Control of particle agglomeration with relevance to after-treatment gas processes

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Motivation

- Particulate emission from internal combustion engines(ICE) are a major health issue.
- Such emission contain fine particles with a size distribution around the order of nano sized particles.
- These small particles are able to penetrate through the human respiratory system and potentially cause health problems.
- Larger particles on the other hand are easier to filtrate and are less likely to contribute to respiratory disorders.
- Particle agglomeration is one way in which larger particles can be obtained from ICE particulate emissions.

Findings of the EEA report No 5/2014

- According to a report published by the European Environmental agency in 2014, particulate matter can have adverse affects not only on humans but also on animals and plants. They can also damage buildings.
- An ETC/ACM systematic estimate of the health impacts attributable to exposure to particulate matter(PM) was reported. It showed that the effect of $PM_{2.5}$ concentrations on total mortality lead to about 458 000 premature deaths per year in Europe. The estimate was based on the concentration levels found in 2011.

Scope of the project

- One of the main goals of the project is to find methods for enabling agglomeration of particles, based on manipulation of the hydrodynamic and acoustic fields, in the ICE flow exhaust system.
- This project will focus on building the theoretical framework concerning particle motion and grouping in oscillatory flows and acoustic fields using computational tools.
- Suitable models will be developed after a basic understanding of the physical phenomena involved is reached. These models will later be used to simulate a real engine exhaust system.

Short term goals

- Simulate simplified cases of single & two-phase flows using 1D models.
- Identify benchmark cases to be used for model verification and validation.
- Perform sensitivity studies in order to investigate the effects of different parameters on "Inertia" grouping/agglomeration.
- Examine the possibility of incorporating acoustic forcing within the modeling framework.
- Look towards more complex models utilized to simulate 2D and 3D geometry.
- Identify benchmark cases for software verification.

Preliminary study

- Initial literature review has been performed on the papers published by David Katoshevski.
- Numerical experiments have been performed in order to reproduce results presented in his papers.
- A simple 1D model is used in order to study the process of grouping of particles in an oscillating flow field.

Description of the simplified 1D model

- The model considers an oscillating Stokesian flow in the frame of reference moving with the phase velocity of the wave.
- In order to simplify the analysis a few assumptions have been made.
- The effects of particles on the host gas have been ignored.
- The equation governing the dynamics of the particle only take into account viscous forces.

Mathematical representation

The velocity of the flow field at position x at time t is given by

$$v_g(x,t) = V_a - V_b \sin(kx - \omega t),$$

where V_a is the dimensional mean flow velocity, V_b is the dimensional amplitude of the oscillations in the x-direction, k is the wave number and ω is the angular velocity.

The equation governing the dynamics of the particles inside this flow field can be expressed as:

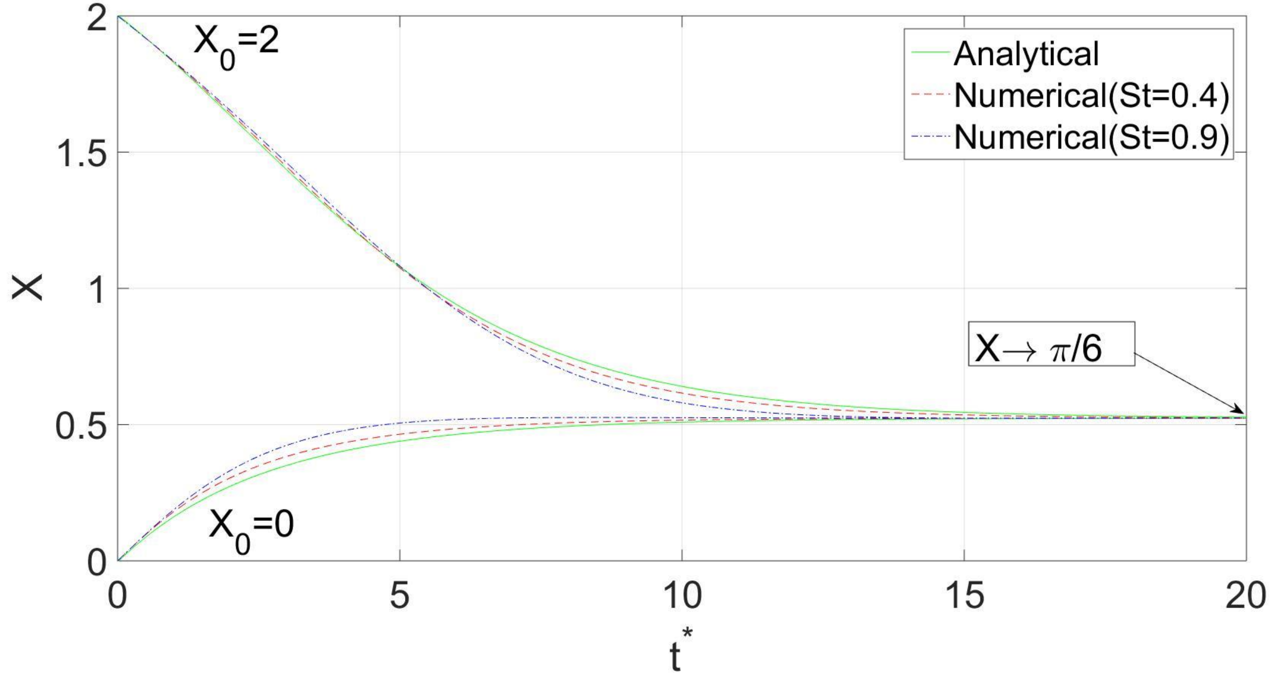
$$\ddot{x} = \frac{1}{\tau_p}\left(v_g - \dot{x}\right),$$

where $\tau_p = \frac{\rho_p D_p^2}{18\mu}$, with ρ_p being the particle density, D_p being the particle diameter and μ being the dynamic viscosity of the gas.

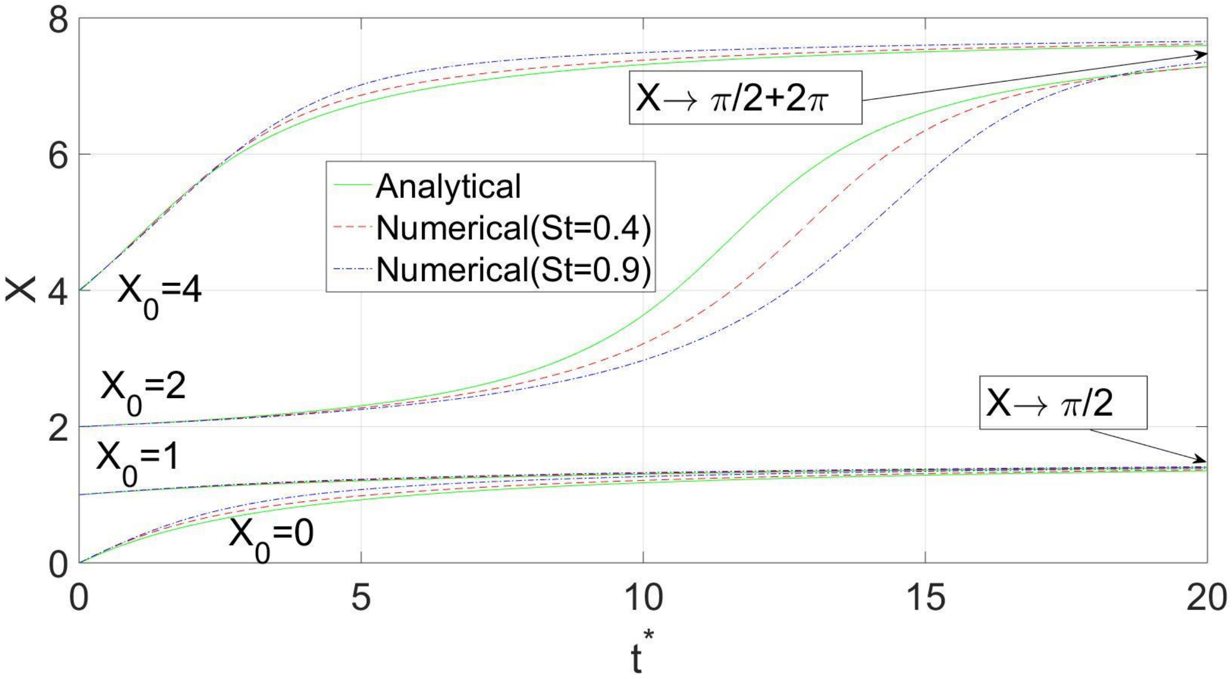
Results from theoretical analysis

- For this particular model it was observed that a parameter β played a crucial role in identifying cases where grouping occurs.
- The parameter is defined as $\beta = \frac{U_a - 1}{U_b}$, where U_a and U_b are non dimensional versions of V_a and V_b.
- Three cases were analyzed: $|\beta| < 1$, $|\beta| = 1$ and $|\beta| > 1$.
- It was observed that grouping occurs for the first two cases but not for the last case.

Results produced for the case of $|\beta| < 1$



Results produced for the case of $|\beta| = 1$



Future plans

- Understand the limitations of this model in order to see the extent of its applicability.
- Identify more complex models and approaches for simulating particles inside an oscillating flow field with or without external forcing.
- Carry out further experiments in order to examine the significance of other parameters with regards to agglomeration.
- Look into the possibility of incorporating acoustic forcing.

References

1. S.Sazhin et al., Particle grouping in oscillating flows. European Journal of Mechanical B/Fluids(2007).
2. D.Katoshevski et al., Grouping and trapping of evaporating droplets in an oscillating flow. International Journal of Heat and Fluid Flow 29(2008) 415-426.
3. D.Katoshevski et al., Aerosol Clustering in oscillating flows: Mathematical Analysis. Atomization and Sprays, vol. 15 , 2005.
4. D.Katoshevski et al., Particle grouping, a new method for reducing emission of submicron particles from diesel engines. Fuel 89 (2010) 2411–2416.