International Journal of GEOMATE, Sept., 2019 Vol.17, Issue 61, pp. 35 - 40
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2019.61.4578
Special Issue on Science, Engineering & Environment

DEVELOPING FINE PARTICLE FILTERING SYSTEM FOR MOTORCYCLE EXHAUST USING COCO FIBERS

*Arinto Yudi Ponco Wardoyo[1], Firdy Yuana[1], and Selly Y. A. Elbasari[1]

[1]Faculty of Mathematics and Natural Sciences, University of Brawijaya, Indonesia

*Corresponding Author, Received: 26 Nov. 2018, Revised: 19 Jan. 2019, Accepted: 05 Feb. 2019

ABSTRACT: Fine particles from motor vehicle exhaust emissions become a major problem for the environment and human health. This burden requires a new technology of filtering system with high efficiency. However, the filtering system for motorcycle exhaust is still limited. Thus, we developed a new filtration system using coco fibers mixed to tapioca glues with the variation ratio such as 50:50 (Filter 1); 60:40 (Filter 2); 70:30 (Filter 3); and 80:20 (Filter 4). The efficiency is calculated by the ratio of the fine particle concentration in the exhaust emission before and after passing through the filter. The fine particle concentration was measured using a Digital Dust Monitor (Kanomax, Model 3443) when the motorcycle was operating in the idle condition. The fine particle concentration was measured for twenty sampling time. The filter efficiency was tested using three different motorcycles (M1, M2, and M3). The result showed that the filter efficiency was found between 12% and 33% depending on the filter thickness, density, and composition of the coco fiber and the glue.

Keywords: Fine particles, Coco fiber filter, Motorcycle, Exhaust emission, Efficiency

1. INTRODUCTION

The population of a motor vehicle in the world has been increasing from year to year. Some factors that influence the growth rate of motor vehicles are the increased population and economic growth [1]. The growth rate of motor vehicles was also related to the urbanization [2]. From many kinds of motor vehicles, the motorcycle is widely used as the common vehicle due to its high efficiency, low fuel consumption, long durability, and easy of use. Thus, the motor vehicle population growth can be linked to the emission of motor vehicles (particulate matter and gaseous emissions) that influence the air quality level.

Particulate matter (PM) is a key component of air pollution in which the motorcycle is one of the sources. Thus, PMs become a major problem for the environment. The size of PMs ranges from nanometers (submicron) to microns in the diameter size. Generally, they are classified into $PM_{0.1}$ (ultrafine particles), $PM_{2.5}$ (fine particles), and PM_{10} (coarse particles).

Especially for the particulate matters with the diameter less than 2.5 µm, $PM_{2.5}$ consists of major and minor elements, inorganic ions, elemental carbons, and some organic compounds [3]. The accumulation concentrations of $PM_{2.5}$ in the ambient air, whether the indoor or outdoor environment, may affect ecological balance and does have an impact on human health. In an indoor environment, fine particle toxicity was influenced by its deposition velocity onto human body surfaces [4]. Long-term exposure to fine particles was associated with the blood pressure alteration [5]. Many epidemiologic studies have been conducted to investigate the pulmonary responses to the exposure to fine particles in a mice model [6]. The previous studies have confirmed that fine particles have an association with coronary artery disease [7]. They can induce oxidative stress and to cause inflammatory cytokines gene expression and secretion [8].

Several studies have been conducted to improve the filtration technology in the motor vehicle exhaust system. A diesel particulate filter (DPF) of the heavy-duty diesel trucks has been investigated recently [9]. The previous study confirmed the latest filtration technology using an electrostatic force to reduce the concentrations of ionic ultrafine particles [10]. Even, the thermal energy generated from the motorcycle muffler has been utilized to reduce the concentration of fine particles [11].

In other sides, the data about a porosity-based filter developed from the coconut fiber has not been available. Meanwhile, the reference of the biomass particulate filter for the motorcycle exhaust system is still limited. In this study, four variations of biomass fine particle filters were tested in a laboratory test bench. The study included three motorcycle samples in different manufacturers and engine types that selected randomly. This research aimed to provide detail information about the performance of the particulate filter in reducing the concentrations of fine particles emitted by motorcycle, including the factors that related to the filter efficiency.

2. MATERIALS AND METHODS

2.1 Motorcycle Samples

The study included three different motorcycle samples preferred randomly in Malang, East Java, Indonesia. The description of the vehicle samples is presented in Table 1. The names of the motorcycle samples are replaced by the letter code of M1-M3.

Table 1 Motorcycle samples classification

Motor Samples	Engine Capacity (cm^3)	Model Years
M1	150	2013
M2	150	2013
M3	150	2013

Note: Each motorcycle sample was purchased from a random user in a standard engine condition (4-stroke engine, manual transmission) with the same gasoline type and octane number.

2.2 Fine Particle Filters

The coco fibers were purchased from the local market around Brawijaya University, Malang, Indonesia. The coco fibers were chopped up and naturally air-dried to reduce the moisture content. When the fibers were dry (moisture content < 15%), the coconut fibers were ground to become the fine-grained powder. The powder was mixed with the tapioca glue in four different variation ratios to generate four different filters: F1, F2, F3, and F4. The filter cake was mixed with the dilution water. When it came blended, it was pressed on a metal screen with constant pressure to generate a filter sheet with the specific thickness (Table 2). The filter sheet was naturally air-dried.

Table 2 Specifications of the fine particle filters

Parameter	F1	F2	F3	F4
Coco Fiber : Glue (Ratio)	50:50	60:40	70:30	80:20
Diameter [cm]	7.620	7.620	7.620	7.620
Thickness [cm]	0.154	0.178	0.205	0.241
Density [g/cm^3]	0.232	0.215	0.201	0.195
Dilution Water [cm^3]	500	500	500	500

2.3 Fine Particle Concentration Measurement

Particle measurement was conducted at the Laboratory of Air Quality and Astro Imaging Physics Department, Brawijaya University, Malang, Indonesia. The measurement was conducted in an indoor room (laboratory test bench), with constant room temperature and fine particle concentration during ambient monitoring ($T_{ambient}$ = 27ºC – 28ºC). The location of the measurement was also greater than 1000 m from the nearest public roadway. The particle measurement set-up (filter test bench) is represented in Fig.1.

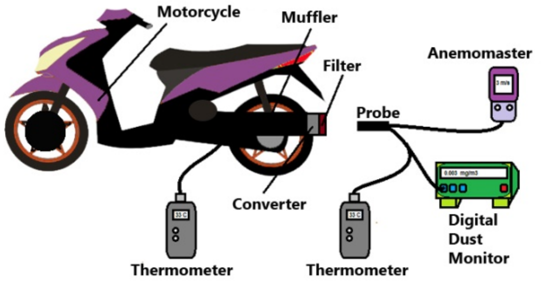

Fig.1 Schematic of the bench-scale fine particle filters test system

Each filter was installed individually on the outlet of the motorcycle muffler using a filter converter kit (diameter: 76.2 mm). The motorcycle engine was turned on for 1 minute for warming up the process, with a constant condition (idling state at 1000 RPM). A Digital Dust Monitor (Kanomax Inc., Model 3443) was used to measure the fine particles concentration. The pressure drop of the exhaust flow rate after treatment (v_{out}) was monitored by an Anemomaster (Kanomax Inc., Model A031). The inlet (T_{in}) and outlet temperatures (T_d) were measured with digital thermometers. The ambient temperature ($T_{ambient}$), relative humidity, and gaseous emissions (CO and CO_2) were reported from a Q-Trak (TSI, Model 8554). These measurements were conducted before (C_{in}) and after (C_{out}) applying the filter to the motorcycle muffler in every 10 seconds as the interval time of the measurement. All measurements were repeated three times.

2.4 Statistical Analysis

The recorded fine particle concentrations were analyzed using Eq. (1) to determine the filter efficiency (*Ef*) [10].

$$Ef = [(C_{in} - C_{out}) / (C_{in})] \times 100\% \quad (1)$$

The filter efficiency was interpreted as the mean ± SD (standard deviation) from all motorcycle samples (n = 3, M1, M2, and M3). The differences between the two groups (for examples F1 and F2, F1-F3, F1-F4, F2-F3, and so on) were determined using a Student's t-test. p-values of less than 0.05 were considered to be statistically significant [6].

The associations between the filter thickness vs filter efficiency, filter thickness vs pressure drop, and filter density vs pressure drop were interpreted by linear regression analysis, in which $R^2 > 0.80$ was considered as significantly correlated. The statistical analysis was carried out using Microsoft Excel 2016.

3. RESULTS

3.1 Fine Particles Concentration

In order to understand the filtration behavior on the fine particles reduction, the concentrations of fine particles were measured before and after applying the filter (Table 3). Fig.2 shows the effects of the installed filters with a constant condition. Compared to the fine particles concentration before using a filter (C_{in}), all filters could decrease the concentrations of fine particle emissions ($p < 0.05$).

Table 3 Mean fine particle concentrations

Filter Samples	Concentrations (x10^{-3} mg/m^3)		
	M1	M2	M3
	C_{in}		
F1	22.85	24.60	23.70
F2	21.15	23.60	23.95
F3	18.10	24.75	24.45
F4	15.95	26.45	28.00
	C_{out}		
F1	20.15	20.75	20.55
F2	17.65	18.85	19.65
F3	13.65	17.80	17.50
F4	10.75	17.90	19.10

Note: All measurements were conducted in an indoor room. The values represent the means of each measurement result.

3.2 Filter Efficiency

Filtration test was conducted to determine the filter efficiency in reducing fine particles. Fig.3 below represents the filter performances (mean ± SD, for all motorcycle samples, n = 3), as calculated using Eq. (1).

Figure 3 shows the efficiency of the four different filters with the different thickness level. Based on the filter thickness, F4 had the highest efficiency when applied in M1 (33%), whereas the lowest efficiency was obtained at F1 applied in M1 (12%). The similar results were found in M2 and M3. In the sample of M2, F1, F2, F3, and F4 generated 16%, 20%, 28%, and 32% of the filter efficiencies, respectively.

Similarly, F1 and F2 generated 13% and 18% of the filter efficiencies when applied in M3. On the other hands, the efficiencies of the filters F3 and F4 in M3 were 28% and 32%, whereas the F4 generated the highest efficiency. The value was significantly higher than the efficiency of F1 (up to 19% higher). Among the three different motorcycle samples, F4 has the highest efficiency. This result was consistent with the result obtained from the previous study [12].

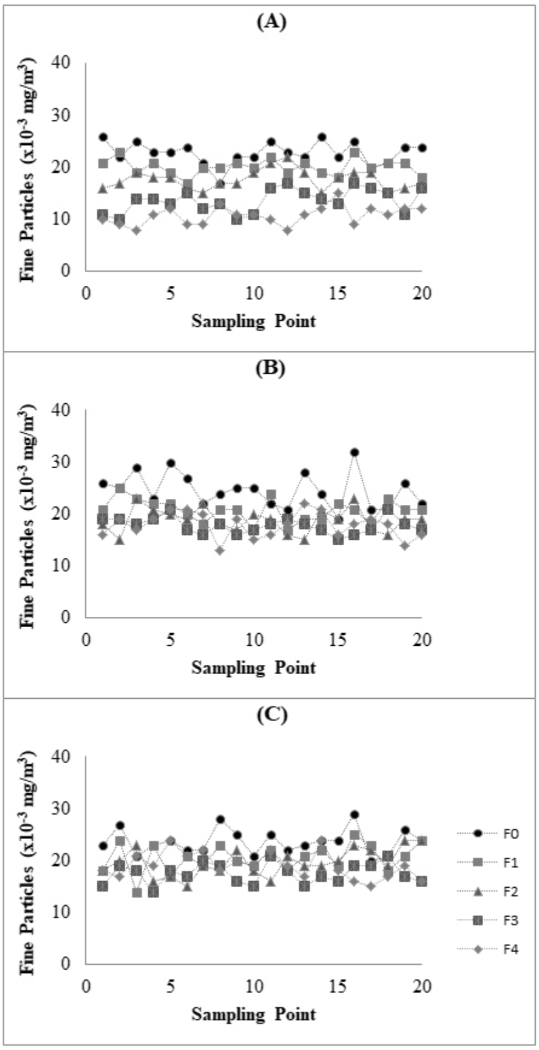

Fig.2 Fine particle concentrations of F0 (C_{in}) and C_{out} from Filter 1 (F1) - Filter 4 (F4) for all motorcycle samples: (A) M1; (B) M2; and (C) M3

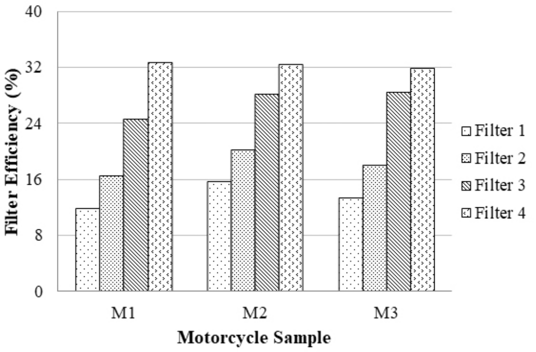

Fig.3 Fine particle concentrations of F0 (C_{in}) and C_{out} from Filter 1 (F1) - Filter 4 (F4) for all motorcycle samples: (A) M1; (B) M2; and (C) M3

4. DISCUSSION

Figure 3 depicts the mean efficiency, in which the filter efficiency is influenced by the thicknesses of the filters. This tendency is proven in this study, as the thickness variation of the filter was investigated to determine the efficiency. According to the results, the increase in the filter thickness has better ability in reducing fine particles showing to the higher efficiency. In order to get a better understanding, Fig.4 below interprets the correlation between the filter thickness and the filter efficiency.

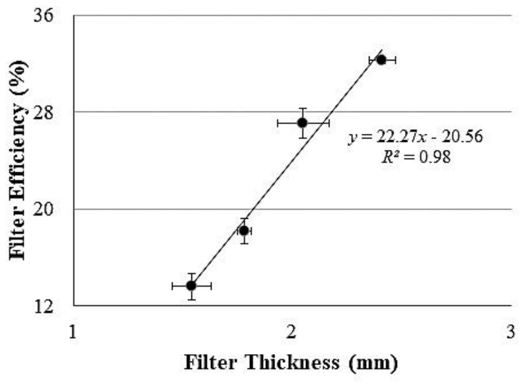

Fig.4 The correlation between filter thickness and filter efficiency

Based on Fig.4, the linear regression analysis shows an extreme positive correlation between the filter thickness and the filter efficiency, since the R^2 value is 0.98 (≈1). The correlation is interpreted as a linear function with the approximation equation $y = 22.27x - 20.56$. This trendline indicates that there is a strong correlation between the filter thickness and the filter efficiency.

The different efficiency level *Ef* of the filters might be related to the filter porosity. In this state, the porosities across the substrate of the coconut fibers might influence the filter efficiency. As confirmed in the previous study, the porosity distribution of the filter, including the pore size distribution, can represent the performance of a particulate filter [13]. The porosity level of a filter has a correlation with the filter thickness and density.

According to the results, F4 had the highest filter efficiency. Interestingly, the thickness of F4 was the highest, 0.24 cm. In contrast, the density of the filter F4 was only 0.195 g/cm^3. Although F4 was the thickest filter, F4 had the lowest density level. These results indicated that F4 had the most porosity level due to their lowest density level.

As shown in Table 2, F4 is the thickest filter (0.36 – 0.87 mm thicker than other filters) with the lowest porosity level. Thus, as expected F4 has the highest efficiency level, related to the filter thickness. As the thickest filter, F4 might have more fibroin content due to its high coco fiber ratio (80%). The coco fiber ratio of F4 was up to 10% higher than F3, F2, and F1. These different coco fiber ratio might influence the porosity of the filters since the fluid flow through porous media is related to the media porosity [14]. Since the filter density is not only the influencer factor, the filter efficiency is much more influenced by the filter thickness.

The density and porosity might indicate the existence of pressure drop that reflected filter performance [15]. As interpreted below (Fig.5), we had measured the level of pressure drop related to the flow rate of the emission [16-17]. The results showed that F1 had the most pressure drop (58%). Meanwhile, the lowest pressure drop level was referred to F4, as the most porous filter (22%). Based on the flow rate measurements of the outlet, the values of v_{out} was 0.09 m/s, 0.10 m/s, 0.11 m/s, and 0.16 m/s for F1, F2, F3, and F4 respectively. In other sides, the v_{in} was 0.21 m/s. There was no difference between T_{in} and T_d.

These results reflect the correlation (linear regression functions) between the filter density – filter thickness and pressure drop, together with the filter performance *Ef*. The thickness of the fibrous media structures influences the permeability and the airflow [18]. The more porous filter had more tapioca glue. The more concentration of coco fiber increased the filter efficiency, together with the decreasing amount of the pressure drop. These results indicated that the thickest filter F4, with the highest coco fiber ratio, could decrease the finest particles concentration though it had the lowest density level.

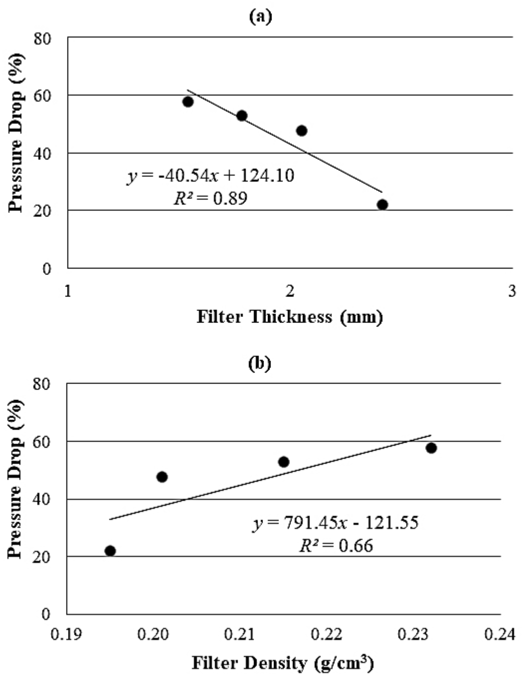

Fig.5 a). Filter thickness vs pressure drop (R^2 = 0.89), and b). Filter density vs pressure drop (R^2 = 0.66)

5. CONCLUSIONS

We have developed the filter using coco fibers for motorcycle fine particles. In all motorcycle samples (M1-M3), the fine particles concentrations before using a filter (C_{in}) were 15.95 x 10^{-3} to 28.00 x 10^{-3} mg/m^3. Compared to the fine particles concentration before using a filter (C_{in}), all filters could decrease the concentrations of fine particle emissions. The concentrations of fine particles after being filtered (C_{out}) were 10.75 x 10^{-3} to 20.75 x 10^{-3} mg/m^3. The filters could decrease fine particle concentrations with the efficiency in the range of 12% to 33% depending on the filter thickness, density, and the composition ratio between coco fibers and tapioca glue. These results indicated that the thickest filter F4, with the highest coco fiber ratio, could decrease the finest particles concentration though it had the lowest density level.

6. ACKNOWLEDGMENTS

The authors wish to acknowledge Arif Budianto, Mia A. Pawestri., Ayu Wenda Inneke Putri, Agustina Wahyuningrum, Bagus Aditya Muslim, Rudi Andika, and Renado Anggara for their excellent technical assistance.

7. REFERENCES

[1] Dayal Sharma R., Jain S., and Singh K., Growth rate of Motor Vehicles in India - Impact of Demographic and Economic Development, J. Econ. Soc. Stud., Vol. 1, No. 2, 2011, pp. 137–154.

[2] Riley K., Motor Vehicles in China: The Impact of Demographic and Economic Changes, Popul. Environ., Vol. 23, Issue 5, 2002, pp. 479–494.

[3] Minguillón M. C., Rivas I., Moreno T., Alastuey A., Font O., Córdoba P., Álvarez-Pedrerol M., Sunyer J., and Querol X., Road traffic and sandy playground influence on ambient pollutants in schools, Atmos. Environ., Vol. 111, 2015, pp. 94–102.

[4] Shi S., Li Y., and Zhao B., Deposition velocity of fine and ultrafine particles onto manikin surfaces in the indoor environment of different facial air speeds, Build. Environ., Vol. 81, 2014, pp. 388–395.

[5] Chan S. H., Van Hee V. C., Bergen S., Szpiro A. A., DeRoo L. A., London S. J., Marshall J. D., Kaufman J. D., and Sandler D. P., Long-term air pollution exposure and blood pressure in the sister study, Environ. Health Perspect., Vol. 123, No.10, 2015, pp. 951–958.

[6] Bai R., Zhang L., Liu Y., Meng L., Wang L., Wu Y., Li W., Ge C., Le Guyader L., and Chen C., Pulmonary responses to printer toner particles in mice after intratracheal instillation, Toxicol. Lett., Vol. 199, 2010, pp. 288–300.

[7] McGuinn L. A., Ward-Caviness C., Neas L. M., Schneider A., Di Q., Chudnovsky A., Schwartz J., Koutrakis P., Russell A. G., Garcia V., Kraus W. E., Hauser E. R., Cascio W., Diaz-Sanchez D., and Devlin R. B., Fine particulate matter and cardiovascular disease: Comparison of assessment methods for long-term exposure, Environ. Res., Vol. 159, 2017, pp. 16–23.

[8] Cachon B. F., Firmin S., Verdin A., Ayi-fanou L., Billet S., Cazier F., Martin P. J., Aissi F., Courcot D., Sanni A., and Shirali P., Proinflammatory effects and oxidative stress within human bronchial epithelial cells exposed to atmospheric particulate matter (PM2.5 and PM>2.5) collected from Cotonou, Benin, Environ. Pollut., Vol. 185, 2014, pp. 340–351.

[9] Quiros D. C., Yoon S., Dwyer H. A., Collins J. F., Zhu Y., and Huai T., Measuring

particulate matter emissions during parked active diesel particulate filter regeneration of heavy-duty diesel trucks, J. Aerosol Sci., Vol. 73, 2014, pp. 48–62.
[10] Wardoyo A. Y. P., Budianto A., and Abdurrouf, Filtration of submicron particles from motorcycle emission using a DC low electrostatic filter, Int. J. Appl. Eng. Res., Vol. 12, No.8, 2017, pp. 1725–1728.
[11] Wardoyo A. Y. P., Nuriyah L., and Darmawan H. A., Developing Reheated Filter of Motorcycle Exhaust for Reducing $PM_{2.5}$ Emissions, in Proc. Int. Semin. Sensor, Instrumentation, Meas. Metrol., 2017, pp. 42–45.
[12] Wardoyo A. Y. P., Juswono U. P., and Riyanto S. Developing particulate thin filter using coconut fiber for motor vehicle emission, in Proc. AIP Conf. Proc. 1719, 2016, pp. 030043-1-030043-4.
[13] Gong J., Stewart M. L., Zelenyuk A., Strzelec A., Viswanathan S., Rothamer D. A., Foster D. E., and Rutland C. J., Importance of filter's microstructure in dynamic filtration modeling of gasoline particulate filters (GPFs): Inhomogeneous porosity and pore size distribution, Chem. Eng. J., Vol. 338, 2018, pp. 15–26.
[14] Tien C. and Ramarao B. V., Can filter cake porosity be estimated based on the Kozeny-Carman equation?, Powder Technol., Vol. 237, 2013, pp. 233–240.
[15] Rapagnà S., Gallucci K., and Foscolo P. U., Olivine, dolomite and ceramic filters in one vessel to produce clean gas from biomass, Waste Manag., Vol. 71, 2018, pp. 792–800.
[16] Budianto A. and Wardoyo A. Y. P., DC low electrostatic voltage particulate filter: $PM_{0.1}$ and $PM_{2.5}$ emission efficiency measurement, in Proc. Int. Semin. Sensor, Instrumentation, Meas. Metrol., 2016, pp. 115–118.
[17] Wardoyo A. Y. P. and Budianto A., A DC low electrostatic filtering system for $PM_{2.5}$ motorcycle emission, in Proc. Int. Semin. Sensor, Instrumentation, Meas. Metrol., 2017, pp. 51–54.
[18] Gervais P., Bémer D., Bourrous S., and Ricciardi L., Airflow and particle transport simulations for predicting permeability and aerosol filtration efficiency in fibrous media, Chem. Eng. Sci., Vol.165, 2017, pp. 154–164.