CONEM 2016 CONGRESSO NACIONAL DE ENGENHARIA MECÂNICA
21 - 25 AGOSTO DE 2016 FORTALEZA - CEARÁ
ABCM 40 anos Associação Brasileira de Engenharia e Ciências Mecânicas

LOGNORMAL ANALYSIS OF DIESEL EXHAUST FROM A LOW COST METHOD TO GRIP PARTICLES

Fábio César Miranda de Oliveira, fah_hc@hotmail.com[1]
Daniel Mousinho Lago, danielm.lago@yahoo.com.br[1]
Antônio Adalberto Cavalcante Moreira Filho, adalbertocmoreira@gmail.com[1]
João Telésforo Nóbrega de Medeiros, jtelesforo@yahoo.com[1]
Manoel Fernandes Oliveira Filho, manoel.fernandes@ifrn.edu.br[1,2]

[1]Federal University of Rio Grande do Norte, Avenida Senador Salgado Filho, 300 - Lagoa Nova, CEP 59078-970, Natal/RN,
[2]Federal Institute of Rio Grande do Norte, Avenida Senador Salgado Filho, 1559 - Tirol, CEP 59015-000, Natal/RN.

Abstract: *Particulate matter of diesel engine exhaust causes several impacts in the optical properties of air, atmosphere chemistry and human health. These impacts are related to particulate shape, composition and size. This study analyze the evolution of particulate size through a lognormal distribution using a low cost approach to grip the particulate matter. A blend of S10 diesel oil and 6% biodiesel was employed as fuel. The data base created by SEM (Scanning Electron Microscopy) and microanalysis by EDS (Energy Dispersive X-Rays Spectroscopy) fit very good as a lognormal distribution. The results expose an increase of the particles size mainly after the first 20 hours, this behavior is accompanied by a reduction of wear rate attributed to the decrement of aluminum and silicon concentration.*

Keywords*:* *Particulate matter, Biodiesel, Lognormal, Environmental health.*

1. INTRODUCTION

Particulate matter (PM) produced by diesel engines exhaust causes several impacts on the environment and on the human health. PM is made mainly of non-combustible fraction, the carbonaceous fraction, soot and ash (Liati et al., 2012). The inspiration of PM can result in heart problems, lung diseases, cancer and elevated blood pressure (Ushakov et al. 2013). Recently, much attention has been given to the influence of very small particles on this problems, mainly particles above 10 µm (PM10). A lot of studies concerns are associated to PM10 seize distribution, surface area and chemical composition. Surface area have a strong importance in this problem because chemical reactions in the atmosphere and human body depends on it. It is important to realize the mechanism of lung injury caused by ultrafine particles is a result of a large surface area for the release of transition metals (Brown et al, 2001).

To protect the human health, government programs stipulate PM emission limits, the objective is through the technology development in engine design, materials and fuel reduces PM emissions. These programs regulate limits on mass particulate emitted, which usually does not include PM10 with less mass. The number of particles and particle surface area per unit mass increases with decreasing particle size. In this scenario, biodiesel is a promising fuel for the reduction of carbon monoxide, unburned hydrocarbon and PM emissions, but increase NOx (Chuepeng et al., 2011).

Measurement of PM10 at these levels requires sensitive measurement procedures, the methods used to this are too expensive, furthermore, most of them analyze only the particles size distributions, which are considered as a sphere. Particles between 5 and 50 nm diameter are agglomerated into aggregates which may have different formats. Exhaust filters may be used to capture diesel particulate emissions and subsequently taken under microscope, showing different size depending on the engine performance. The particles distributions are trimodal, lognormal in form. Lognormal distributions usually fit actual data very well (Bartoletti and Loperfid, 2010).

The present research has carried out a more detailed investigation into the PM number and surface area distribution using a low cost method to grip particles. The nature of particles is described and specific mechanisms of their possible formation are discussed.

2. MATERIALS AND METHODS

The engine used for the tests is a single-cylinder, four stroke, air-cooled, direct injection stationary diesel engine Branco model BD-5.0, 5 hp. The scheme of the experimental test is presented in Figure 1. Constant load of 333W was applied to the engine through a synchronous generator Kohlbach and a rotation of 2600 ± 100 cpm was maintained in all tests.

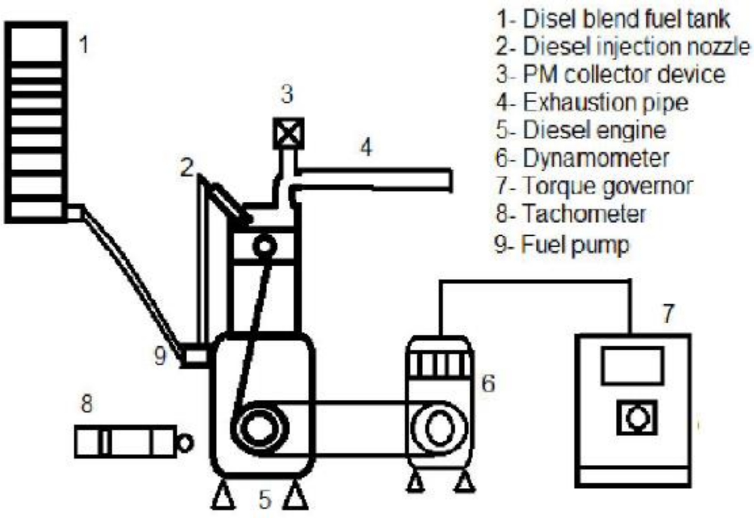

Figure 1. Scheme of the experimental test.

A blend of S10 diesel oil and 6% biodiesel acquired in a Brazilian gas station was used in all the tests. A textile element was encapsulated into a device built to this purpose which is attached to the engine's exhaustion pipe (Figure 2). The device is placed as close as possible of the cylinder's discharge, assuring that no PM will be lost by the sample. Emission gases were collected in a new textile collector each time at a rate of one sample by hour. The samples were analyzed by SEM images and x-ray diffraction to check the efficiency of the method. The textile element has elliptical holes with approximately 4 µm (Figure 3).

Figure 2. Textile element encapsulated into a device.

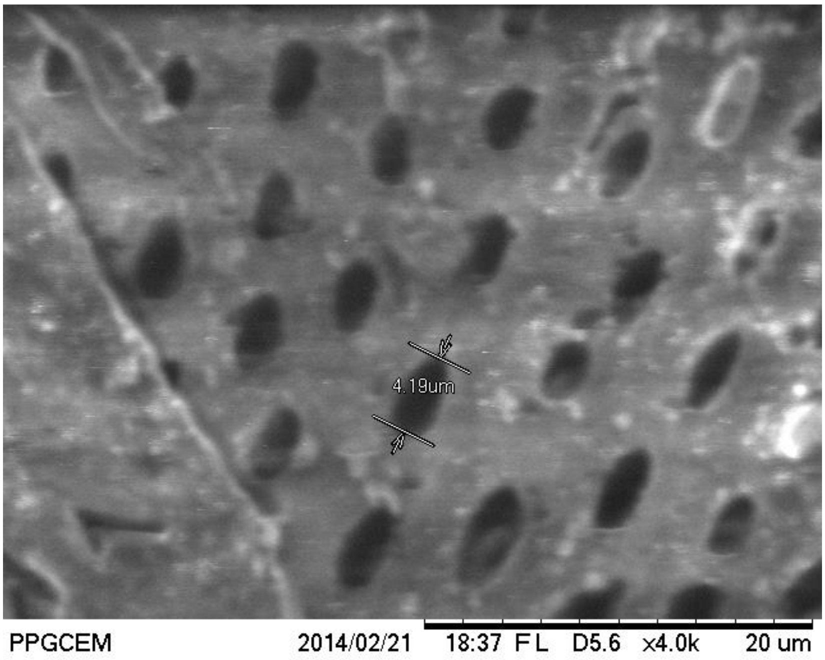

Figure 3. Textile element with elliptical holes.

The images of collected particles were analyzed, and measured with the image software ImageJ, a public domain Java image processing program. All the images have the same area, 7,22 ($x10^3$ μm^2). The statistical dimension of PM in a textile element image from biodiesel engine was the focus of this work.

The tests were performed in the Tribology and Structural Integrity Studies Group of Federal University of Rio Grande do Norte, in partnership with the Research and Teaching Nucleus of Oil and Gas (NUPEG-UFRN).

3. RESULTS AND DISCUSSIONS

The images sampled after 20 hours are showed in Figure 4. Particles presented in Figure 4 have nonhomogeneous aspects of size and shape. The patterns of shape show smaller particles with spherical outlines, others with random outlines and smooth surfaces. The largest particles, above 10 µm, have irregular shapes and surfaces, with some scratches. Considering that presented irregularities, the surface area distribution is an important parameter related to the toxicity of the particulate (Brown et al, 2001). Figure 5 presents the surface area distribution after 20 hours of test, the lognormal distribution gives a very good fit to the data.

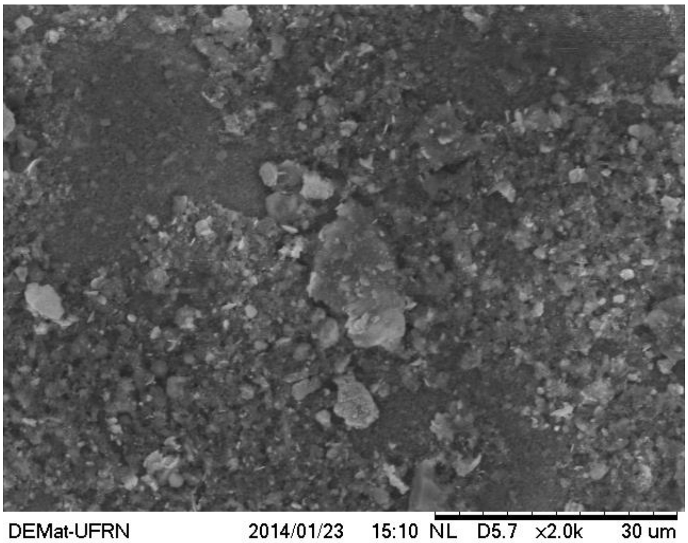

Figure 4. PM sample collected from after 20 hours.

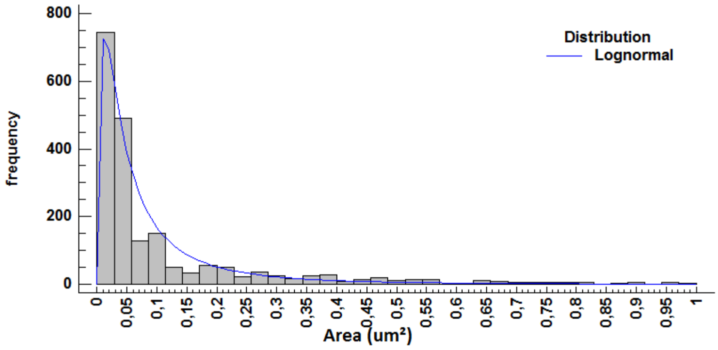

Figure 5. Surface area distribution after 20 hours.

After 130 hours a new sample was collected (Figure 6). The particles agglomerates are bigger and the number of particles collected was about ten times lower than the test after 20 hours. Figure 7 shows the surface area distribution at the Figure 6 sample, the curve behavior showed greater fluctuations.

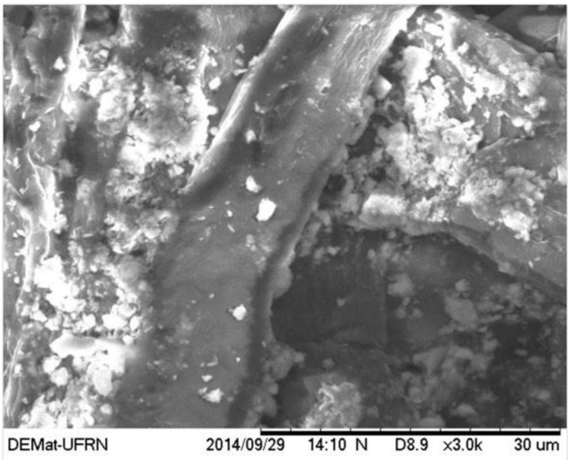

Figure 6. PM sample collected from after 130 hours.

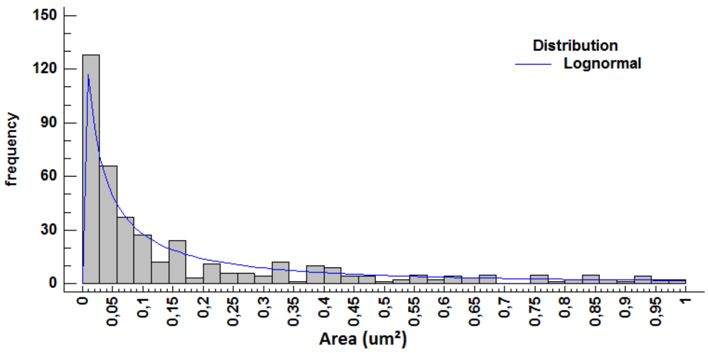

Figure 7. Surface area distribution after 130 hours.

Graphic asymmetry of two samples may indicate that smaller particles passed through the holes of the textile element, thus were not captured by the image. The particle numbers of the exhaust aerosol from 20 hours sample are much higher for smaller diameters (nuclei mode) compared to the other image. It is clearly shown that the particle area concentrations and shape are dependent of engine operating time condition. For particles with size between 0.1 and 10 µm diameter range a residence time in the atmosphere about one week (Kittelson, 1998). For the most of the particles with circumferential shape detected on the test, this diameter corresponds to an area between 0,008 and 78, 5 µm^2. For particles above 10 nm, the residence time is about 15 min (Harrison, 1996). These tiny particles are removed by coagulation with particles in the accumulation mode with larger size.

The behavior of 20 hours sample is accompanied by high concentrations of aluminum and silicon debris, showing the relation between the number of particles emitted and the engine wear (Table 1). For the wear debris classification, the most relevant features include: size, shape, surface texture, edge detail, thickness ratio, and also the color of the debris. Although the wear regime can be described by analyzing the size parameters and size distribution, for the wear mechanism that generates the particles, the shape analysis is required (Raadnui, 2005). The wear debris present in PM have irregular shapes. The parameters associated to the debris' shape only provide initial information about different particle types and the wear mechanisms. This way, a more detailed shape analysis in the form of edge detail characteristic is required (Raadnui, 2005). Also, the presence of sulfur leads to the formation of sulfuric acid and a stronger corrosive wear in the engine.

Table 1. 20 hours sample description.

Element	Weight %	Weight % σ	Atomic %
Aluminum	38.494	15.763	42.159
Silicon	32.734	14.821	34.441
Phosphorus	7.766	18.007	7.409
Sulfur	15.242	13.041	14.048
Strontium	5.764	27.385	1.944

After 130 hours of test, the PM shows a strong tendency to accumulate in brittle agglomerates, varying in size of one order magnitude. The wear mechanism is less severe and chemical processes taking place in a fully developed burning plume in the cylinder (Table 2). The hypothesis for the elevate level of carbonaceous particles is that they are formed during combustion and most of them are oxidized. In addition, lubricating oil may infiltrate into combustion chamber and form carbonaceous particles as combustion products (Kittelson and Kraft, 2014). The presence of calcium is an evidence that metallic additives in the lube oil may be converted to gas-phase compounds, and then, converted from gas to particle due to the expansion and cooling processes of the combustion gases (Kittelson and Kraft, 2014). The oil infiltration in the combustion chamber can contribute to form more carbon particles as combustion products.

Table 2. 130 hours sample description.

Element	Weight %	Weight % σ	Atomic %
Carbon	81.569	1.372	86.159
Oxygen	16.806	1.390	13.327
Calcium	1.621	0.079	0.513
Manganese	0.004	0.059	0.001

4. CONCLUSIONS

Although this investigation is based on a relatively limited sample is possible to realize that this new approach to grip the PM emitted by a diesel engine using textile sheets is efficient. The following conclusions are drawn:

1. After 20 hours PM have nonhomogeneous aspects of size and shape;
2. The PM nonhomogeneous aspects show the need to analyze the surface area distribution, because it is an important parameter related to toxicity of the particle;
3. The lognormal distribution gives a very good fit to the surface area of PM and can be used for future analysis;
4. The lognormal graphic asymmetry may indicate that smaller particles passed through the holes of the textile element, thus were not captured by the image, this shows that the engine produces particles with smaller area than 0,003 μm^2;
5. 20 hours sample showed particles very dispersed and with characteristics of different wear mechanisms, this behavior can be the main cause the total number of small particles to be one magnitude above the sample of 130 hours;
6. For a better understanding of the wear mechanisms a more detailed shape analysis in the form of edge detail characteristic is required;
7. 130 hours sample shows less wear debris and the particles form more agglomerates, further analyzes are required for a better understanding of the behavior;
8. The entrained of lubricating oil into burning fuel is evidenced by the presence of calcium, this factor can contribute to the increase in carbon content as a product of combustion.
9. For more representative data, is necessary a larger number of samples in a shorter time interval.

5. REFERENCES

Bartoletti, S. and Loperfido, N., 2010, “Modelling air pollution data by the skew-normal distribution”, Stochastic Environmental Research and Risk Assessment, v. 24, n. 4, p. 513–517.

Brown, D. M. et al., 2001, “Size-dependent proinflammatory effects of ultrafine polystyrene particles: a role for surface area and oxidative stress in the enhanced activity of ultrafines", Toxicology and applied pharmacology, v. 175, n. 3, p. 191–199.

Chuepeng, S. et al., 2011, "Particulate Matter size distribution in the exhaust gas of a modern diesel Engine fuelled with a biodiesel blend", Biomass and Bioenergy, v. 35, n. 10, p. 4280–4289.

Harrison, R. M., 1996, "Airborne particulate matter in the United Kingdom, third report of the quality of urban air review group", The University of Birmingham, Edgbaston, England.

Kittelson, D. B., 1998, "Engines and nanoparticles: A review. Journal of Aerosol Science", v. 29, n. 5-6, p. 575–588.

Kittelson, D. and Kraft, M., 2014, "Particle Formation and Models in Internal Combustion Engines", Como.Cheng.Cam.Ac.Uk, n. 142.

Liati, A. et al., 2012, "Investigation of diesel ash particulate matter: A scanning electron microscope and transmission electron microscope study", Atmospheric Environment, v. 49, p. 391–402.

Raadnui, S., 2005, "Wear particle analysis-utilization of quantitative computer image analysis: a review", Tribology International, Vol. 38, pp. 871-8.

Ushakov, S. et al., 2013, "Particle size distributions from heavy-duty diesel engine operated on low-sulfur marine fuel" Fuel Processing Technology, v. 106, p. 350–358.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.

ANÁLISE LOGNORMAL DA EXAUSTÃO DIESEL ATRAVÉS DE UM MÉTODO BAIXO CUSTO PARA CAPTURAR PARTÍCULAS

Fábio César Miranda de Oliveira, fah_hc@hotmail.com[1]
Daniel Mousinho Lago, danielm.lago@yahoo.com.br[1]
Antônio Adalberto Cavalcante Moreira Filho, adalbertocmoreira@gmail.com[1]
João Telésforo Nóbrega de Medeiros, jtelesforo@yahoo.com[1]
Manoel Fernandes Oliveira Filho, manoel.fernandes@ifrn.edu.br[1,2]

[1]Universidade Federal do Rio Grande do Norte, Avenida Senador Salgado Filho, 300 - Lagoa Nova, CEP 59078-970, Natal/RN,
[2]Instituto Federal do Rio Grande do Norte, Avenida Senador Salgado Filho, 1559 - Tirol, CEP 59015-000, Natal/RN.

Resumo: *Material particulado da exaustão de motores diesel causam impactos severos nas propriedades opticas do ar, na química da atmosfera e na saúde humana. Esses impactos estão relacionados ao formato, composição e tamanho da partícula. Esse estudo analisa a evolução do tamanho das partículas através de uma distribuição lognormal utilizando um dispositivo de baixo custo para capturer partículas. Uma mistura de óleo diesel S10 e 6% de biodiesel foi utilizado como combustível. A base de dados criada por MEV (Microscopia Eletrônica de Varredura) e microanálise por Espectroscopia de Raios X por Dispersão em Energia (EDS) obtiveram um bom encaixe em uma distribuição lognormal. Os resultados mostram um aumento no tamanho das partículas após as primeiras 20 horas, esse comportamento é acompanhado pela redução na taxa de desgaste atribuída a diminuição na concentração de alumío e silício.*

Palavras-Chave: *Material particulado, Biodiesel, Lognormal, Saúde ambiental.*