Breakup of finite size colloidal aggregates in turbulent flow investigated by 3D-PTV

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Breakup of aggregates
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- Processing of industrial colloids (polymers, metal oxides, pharmaceuticals)
- Flocculation operations in (waste)water treatment

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- Evolution and transport of sediments and marine snow in natural waters

*Picture: Satellite image River Plate Estuary, 2010-03-10 ([www.eosnap.com](http://www.eosnap.com), 2014-03-12), H. Grossart, Leibniz Institute of Freshwater Ecology*
Aim of this work

Breakup mechanism in turbulence
Experimental setup

- Stationary turbulence, monitored by 3D PTV

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- Inject a single pre-formed aggregate

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- Inject a single pre-formed aggregate
- Follow the aggregate until (and beyond) breakup
- Determine local flow conditions that prevail at breakup

Experimental setup

**Flow device**
- $R_\lambda \approx 117$
- $\langle \varepsilon \rangle \approx 19 \text{ cm}^2/\text{s}^3$
- $\eta \approx 0.15 \text{ mm}$

**Aggregates**
- Made out of polystyrene colloids, $d_p = 420 \text{ nm}$
- Grown *in-situ* in the feed pipe, under oscillatory flow
- $d_{\text{agg}} = 1.4 \pm 0.4 \text{ mm}$
  Fractal dimension $d_f \sim 2.2$

Breakup experiments

Example of a breakup experiment

- $R_\lambda \approx 117$
- $\langle \varepsilon \rangle \approx 19 \text{ cm}^2/\text{s}^3$
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Hydrodynamic stress

**Aggregate motion**

- \( \frac{d_{\text{agg}}}{\eta} \approx 9 \pm 3 \)

- Aggregate Stokes number

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St = \frac{1}{18} \frac{\rho_{\text{agg}}}{\rho_f} \left( \frac{d_{\text{agg}}}{\eta} \right)^{3/4} = 0.3 \pm 0.1
\]

⇒ Aggregate motion is influenced by inertia
Hydrodynamic stress

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Shear stress

\[
\sigma_{\varepsilon} \sim \mu (\varepsilon/\nu)^{1/2}
\]

Drag stress

\[
\sigma_{st} \sim \frac{3 \mu |v - u|}{d_{agg}}
\]
Results

Time lag from release to breakup

Shear stress at breakup

Drag stress at breakup

\begin{align*}
\text{Weak} & \quad \text{Strong} \\
\text{Aggregate strength} & \quad \text{Aggregate strength} \\
\end{align*}
Results

Accumulation of shear stress

\[ \bar{\sigma}_i = \frac{1}{\Delta t} \int_{t_b-\Delta t}^{t_b} \sigma_i \, dt \quad \Delta t \sim \tau_\eta \]

Accumulation of drag stress

\[ R^2 = 0.022 \]

\[ R^2 = 0.21 \]
Conclusions

We studied the breakup of finite size aggregates made out of fully destabilized polystyrene colloids in homogeneous isotropic turbulence by means of 3D-PTV.

Major findings are:

- Hydrodynamic stress is dominated by drag.
- Breakup is caused by weak accumulation of stress.

Both these findings are an effect of the large aggregate size.

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Breakup mechanism: limiting cases

**Soft aggregates (slow breakup)**

- Bond breakup due to thermal motion of the colloids [1].

  - Depends on the duration the aggregate is subject to hydrodynamic stress.
  - *If true:* weak aggregates (=large aggregates) break earlier than stronger ones.

**Brittle aggregates (fast breakup)**

- Breakup caused by an abrupt breakup of bonds [2].

  - Occurs when the hydrodynamic stress exceeds a critical threshold.
  - *If true:* the hydrodynamic stress at breakup correlates with the aggregate size.

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3D PTV with large aggregates

- Hydrodynamic stress dominated by drag
- Breakup is caused by weak accumulation of stress

Drag originates from the finite aggregate size

Finite stress propagation inside the aggregate

Sub-Kolmogorov aggregates

- Stress on small aggregates (in liquid) dominated by shear
- Small aggregates exhibit faster response
Aim: Investigating the mechanism of breakup in turbulence by monitoring individual breakup events in well controlled experiments
Aim of this work

Previous work: Dynamics of breakup

This work: Mechanism of breakup
Aim of this work

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