dustfall can occur in one of four following ways, i.e., (1) if there is a reduction in wind speed and turbulence; (2) if the particles are "captured" by collision with rough, moist, or electrically charged surfaces; (3) if the particles become charged and form aggregates that settle back to the ground; and (4) if the particles are washed out from atmospheric suspension by precipitation.

Therefore, those above mentioned mathematical expressions (Equation 2 and 3) could fulfil the need of quantitative approach to estimate the dustfall that would be generated by any natural and anthropogenic factors in an environmental impact assessment carried out in Indonesia.

CONCLUSIONS

Generation of dustfall positively correlated with the wind speed, but negatively with soil moisture content as well as land vegetation cover. The simple mathematical expressions representing dustfall generation as affected by wind speed, soil moisture content and land cover have been formulated. They are now ready to be applied in the field as an estimation of dustfall generation during an environmental impact assessment in Indonesia by simply inputting wind speed, soil moisture content as well as land vegetation cover.

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