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Filtration of Submicron Particles From Motorcycle Emission Using a DC Low Electrostatic Filter

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Abstract

This study develops a new method for a filtering system of submicron particles ($PM_{0.1}$, as known as ultrafine particles) emitted by motorcycle. The filter is based on electrostatics theory for capturing the particles using a constant DC low electrostatic voltage of 12 Volts from the motor battery. The filter consists of multilevel capacitors with the gap distance in the range of 9 to 36 mm called F1, F2, F3, and F4. The performance of the filter is presented as efficiency defined by the capability of the filter to reduce ultrafine particles showing the difference of ultrafine concentration before and after applying the filter on the motor exhaust. The particle concentrations were measured using a TSI P-Trak Ultrafine Particle Counter Model 8525. The result shows that the filter reduced the ultrafine particles with the efficiency between 5 to 37 % depending on the gap distance of the capacitor.

Keywords: DC electrostatic filter, ultrafine particles, motorcycle, efficiency.

INTRODUCTION

Motor vehicle emissions become interesting phenomenon due to their contribution on air pollution [1]. According to Indonesian Statistic Central Service (2015), the population of motor vehicles in Indonesia in 2013 has reached more than 104 millions. It was dominated by motorcycles with the large amount of more than 84 millions. In Vietnam especially in Ho Chi Minh City, the motor vehicles were dominated 3.46% (cars), 2.8% light trucks, 0.1% buses, and 92% motorcycles [2]. The emissions are mostly in the forms of particles with a different size distribution [3], [4], [5], [6], [7], [8]. The previous study of ultrafine particles emitted from motorcycle showed that the emission factor in the large amounts depending on fuel and engine capacity [9].

In order to reduce ultrafine particles from motorcycle, it needs a filter. The existing filtering system generally can be categorized into electrostatic-based filter, porosity-based filter, and radiation-based filter. All of them have different characteristics and particulate collection efficiencies. The most familiar particulate filters are DPF or Diesel Particulate Filter, a Catalytic Diesel Particulate Filter [10], electrostatic filter, and many others. The electrostatic filter itself mostly has been applied for industrial purposes [11], [12]. However, the electrostatic filter for motor vehicles especially motorcycle has not been found yet.

This study developed a new method for filtering system based capacitor principle by using a DC voltage from the motor battery to reduce the concentration of the ultrafine particles. The aim of this study was to develop an ultrafine particle filtering system especially for motorcycle with a high efficient by taking an advantage of motor battery usage as the electrical source of the filter.

EXPERIMENTAL

Motorcycle Samples. There were four standard motorcycles used for testing the filter in this research. They were randomly selected and named as M1, M2, M3, and M4.

Filter Construction. The filter was made of aluminum plates (width x length: 40 x 80 mm^2; 0.22m in the thickness). The filter was constructed as multilevel capacitors, with the variation of gap distance, (d) and the capacitor number (n). We used the motor battery of DC voltage 12 Volts as the constant source. The first aluminum plate was determined as an anode, and the other plate was connected to the negative as a cathode. Filters were classified into Filter 1, Filter 2, Filter 3, and Filter 4 (Table 1).

Table 1. The filter specification

Filter	n	d (mm)
Filter 1	1	36
Filter 2	2	18
Filter 3	3	12
Filter 4	4	9

The filter was installed in the front of the outlet of the motorcycle exhaust. An acrylic box was used as the inner insulator for the filter. This filter frame was covered by a metal sleeve and set in the front of the outlet of the motorcycle exhaust (Fig. 1).

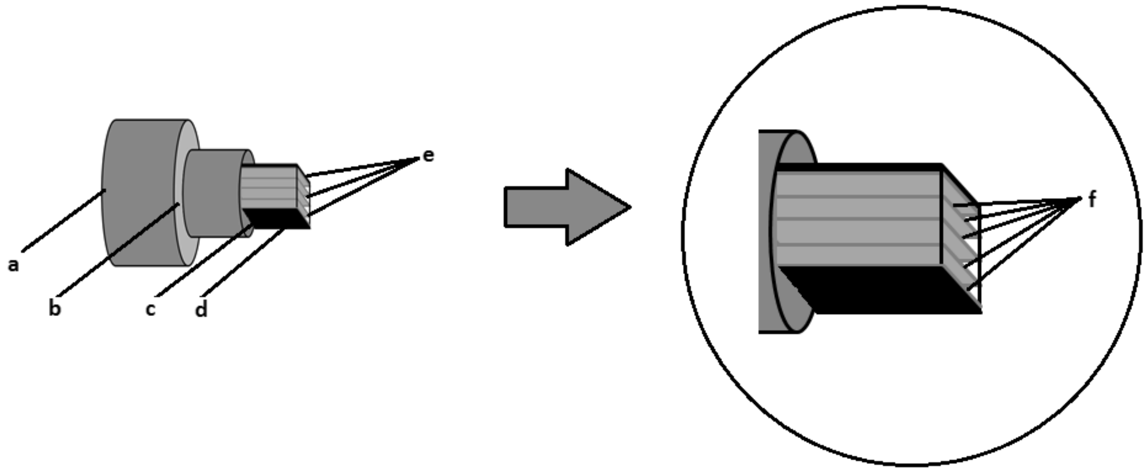

Figure 1. Schematic diagram of the filter (a. filter inlet, connected to the exhaust; b. metal sleeve; c. filter outlet; d. acrylyc insulator; e. filter gap; f. filter electrodes, connected to the voltage source)

Experimental Setup. The experimental setup is shown in Fig. 2. It consists of the following arranged components: a) TSI P-Trak Ultrafine Particle Counter Model 8525, b) Measurement probe, c) TSI Q-Trak, d) Accumulator, e) Digital Thermometer (SHT-11), f) Cables, g) Electrostatic filter, and h) Motorcycle sample. The concentrations of ultrafine particles were measured every 5 minutes. The concentration measured before installing the filter is called F_0. Meanwhile, the measured concentration after installing the filter is named F_n.

The filter efficiency (η) is calculated using Eq. (1):

$$\eta = \frac{F_0 - F_n}{F_0} x100\% \qquad (1)$$

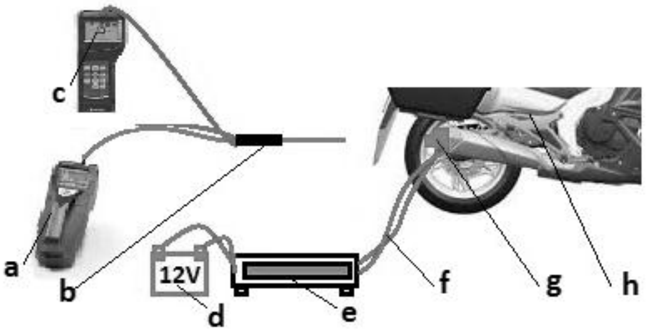

Figure 2. Set up of filter test

RESULTS AND DISCUSSION

Particulate Concentrations. Table 2 shows the average ultrafine particle concentrations measured for the sample motor M1, M2, M3, and M4. The measured concentrations without filter is presented as F_0. Meanwhile, F_1, F_2, F_3, and F_4 are the particle concentrations measured after applying the filter of Filter 1, Filter 2, Filter 3, and Filter 4 respectively.

Table 2. The average concentrations of ultrafine particle

Samples	**Ultrafine Particle Concentrations (x 10^5 particles/cm^3)**				
	F_0	**F_1**	**F_2**	**F_3**	**F_4**
M1	1.28	1.16	1.13	0.97	0.83
M2	1.22	1.00	0.99	0.10	0.08
M3	0.39	0.38	0.29	0.28	0.28
M4	0.45	0.37	0.36	0.35	0.27

Table 2 shows the interesting results that applying of the filter significantly affecting the concentration of ultrafine particles. The concentration decreases when the filter is put on the exhaust. It means the filter works properly. The reduction of ultrafine particles happens when the filter was employed to all motorcycle samples. Every motorcycle sample produces ultrafine particles with a variation of the concentrations depending on the engine condition. After applying the filters, the concentrations decrease with a certain ratio. The reducing concentration is found depending on the filter gap. The filter with a large gap distance results in a small decreasing of the particle concentration, meanwhile the thin gap filter gives a large reducing of the concentration. The trend is valid when the filter is applied to all motorcycle samples.

Filter Efficiency. The filter efficiency is calculated using Eq. (1). The efficiency is presented in the average and deviation standard. Filter 1 which is the filter with the gap distance between two plate of 36 mm, reduce the particle concentration up to 10.1 % for the sample motor M1, 10.1 % for the sample motor M2, 11.7 % for the sample motor M3, and 9.3 % for the sample motor M4. The efficiency of the Filter 1 is obtained in the range of 9.3 % and 11.7 %. The efficiency of the Filter 2 (the gap width of 18 mm) is calculated to 14.4 % for the sample motor M1, 16.1 % for the sample motor M2, 14.8 % for the sample motor M3, and 17.9 % for the sample motor M4. The efficiency become larger for the filter of F3 having a wider gap of 12 mm. The efficiency is 19.8 % for the sample motor M1, 23.7 % for the sample motor M2, 22.0 % for the sample motor M3, and 21.9 % for the sample motor M4 representatively. Among the filters, the F4 filter give the largest efficiency. The average particulate collection efficiency is presented in the Fig. 3.

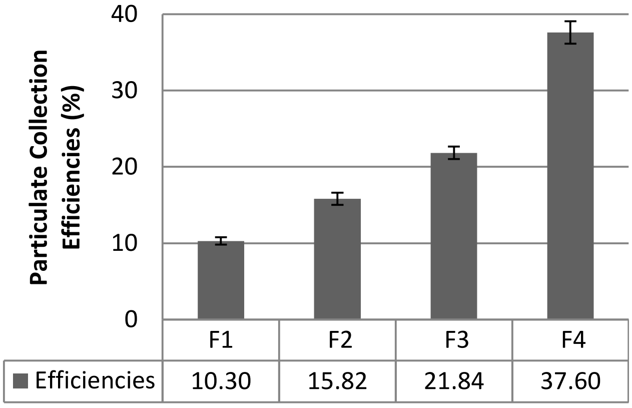

Figure 3. The average particulate collection efficiencies of the filter for gap variation 9.0 to 36 mm

In order to obtain a better understanding the filter efficiency related to the gap distance of the filter, we plot a graph between the efficiency and the gap distance as shown in Fig. 4.

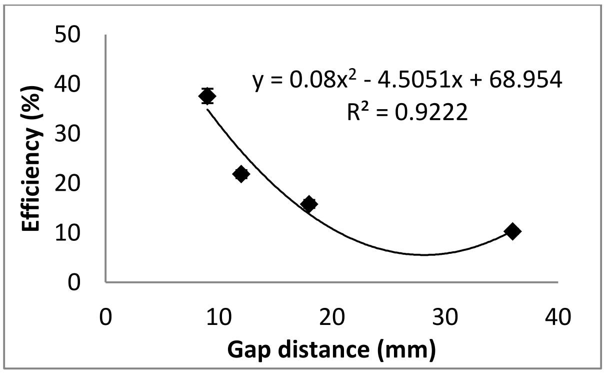

Figure. 4. The correlation between collection efficiencies and the gap distances

The correlation between the filter efficiency and the gap distance is obtained by approaching of a best fitting using a 2nd order of polynomial regression with R^2 0.9222 shown in Fig. 4. The correlation coefficient R^2 of 0.9222 means that this result shows Statistically the significant correlation between the filter efficiency and filter gap [13]. The efficiency of the filter depends on the gap distance. Larger gap distance of the filter results in lesser efficiency.

DISCUSSION

The ultrafine particle concentrations were measured with the concentration in the range of 7.49×10^3 to 1.27×10^5 particles/cm^3 depending on the motorcycle engine condition. The concentrations reduced significantly between 5 % and 38 % when the filter was installed. The reduction of the particle concentration because the filters electrostatically captured the ionized particles to the cathode and anode of the filter plates. The applied voltage definitely generates an electrostatic potential and electric field. The cathode withdraws positive ion particles, and the anode attracts negative ion particles. Consequently the amounts of the particles passing the filter decrease which is shown by the reducing of the particle concentration. The previous study reported that a DC low electrostatic voltage particulate filter (made of aluminum plates) with a constant gap (9 mm) connected to the varied voltages of 4, 6, 8, 10, and 12 Volts. The filter efficiency for $PM_{0.1}$ and $PM_{2.5}$ was reported of 23-35% for $PM_{0.1}$ and 29-40% for $PM_{2.5}$ [14].

In this research, we use a DC 12 volt constant voltage for the source of the filter. The source voltage produce a proportionally electrical field. The electrical field generates an electrostatic force to attract the ion particles. The field is inversely proportional to the gap distance. We varied the distance of the gap in order to get the different electrical field. The filter F1 which the largest gap distance produces smallest electrical field, and the force used to capture the ion particles is the smallest. Consequently, the filter F1 have the smallest efficiency. For the Filter of F4 having the smallest gap distance of 9 mm, has the highest efficiency among the other filters. With the gap distance, the filter attaches the ion particles with the highest force. As a result, the ability of the filter in reducing the particles become the biggest, and the efficiency is the biggest as well.

We also investigated the other parameter influencing the filter efficiency such as air ambient parameter : ambient temperature and relative humidity. We find that the ambient temperature - relative humidity do not affect the performance of the filter. The efficiency is relative constant for the change of air temperature and relative humidity.

CONCLUSION

Based on our results, it can be concluded that:

1. The DC electrostatic low voltage filter works well to reduce ultrafine particles emitted by motorcycle.
2. The efficiency of the filter depends on the gap distance of two plates. Smaller gap distance decreases ultrafine particle rather than a bigger one.

AVAILABILITY OF DATA AND MATERIALS

The data supporting the conclusion of this article are included within the article.

REFERENCES

[1] J. Tsai, P. Huang, and H. Chiang, “Characteristics of volatile organic compounds from motorcycle exhaust emission during real-world driving,” *Atmos. Environ.*, vol. 99, pp. 215–226, 2014.

[2] B. Q. Ho and A. Clappier, “Road traffic emission inventory for air quality modelling and to evaluate the abatement strategies: A case of Ho Chi Minh City, Vietnam,” *Atmos. Environ.*, vol. 45, no. 21, pp. 3584–3593, 2011.

[3] M. Kampa and E. Castanas, “Human health effects of air pollution.,” *Environ. Pollut.*, vol. 151, no. 2, pp. 362–367, 2008.

[4] L. Morawska and J. J. Zhang, “Combustion sources of particles . 1 . Health relevance and source signatures,” vol. 49, pp. 1045–1058, 2002.

[5] K. Sabaliauskas, G. Evansa, and C.-H. Jeonga, “Source Identification of Traffic-Related Ultrafine Particles Data Mining Contest,” *Procedia Comput. Sci.*, vol. 13, pp. 99–107, 2012.

[6] C. Sioutas, R. J. Delfino, and M. Singh, “Review Exposure Assessment for Atmospheric Ultrafine Particles (UFPs) and Implications in Epidemiologic Research,” *Environ. Health Perspect.*, vol. 113, no. 8, pp. 947–956, 2005.

[7] a. Pandey and C. Venkataraman, “Estimating emissions from the Indian transport sector with on-road fleet composition and traffic volume,” *Atmos. Environ.*, vol. 98, pp. 123–133, 2014.

[8] M. Vanhulsel, B. Degraeuwe, C. Beckx, J. Vankerkom, and I. De Vlieger, “Road transportation emission inventories and projections – Case study of Belgium: Methodology and pitfalls,” *Transp. Res. Part D Transp. Environ.*, vol. 27, pp. 41–45, 2014.

[9] A. Y. P. Wardoyo, U. P. Juswono, A. Valentino, and F. B. Huda, “Quantification of Ultrafine Particle Emission Factors From Motor Bikes,” *Int. J. Appl. Eng. Res.*, vol. 10, no. 19, pp. 40276–40281, 2015.

[10] Q. Zhou, K. Zhong, W. Fu, Q. Huang, Z. Wang, and B. Nie, “Nanostructured platinum catalyst coating on diesel particulate filter with a low-cost electroless deposition approach,” *Chem. Eng. J.*, vol. 270, no. x, pp. 320–326, 2015.

[11] Z. Feng, Z. Long, and T. Yu, “Filtration characteristics of fibrous filter following an electrostatic precipitator,” *J. Electrostat.*, vol. 83, pp. 52–62, 2016.

[12] X. Xu *et al.*, “Effect of electrode configuration on particle collection in a high-temperature electrostatic precipitator,” *Sep. Purif. Technol.*, vol. 166, pp. 157–163, 2016.

[13] M. Eeftens *et al.*, “Spatial and temporal variability of ultrafine particles, NO2, PM2.5, PM2.5 absorbance, PM10 and PMcoarse in Swiss study areas,” *Atmos. Environ.*, vol. 111, no. 2, pp. 60–70, 2015.

[14] A. Budianto and A. Y. P. Wardoyo, “DC Low Electrostatic Voltage Particulate Filter : PM 0 . 1 And PM 2 . 5 Emission Efficiency Measurement,” *Int. Semin. Sensors, Instrumentation, Meas. Metrol.*, no. August, 10-11, pp. 115–118, 2016.