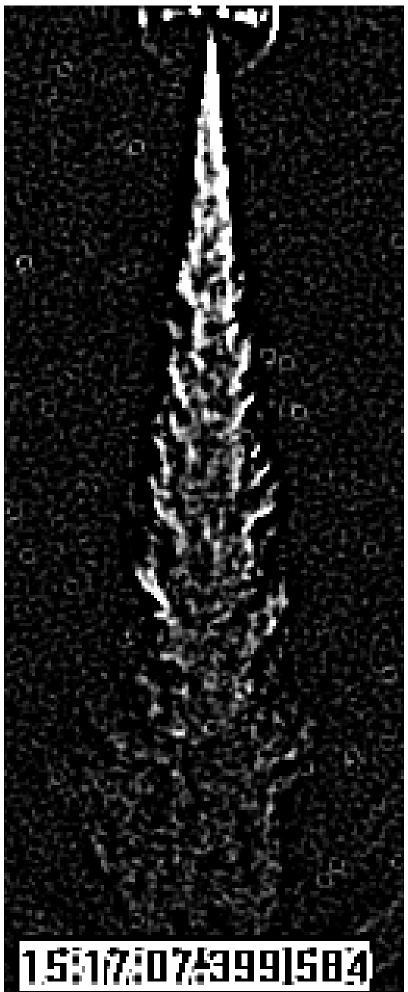
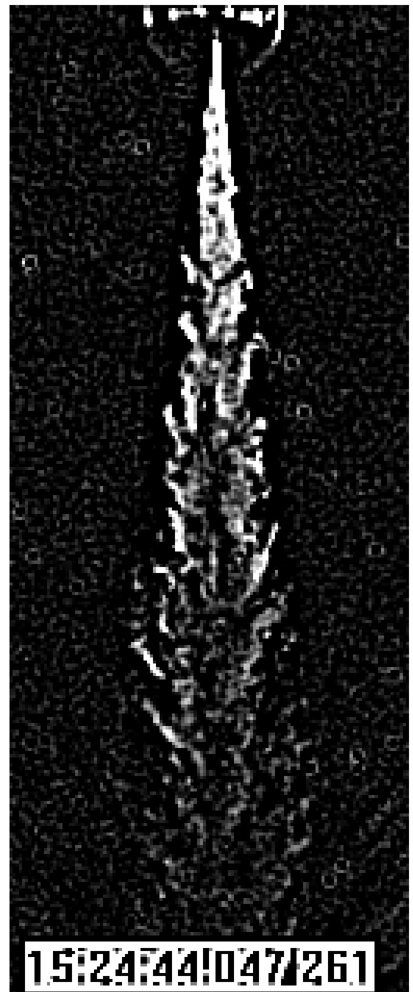
Coupling between Grouping and Evaporation of Fuel Droplets in Internal Combustion Engines (ICEs)

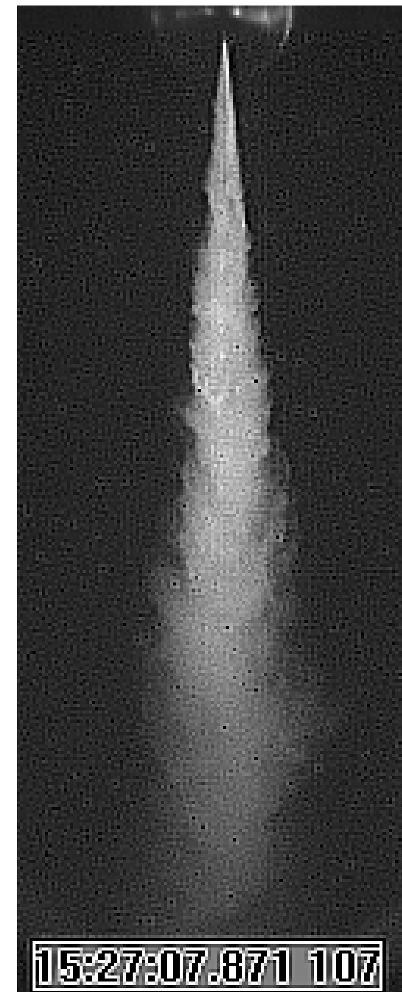
David Katoshevski

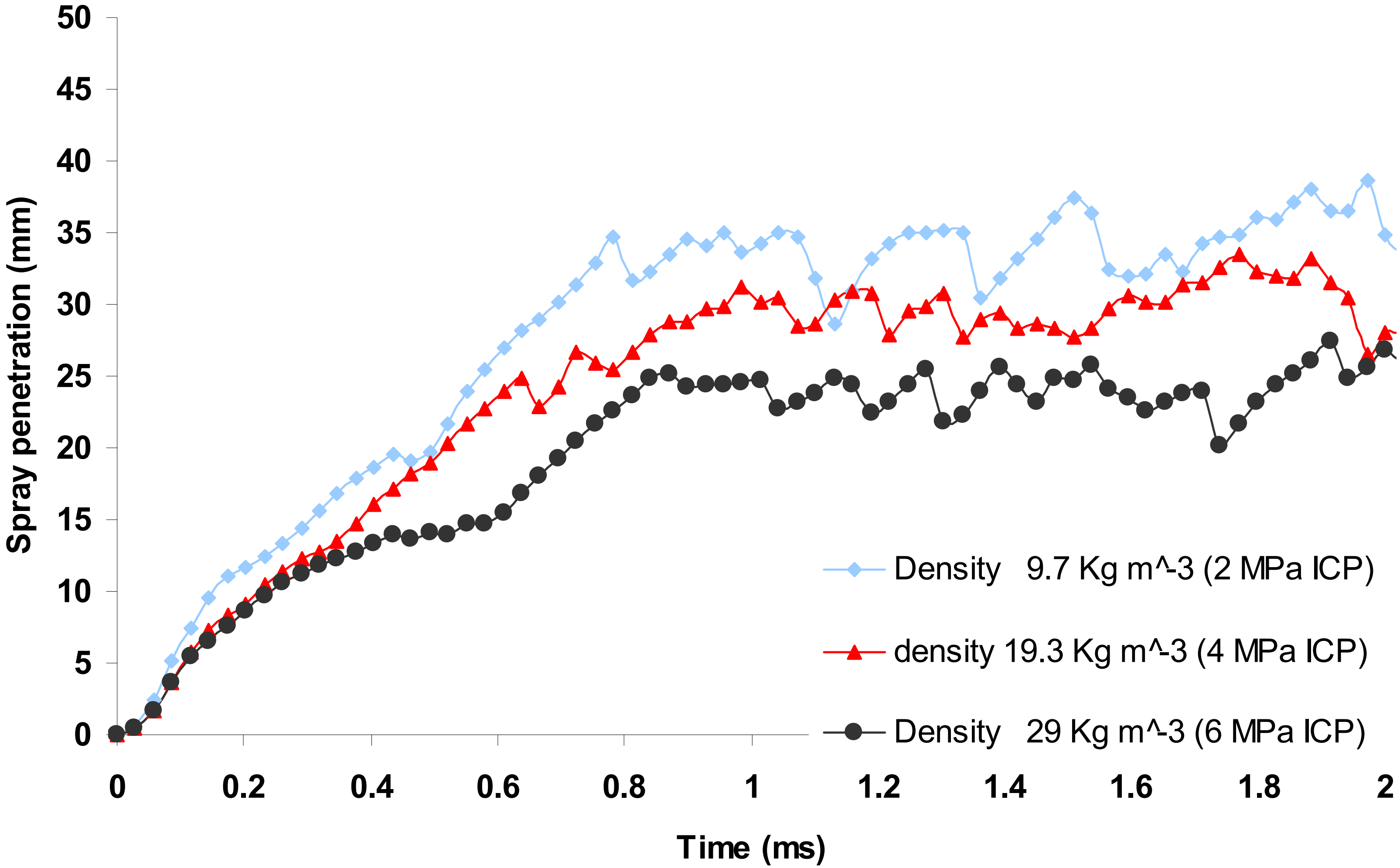
Environmental Engineering
Faculty of Engineering Sciences
Ben-Gurion University of the Negev
Beer-Sheva, Israel

From Experimental Spray Studies



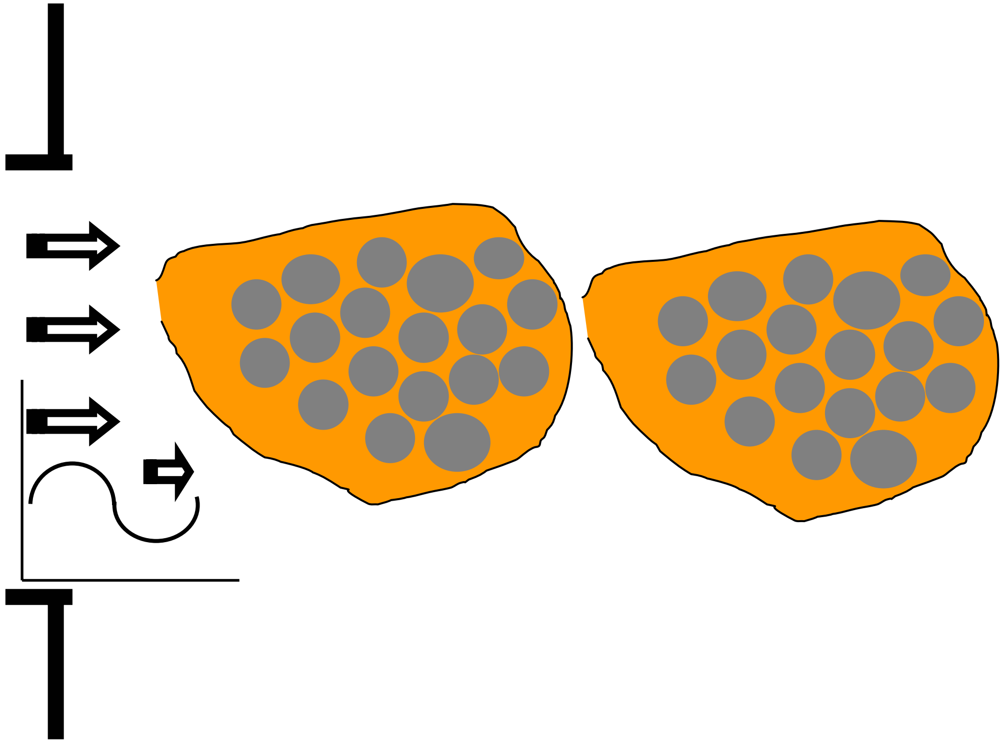






Spray penetration (mm)
50
45
40
35
30
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (ms)
Density 9.7 Kg m^-3 (2 MPa ICP)
density 19.3 Kg m^-3 (4 MPa ICP)
Density 29 Kg m^-3 (6 MPa ICP)

Travel-Grouping of Evaporating Fuel Spray Droplets



Model

Assuming, for the host gas:

$$u(x,t) = U_a - U_b \sin(kx - \omega t)$$

t- time, *x*- distance

k- wave number, *ω*- angular velocity

The equation of particle motion leads to

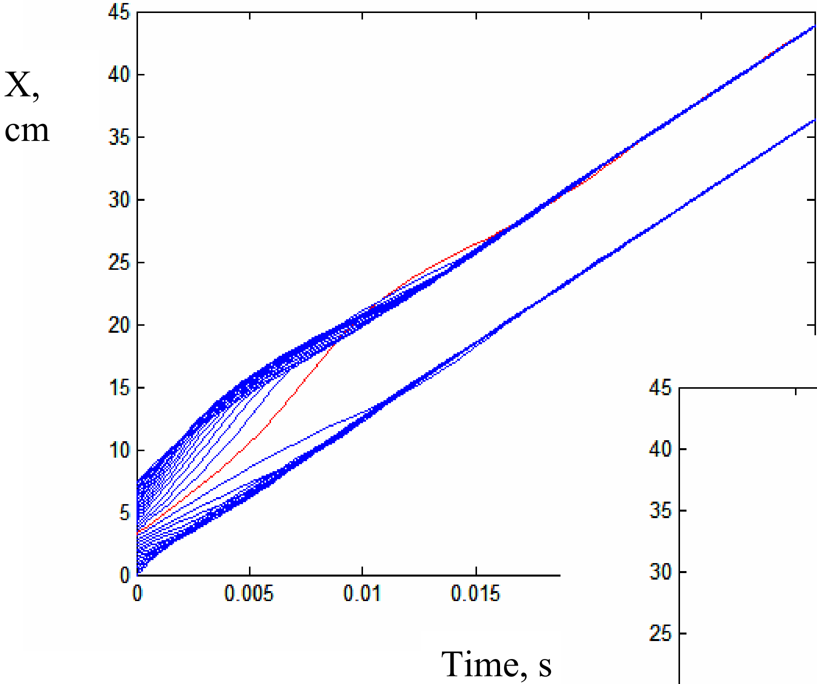
$$\theta'' + \alpha\theta' + \sin\theta = \beta$$

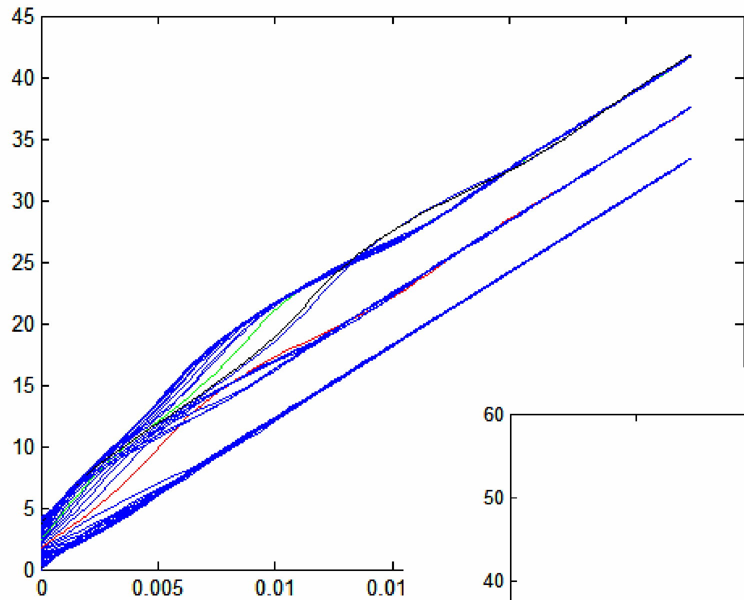
$$\theta = x - t$$

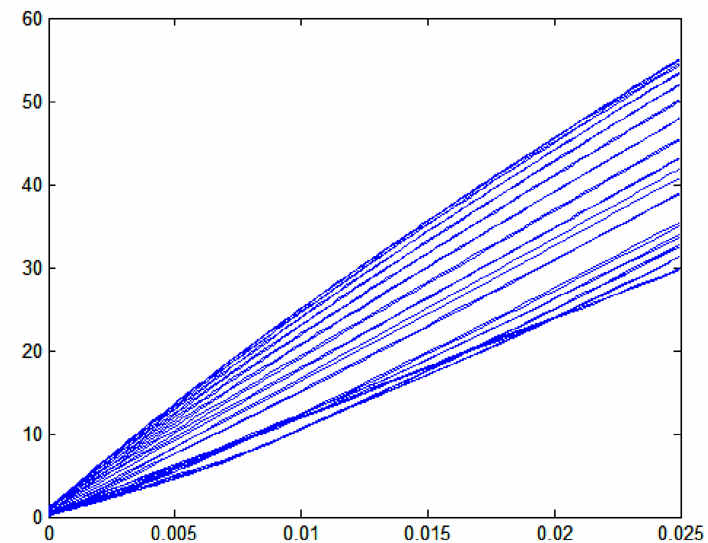
$$\beta = \left(U_a - 1\right)/U_b \qquad \alpha = 1/\sqrt{U_b\, St}$$

where, for normalization we use: $U_w = \omega / k$

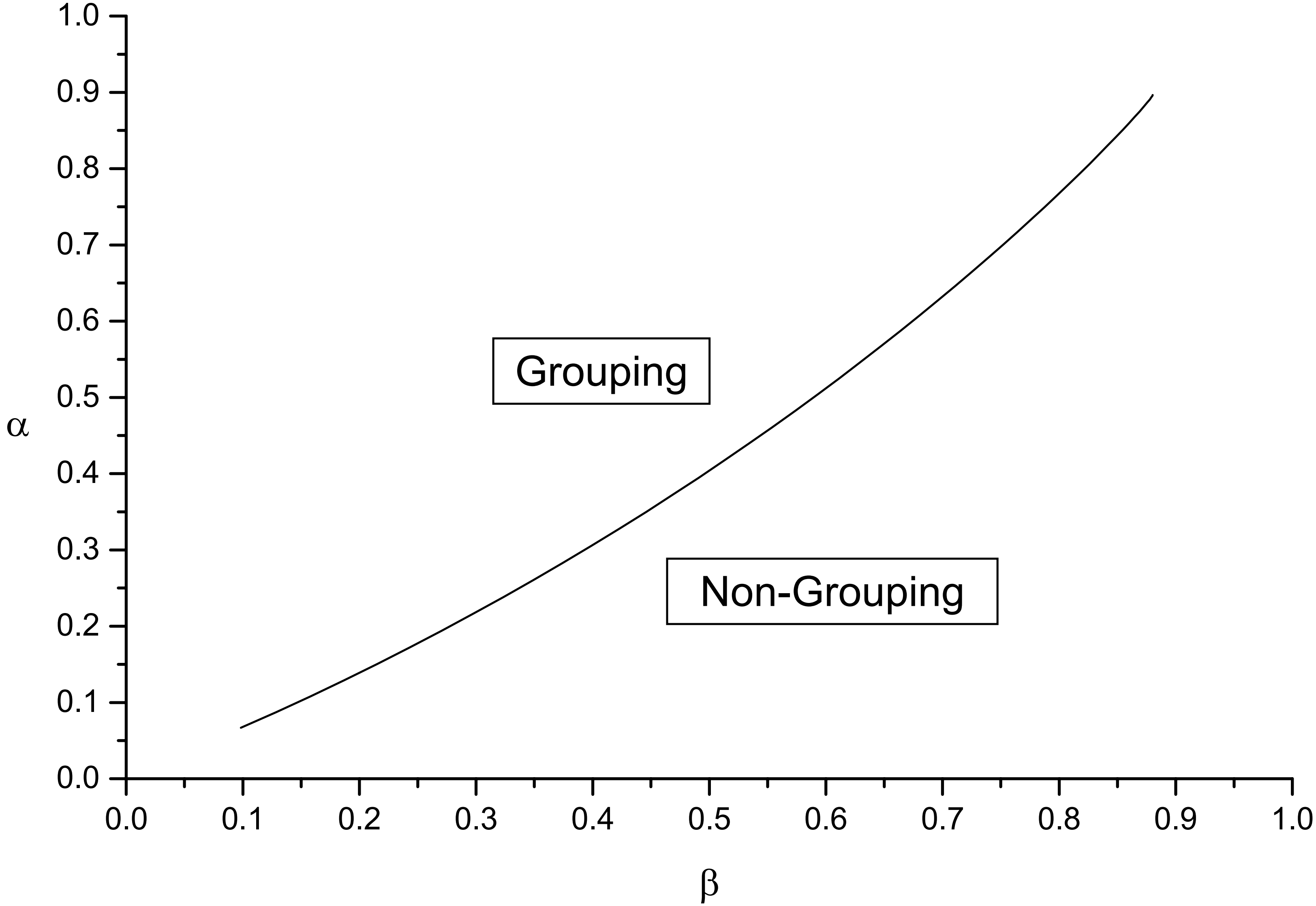
Grouping/ Non-Grouping of 30-microns droplets







Increase in oscillation frequency

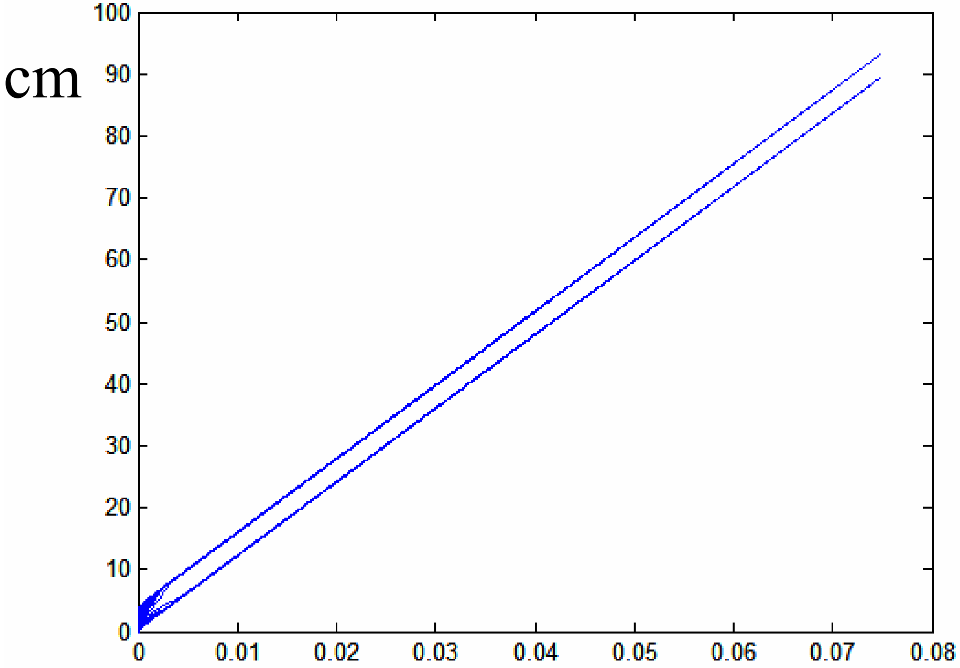


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
α
Grouping
Non-Grouping
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
β

We find that

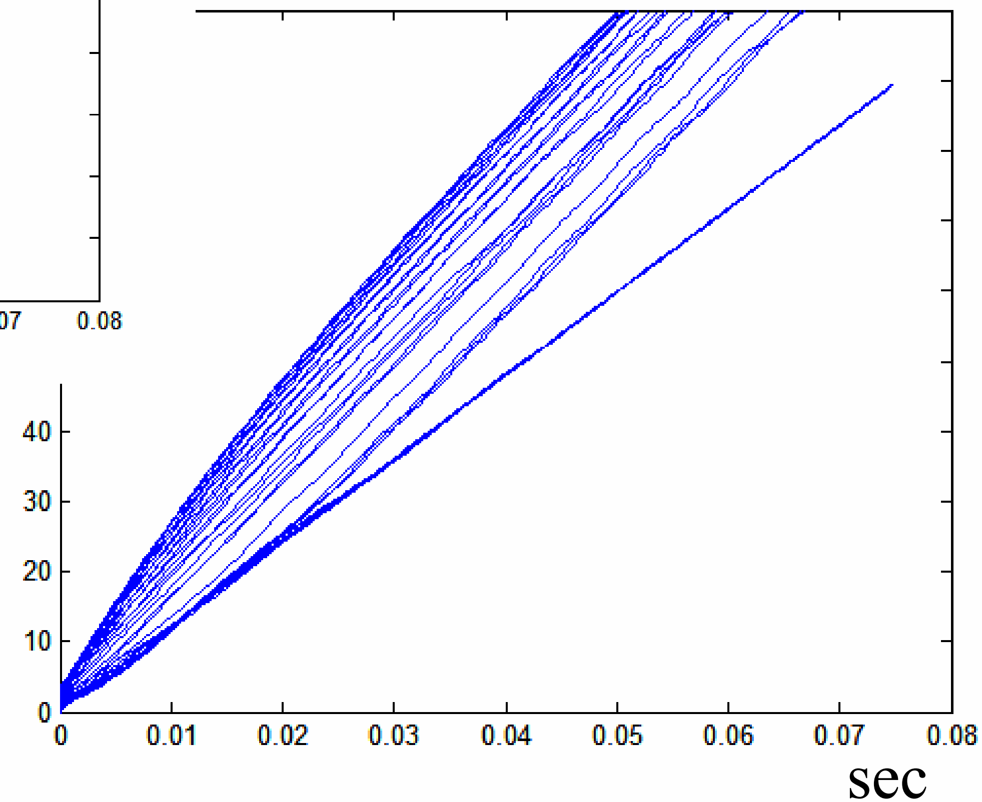
$$NG = \frac{U_a - 1}{\sqrt{U_b}} \sqrt{St} >> 1$$

- *NG* – Non-Grouping conditions



NG<1

(10 microns)



NG~5

(70 microns)

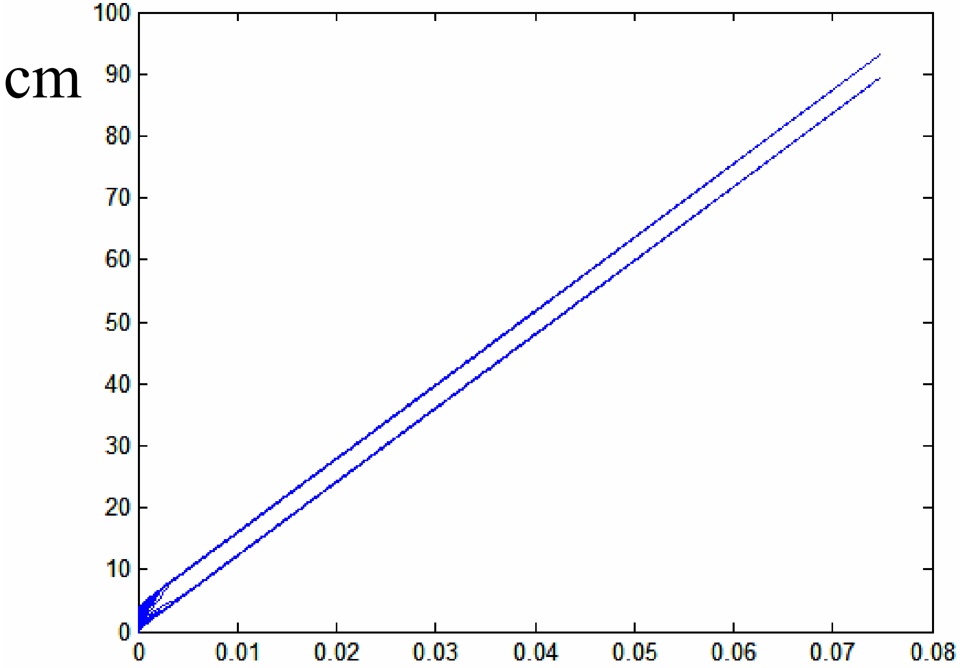
For the evaporation, the “D-Square Law” was employed in which: $D^2(t) = D^2(t_0) - Kt$

As grouping occurs, evaporation rate decreases (Sirignano, 1999)

Vaporisation constant, K, for several fuels

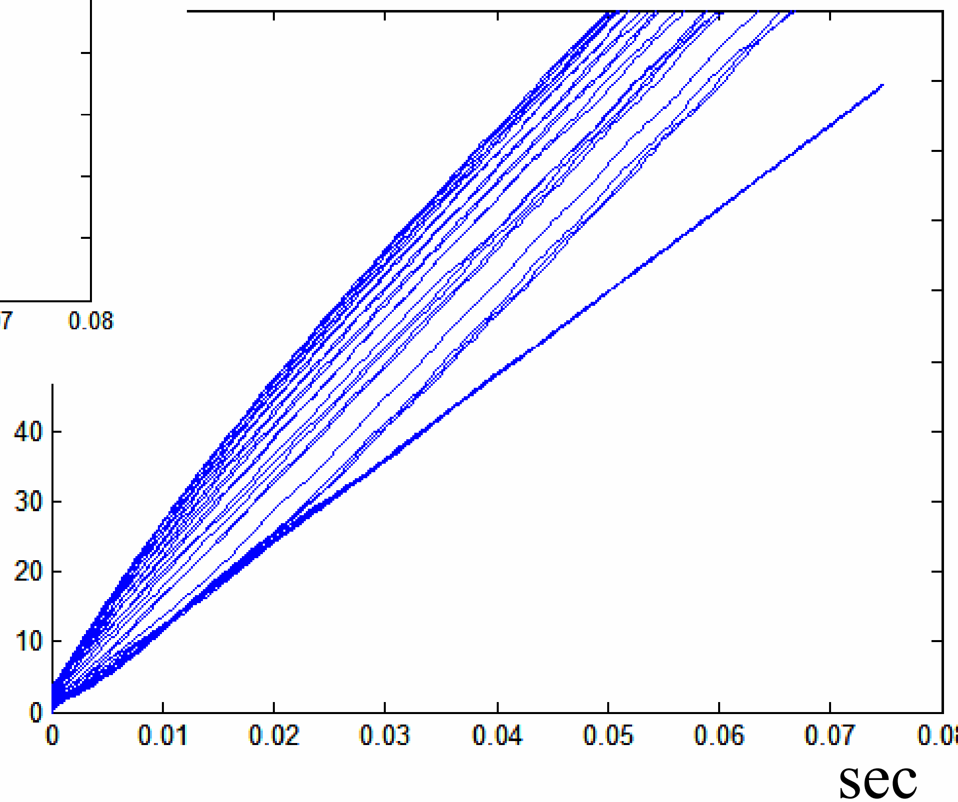
Fuel -	K (mm^2/s)
Petroleum ether	0.99
Petroleum	0.96
Ethanol	0.81
Benzene	0.97
Ethyl benzene	0.87
O-Xylene	0.79
Iso-propyl benzene	0.79
n-Heptane	0.97

- We find that the effect of evaporation on droplets’ trajectories is **negligible**



NG<1

(10 microns)



NG~5

(70 microns)

Due to the coupling between size and the grouping phenomena, the evaporation rate of various droplet - sizes become closer.

Hence, when we have an oscillating flow, the optimized size distribution is not necessarily the one with the smallest droplets (or smallest SMD) !

This may affect the design of the injectors of ICEs and the combustion efficiency, and thus emissions

Once a grouping or a non-grouping mode of behavior has been established,

evaporation does not change this behavior as time passes, or

in other words, “droplet’s history” determines a single mode of time-behavior.

THE INITIAL *NG* IS THE KEY FACTOR

To summarize

Such an analysis is aimed at:

- defining the operating conditions that will minimize fuel spray grouping in ICEs.
- pointing out the optimized droplet size distribution

Thus, maximizing evaporation, leading to a more homogenous mixture and **enhancement of the desired auto-oxidation in ICEs** .

A preliminary paper on the mathematical basis (without evaporation) will soon appear in the Journal *Atomization and Sprays*

"Aerosol Clustering in Oscillating Flows – Mathematical Analysis"

By: David Katoshevski, Zusia Dodin and Gennady Ziskind