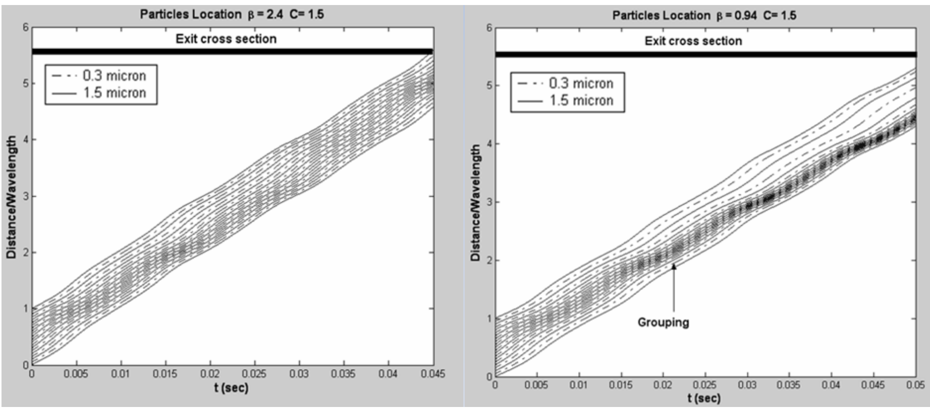
Particle Grouping- Increasing diesel PM size and reducing health risk

Michal Ruzal-Mendelevich, Itamar Hite, Tal Shaked, Eran Sher, David Katoshevski

A new vehicle exhaust concept is described which leads to a reduced risk for the health and for the environment from Particulate Matter emission. The current concept is based on the phenomenon of particle grouping/clustering in oscillating flows. Small particles, in the micron and submicron-size range have higher tendency to group in those conditions. The geometry of the exhaust induces particle grouping and coagulation leading to a shift in particle size distribution, which increases the mass/number of the larger particles at the expense of the reduction in the amount of smaller ones. Such a shift in size distribution has implications with respect to particle capturing from diesel engines and other facilities, and with respect to lower residence time of particles which are emitted to the air.

The particle's trajectory on the centerline of a pipe in an oscillation field for standing wave represents as: $\ddot{\theta}+\dot{\theta}+\alpha\cos(\theta+t^*)\left[\sin(t^*)+C\right]=\beta$ where $\alpha=\dfrac{1}{\sqrt{StU_b^*}}$ and $\beta=\dfrac{\left(U_a^*-1\right)}{U_b^*}$.

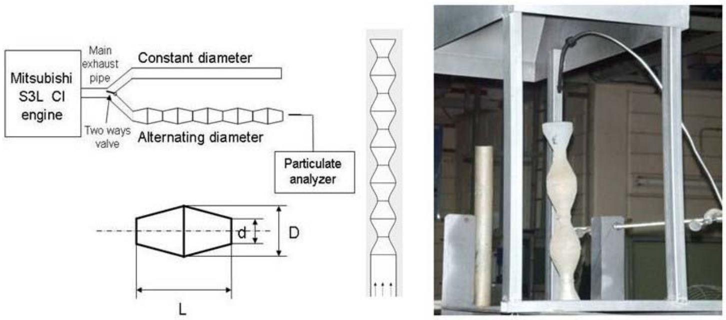
A numerical analysis has concluded that in order to ensure a stable grouping as the conditions of β<1 must be fulfilled as seen in figure 1. α and β are the main parameters in our experiment.



Figures. 1 Grouping of particle trajectories for different β and C=1.5 values. Exit cross section of the pipe is indicated. Particle sizes are: 0.3μm and 1.5 μm.

The first and foremost goal of our research is to come up with a knowledge and understanding of how to reduce the health risk associated with diesel particulate emission employing a particle grouping phenomenon in the exhaust system. The scientific tool which we utilize to understand this phenomenon is based on a combined mathematical and experimental study.

Two kinds of exhaust pipes were employed as seen in figures 2-4; the first pipe is a regular one with constant cross-section profile, while the second pipe has an alternating diameter to enhance flow resonance. In each test, the engine was operated under a set of operation conditions (engine speed and engine load). The engine was run under the specified conditions to attain steady-state operation, and then the exhaust gas was sampled first from the regular pipe and subsequently from the resonating pipe. Each sample was averaged during a time interval of 30 seconds.



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Figures. 2-4- 1-Experimental setup scheme, 2-pipe scheme, 3-experiment picture.

The effect of the alternating diameter pipe is clearly demonstrated in figure 5. It should be stated that there was no change in back pressure because of the pipe's geometry. Figure 5 shows how the size distribution of the exhaust particles is affected in different loads with 1700 rev/min; the apparent mass fraction of the small particles (in particular in the nano-sub-micron region) has been reduced the mass fraction of the larger ones has been increased. While particles smaller than *0.3μm* are not detectable by the present particulate size analyzer, mass conservation suggests that the remarkable increase in the mass fraction of the larger-size particles, may confidently be attributed to the grouping (leading to agglomeration) of the undetected smaller-size particles.

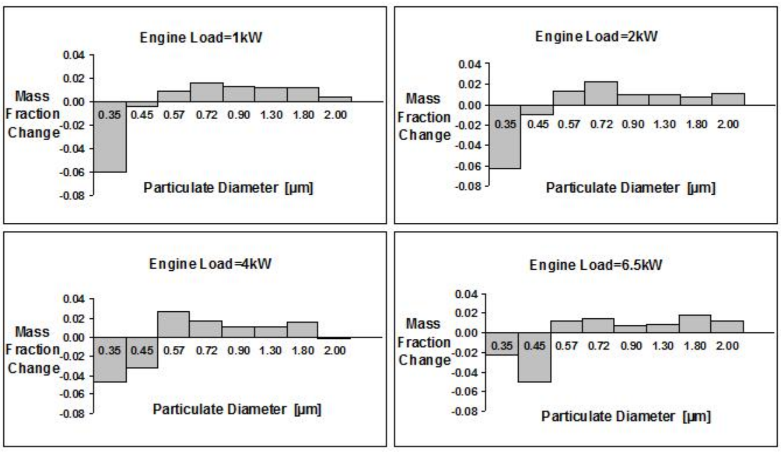

Figure 5- the effect of alternating exhaust diameter on the particulates' size distribution. Engine speed=1,700 rev/min.

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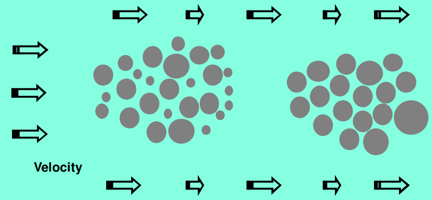
Grouping Phenomenon

Small particles, in the micron and sub micron size range, have higher tendency to move as groups and cluster in an oscillating flow. In such conditions, particles may coagulate and increase their size.



Mathematical Model

We account for standing wave oscillating flow field of the

$$U = U_a - U_b \cos(kx)\left(\sin(\omega t) + C\right)$$

Inserting the particle's forces and normalize:

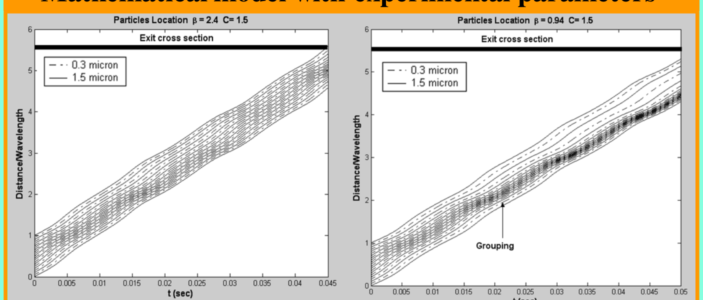
$$\ddot{\theta} + \alpha\dot{\theta} + \cos(\theta + t^*)\left(\sin(t^*) + C\right) = \beta$$

Where:

$$\alpha = \frac{1}{\sqrt{St \cdot U_b^*}} \qquad \beta = \frac{\left(U_a^* - 1\right)}{U_b^*}$$

Stable GROUPING appears when β<1.

Mathematical model with experimental parameters



Stable GROUPING at β<1

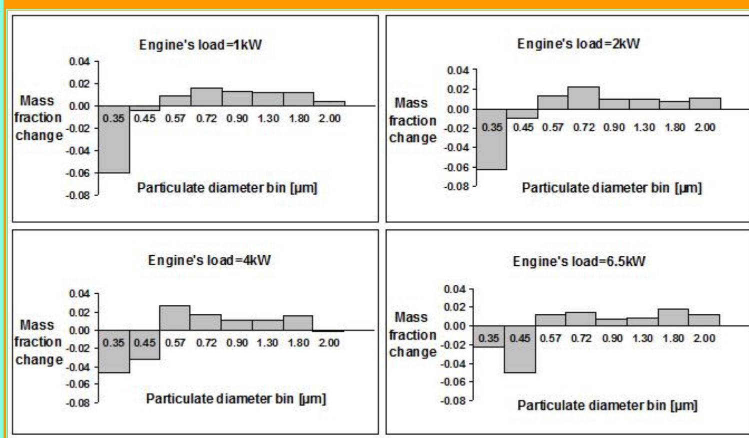
We demonstrate this concept in an exhaust pipe of a diesel engine, and show how the emission of sub-micron particles (PM) can be significantly reduced

Experiment- Particle Grouping

Funded by MANOF foundation

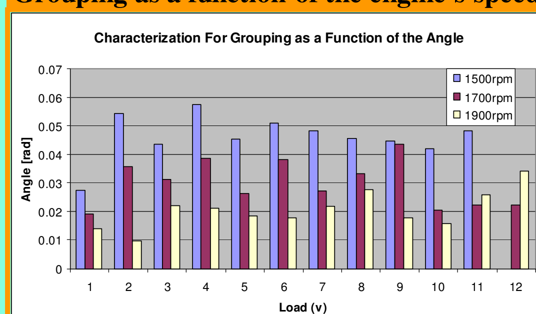
Experimental Results

Change in mass fraction as a function of the particle's diameter



Decrease of the small particles mass fraction

Grouping as a function of the engine's speed



Strong GROUPING in low rpm

Conclusions

Grouping of particles enhances coagulation and thus proposes important implications in various systems: in the atmosphere, in industrial systems, in medical aerosols, fuel sprays as well as in exhaust systems. We have examined both standing wave and moving wave flow field and found similar grouping behavior in both configurations.

References

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