Measurement and Analysis of PM Particles Emitted by Automotive Brakes

Emil Iontchev[1], Rosen Miletiev[2], Rumen Yordanov[3] and Ilian Damyanov[4]

Abstract – **All vehicles emit fine particles into the air during the braking due to the tyres and brakes friction. The brakes may be the most significant particulate matter (PM) contributor, especiallyin places with a high traffic density and braking frequency. As the PM particles are associated with different respiratory symptoms even sometimes with a premature death it is important to analysed the PM emitted by the automotive brakes and their distribution from PM0.3 to PM10. The current paper discusses the measurement and analysis of the PM particle sizes from 0.3μm to 10μm during the slow down process, their time and size distribution according to the brake intensity.**

Keywords – **Brakes, Fine particles, Particle distribution.**

I. Introduction

The particulate matters (PM) are divided into three categories– coarse (diameter of between 2.5μm and 10μm), fine (0.1 to 2.5μm in diameter) and ultrafine (<0.1μm in diameter) particles [1]. The particles over 10μm in diameter are efficiently filtered in the nose while the particles below <0.1μm in diameter directly pass to the blood steam through the alveoli. The particles less than 2.5μm in diameter are associated with respiratory problems while the particulate matter particles with diameter between 2.5 and 10 μm are responsible for asthma symptoms, eye and lung problems and premature death [2]. At presentthe real-time PM counting methods are based on light scattering or absorption processes. The most of the commercial low-cost PM counting sensors have the typical accuracy from 10 to 15% [3-5] and may separate the above mentioned PM groups. The comparison study of some PM sensor performance was established at [6].

The vehicles are one of the major source of PM particles due to the tyres and brakes friction [7]. A recent review shows that brake-wear emissions are more than50% by mass of total non-exhaust traffic-related PM10 emissions and up to 21% by mass to total traffic-related PM10 emissions [8]. But most of the studies concern the particles with diameter over 2.5μm while the emission of fine and ultrafine particles are still poorly studied.

The current paper discusses the measurement and the analysis of the brake particle emissions during the slow down processes with diameter from 0.3μm to 10μm. In the same time a temperature monitoring of the rotation disk is accomplished to measure the thermal heating using the thermal imaging estimation method [9]. The analysis shows the particle concentration of all three PM categories and particle count @ 0.1L air for six different particle sizes – from 0.3μm to 10μm.

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II. PM Measurement Method

The particulate matter emission measurements are implemented on the front disc brakesof passenger vehicleas the braking force is greater than the rear wheels.As the brake particles are evolved during the braking process, the particle movement direction is expected to lieinto the coarse size fraction [8], the PM sensor input is positioned under the brake shoes to collect the maximum portion of the emitted particles (Fig. 1). The tire is also removed as the air ventilation during the disk rotation scatters the brake wear particles.

Fig. 1. Particulate measurement method and assembly

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The particulate matter are measured using a low-cost sensor type CP-15-A4-CG, which is commercial grade laser-based sensor with digital outputs (UART and PWM) (Fig. 2). The measurement range is defined as 0.3-10µm, TTL 3.3V level outputs, 3s response time and PM2.5 consistency of ±10µg/m^3 or ±10% [10]. The declared degree of the approximation to the professional instrument is equal to 98%.

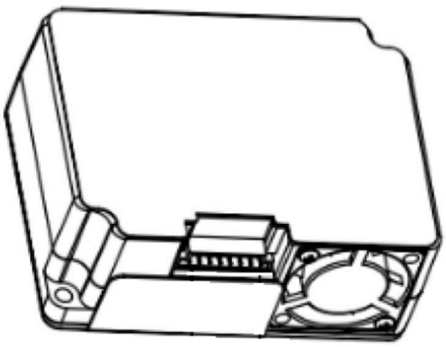

Fig. 2. PM sensor type CP-15-A4-CG

The PM sensor is connected to USB port via TTL to USB converter and the sensor is powered from USB port as the maximum sensor power consumption not exceeded 100mA. The sensor measurement packets are captured, recorded and analyzed by PM measurement tool (Fig. 3) specially designed tool at MATLAB environment on virtual COM port, which is created by the TTL/USB converter.

Each measurement data are saved as HEX values (RAW format) and stored in a TXT file (decoded format) using CSV format:

- Time (seconds from start recording)
- PM1.0 (µg/m^3)
- PM2.5 (µg/ m^3)
- PM10 (µg/ m^3)
- particles 0.3µm @ 0.1L air
- particles 0.5µm @ 0.1L air
- particles 1.0µm @ 0.1L air
- particles 2.5µm @ 0.1L air
- particles 5.0µm @ 0.1L air
- particles 10µm @ 0.1L air

The measurement process is initiated by selecting the real or virtual COM port from “Serial port:” menu and open it by clicking on OPEN button. As the connections is established, the recording process is started when the START button is pressed the system shows the recording time in “Scan time” field. The recording process is finished when the STOP button is pressed and the PM graphics may be generated by clicking on “Data analysis” button. During the measurement the real-time values of the PM concentrations and particle numbers are shown in the corresponding field in the tool.

As the recording process is accomplished the disk thermal image is made by FLIR camera installed laterally to the rotation disk.

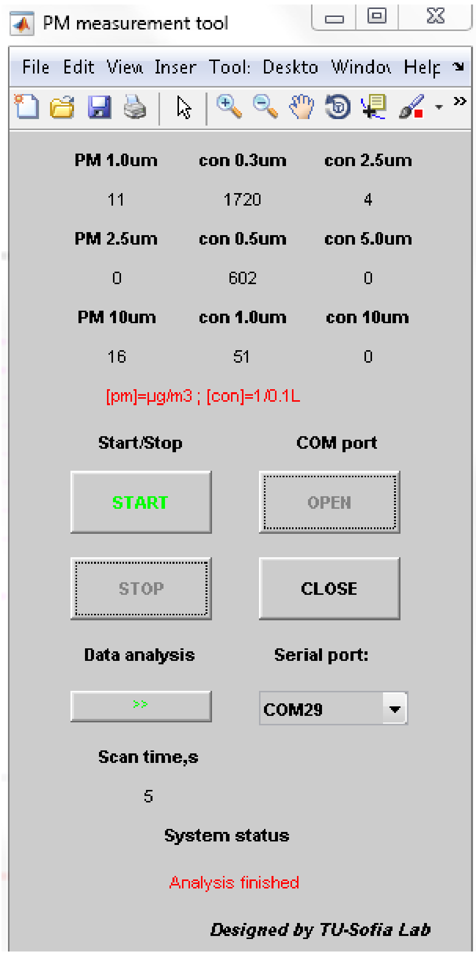

Fig. 3. Measurement and recording tool

III. Experimental Results and Analysis

The PM measurements are accomplished using different situations:

- Test 0 - no brakes
- Test 1 – speed 40km/h, 3-th gear, no blocking brakes, low load slow down
- Test 2 – speed 40km/h, 3-th gear, blocking + no blocking brakes
- Test 3 – speed 30km/h, continuous brake, slow stop
- Test 4 – speed 50km/h, high load slow down
- Test 5 – speed 60km/h, extremely high load slow down

The first test (Test 0 – no brakes) is performed to measure the PM levels in the test environment and compare the levels with the other experimental results. The measured PM concentrations are as follows PM1.0 = 34 (µg/m^3), PM2.5 = 38(µg/m^3), PM10 = 53 (µg/m^3), while the particle numbers @ 0.1L air are equal to 5500 (0.3µM), 1925 (0.5µM), 165 (1.0µM), 13 (2.5µM), 1 (5.0µM), 2 (10µM).

Fig. 4 represents the PM concentrations during the tests from Test 1 (case a) to Test 5 (case e), while Figure 5 represents the particle count @ 0.1L air during the tests from Test 1 (case a) to Test 5 (case e).

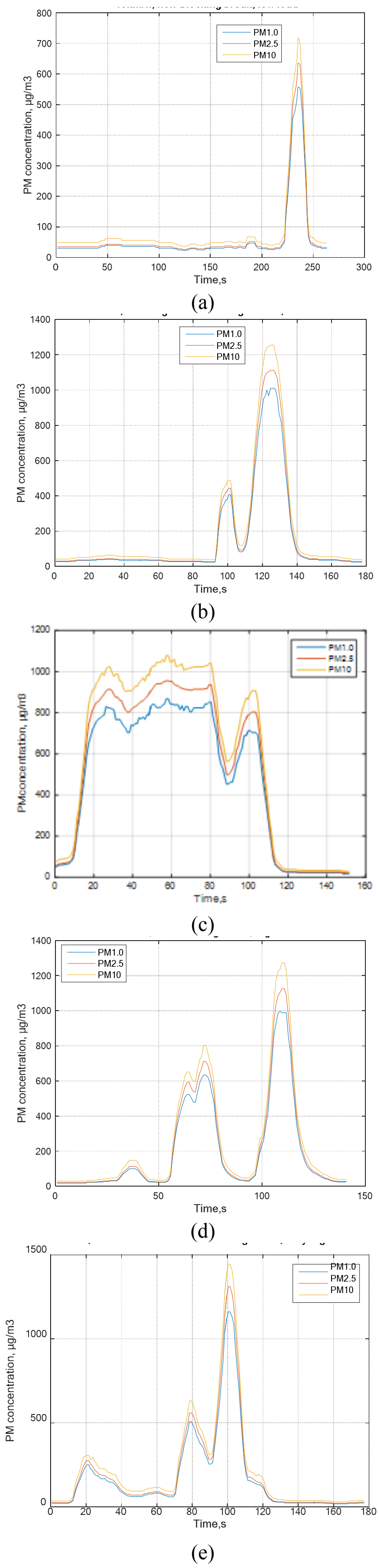

Fig. 4. PM concentration for Test 1÷5

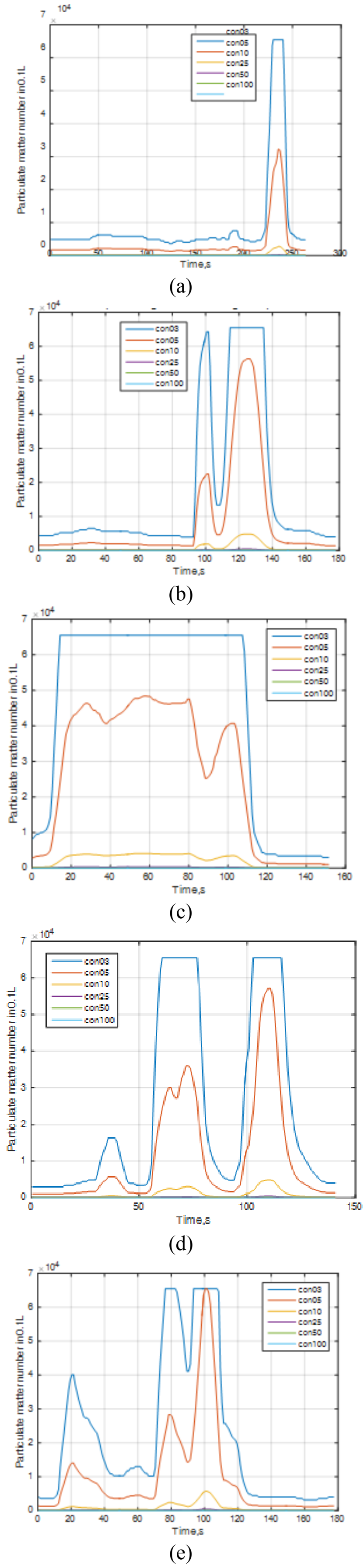

Fig. 5. Particle count @0.1L air for Test 1÷5

The PM measurements shows that during the slow down process the particle concentrations rise significantly from 50µg/m^3 (Test 0 levels) to approximately 1500µg/m^3 and remain at the constant levels during the slow down duration (Fig. 4*c*) for all particle sizes. The PM10 particles are dominant but PM1.0 and PM2.5 concentrations exceeded 15-20 times the Test 0 levels.

The particle count analysis shows that the particle numbers are also changed dramatically during the slow down process. The number of the smallest size particles (below 0.5µm) exceeded the sensor measuring range of 65535 particles (the particle number is sent as a 16bit value) in all cases especially during the continuous time braking (Fig. 5*c*).

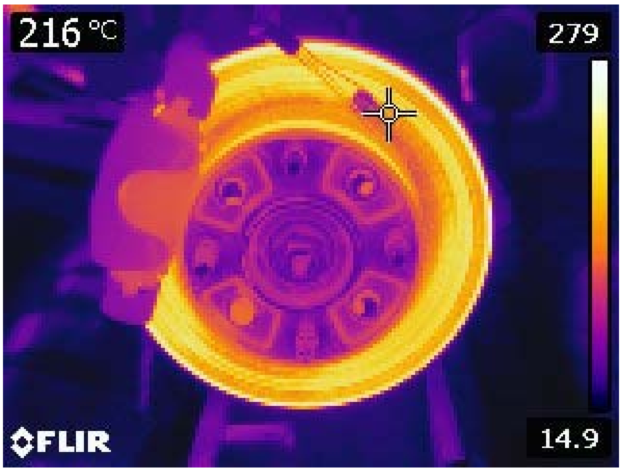

Fig. 6. FLIR thermal image of the rotating disk

The FLIR thermal image of the rotation disk at the end of the experiments shows significant rise of the disk surface temperature to 216ºC due to the friction. Therefore the complete particle analysis also requires to take into account not only the distribution of the particles according to their size but also the high process temperature and possible chemical compounds used in the rotation disk and brake shoes production process as the metal and fiber particles may have different influence on the human health.

IV. Conclusion

The experiment results represent that the braking process emits significant number of particulate matters of all sizes which are associated with asthma and respiratory symptoms. Therefore the emitted PM particles, particularly in urban environments and major cities, may cause several lung problems and their emissions have to be reduced significantly by adding the particle collecting system to the automotive construction.

Acknowledgement

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References

[1] J. Thongplang, "Particulate Matters: Why Monitor PM_{10} and $PM_{2.5}$?", Last Updated: Dec 19, 2018.

[2] M. Morais-Almeida, N. Santos, A. M. Pereira, M. Branco-Ferreira, C. Nunes, J. Bousquet, and J. A. Fonseca, "Prevalence and Classification of Rhinitis in Preschool Children in Portugal: a Nationwide Study", Allergy, vol. 68, no. 10, 1278-1288, 2013.

[3] P. Kumar, L. Morawska, C. Martani et al., "The Rise of Low-Cost Sensing for Managing Air Pollution in Cities", Environment International, vol. 75, pp. 199-205, 2015.

[4] E. G. Snyder, T. H. Watkins, P. A. Solomon et al., "The Changing Paradigm of Air Pollution Monitoring", Environmental Science & Technology, vol. 47, no. 20, pp. 11369-11377, 2013.

[5] N. Castell, F. R. Dauge, P. Schneider et al., "Can Commercial Low-Cost Sensor Platforms Contribute to Air Quality Monitoring and Exposure Estimates?", Environment International, vol. 99, pp. 293-302, 2017.

[6] M. Badura, P. Batog, A. Drzeniecka-Osiadacz, and P. Modzel, "Optical Particulate Matter Sensors in $PM_{2.5}$ Measurements in Atmospheric Air", 10th Conference on Interdisciplinary Problems in Environmental Protection and Engineering EKO-DOK, vol. 44, 2018.

[7] A. Thorpe, R. M. Harrison, "Sources and Properties of Non-Exhaust Particulate Matter from Road Traffic: A Review", Sci. Total Environ., vol. 400, Issues 1-3, August 2008, pp. 270-282.

[8] T. Grigoratos, G. Martini, "Brake Wear Particle Emissions: A Review", Environ Sci Pollut Res, vol. 22, 2015, pp. 2491-2504.

[9] S. Pleshkova, A. Bekiarski, and K. Peeva, "Testing Thermal Images Characteristics for Thermal Images Quality Estimation", Latest Trends on Systems – Volumes I & II, Proceedings of the 18th International Conference on Systems, (part of CSCC '14), Santorini Island, Greece, July 17-21, 2014, pp. 251-256.

[10] http://yeetcen.youhaovip.com/products/p000006 - A4 CG Laser PM2.5 Sensor description, accessed 10.2019