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Paper/Poster-Abstract Form

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Title: Agglomeration Inducing Exhaust Pipe / impact on particle number and morphology

Abstract: (min. 300 – max. 500 words)

The abstracts for papers and posters must contain unpublished information on your research subject: background, investigation methods, results and conclusions. Graphs and references are very welcome. Acronyms should be avoided. Abstracts with < 300 words can not be considered. General information on products which are already commercially available can not be accepted as presentations for the conference but are very welcome at the exhibition of particle filter systems and nanoparticle measurement instruments.

The research and theorization of sub-micron particle grouping and agglomeration was started by Katoshevski and co-workers in 1995, and reached conclusive empirical bench tests on diesel engines in 2007.
The PEMRED concept is based on the above research and enhances particle grouping, leading to their coagulation and hence to a shift in the size distribution. Small particles in the nanometre and micron range have a higher tendency to group in specific conditions, and the PEMRED pipe is manipulating the operating conditions in the exhaust line accordingly. This is achieved by an engine-specific exhaust geometry which leads to the desired outcome - the formation of larger particulates and a decrease in the total particle number, reducing the PN by 50% and beyond.
The PEMRED project began in 2012 with the aim to apply the concept to internal combustion engine emissions, in automotive and stationary applications. During 2012, the PEMRED team applied and tested the concept on a Gasoline Direct Injection car. A second campaign used a bench-mounted diesel engine to investigate the particles evolution along the exhaust system. Building upon the knowledge acquired in these campaigns, a third one worked on a bus (heavy duty diesel engine) equipped with a PEMRED prototype and combined two complementary analysis methods – particle count and morphological study - sampling particles from the entire length of the exhaust system and analyzing the samples with a particle counter and with an electrons microscope.
The present poster highlights the results and conclusions of this research, which is of high relevance to the introduction of the EURO 6 PN regulations.
EURO 6 in fact acknowledges the excellent performance of DPF's in limiting emitted particles mass, shifting the focus to the highly toxic effects of the numerous ultrafine particles which continue to be emitted by Diesel and GDI engines alike. The results obtained by the PEMRED team imply that the Agglomeration Inducing Exhaust Pipe reduces the particles quantity to a

compliance level, paving the way for much cleaner and less toxic Internal Combustion engines and vehicles.

Main conclusions:

- The grouping effect impacts exhaust particles for wide range of particle sizes, from the nano-meter scale and up to the micron scales. The effect was observed in raw diesel emissions rich in micron-scale particles as well as in catalyzed GDI emissions containing mostly ultrafine particles.
- For a given engine, the agglomeration is more intensive in higher particle concentrations.
- The grouping effect is resilient to changes in the exhaust flow rate – similar results were observed in stabilized and transient engine operations.
- Nucleation of particle precursors is very significant along the exhaust system, and the ability to distinguish between the particulate types (toxic vs. non-toxic) is critical when it comes to regulatory compliance measures.

REFRENCES:

Katoshevski, D., Ruzal, M., Shakked, T., & Sher, E. (2010a). Particle grouping, a new method for reducing emission of submicron particles from diesel engines. *Fuel*, 89, 2411-2416.

Short CV:

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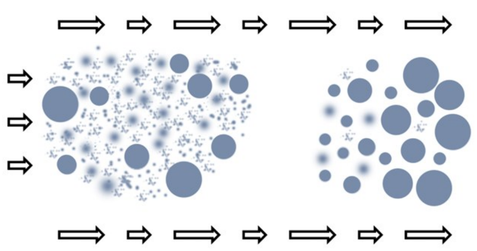
Agglomeration Inducing Exhaust Pipe / impact on particle number and morphology

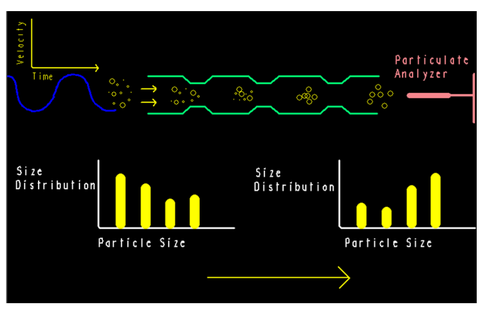
Michal Ruzal-Mendelevich, David Katoshevski, Eran Sher (Ben-Gurion University of the Negev, Israel), and Avigdor Luttinger (PEMRED)

Grouping Theory[1]

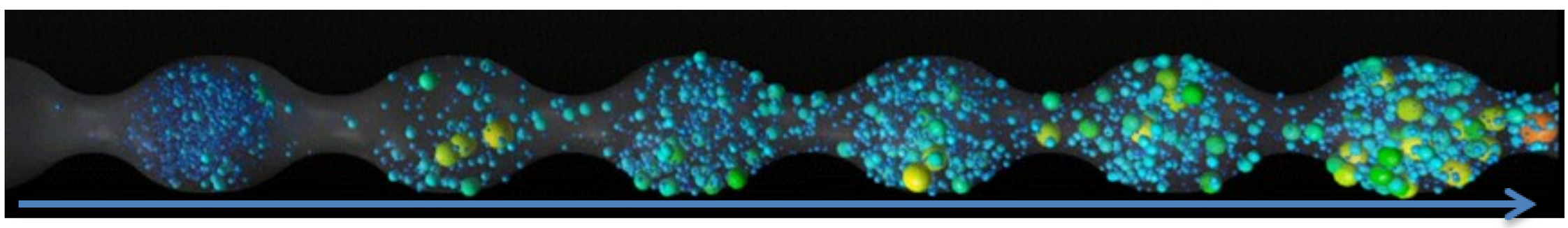


Small particles in the submicron-size range have a higher tendency to group when they are in oscillating flows (the Grouping effect). Upon collision, sticky exhaust particles agglomerate and coagulate. The Grouping effect enhances ultrafine particles coagulation, agglomeration and adhesion, which shifts the size distribution; the nano-scale particles are induced to group and to cluster, resulting in fewer larger particulates.

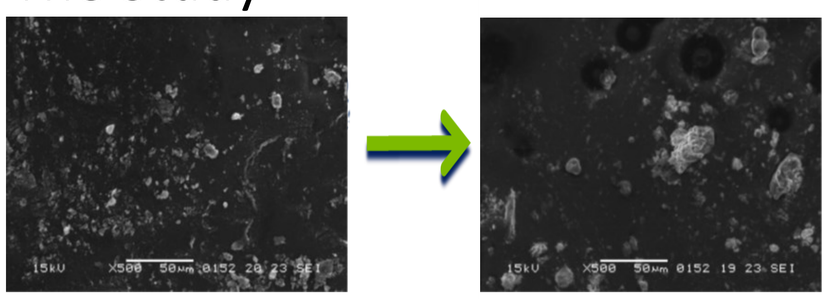
Validation in IC[2]



A wavy Exhaust Pipe segment of 50cm-100cm length which has a specific geometry as a function of engine characteristics, creates precisely tuned oscillating flows in the exhaust system. The geometry is determined for each engine type with the help of mathematical modeling and computer simulations. While passing through the pipe, particles collide and stick together due to chemical and electrical forces, forming agglomerates. The resulting reduction in particle count (PN) enables EURO 6 compliance without additional filtering.



The Study



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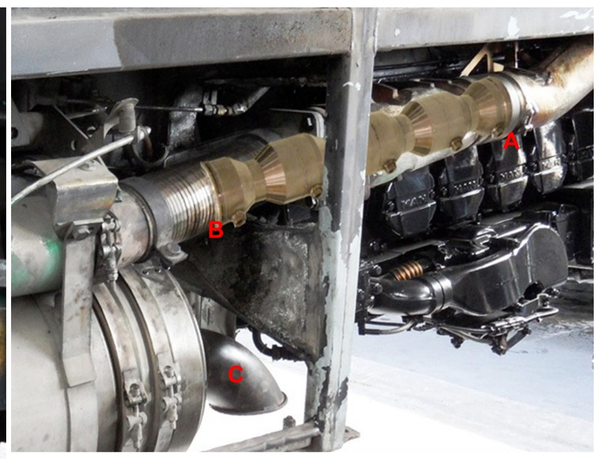
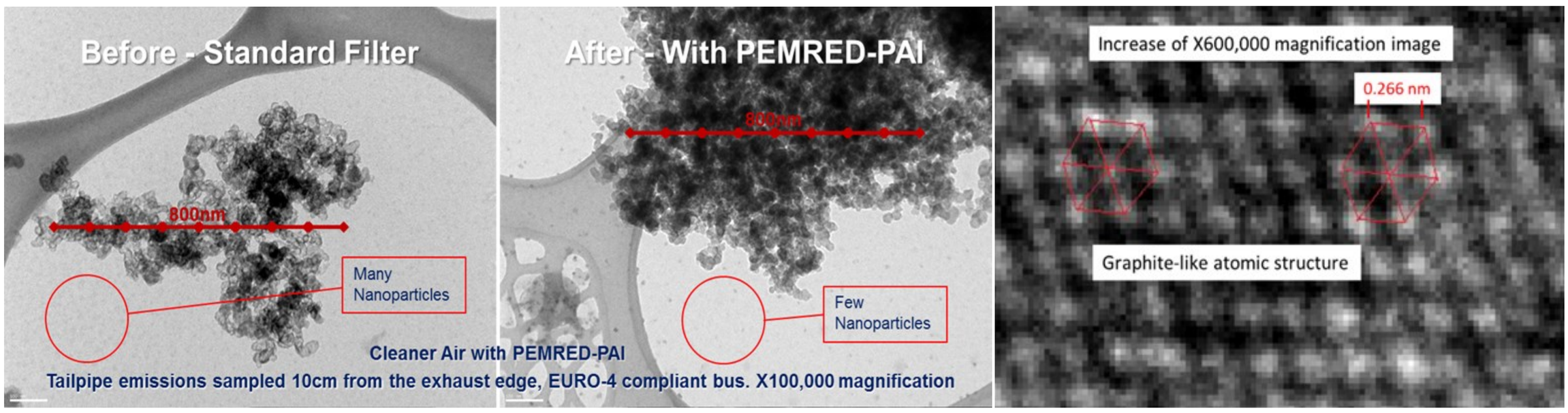


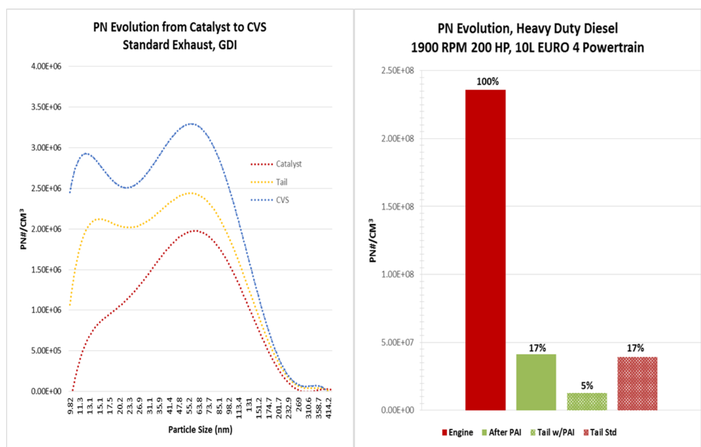
Measurement points:
A – Before PAI, B – After PAI before PM-CAT, C- Tailpipe

The Results



- After being grouped in agglomerates, particle sintering takes place – it is a slower process that avoids disintegration after emission into the atmosphere.
- These sequential processes explain the agglomerate surface changes observed between the beginning and exit of the exhaust pipe.
- The Graphite-like structures imply a carbon content of the particles with possible oxygen and other elements, typical of soot.

This study strongly supports the effectiveness of PEMRED-PAI in agglomerating soot nanoparticles and reducing their number in a persistent manner.



[1] Katoshevski, D., Dodin, Z. and Ziskind, G. (2005), Aerosol Clustering in Oscillating Flows:Mathematical Analysis. *Atomization and Sprays,* 15:401-412 .

[2] [Katoshevski, D., Ruzal, M., Shakked, T., & Sher, E. (2010). Particle Grouping, A New Method for Reducing Emission of Submicron Particles from Diesel Engines. Fuel, 89,