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DEVELOPING REHEATED MOTORCYCLE EXHAUST FOR $PM_{2.5}$ EMISSION

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ABSTRACT: Motor engine has been identified to produce particulate emission in different size distribution and has serious impacts on health and influence of air quality. Especially, $PM_{2.5}$ which are known as particulate matters with the diameter less than 2.5 µm, induce a major health problem due to the reactive characteristic and the high exposure level in the human. In order to reduce the concentration of $PM_{2.5}$ in the ambient, we have developed a new exhaust used to maximize the released combustion energy for reducing $PM_{2.5}$ concentration. The exhaust was accomplished with a heating chamber and a copper net tube in the dimension of 25 cm in diameter and the varied length of 4 cm, 5 cm, and 6 cm. The tube was wired by copper with the diameter of 0.5 cm. The exhaust was characterized by measuring temperature and the capability in reducing $PM_{2.5}$ concentration. The result showed that the exhaust worked well in reducing $PM_{2.5}$ concentration with the efficiency reaching up to 24 % depending on the dimension of the net tube.

Keywords: Design, Motorcycle exhaust, $PM_{2.5}$, Thermal Radiation, Efficiency

1. INTRODUCTION

Particulate matters or particles mostly are from natural sources such as fire forest or dust storm [1]. Moreover, industrial process [2] and vehicles usage [3] have contributed significantly in addition to particles in the air. Industrial particle emissions affect directly into the human health especially for people living in the range of the exposure area (Eeftens et al. 2015; Smargiassi et al. 2014). Meanwhile, vehicle particles widely have an impact on the people living close to road and motor users [6].

The motorcycle is one type of motor vehicles commonly used in developing countries. The number of motorcycles has increased extensively in the last decade (Marquet & Miralles-guasch 2016; Mishima 2004; DayalSharma et al. 2011). Motorcycle particles have been reported increasingly in the ambient air [10]. In the previous research, there was shown a relation between the motor vehicle usage and the particle concentration [11]. This result brought bad news for the human by the fact that the particles are very dangerous especially for the health [12]. Motorcycle particles are produced by the incomplete burning process of the fuel [13], [14]. The particles are in different size distribution and chemical substances (Tsai et al. 2014; Morawska et al. 2008). The particles have the ability to move freely in the air, increase the health risk [16], [17], and penetrate in cellular level [18] and into a human through the skin via intracellular process [19] . Even though, the particles were found to have an ability to infiltrate into human cardiovascular via respiratory system [20]–[22]. A variety of health problems due to vehicle particle emission has been reported in the previous studies [23]–[26].

Reducing motorcycle particles has been attempted in the past decade. Various methods have been developed and tested in order to reduce the concentration. Planting of trees in the roadside is the common method to reduce ambient particles (Gromke & Blocken 2015; Nowak et al. 2013). Another method was conducted by improving the engine capability to burn the fuel more efficient [30]–[32]. The exhaust filtering system has been developed for gas emissions [33]–[35]. Exhaust filtering system has limited to particle emissions because of high particle concentration leading to the filter saturation that increases a risk of the filter or even the engine damage [36].

A particulate filer using coconut fiber for motorcycle emission was developed before. In the research, the filter was depended on the number of the filter layer [37]. In the other research, a particulate filter was build by using capacitive concept with low DC current to generated electric field to trapping the charge particulate emission . The efficiency of the filter was found depend on the number of the gap to traps the particulate matter [38]. In this study, we develop an exhaust accomplished by an particulate removal system to optimize the released heat for reducing $PM_{2.5}$.

2. METHODS

A heating compartment was designed in the motorcycle exhaust to optimize the waste engine thermal energy capture. The compartment was constructed in the tube form with the dimension of 10 cm in the height and 9 cm in the diameter. A cooper wired aluminum net was positioned in the compartment in order to capture the released heat in the chamber. The net was arranged as a tube with the diameter of 2.5 cm and the length that was varied of 4 cm, 5 cm, and 6 cm labeled as F1, F2, and F3 respectively. The cooper wire with diameter 0.2-mm was applied spirally in the tube with the distance for each winding of 0.5-cm. The geometry detail of the designed compartment and the net position is shown in the Fig.1.

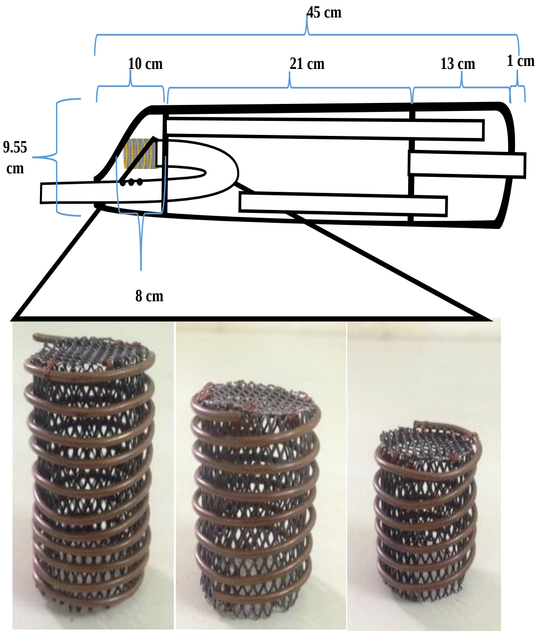

Fig.1 The exhaust design and cooper wired aluminum net

Three motorcycles with same engine capacity and fuel type were used to test the exhaust. The brand of motorcycles was hidden to avoid any a conflict of interest. The motorcycle was labeled as M1, M2, and M3 respectively. The observation was conducted for four configurations consist of without exhaust system (C0), the designed exhaust without system (Cf0), with F1 (Cf1), F2 (Cf2), and F3 (Cf3) every motorcycle. The exhaust test was carry out for the motorcycle was operating in the idle condition to avoid a driving style, vehicles load, and roads factor for 30-minutes.

Kanomax Digital Dust monitor model 3443 was used to measure the $PM_{2.5}$ concentration. The measurement was processed in the semi-isolated room with the temperature 27^0 and humidity under 50%. The measurement was done by quantify the concentration of $PM_{2.5}$ in the distance of 30-cm from the exhaust. At least 10 data was recorded in every 5-minute for 30-second engine run. The route was repeated for the C_F1, C_F2, and C_F3 in cold engine start procedure. The temperature in the exhaust compartment was measured by using thermocouple and stated as T0, Tf0, Tf1, Tf2, and Tf3. The efficiency of the system was calculated by comparing the concentration of the $PM_{2.5}$ from the engine before entering the exhaust and after passing out the exhaust using Eq. (1).

$$Eff\% = (C_0 - C_F)/C_0 \text{ x } 100\% \quad (1)$$

With C_f is the concentration of the $PM_{2.5}$ with the designed exhaust and system applied (F1, F2, and F3). C_0 is the concentration of the $PM_{2.5}$ without exhaust. A smoke flow rate was measured by using Kanomax *anemomaster flowrate* A310 series in the exhaust output. An analyst was conducted to find the relationship of the thermal energy increase that effected the $PM_{2.5}$ reduction.

3. RESULT

3.1 Smoke Flow Rate

Applying the exhaust system resulted in the reduction of the smoke flow rate as presented in the table.1. The flow rate of the emission from the engine was measured of 3.2 m/s in average for M1 and M2. For the M3, the average flow rate was measured of 4.4 m/s. After the designed exhaust was applied, the flow rate reduced to 20% for M1 and M2, but 30% for M3. The flow rate reduction was found the same for F1, F2, and F3.

Table 1 The smoke flow rate of the emission for M1, M2, and M3

		Flow rate (m/s)					
Minute	Net	5	10	15	20	25	30
M1	Ex 0	3.4	3.2	3.1	3.1	3.8	3.3
	F1	2.5	2.2	2.6	2.5	2.2	2.5
	F2	2.9	2.9	3.0	2.9	2.9	2.9
	F3	2.5	2.5	2.4	2.5	2.4	2.5
M2	Ex 0	3.3	3.4	3.0	3.4	3.3	3.1
	F1	2.6	2.4	2.3	2.4	2.5	2.5
	F2	2.8	3.0	2.8	2.7	2.6	2.5
	F3	2.3	2.3	2.4	2.5	2.6	2.4
M3	Ex 0	4.4	4.3	4.5	4.4	4.5	4.4
	F1	3.1	3.0	3.0	3.0	3.1	3.0
	F2	3.4	3.2	3.0	3.3	3.2	3.2
	F3	3.0	3.3	3.0	3.1	3.1	3.3

3.2 Exhaust Temperature

The increase of the compartment temperature is caused by the released heat emission and by the effects of the cooper wired aluminum net. By operating the motor engine results in a released heat emission.

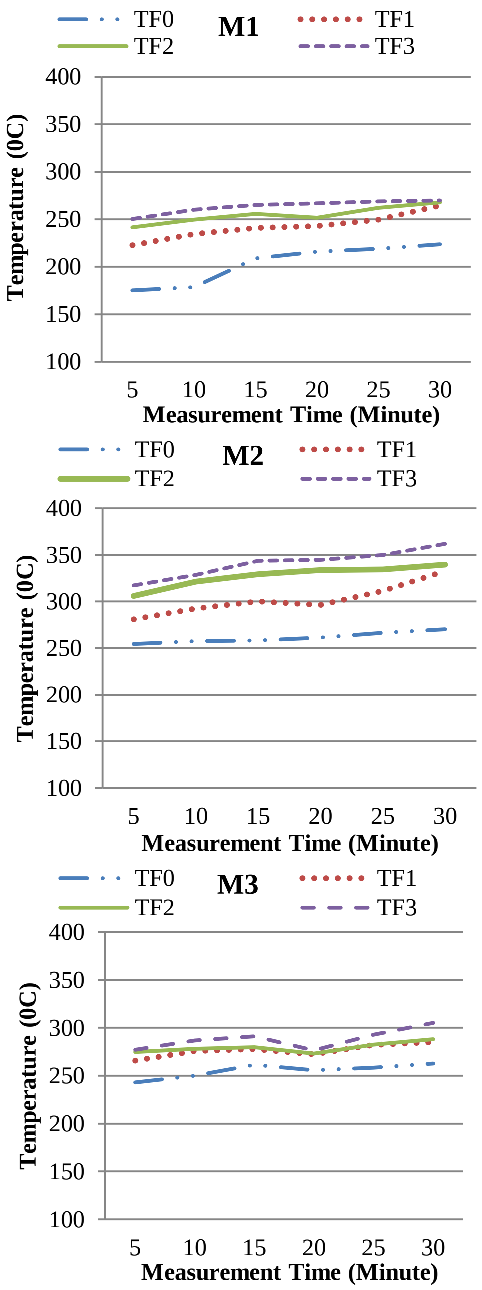

Fig.2 The exhaust temperature for the system with F3 was measured for M1, M2, and M3. Longer engine run was observed to increase the temperature

The heat emission was observed increase by the longer engine activation. In the minute five of engine runs, we observed the temperature TF0 of 175^0C. In the minute 10, the temperature became to 179^0C. In the minute 15, 20, 25, the temperature was recorded of 209^0C, 216^0C, and 219^0C respectively. In the minute 30, the temperature reached to 224^0C. For the sample motorcycle M3, we found the temperature increase in the different trend. The temperature was in a saw tooth pattern. The temperature was of 243^0C, 250^0C, and 261^0C in the minute 5, 10, and 15. In the minute 20, the temperature reduced to 256^0C and gradually increases into 258^0C and 263^0C in the minute 25 and 30. The temperature trend was obtained similarly by applying the filter of F1, F2, and F3.

The effect of applying the cooper wired aluminum net in the exhaust, the temperature increases was found larger rather than without applying the net. The temperature increase was 46^0C for applying F1, 67^0C for F2, and 75^0 C for F3. This shows that the dimension of the filter influencing the heat energy increase in the exhaust. The increasing temperature as the effect of applying the F1, F2, and F3 for all sample motor are present in the Fig.2. In the Fig.2, the double dot dash line presents the temperature of the system before the net applied. The dot, line, and dash line show the system with F1, F2, and F3.

3.3 $PM_{2.5}$ Concentration

The $PM_{2.5}$ concentration became lower for the longer engine run and the longer net. For the engine is operated for a long period of time, the temperature become higher and reduce particulate concentration due to the perfect combustion [39]. In this study, we found the $PM_{2.5}$ concentration for longer period of the engine operating. For the M1 and M2, we observed the $PM_{2.5}$ concentration to reduce gradually from 35.8 x 10^{-3}mg/cm^3 and 33.2 x 10^{-3}mg/cm^{3}in the minute 5 into 27.8 x 10^{-3}mg/cm^3 and 27.0 x 10^{-3}mg/cm^3 in the minute 30. Meanwhile in the sample motorcycle M3, we found the highest $PM_{2.5}$ concentration in the minute 20, then the concentration reduced in the minute 5, 10, and 15 minutes which was of 31.2 x 10^{-3}mg/cm^3, 30.8 x 10^{-3}mg/cm^3. We assumed that the motorcycle characteristic was responsible for this.

The effect of applying the net in the exhaust, we found the relationship between the $PM_{2.5}$ concentration reduction and the temperature increase. The correlation was found consistently when the system was applied for the different motor samples. The measured concentration of $PM_{2.5}$ for the motor samples with and without applying the filtering system is shown in Table 2.

Table 2 The measured $PM_{2.5}$ concentration

Time (Minute)	$PM_{2.5}$ in C x 10^{-3} mg/cm^3				
	C0	Fc0	Fc 1	Fc 2	Fc 3
M1					
5	35.8	34.2	32.6	29.6	28.6
10	34.4	32.6	30.4	29.2	26.2
15	31.6	29.2	28.2	26.0	24.0
20	29.6	28	27.2	26.2	24.8
25	29.4	27.6	25.8	25.4	23.6
30	27.8	24	23.8	23.4	21.4
M2					
5	33.2	31.8	28.8	28.8	27.8
10	32.0	30.6	28.2	28.0	25.6
15	32.0	29.2	27	26.0	24.2
20	31.0	29.4	26.2	26.6	24
25	29.7	27.2	25.2	25.2	22.2
30	27.0	25.0	23.8	23.6	20.4
M3					
5	31.2	30	27.2	26.8	25.2
10	29.4	28.2	26.6	25.6	23.4
15	26.8	25.6	24.0	21.8	20.2
20	30.8	29.8	26.0	25.2	24.8
25	26.2	25.2	23.0	22.8	21.4
30	25.0	23.0	22.0	20.8	19.8

3.1 Filter Efficiency

Fig.3 shows the efficiency of the $PM_{2.5}$ removal system. The length of the applied net in the exhaust influences the ability of reducing $PM_{2.5}$ concentration. The efficiency varies for different period of the engine operating. The efficiency change is in the range of 8%-16% for Fc1, 12%-19% for Fc2, and 16%-25% for Fc3. The average efficiency of the system is 12%, 15%, and 21% for Fc1, Fc2, and Fc3 respectively.

4. DISCUSSION

Particulate matter with the diameter less than 2.5 μm or $PM_{2.5}$ can be formed in the several ways. In this study, $PM_{2.5}$ are formed by the fuel combustion in the engine chamber [40]. In the engine, the fuel is injected into the combustion chamber together with the air before igniting in a high compression level [41]. The result is a very high kinetic energy that is used to push the piston and to move the vehicle [42]. The combustion process results in emissions (gas and particles) and thermal energy as the products. In the other word, the thermal energy leaves the engine through a convection process. The exhaust system such as a muffler or a silencer that is made of metal is used to absorb the thermal energy. Consequently, the emission eventually loses their temperature and become a cooling down [43]. This process leads to develop the secondary particles.

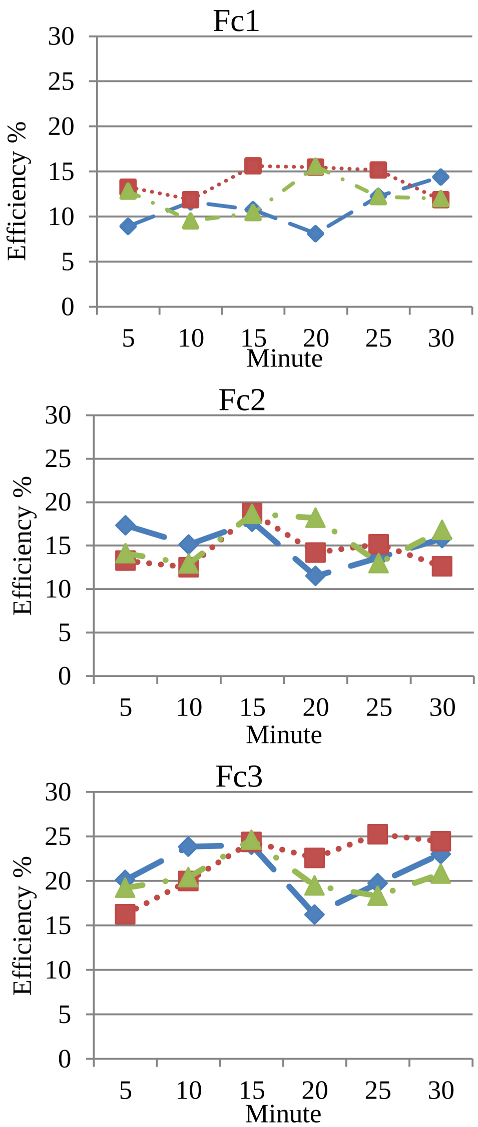

Fig.3 The exhaust efficiency with applying a net with different length

The research was focused on the filter regeneration to increase the system life span [46]. The self-regeneration filter was pursued in order to build a longer filter usage [47], [48]. However, self-regeneration filter was resulted in the increase of operational cost.

A commercial filter is used porosity based system that works by capturing the designed particulate only [44]. In the longer usage periods, the particulate was found to block filter porous and lead into the engine damage [45]. Another study was

In this study, we applied the metal net as a filter that increases the temperature through radiation process when it is passed by the convective thermal energy released by the motor engine. The thermal radiation energy is shown by increasing the temperature of the system. The metal net enlarges the radiation area and raises the surrounding temperature [49]. The radiation thermal energy may reduce a particle nuclei radius [50]. In our design, we do not try to filter but deform the particulate emission. The method would have some benefit in the system life span and risk of particle blockades the system as soot [51].

The flow rate reduction was found in the same level for M1, M2, and M3 that indicates the net effect in the flow rate reduction is insignificant. The flow rate of the system was found constant after the engine run for 30 minutes. This result indicates that the blocking effect of the system is low. For example, the flow rate of the emission in the minute 5, 15, 10, 50, 25, and 30 was measured reduces of 0.2 for M1 with F1. The F2, and F3 for M1, M2, and M3 were found in similar manner. By taking into account this result, the system regeneration may unneeded.

The $PM_{2.5}$ concentration reduces after applying the net in the exhaust. We found the temperature increases was up to 362 ^{0}C while the reduction of the concentration was up to 25%. The $PM_{2.5}$ concentration reduction is found inversely with the temperature with the R^2 = 1, This shows that the strong correlation between the temperature increase and particulate concentration [52]. The dimension of the metal net influences to the exhaust efficiency in reducing the $PM_{2.5}$ concentration.

In the filtering system based on the porosity, the risk of the system blocking the emission flow is high when the efficiency of the system is high [51], [53]. The result would be fatal in the engine. However, in this research, we found the efficiency of the system in reducing particulate matter that was relatively constant of 12 %, 15%, and 1 % for Fc1, Fc2, and Fc3 respectively. The system is unblocked of the particulate emission due to the heat radiation in removing $PM_{2.5}$.

5. CONCLUSION

The motorcycle exhaust that was developed based on thermal radiation had an ability in reducing the PM2.5 emission depending on the dimension of the applying metal net. Longer metal net resulted in higher thermal radiation having the consequent in reducing the PM2.5 concentration.

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7. REFERENCES

[1] Borgie, M.; Ledoux, F.; Dagher, Z.; Verdin, A.; Cazier, F.; Courcot, L.; Shirali, P.; Greige-gerges, H.; Courcot, D. Chemical Characteristics of PM2.5–0.3 and PM0.3 and Consequence of a Dust Stormepisode at an Urban Site in Lebanon. *Atmos. Res.* 2016, *180*, 274–286.

[2] Irfan, M.; Riaz, M.; Saleem, M.; Muhammad, S.; Saleem, F.; Berg, L. Van Den. Estimation and Characterization of Gaseous Pollutant Emissions from Agricultural Crop Residue Combustion in Industrial and Household Sectors of Pakistan. *Atmos. Environ.* 2014, *84*, 189–197.

[3] Lang, J.; Zhou, Y.; Cheng, S.; Zhang, Y.; Dong, M.; Li, S.; Wang, G.; Zhang, Y. Science of the Total Environment Unregulated Pollutant Emissions from on-Road Vehicles in. *Sci. Total Environ.* 2016, *573*, 974–984.

[4] Eeftens, M.; Phuleria, H. C.; Meier, R.; Aguilera, I.; Corradi, E.; Davey, M.; Ducret-stich, R.; Fierz, M.; Gehrig, R.; Ineichen, A.; et al. Spatial and Temporal Variability of Ultra Fi Ne Particles , NO 2 , PM 2 . 5 , PM 2 . 5 Absorbance , PM 10 and PM Coarse in Swiss Study Areas. *Atmos. Environ.* 2015, *111* [2], 60–70.

[5] Smargiassi, A.; Goldberg, M. S.; Wheeler, A. J.; Plante, C.; Valois, M.; Mallach, G.; Marie,

L.; Shutt, R.; Bartlett, S.; Raphoz, M.; et al. Associations between Personal Exposure to Air Pollutants and Lung Function Tests and Cardiovascular Indices among Children with Asthma Living near an Industrial Complex and Petroleum Re Fi Neries. *Environ. Res.* 2014, *132*, 38–45.

[6] Morawska, L.; Ristovski, Z.; Jayaratne, E. R.; Keogh, D. U.; Ling, X. Ambient Nano and Ultrafine Particles from Motor Vehicle Emissions : Characteristics , Ambient Processing and Implications on Human Exposure. *Atmos. Environ.* 2008, *42* [35], 8113–8138.

[7] Marquet, O.; Miralles-guasch, C. City of Motorcycles . On How Objective and Subjective Factors Are behind the Rise of Two-Wheeled Mobility in Barcelona. *Transp. Policy* 2016, *52*, 37–45.

[8] Mishima, K. Motorcycle Industry in Vietnam , Thailand and Indonesia. 2004, 1–3.

[9] DayalSharma, R.; Jain, S.; Singh, K. Growth Rate of Motor Vehicles in India - Impact of Demographic and Economic Development. *J. Econ. Soc. Stud.* 2011, *1* [2], 137–154.

[10] Chen, Y.; Chen, L.; Jeng, F.; Chen, Y.; Chen, L. Analysis of Motorcycle Exhaust Regular Testing Data — A Case Study of Taipei City. *J. Air Waste Manage. Assoc.* 2009, *59* [November], 757–762.

[11] Tung, H. D.; Tong, H. Y.; Hung, W. T.; Anh, N. T. N. Science of the Total Environment Development of Emission Factors and Emission Inventories for Motorcycles and Light Duty Vehicles in the Urban Region in Vietnam. *Sci. Total Environ.* 2011, *409* [14], 2761–2767.

[12] Thi, N.; Oanh, K.; Thi, M.; Phuong, T.; Permadi, D. A. Analysis of Motorcycle Fl Eet in Hanoi for Estimation of Air Pollution Emission and Climate Mitigation Co-Bene Fi T of Technology Implementation. *Atmos. Environ.* 2012, *59*, 438–448.

[13] Macedo, C.; Daemme, L. C.; Penteado, R.; Heloísa, N.; Corr, S. M. BTEX Emissions from Fl Ex Fuel Motorcycles. *Atmos. Pollut. Res. J.* 2017, 1–10.

[14] Li, L.; Ge, Y.; Wang, M.; Li, J.; Peng, Z.; Song, Y. Effect of Gasoline / Methanol Blends on Motorcycle Emissions : Exhaust and Evaporative Emissions. *Atmos. Environ.* 2015, *102*, 79–85.

[15] Tsai, J.; Huang, P.; Chiang, H. Characteristics of Volatile Organic Compounds from Motorcycle Exhaust Emission during Real-World Driving. *Atmos. Environ.* 2014, *99*, 215–226.

[16] Yu, Q.; Lu, Y.; Xiao, S.; Shen, J.; Li, X.; Ma, W.; Chen, L. Commuters ' Exposure to PM 1 by Common Travel Modes in Shanghai. *Atmos. Environ.* 2012, *59*, 39–46.

[17] Yan, C.; Zheng, M.; Yang, Q.; Zhang, Q.; Qiu, X.; Zhang, Y.; Fu, H.; Li, X.; Zhu, T.; Zhu, Y. Commuter Exposure to Particulate Matter and Particle-Bound PAHs in Three Transportation Modes in Beijing , China. *Environ. Pollut.* 2015, *204*, 199–206.

[18] Lu, S.; Zhang, W.; Zhang, R.; Liu, P.; Wang, Q.; Shang, Y.; Wu, M.; Donaldson, K.; Wang, Q. Comparison of Cellular Toxicity Caused by Ambient Ultrafine Particles and Engineered Metal Oxide Nanoparticles. *Part. Fibre Toxicol.* 2015, 1–12.

[19] Eun, K.; Cho, D.; Jeong, H. Air Pollution and Skin Diseases : Adverse Effects of Airborne Particulate Matter on Various Skin Diseases. *Life Sci.* 2016, *152*, 126–134.

[20] Iversen, N. K.; Frische, S.; Thomsen, K.; Laustsen, C.; Pedersen, M.; Hansen, P. B. L.; Bie, P.; Fresnais, J.; Berret, J. F.; Baatrup, E.; et al. Superparamagnetic Iron Oxide Polyacrylic Acid Coated γ-Fe2O3 Nanoparticles Do Not Affect Kidney Function but Cause Acute Effect on the Cardiovascular Function in Healthy Mice. *Toxicol. Appl. Pharmacol.* 2013, *266* [2], 276–288.

[21] Nemmar, A.; Al-Maskari, S.; Ali, B. H.; Al-Amri, I. S. Cardiovascular and Lung Inflammatory Effects Induced by Systemically Administered Diesel Exhaust Particles in Rats. *Am. J. Physiol. Lung Cell. Mol. Physiol.* 2007, *292* [3], L664–L670.

[22] Mühlfeld, C.; Rothen-Rutishauser, B.; Blank, F.; Vanhecke, D.; Ochs, M.; Gehr, P. Interactions of Nanoparticles with Pulmonary Structures and Cellular Responses. *Am. J. Physiol. Lung Cell. Mol. Physiol.* 2008, *294* [5], L817–L829.

[23] Sierra-Vargas, M. P.; Guzman-Grenfell, A. M.; Blanco-Jimenez, S.; Sepulveda-Sanchez, J. D.; Bernabe-Cabanillas, R. M.; Cardenas-Gonzalez, B.; Ceballos, G.; Hicks, J. J. Airborne Particulate Matter PM2.5 from Mexico City Affects the Generation of Reactive Oxygen Species by Blood Neutrophils from Asthmatics: An in Vitro Approach. *J. Occup. Med. Toxicol.* 2009, *4*, 17.

[24] Kumar, P.; Morawska, L.; Birmili, W.; Paasonen, P.; Hu, M.; Kulmala, M.; Harrison, R. M.; Norford, L.; Britter, R. Ultrafine Particles in Cities. *Environ. Int.* 2014, *66*, 1–10.

[25] Feng, C.; Li, J.; Sun, W.; Zhang, Y.; Wang, Q. Impact of Ambient Fine Particulate Matter [PM 2 . 5] Exposure on the Risk of Influenza-like-Illness : A Time-Series Analysis in Beijing , China. *Environ. Heal.* 2016, 1–12.

[26] Zhang, F.; Liu, X.; Zhou, L.; Yu, Y.; Wang, L.; Lu, J.; Wang, W.; Krafft, T. Spatiotemporal Patterns of Particulate Matter [PM] and Associations between PM and Mortality in Shenzhen , China. *BMC Public Health* 2016, 1–11.

[27] Gromke, C.; Blocken, B. Influence of Avenue-Trees on Air Quality at the Urban Neighborhood Scale . Part II : Traf Fi c Pollutant Concentrations at Pedestrian Level. *Environ. Pollut.* 2015, *196*, 176–184.

[28] Wardoyo, A. Y. P.; Morawska, L.; Ristovski, Z. D.; Marsh, J. Quantification of Particle Number and Mass Emission Factors from Combustion of Queensland Trees. *Environ. Sci. {&} Technol.* 2006, *40* [18], 5696–5703.

[29] Nowak, D. J.; Hirabayashi, S.; Bodine, A.; Hoehn, R. Modeled PM 2 . 5 Removal by Trees in Ten U . S . Cities and Associated Health Effects. *Environ. Pollut.* 2013, *178*, 395–402.

[30] An, P.; Sun, W.; Li, G.; Tan, M.; Lai, C.; Chen, S. Characteristics of Particle Size Distributions about Emissions in a Common-Rail Diesel Engine with Biodiesel Blends. *Procedia Environ. Sci.* 2011, *11* [PART C], 1371–1378.

[31] Tang, S.; Laduke, G.; Chien, W.; Frank, B. P. Impacts of Biodiesel Blends on PM 2 . 5 , Particle Number and Size Distribution , and Elemental / Organic Carbon from Nonroad Diesel Generators. *FUEL* 2016, *172*, 11–19.

[32] Geng, P.; Zhang, H.; Yang, S. Experimental Investigation on the Combustion and Particulate Matter [PM] Emissions from a Port-Fuel Injection [PFI] Gasoline Engine Fueled with Methanol – Ultralow Sulfur Gasoline Blends. *FUEL* 2015, *145*, 221–227.

[33] Zhang, R.; Liu, C.; Hsu, P.; Zhang, C.; Liu, N.; Zhang, J. Nano Fi Ber Air Filters with High-Temperature Stability for E Ffi Cient PM 2.5 Removal from the Pollution Sources. *NANO Lett. Am. Chem. Soc.* 2016, *16* [6], 3642–3649.

[34] Ardkapan, S. R.; Johnson, M. S.; Yazdi, S.; Afshari, A.; Bergsøe, N. C. Filtration Efficiency of an Electrostatic Fibrous Filter : Studying Filtration Dependency on Ultrafine Particle Exposure and Composition. *J. Aerosol Sci.* 2014, *72*, 14–20.

[35] Giechaskiel, B.; Maricq, M.; Ntziachristos, L.; Dardiotis, C.; Wang, X.; Axmann, H.; Bergmann, A.; Schindler, W. Review of Motor Vehicle Particulate Emissions Sampling and Measurement : From Smoke and Filter Mass to Particle Number. *J. Aerosol Sci.* 2014, *67*, 48–86.

[36] Taylor, P.; Presser, C.; Conny, J. M.; Nazarian, A.; Presser, C.; Conny, J. M.; Nazarian, A. Effects on Particle Absorption Optical Properties Filter Material Effects on Particle Absorption Optical Properties. 2014, No. November, 37–41.

[37] Wardoyo, A.; P. Juswono, U.; Riyanto, S. Developing Particulate Thin Filter Using Coconut Fiber for Motor Vehicle Emission. In *AIP Conference Proceedings*; 2016; Vol. 1719, p 30043.

[38] Wardoyo, A. Y. P.; Budianto, A.; Abdurrouf. Filtration of Submicron Particles from Motorcycle Emission Using a DC Low Electrostatic Filter. *Int. J. Appl. Eng. Res.* 2017, *12* [8], 1725–1728.

[39] Wardoyo, A.; Budianto, A. A DC Low Electrostatic Filtering System for PM2.5 Motorcycle Emission. In *Conference: 2017 International Seminar on Sensors, Instrumentation, Measurement and Metrology [ISSIMM]*; 2017; pp 51–54.

[40] Verma, G.; Prasad, R. K.; Agarwal, R. A.; Jain, S.; Agarwal, A. K. Experimental Investigations of Combustion , Performance and Emission Characteristics of a Hydrogen Enriched Natural Gas Fuelled Prototype Spark Ignition Engine. *FUEL* 2016, *178*, 209–217.

[41] Yu, F. Chemiions and Nanoparticle Formation in Diesel Engine Exhaust. *Geophys. Res. Lett.* 2001, *28* [22], 4191–4194.

[42] Olcay, K.; Hikmet, T. Combustion Efficiency Analysis and Key Emission Parameters of a Turboprop Engine at Various Loads. *J. Energy Inst.* 2015, *88*, 490–499.

[43] Haiyang, H.; Qiang, W. Calculation of Wall Temperature for Aircraft Exhaust System with Considering Gas Radiation Heat Transfer. *Chinese J. Aeronaut.* 2009, *22* [6], 590–598.

[44] Choi, S.; Oh, K.; Lee, C. The Effects of Fi Lter Porosity and Fl Ow Conditions on Soot Deposition / Oxidation and Pressure Drop in Particulate Fi Lters. *Energy* 2014, *77*, 327–337.

[45] Hua, X.; Herrin, D. W.; Wu, T. W.; Elnady, T. Simulation of Diesel Particulate Filters in Large Exhaust Systems. 2013, *v*, 1326–1332.

[46] Dwyer, H.; Ayala, A.; Zhang, S.; Collins, J.; Huai, T.; Herner, J.; Chau, W. Emissions from a Diesel Car during Regeneration of an Active Diesel Particulate Filter. *J. Aerosol Sci.* 2010, *41* [6], 541–552.

[47] Tang, T.; Zhang, J.; Cao, D.; Shuai, S.; Zhao, Y. Experimental Study on Filtration and Continuous Regeneration of a Particulate Filter System for Heavy-Duty Diesel Engines. *JES* 2014, *26* [12], 2434–2439.

[48] Zhang, B.; Jiaqiang, E.; Gong, J.; Yuan, W.; Zhao, X.; Hu, W. Influence of Structural and Operating Factors on Performance Degradation of the Diesel Particulate Filter

Based on Composite Regeneration. *Appl. Therm. Eng.* 2017, *121*, 838–852.

[49] Zhang, B.; Qi, H.; Sun, S.; Ruan, L.; Tan, H. Solving Inverse Problems of Radiative Heat Transfer and Phase Change in Semitransparent Medium by Using Improved Quantum Particle Swarm Optimization. *Int. J. Heat Mass Transf.* 2015, *85*, 300–310.

[50] Taylor, P.; Cozzi, C.; Cadorin, D. Growth and Coagulation of Solid Particles in Flames. *Combust. Sci. Technol. Nucleation* , 2007, No. January 2015, 37–41.

[51] Fang, J.; Meng, Z.; Li, J.; Pu, Y.; Du, Y.; Li, J.; Jin, Z.; Chen, C.; G. Chase, G. The Influence of Ash on Soot Deposition and Regeneration Processes in Diesel Particular Filter. *Appl. Therm. Eng.* 2017, *124*, 633–640.

[52] Eeftens, M.; Meier, R.; Schindler, C.; Aguilera, I.; Phuleria, H.; Ineichen, A.; Davey, M.; Ducret-stich, R.; Keidel, D.; Probst-hensch, N.; et al. Development of Land Use Regression Models for Nitrogen Dioxide , Ultrafine Particles , Lung Deposited Surface Area , and Four Other Markers of Particulate Matter Pollution in the Swiss SAPALDIA Regions. *Environ. Heal.* 2016, 1–14.

[53] Fino, D.; Bensaid, S.; Piumetti, M.; Russo, N. Applied Catalysis A : General A Review on the Catalytic Combustion of Soot in Diesel Particulate Filters for Automotive Applications : From Powder Catalysts to Structured Reactors. *Appl. Catal. A Gen.* 2016, *509*, 75–96.