5-26-2016

Segregation of equal-sized particles of different densities in a vertically vibrated fluidized bed

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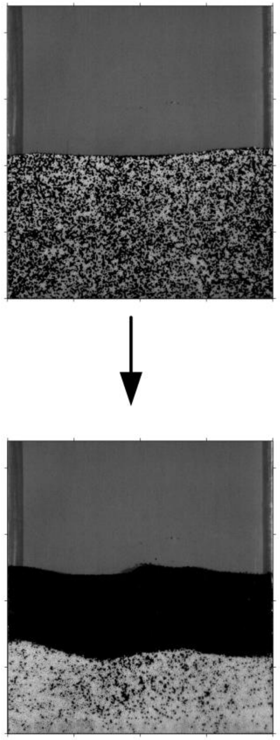
Motivation

- Many operations in the chemical and energy-conversion industries rely on the fluidization of heterogeneous materials.
- During fluidization, particles of different densities can segregate even if they are of the same size.
- In mechanically vibrated fluidized beds, the oscillatory movement of the bed vessel affects the dynamics of the dense and bubble phases.
- This work aims to experimentally characterize density driven segregation in a vibrated fluidized bed.
- Experiments comprise a mixture of spherical particles of two different densities and similar diameter.



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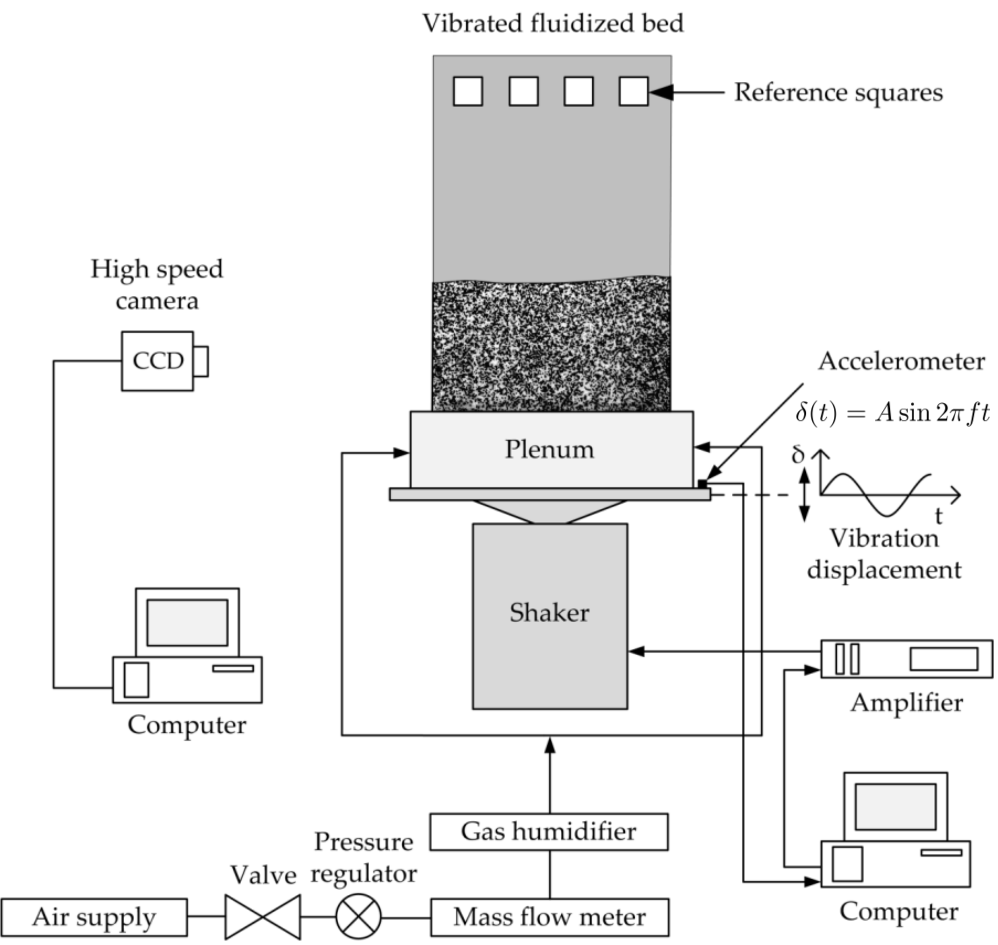
Experimental setup



Dimensions: 0.3 x 0.01 x 0.5 m

	$d_{p,L}$ (mm)	ρ_L (kg/m^3)	$d_{p,D}$ (mm)	ρ_D (kg/m^3)
Mixture 1	1–1.3	2500	1–1.2	6000
Mixture 2	1–1.3	2500	1–1.2	4100

White (dense) particles and black (light) particles are initially mixed.

Different combinations of vibration amplitude, frequency and superficial gas velocity. Central cases:

- f = 15 Hz, A = 4 mm, $U_0/U_{mf,D}$ = 0.91 for Mixture 1.
- f = 15 Hz, A = 4 mm, $U_0/U_{mf,D}$ = 1.16 for Mixture 2.

$$\Lambda = \frac{A(2\pi f)^2}{g}$$

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Segregation Index

Digital Image Analysis was used to characterize the rate and extent of segregation with time

Segregation index based on Lacey's mixing index:

$$SI = 1 - \frac{\sigma_0^2 - \sigma_c^2}{\sigma_0^2 - \sigma_R^2}$$

$\sigma_R^2 = \overline{c}(1-\overline{c})/n_p$ perfectly random mixture

$\sigma_0^2 = \overline{c}(1-\overline{c})$ completely segregated mixture

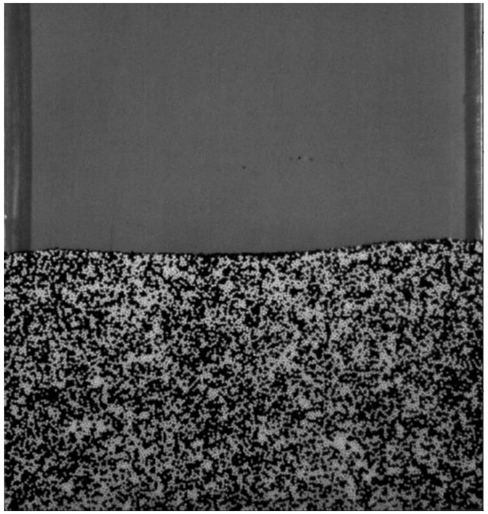
Variance of the concentration of white particles

$$\sigma_c^2 = \frac{1}{N_c - 1}\sum_{k=1}^{N_c}(c_k - \overline{c})^2$$

Bed divided in N_c cells of N_x x N_y pixels

$$c_k = \frac{1}{N_x N_y}\sum_{x_k=1}^{N_x}\sum_{y_k=1}^{N_y}\frac{G_{x_k,y_k} - G_{min}}{G_{max} - G_{min}}\phi_k$$

$$\overline{c} = \frac{1}{Nc}\sum_{k=1}^{N_c} c_k$$



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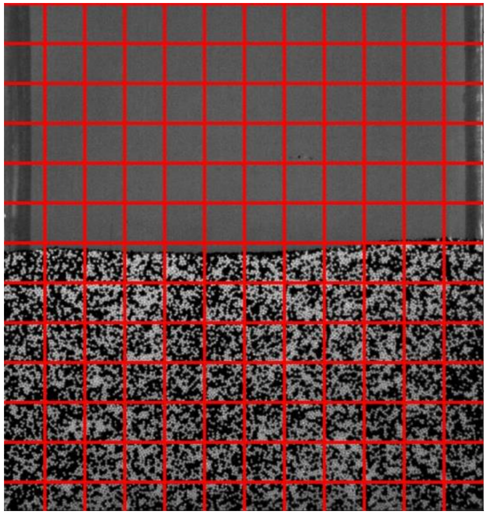

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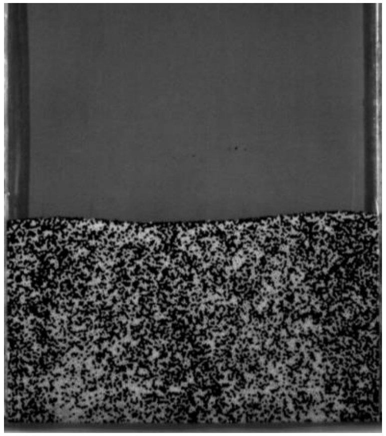
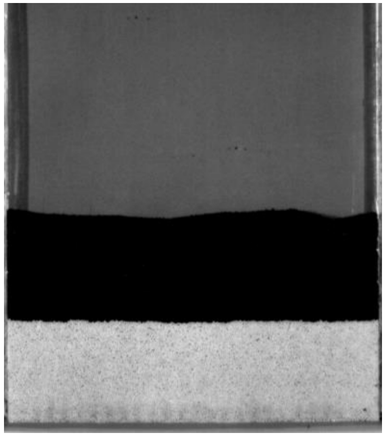
General bed behavior

Gas → Segregation



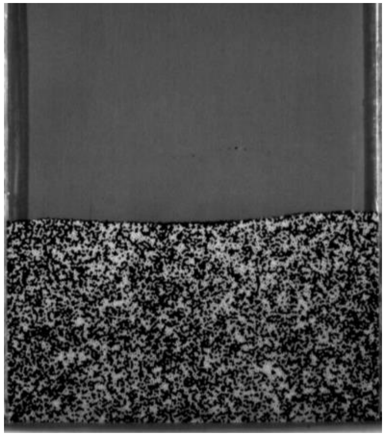
No vibration
$U/U_{mf,D}$=1.07

Vibration → Vibration-induced mixing



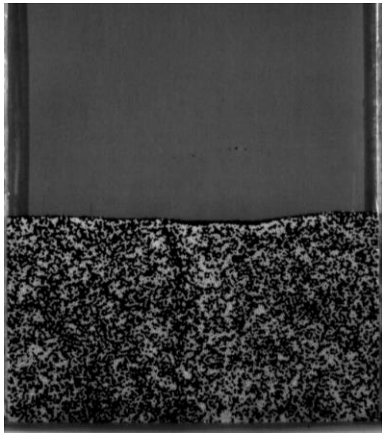
f=15 Hz
A=4 mm
No gas

Low vibration strength + gas → Vibration induced segregation



f=15 Hz
A=4 mm
$U/U_{mf,D}$=0.91

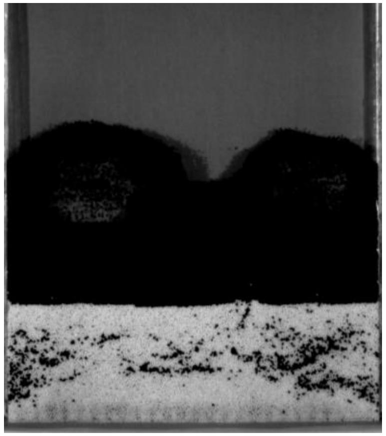
High strength vibration + gas → Low segregation extent



f=20 Hz
A=4 mm
$U/U_{mf,D}$=0.91

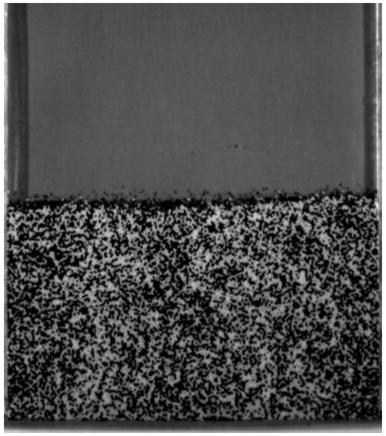
General bed behavior

<u>Gas → Segregation</u>



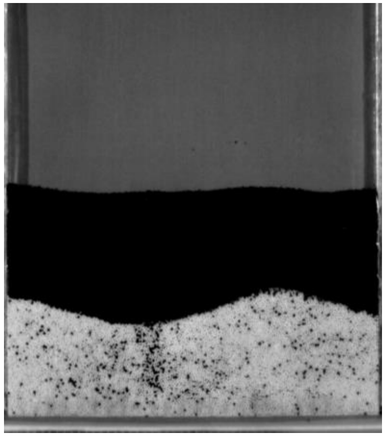
No vibration
$U/U_{mf,D}$=1.07

<u>Vibration → Vibration-induced mixing</u>



f=15 Hz
A=4 mm
No gas

<u>Low vibration strength + gas → Vibration induced segregation</u>



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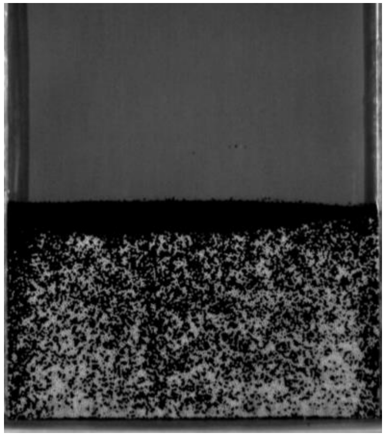

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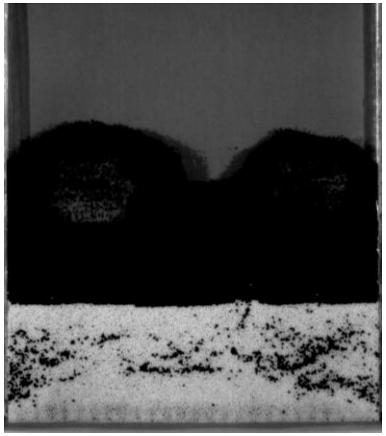

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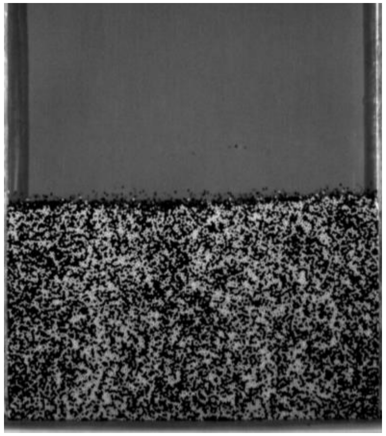

f=15 Hz
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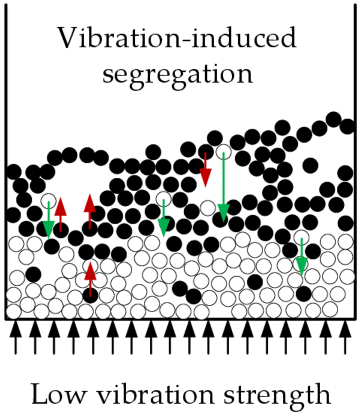
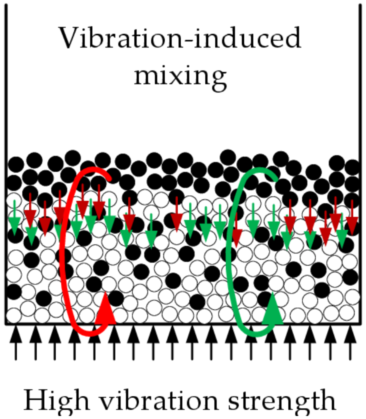
Low vibration strength + gas → Vibration induced segregation



f=15 Hz
A=4 mm
$U/U_{mf,D}$=0.91

High strength vibration + gas → Low segregation extent



f=20 Hz
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General bed behavior

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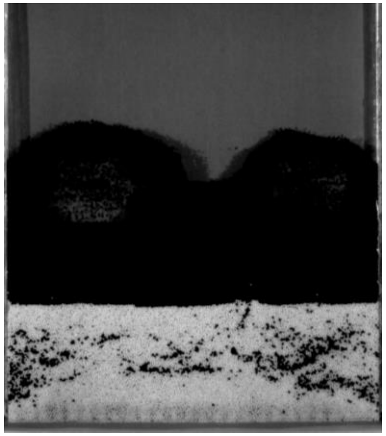

No vibration
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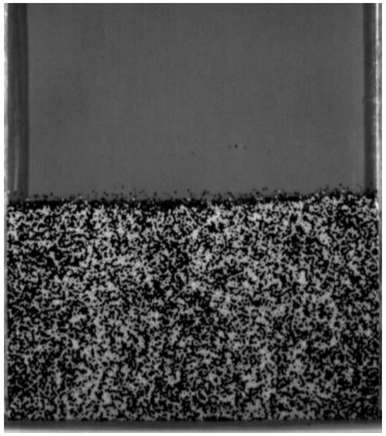
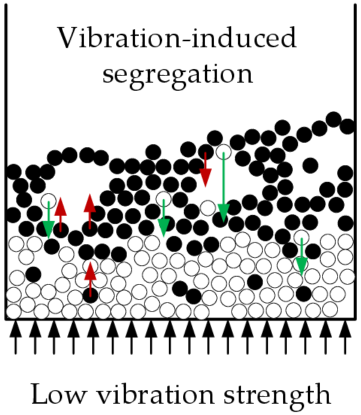
Vibration → Vibration-induced mixing

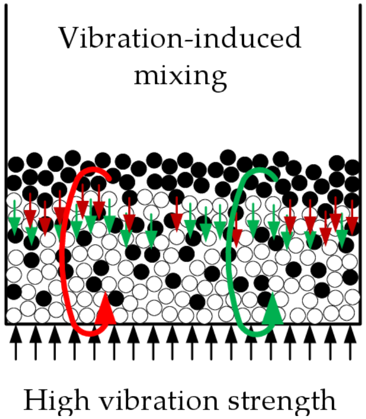


f=15 Hz
A=4 mm
No gas

Low vibration strength + gas → Vibration induced segregation



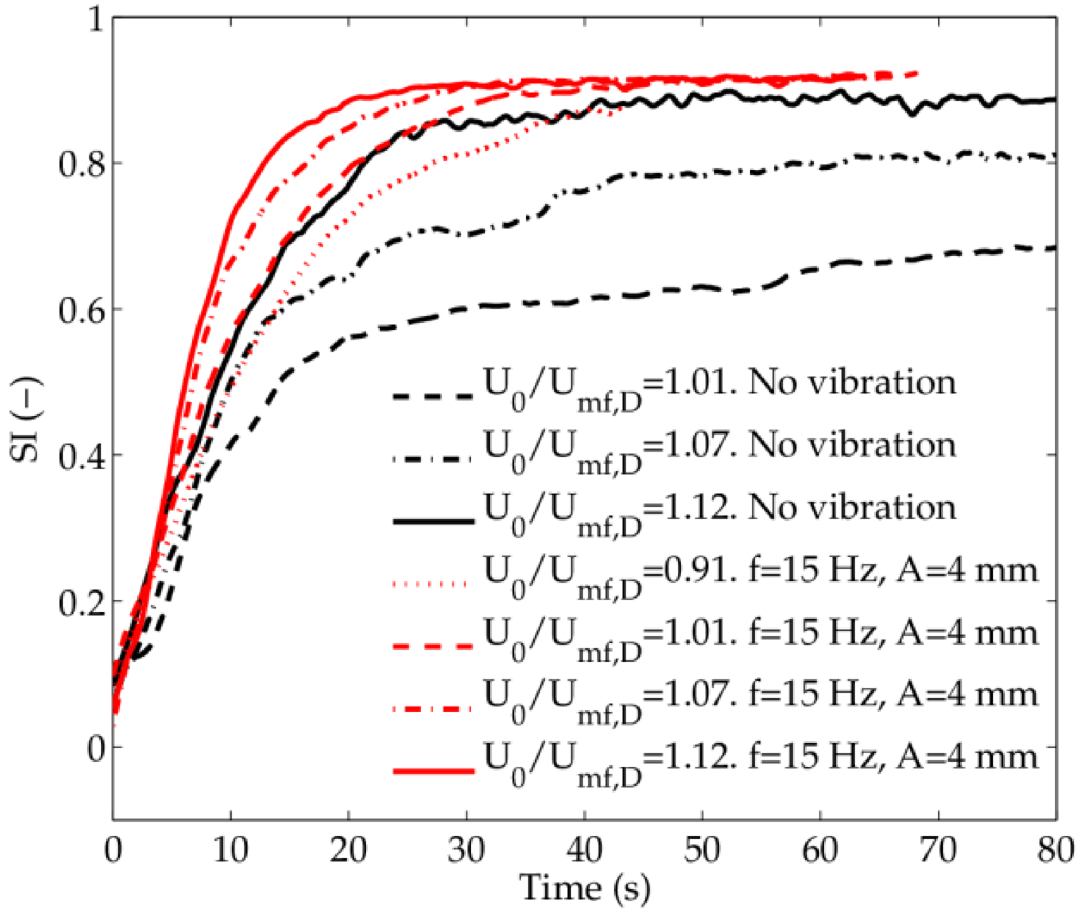
High strength vibration + gas → Low segregation extent



Transitional segregation ←

Mixture 2
f=15 Hz
A=4 mm
$U/U_{mf,D}$=1.1

Segregation index – Mixture 1

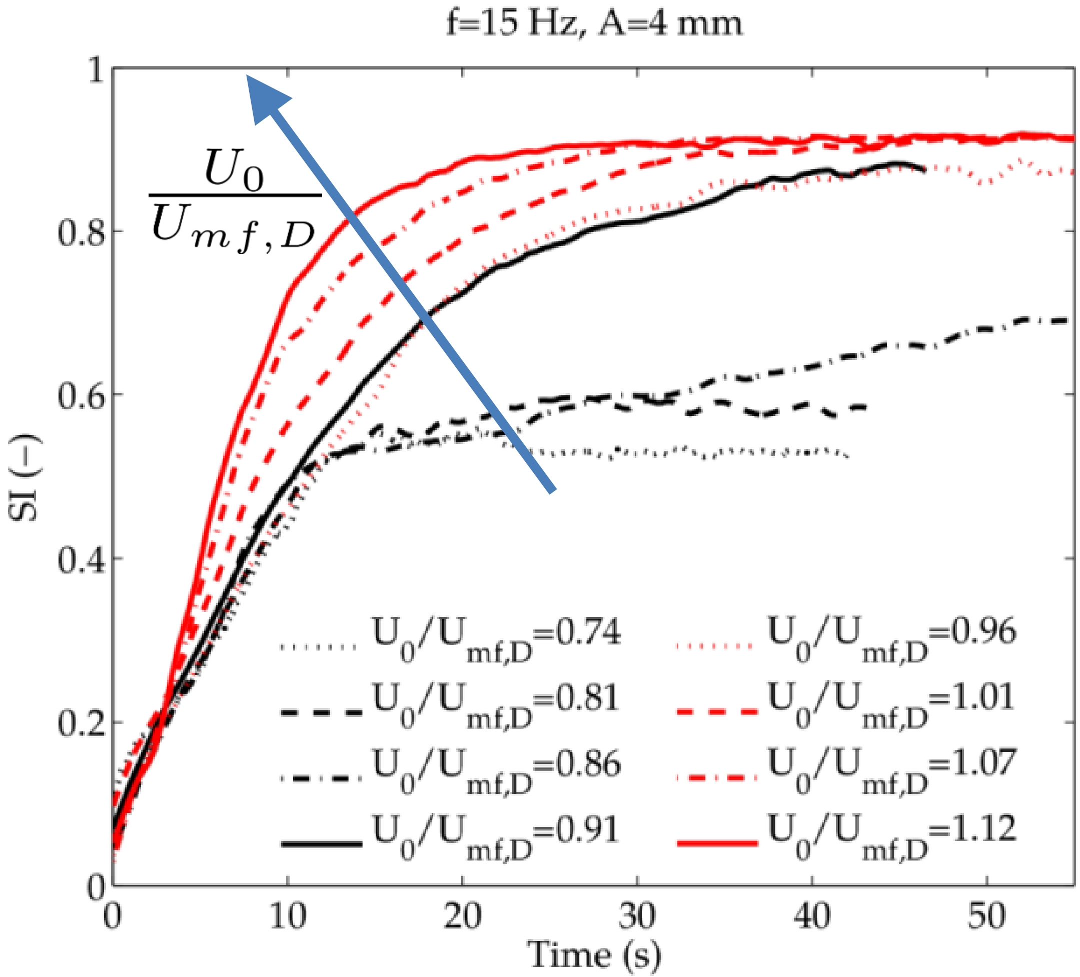


- Vibration allows segregation in cases in which $U_0<U_{mf,D}$

- Vibration reduces the segregation time and increases the segregation extent.

- U_0 increases the segregation index and reduces the segregation time.

Segregation index – Mixture 1

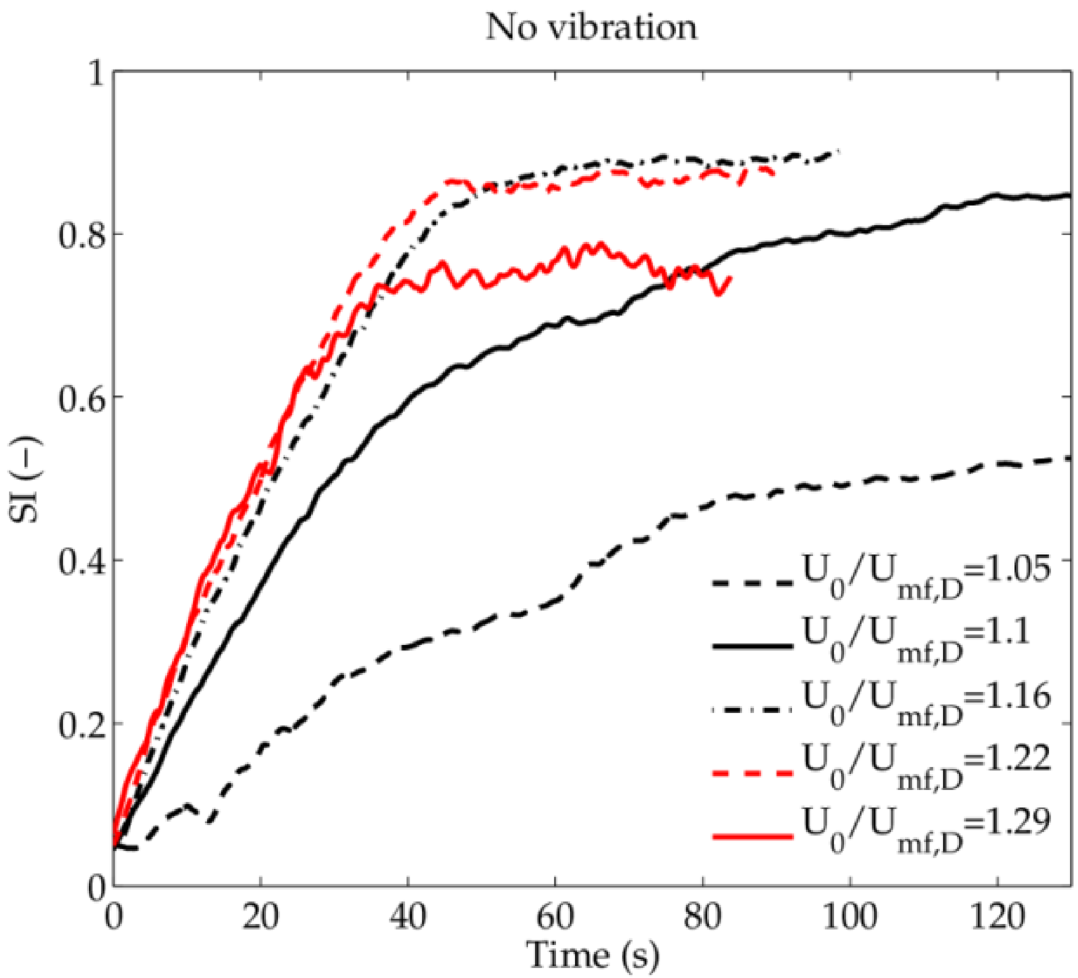


- Vibration allows segregation in cases in which $U_0 < U_{mf,D}$

- Vibration reduces the segregation time and increases the segregation extent.

- U_0 increases the segregation index and reduces the segregation time.

Segregation index – Mixture 2



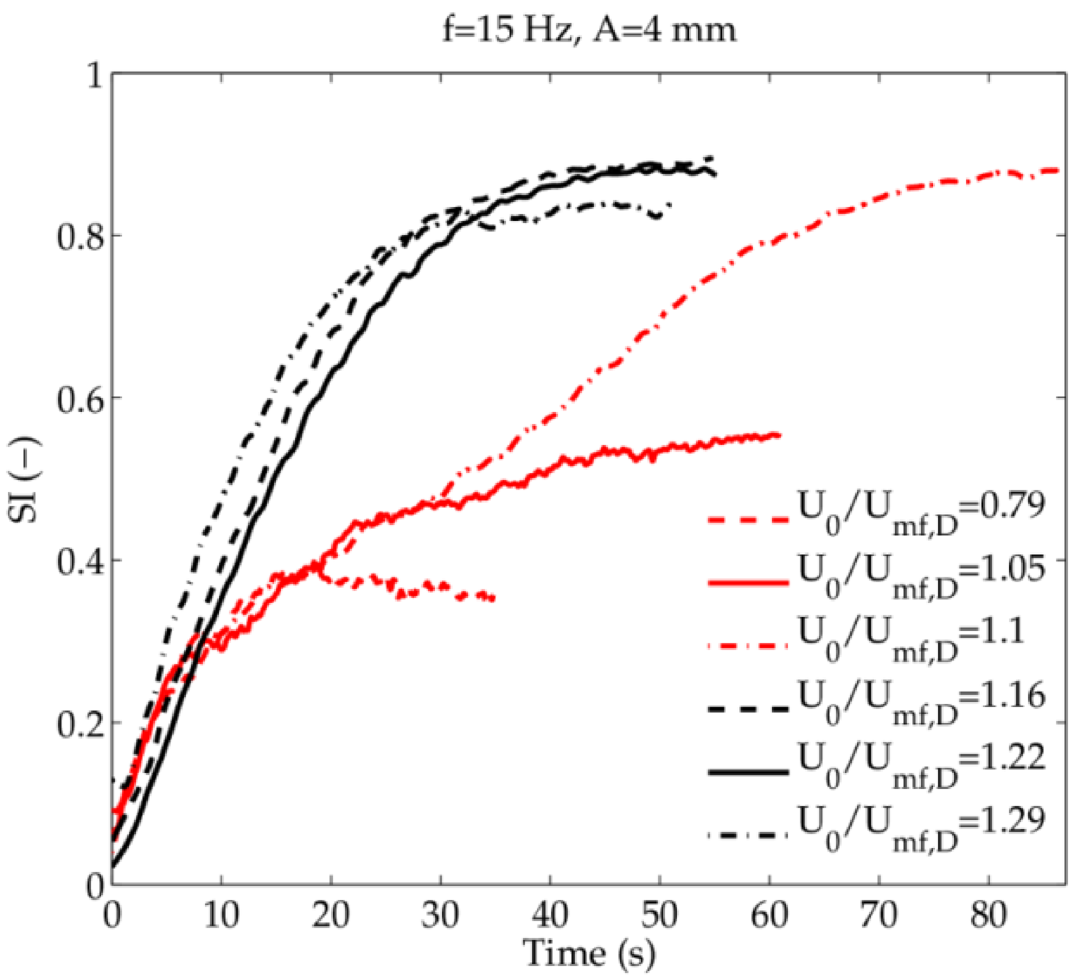
- Vibration allows segregation in cases in which $U_0 < U_{mf,D}$

- Vibration reduces the segregation time and extent.

- U_0 increases the segregation index and reduces the segregation time.

- Large gas velocities decrease the segregation extent.

Segregation index – Mixture 2



- Vibration allows segregation in cases in which $U_0 < U_{mf,D}$

- Vibration reduces the segregation time and extent.

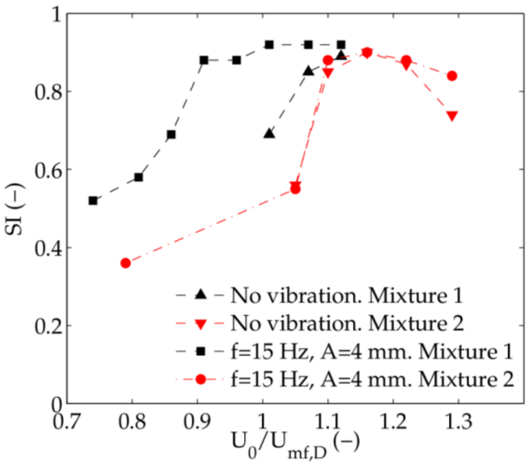
- U_0 increases the segregation index and reduces the segregation time.

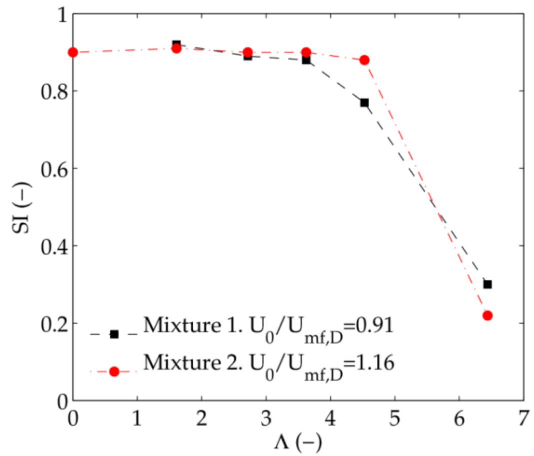
- Large gas velocities decrease the segregation extent.

- Transitional segregation

Comparison of the mixtures

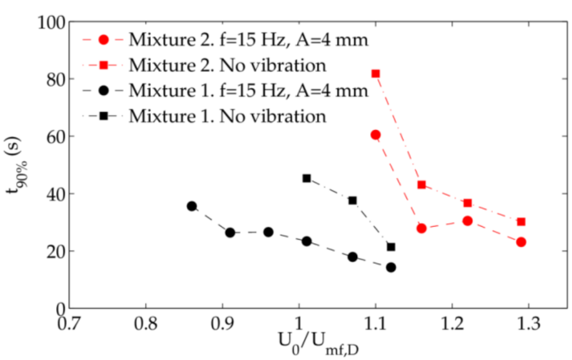
Segregation extent at large *t*

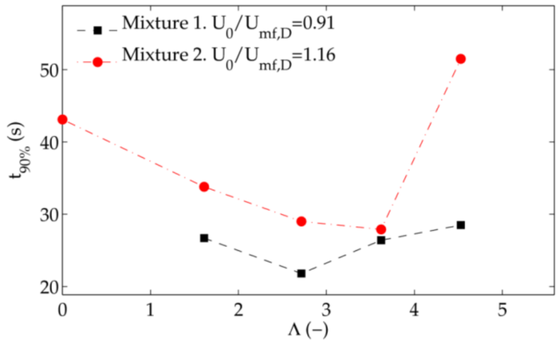




- Vibration extends the range of large SI.
- Large vibration strengths decrease the final SI.
- Optimum combination of Λ and $U_0/U_{mf,D}$.

Time to reach 90% of the maximum segregation





- The segregation time decreases when increasing $U_0/U_{mf,D}$.
- Mixture 1 segregates faster than Mixture 2.

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Conclusions

- A segregation index was developed to quantify segregation from DIA data.
- The gas superficial velocity and the vibration of the bed vessel possess counteracting effects on segregation.
- Gas superficial velocity enhances segregation.
- Low vibration strengths cooperate with gas and enhances segregation.
- High vibration strengths promote mixing.
- There is an optimum combination of Λ and $U_0/U_{mf,D}$ to maximize segregation.

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Thank you for your attention

This work has been partially funded by the Universidad Carlos III de Madrid (Ayudas a la movilidad 2015) and by the Spanish Ministry of Economy and Competiveness (project ENE2015/00188/001)