A new exhaust methodology for decreasing combustion generated nanoparticle emissions

Michal Ruzal-Mendelevich[1], David Katoshevski[1], Eran Sher[2], and Avigdor Luttinger[3]
[1] Environmental Eng. Unit, Ben-Gurion University of the Negev , Israel
[2]Department of Mechanical Eng. Ben-Gurion University of the Negev , Israel
[3]PEMRED, Switzerland

There is a growing concern regarding the adverse health effects of Diesel PM emissions, in particular in the sub-micron range. Since the efficiency of particle deposition in the respiratory tract is a function of particle size - and so is their residence time in the air, the smaller the particle is, the higher the risk it presents. The most efficient after-treatment device presently available is the DPF. The effectiveness of the filters is predominantly determined by the size of the pores and therefore the filters are less efficient in capturing nanoparticles. Hence, a shift in the size distribution that will increase the number of larger particles at the expense of much less of very small ones would be very desirable.

"Particle Grouping" achieves this shift. Particle-Grouping (illustrated in figure 1) is a tendency of very small particles (mostly in the range of 10 – 500 nanometer) to group due to oscillations in the flow, coagulate and form large particulates. The mathematical basis of the Grouping Theory was developed by Katoshevski and co-workers and applied successfully in several systems, such as motion of sediments in water and fuel-spray dynamics **[1-2]**

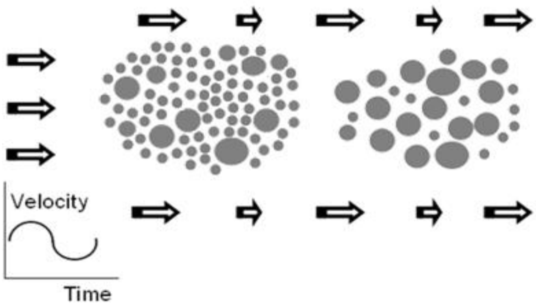


Figure 1- *Grouping of particles in an oscillating flow. The oscillations are in time and in space. The arrows mark downstream velocity variation. Grouping leads to coagulation and reduce the number of smaller particles.*

The mathematical basis was already described in several previous studies [3,4], while here we focus on new results of both the simulations and experiments.

The numerical analysis has concluded that in order to ensure enhanced grouping, one should account on one hand for the engine and exhaust flow characteristics and on the other hand design the exhaust pipe geometry in a tailor-made manner. Figure 2 shows an example of a calculation of particle trajectories as they are in motion through the tailored exhaust system. One can clearly notice the convergence of the trajectories (in the darker area) which implies that the small particles are in the process of grouping which leads to their coagulation.

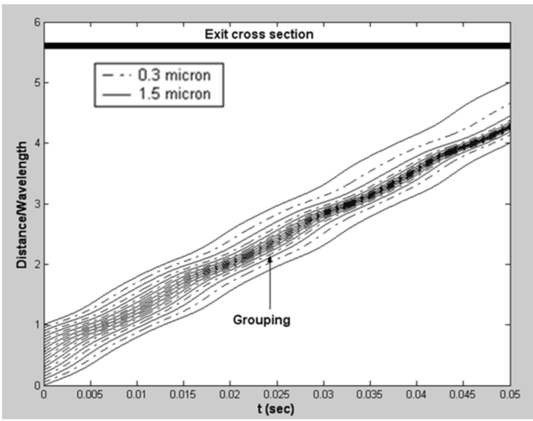


Figure 2- Trajectories of particles with sizes of 0.3 and 1.5 μm, leading to their grouping and coagulation.

Hence, according to the engine's specification and the flow characterizations, exhaust geometry was designed and assembled in parallel with the original exhaust geometry as seen in figure 3.

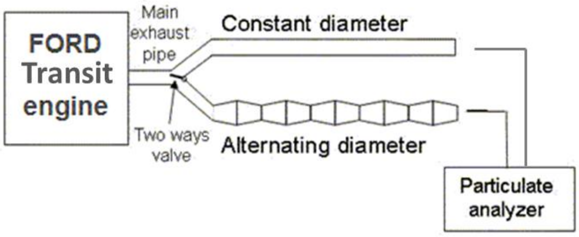


Figure 3- Experimental setup scheme

The engine was run under the specified conditions to attain steady-state operation, and then the exhaust gas was sampled from both the regular pipe and from the tailor-made PEMRED pipe. The effect of the Grouping is shown by the results in figures 4 and 5.

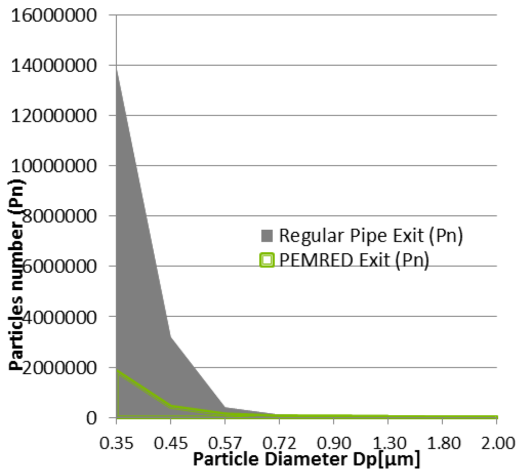


Figure 4- *Reduction of the number of the Ultrafine soot particles by grouping them into larger particles*

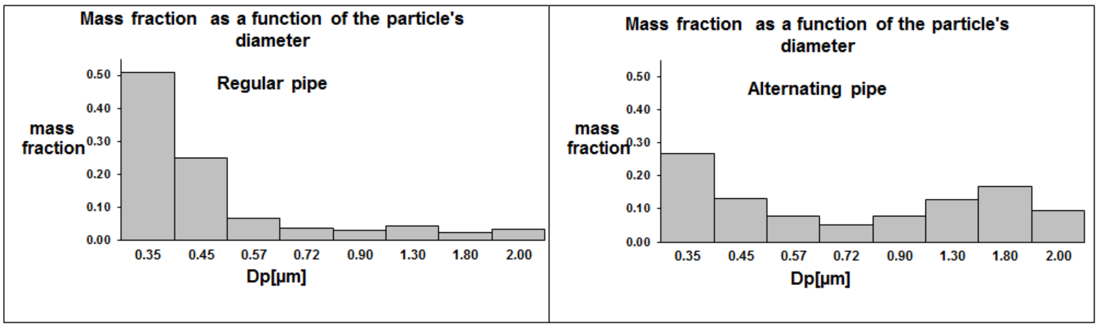
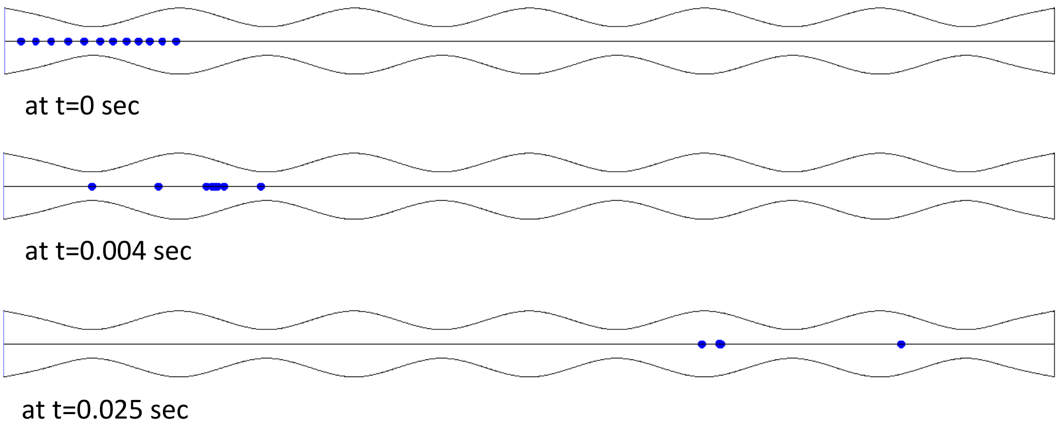


Figure 5- *Mass fraction of particles emitted from the regular pipe and from the alternating pipe.*

As can be seen from the above figures, there is a major reduction of small particles emitted from the new PEMRED exhaust pipe as a result of grouping, clustering and agglomeration/coagulation of the particles.

A recently developed numerical simulation also predicts grouping as shown in figure 6. Particle dynamic is simulated for specific engine's operating conditions. 12 equidistant particles were injected (numerically) at the center of the exhaust pipe inlet. Particle positions were sampled at different times. The simulations (accounting for Brownian motion) shows that even particles in the order of 10 nano-meters can be manipulated to group and coagulate.

Figure 6- Particle *Grouping dynamics simulation*.



To conclude, the experiments and simulations indicate a substantial decrease in the amount of the small particles at the expense of a moderate increase of the larger particles as they are in motion within the exhaust system. In case a filter is used, the filtering would be much more efficient and hence much less particles will be emitted from vehicle to the air. It is important to note that although the study deals with Diesel engine nanoparticle emissions, the new methodology is applicable to other types of combustion generated nanoparticles as well.

References:

[1] Winter C, Katoshevski D , Bartholmä A, Flemming BW. (2007). Grouping dynamics of suspended matter in tidal channels. J. of Geophysical Research;112: doi:10.1029/2005JC003423.

[2] Katoshevski, D., Shakked, T., Sazhin, S.S., Crua, C., & Heikal, M.R. (2008). Grouping and trapping of evaporating droplets in an oscillating gas flow. *International Journal of Heat and Fluid Flow*, 29, 415-426.

[3] Katoshevski, D., Dodin, Z., & Ziskind, G. (2005). Aerosol clustering in oscillating flows: Mathematical analysis. *Atomization and Sprays*, 15, 401-412.

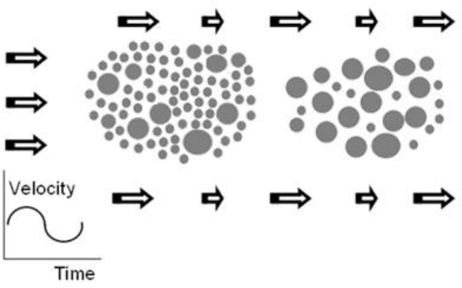
[4] Katoshevski, D., Ruzal, M., Shakked, T., & Sher, E. (2010a). Particle grouping, a new method for reducing emission of submicron particles from diesel engines. *Fuel*, 89, 2411-2416.

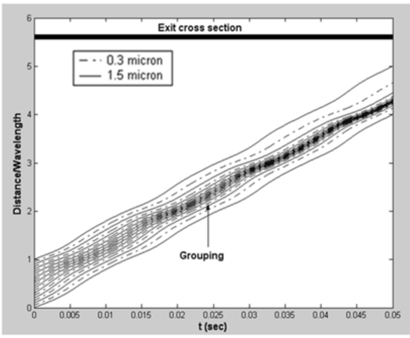
A new agglomeration methodology for decreasing combustion generated nanoparticle emissions

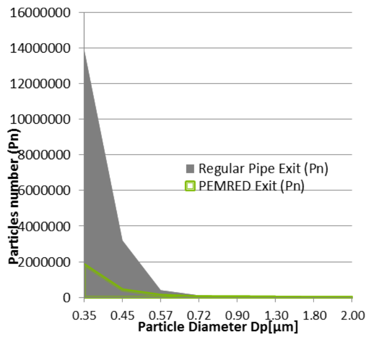
Michal Ruzal-Mendelevich, David Katoshevski, Eran Sher (Ben-Gurion University of the Negev, Israel),
and Avigdor Luttinger (PEMRED)

There is a growing concern regarding the adverse health effects of Diesel PM emissions, in particular in the sub-micron range. Since the efficiency of particle deposition in the respiratory tract is a function of particle size - and so is their residence time in the air, the smaller the particle is, the higher the risk it presents. The most efficient after-treatment device presently available is the DPF. The effectiveness of the filters is predominantly determined by the size of the pores and therefore the filters are less efficient in capturing nanoparticles. Hence, a shift in the size distribution that will increase the number of larger particles at the expense of much less of very small ones would be very desirable.

"Particle Grouping" achieves this shift in particle size. Particle-Grouping (illustrated below) is a tendency of very small particles (mostly in the range of 10 – 500 nanometer) to group due to particular oscillations in the flow, coagulate and form large particulates. The mathematical basis of the Grouping Theory was developed by Katoshevski[1] and co-workers and applied successfully in several systems, such as motion of sediments in water and fuel-spray dynamics and combustion.







Grouping of particles in an oscillating flow. The oscillations are in time and in space. The arrows mark downstream velocity variation. Grouping leads to coagulation, reducing the number of smaller particles. The oscillation parameters determine the grouping effect

The numerical analysis has concluded that in order to ensure enhanced grouping, one should account on one hand for the engine and exhaust flow characteristics and on the other hand design the exhaust pipe geometry in a tailor-made manner. The middle chart above show an example of a calculation of particle trajectories as they are in motion through the tailored exhaust system. One can clearly notice the convergence of the trajectories (in the darker area) which implies that the small particles are in the process of grouping, leading to their coagulation[2]. The empirical results are shown in the right chart above.

In the empirical test, exhaust geometry was designed according to the engine's specification and the flow characterizations, and assembled in parallel with the original exhaust geometry as seen below.

Ford Transit 2.5L 95N Load

Tailored Agglomerating Exhaust

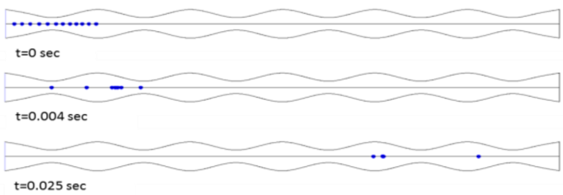
Constant Diameter Exhaust

SENSORS PM-300

The engine was run under the specified conditions to attain steady-state operation, and then the exhaust gas was sampled from both the regular exhaust pipe and from the tailor-made PEMRED pipe.

As can be seen from the above figures, there is a major reduction in the number of small particles emitted from the new PEMRED exhaust pipe as a result of grouping, clustering and agglomeration/coagulation of the particles.

A recently developed numerical simulation facilitates the design of tailored exhaust geometries. Particle dynamic is simulated for specific engine's operating conditions. 12 equidistant particles were injected (numerically) at the center of the exhaust pipe inlet. Particle positions were sampled at different times. The simulations (accounting for Brownian motion) shows that even particles in the order of 10 nano-meters can be manipulated to group and coagulate.



To conclude, the simulations and the experiments show a substantial decrease in the amount of the small particles at the expense of a moderate increase of the larger particles, while they are moving through the exhaust system. In case a filter is used, filtering would be much more efficient, and altogether much less particles will be emitted into the air.

Refs:
[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, 2411-2416.

info@pemred.com