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Reversal of gulf stream circulation in a vertically vibrated triangular fluidized bed

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(MADRID, SPAIN)

Energy Systems Engineering
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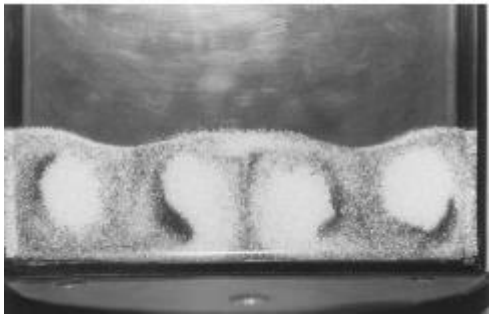
Motivation

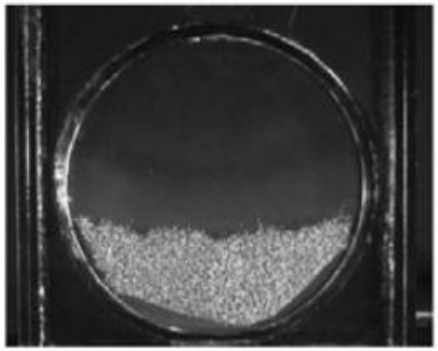
• When vibration energy is introduced in a granular assembly, a great variety of phenomena can appear.

• The appearance of granular patterns in vibrated beds is not only restricted to square-shaped beds.



Aoki et al. (1996)

• Adding gas to a triangular or conical shaped bed → Aerated hoppers or spout fluidized beds.



Lu et al. (2012)

• The present work aims at clarifying the effect of injecting gas through the inclined lateral walls of a vibrated pseudo-2D triangular bed and the identification of the different granular patterns observed.

Motivation

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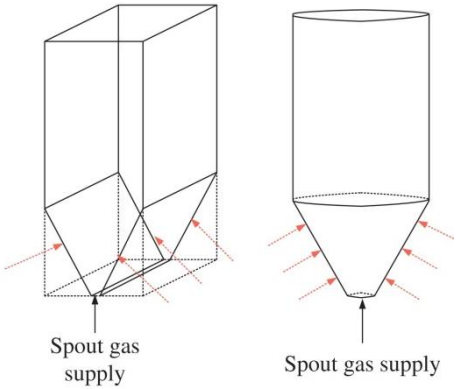
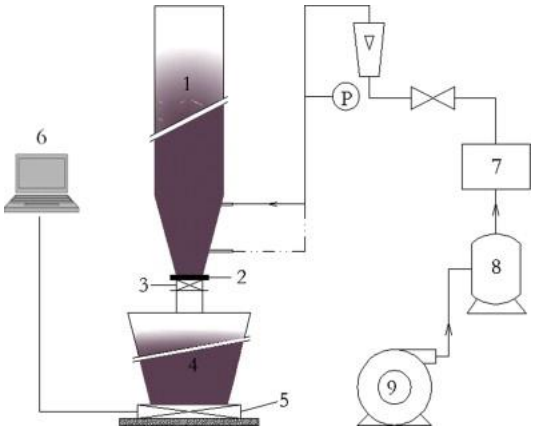


Sutkar et al. (2013)



Chen et al. (2011)

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Experimental setup

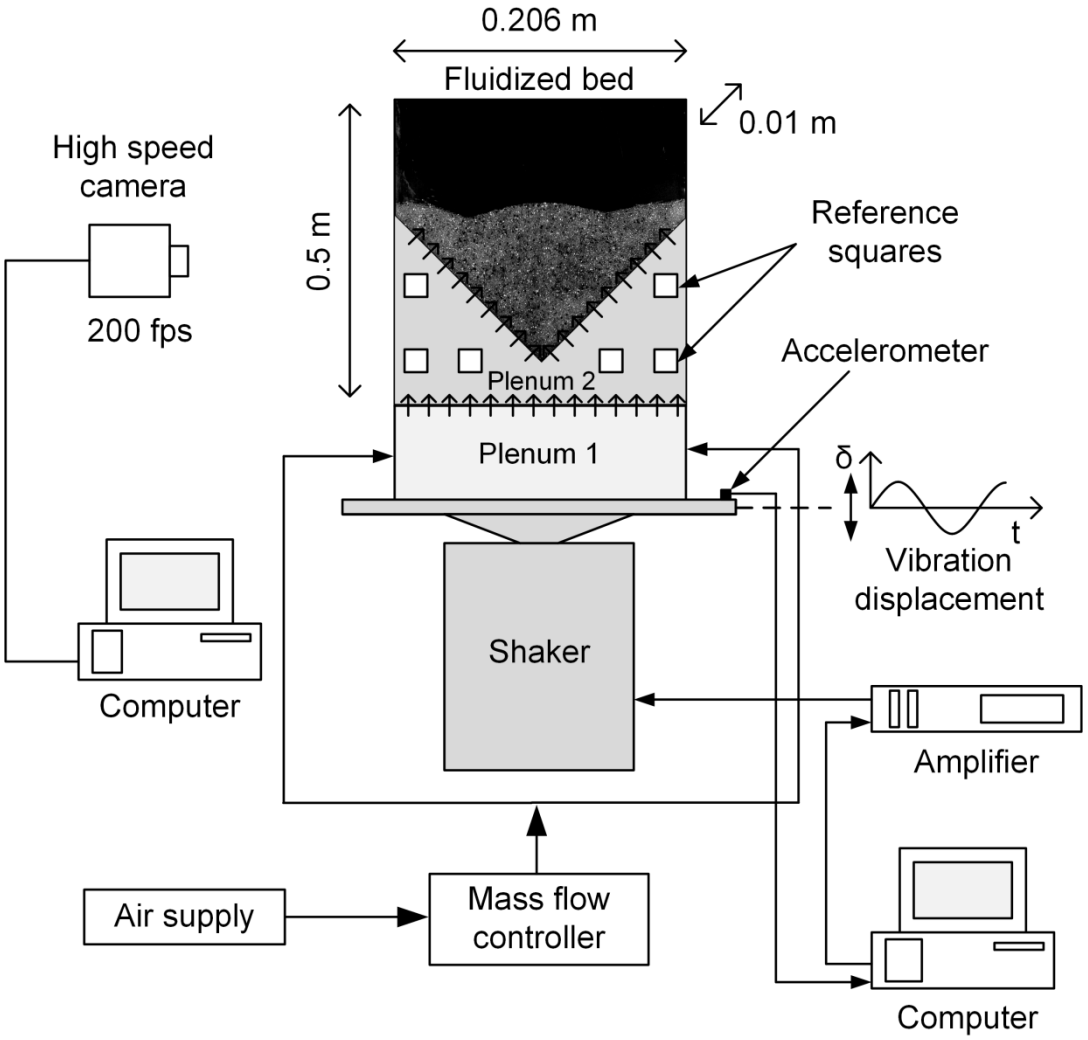

Table 1: Experimental conditions.

f (Hz)	Γ (-)	U_0/U_{mf} (-)
14	3.5	1.2
15	1.5	1.2
15	2	1.2
15	2.5	1.2
15	3	1.2
15	3.5	0.7, 0.9, 1, 1.1, 1.2
16	3.5	1.2

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

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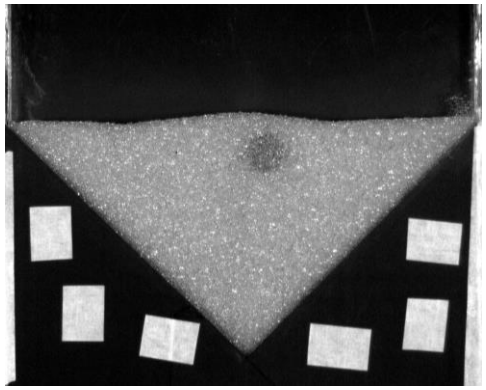
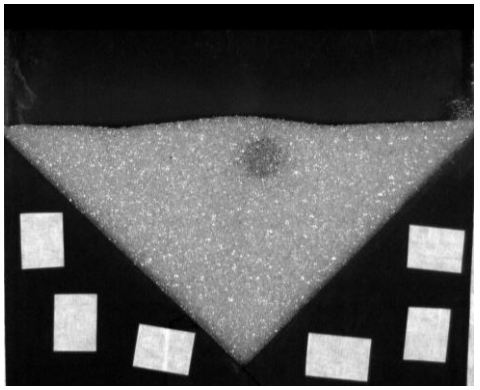
Data processing

PIV (MatPIV) in a relative system of reference that moves with the bed

Absolute



Correction of the image



Relative

Overall average solids velocity

$$\overline{U}_s = \sum_{i=1}^{N} U_i(x,y)/N$$

Phase averaged solids velocity

$$\overline{U}_{s,\phi_k} = \frac{\sum_{i=1}^{N} U_{s,i}(x,y)\delta_{i,k}}{\sum_{i=1}^{N} \delta_{i,k}}$$

where $\delta_{i,k} = \begin{cases} 1 & \text{if } \frac{k-1}{2}\pi < \phi_i < \frac{k}{2}\pi \\ 0 & \text{otherwise} \end{cases}$ and $\phi_i = 2\pi f t$

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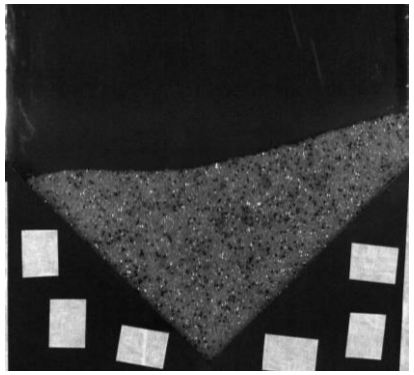
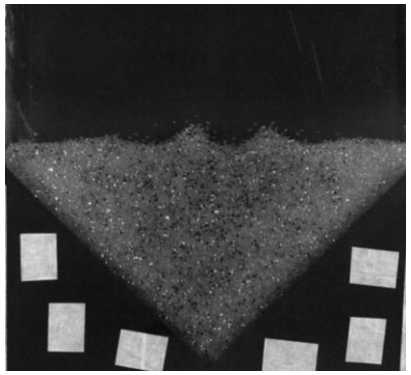
General bed behavior

Different behaviors were observed depending on the gas superficial velocity and the vibration strength and frequency:

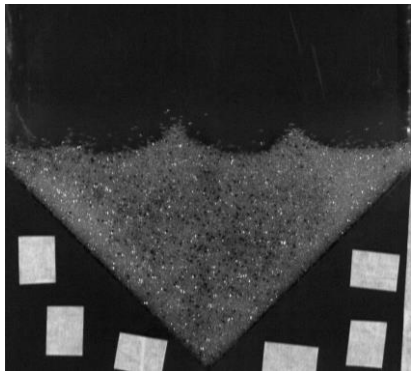
Tilting



f/2 surface waves



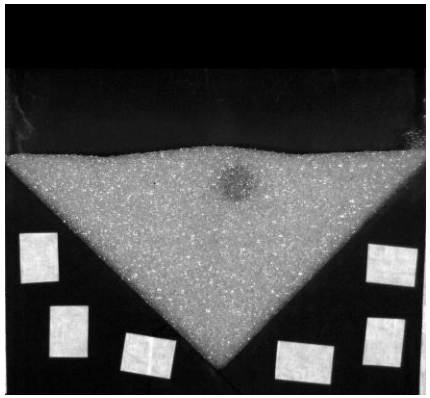
f/4 surface waves

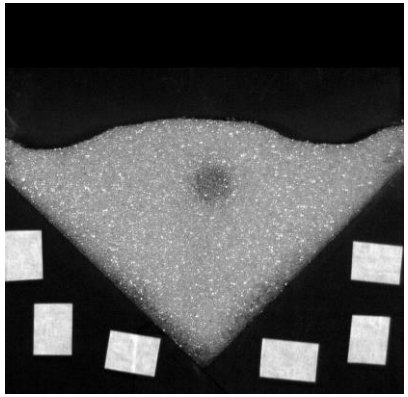


Downward convection

Reversed convection

No gas injection →

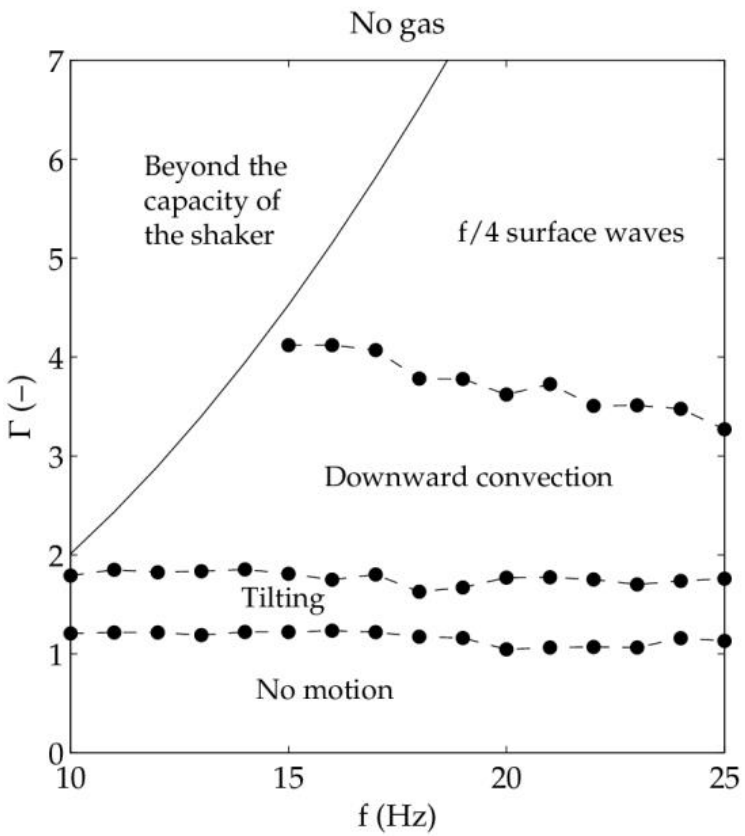


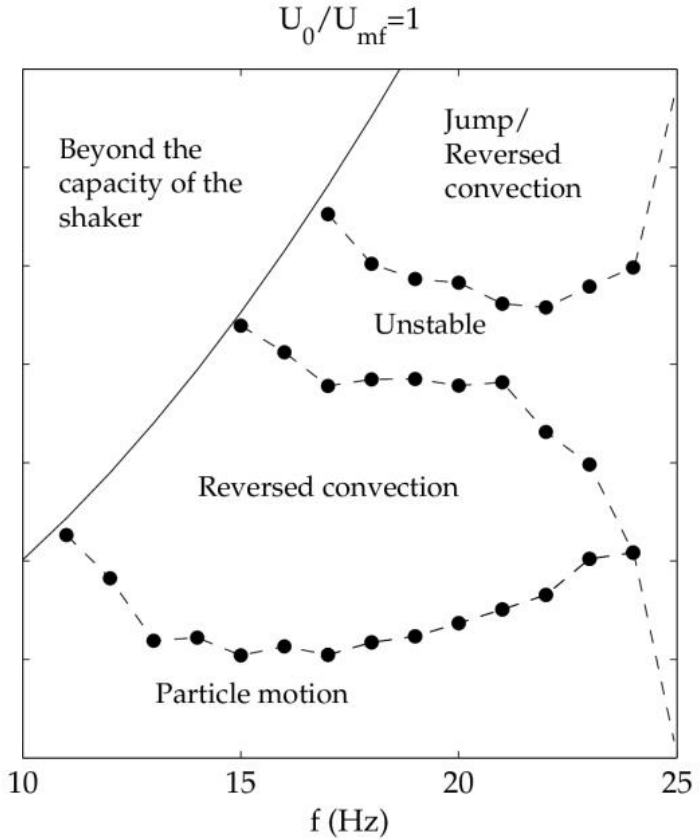


← Gas injection

Transition maps

Γ-f transition maps for different gas superficial velocities

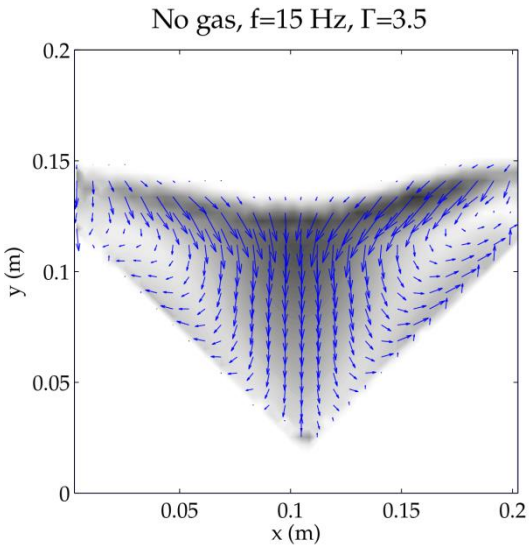




- Different granular patterns are observed
- **Regions of reversed gulf stream circulation of particles**

Solids velocity

- Formation of arching structures close to the lateral walls of the bed
- Four stagnation points when the gulf stream circulation of particles is reversed.



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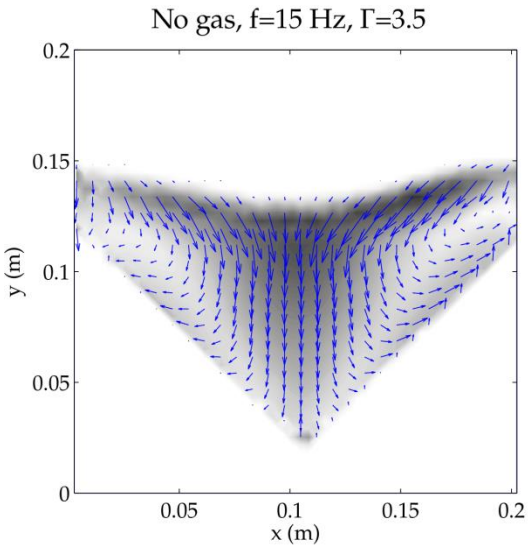

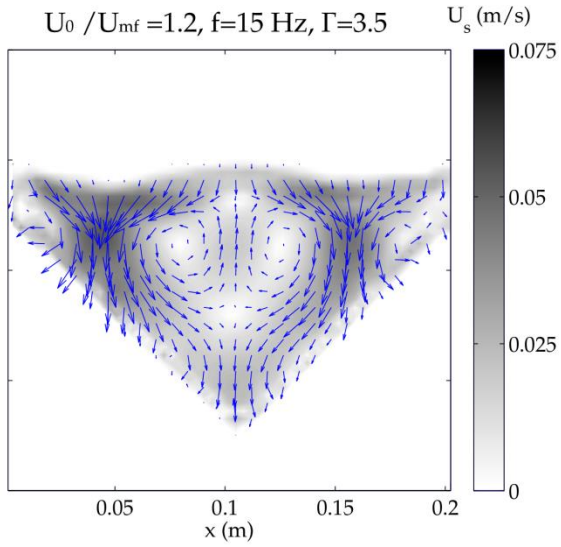

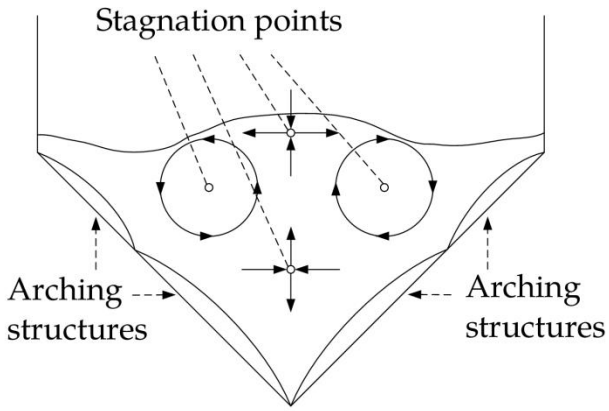

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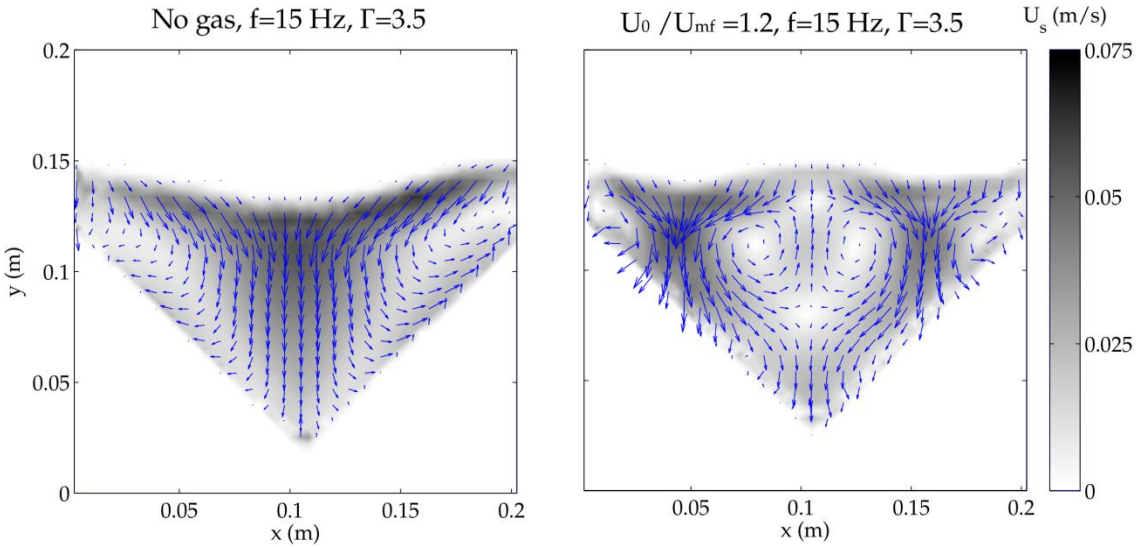
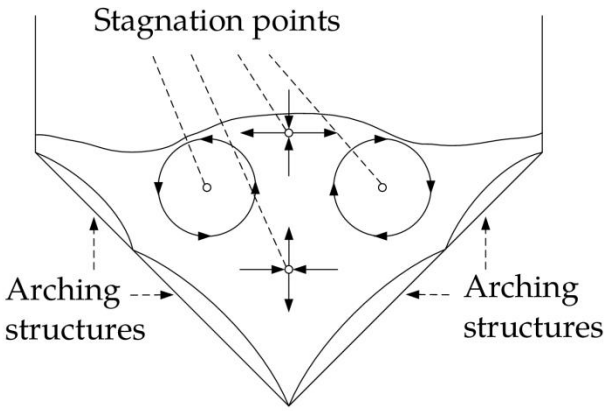
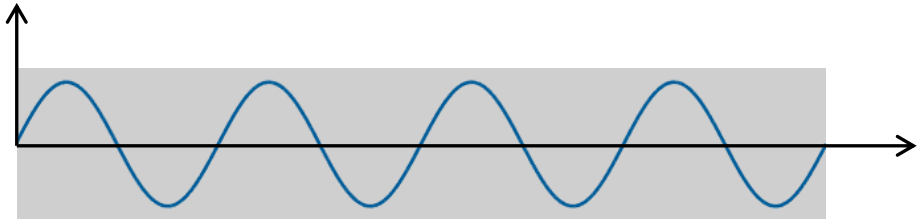


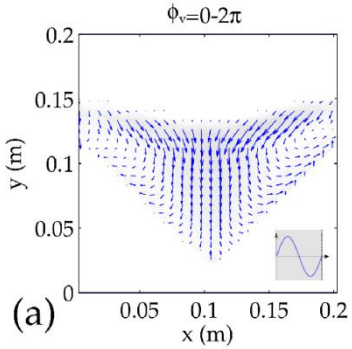


What is the cause of the convective motions?

No gas injection behavior

No gas, f = 15 Hz, Γ=3.5





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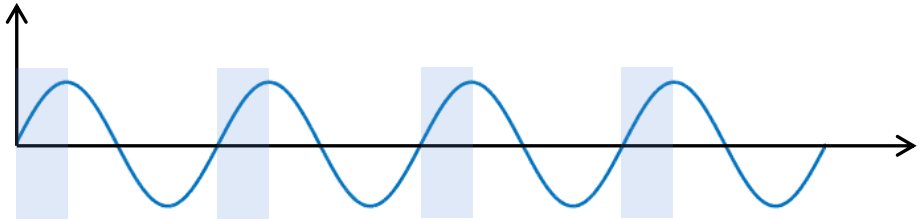

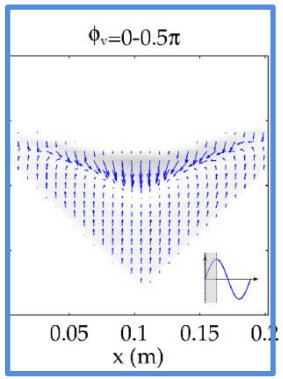

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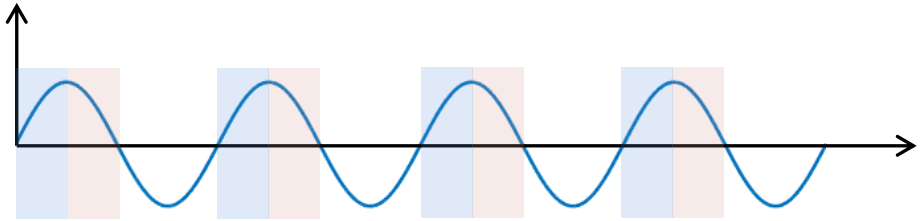

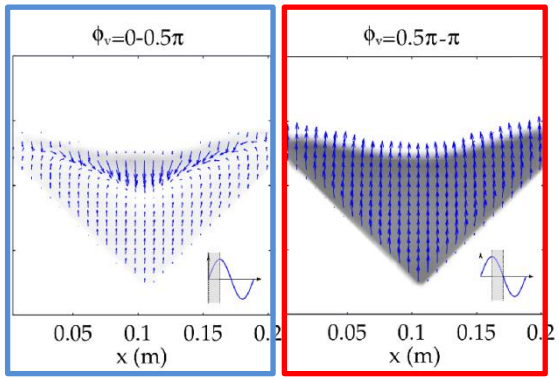

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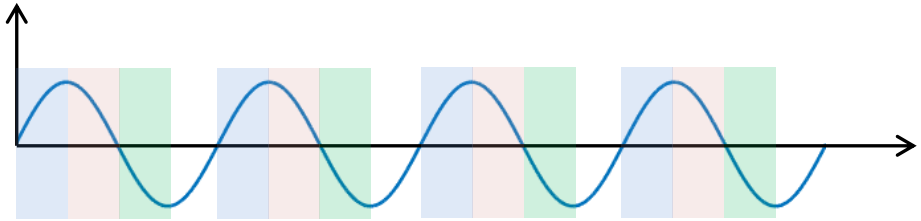

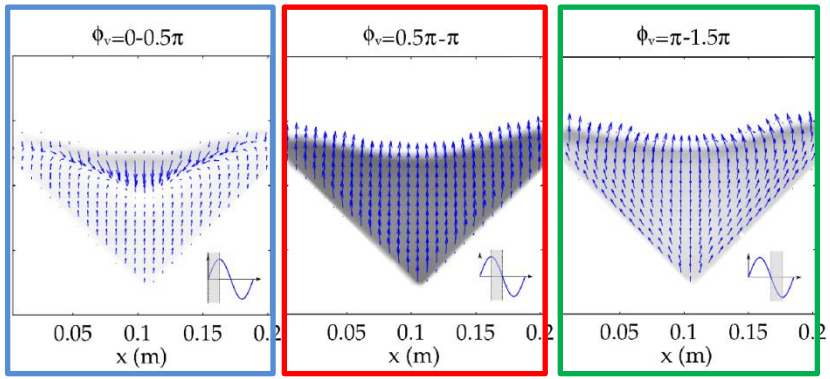

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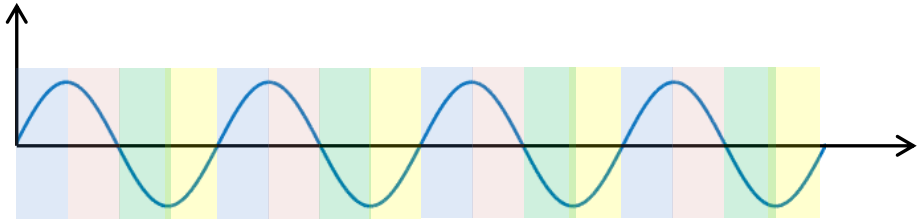

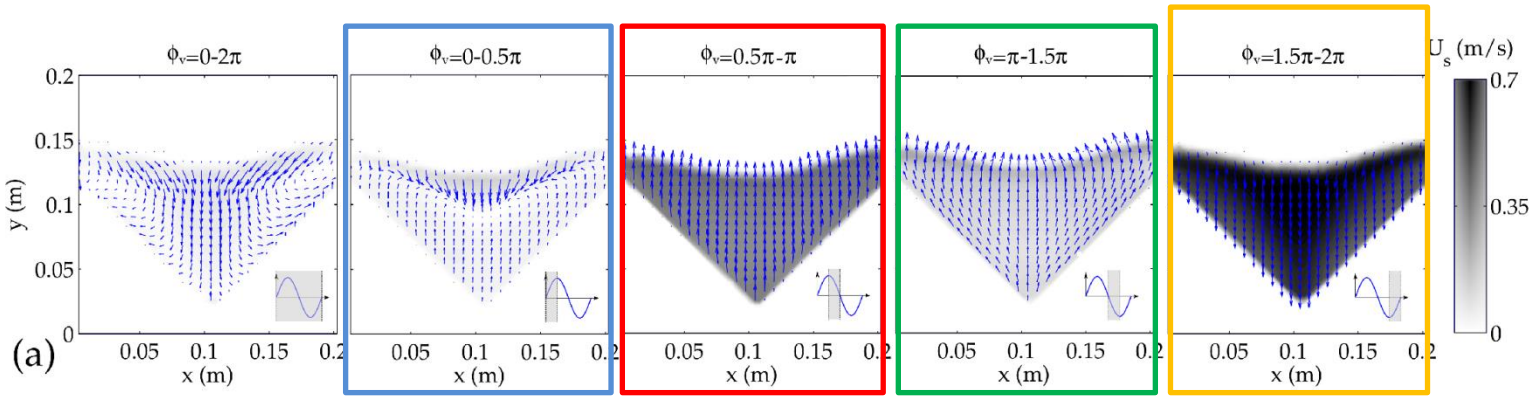

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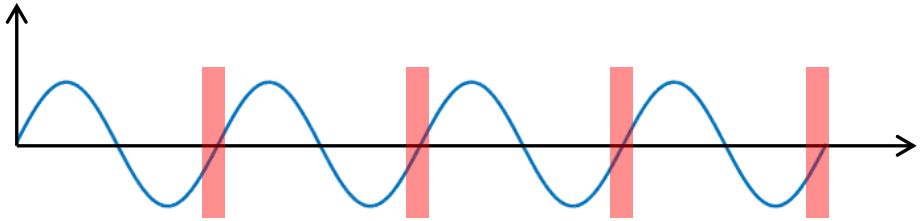
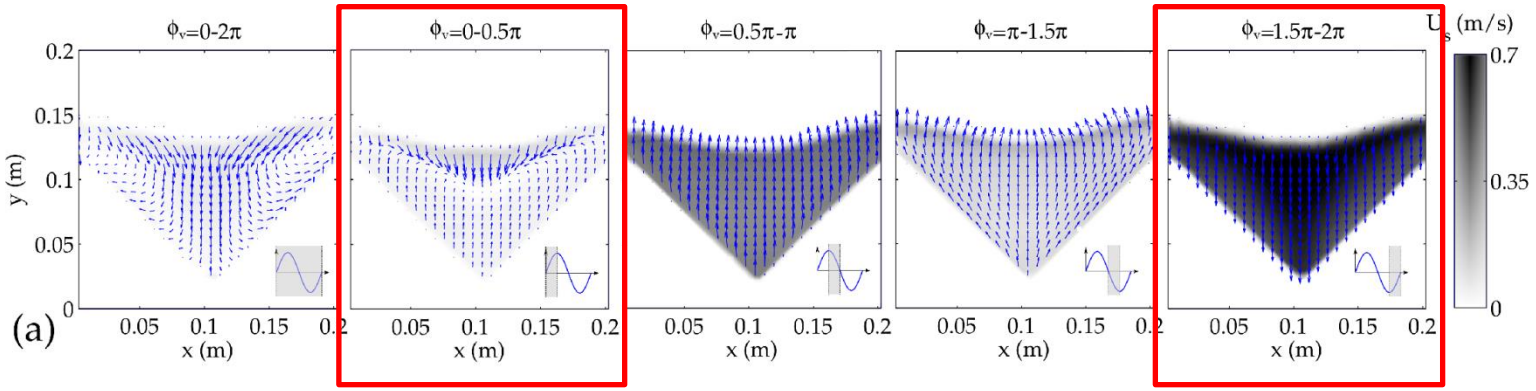
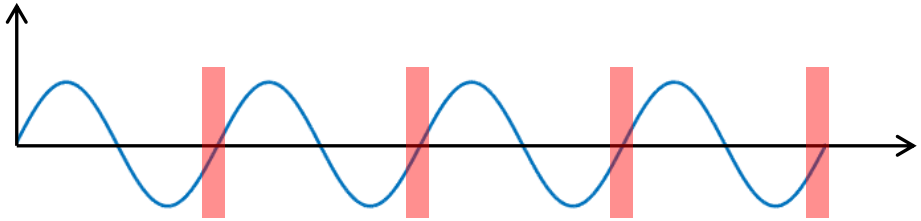


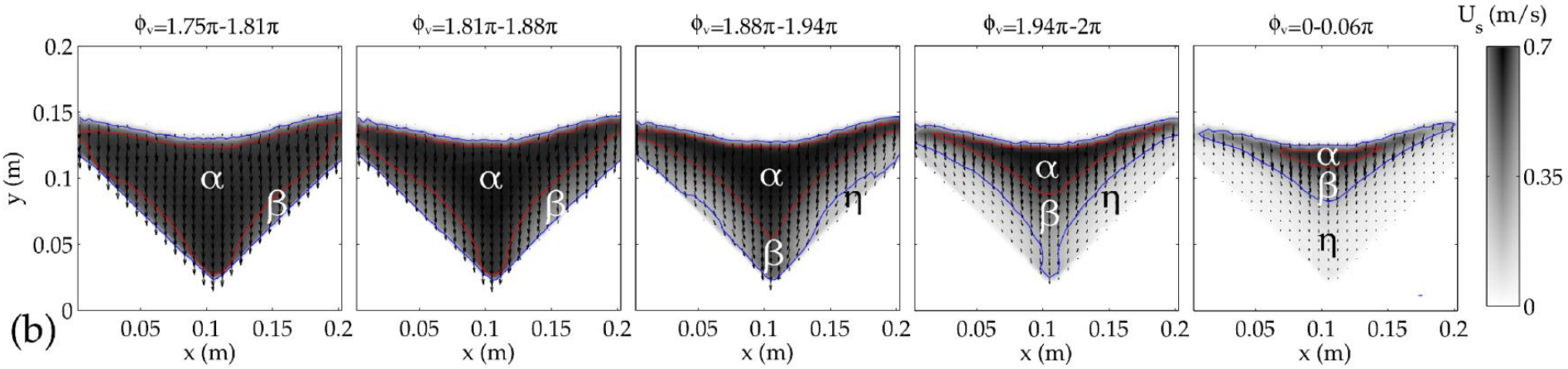


Impact of the bed bulk with the inclined walls

No gas injection behavior

No gas, f = 15 Hz, Γ=3.5

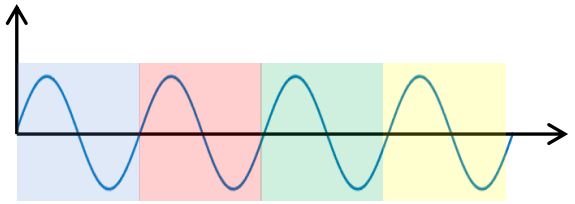


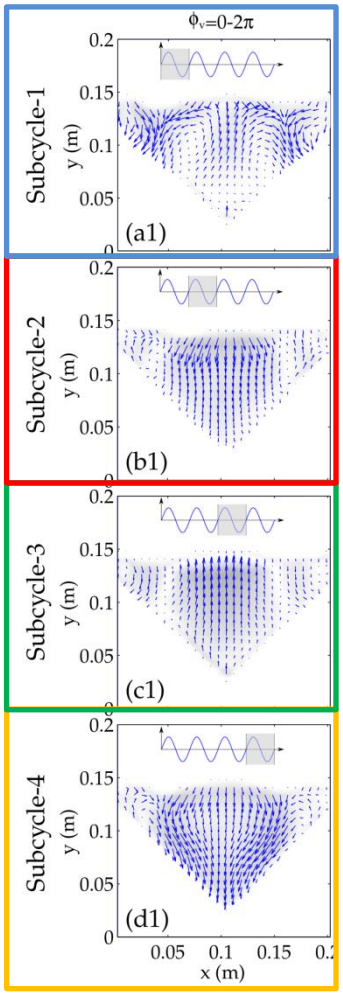


The impact wave propagates from the inclined walls to the central section of the bed.

Reversal of gulf stream circulation

$U_0/U_{mf} = 1.2$, $f = 15$ Hz, $\Gamma = 3.5$





- Four subcycles for each cycle of the bed bulk.
- Two regions: close to the lateral walls and center.
- Average particle motion → reversal of the gulf stream circulation of particles.

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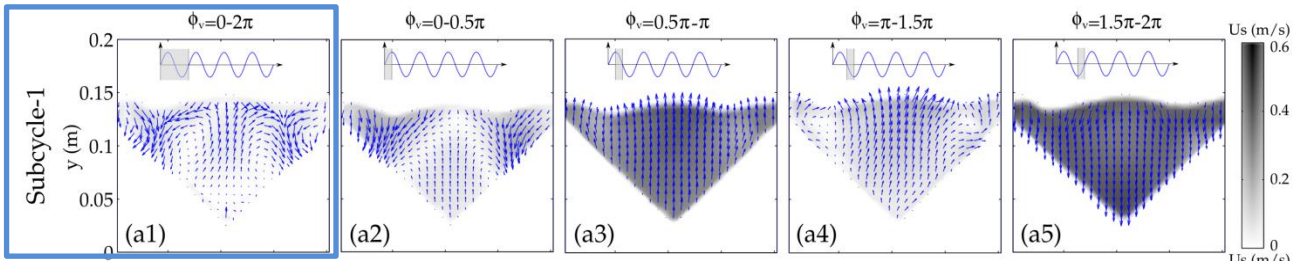

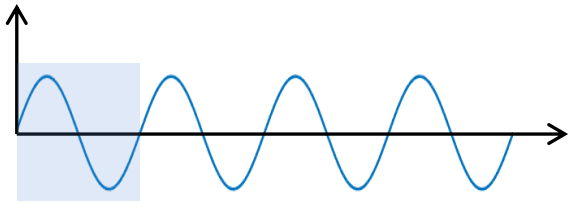

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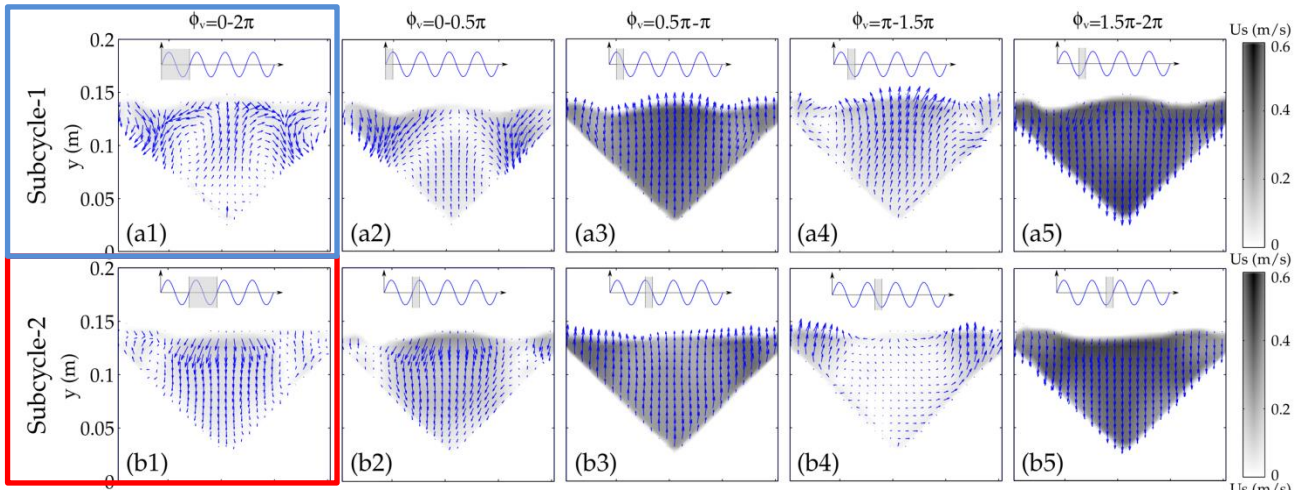

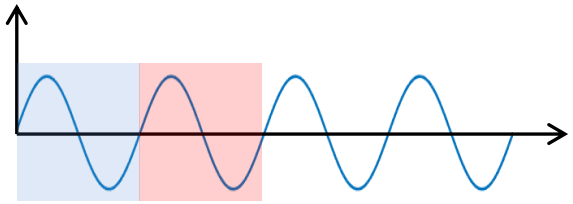

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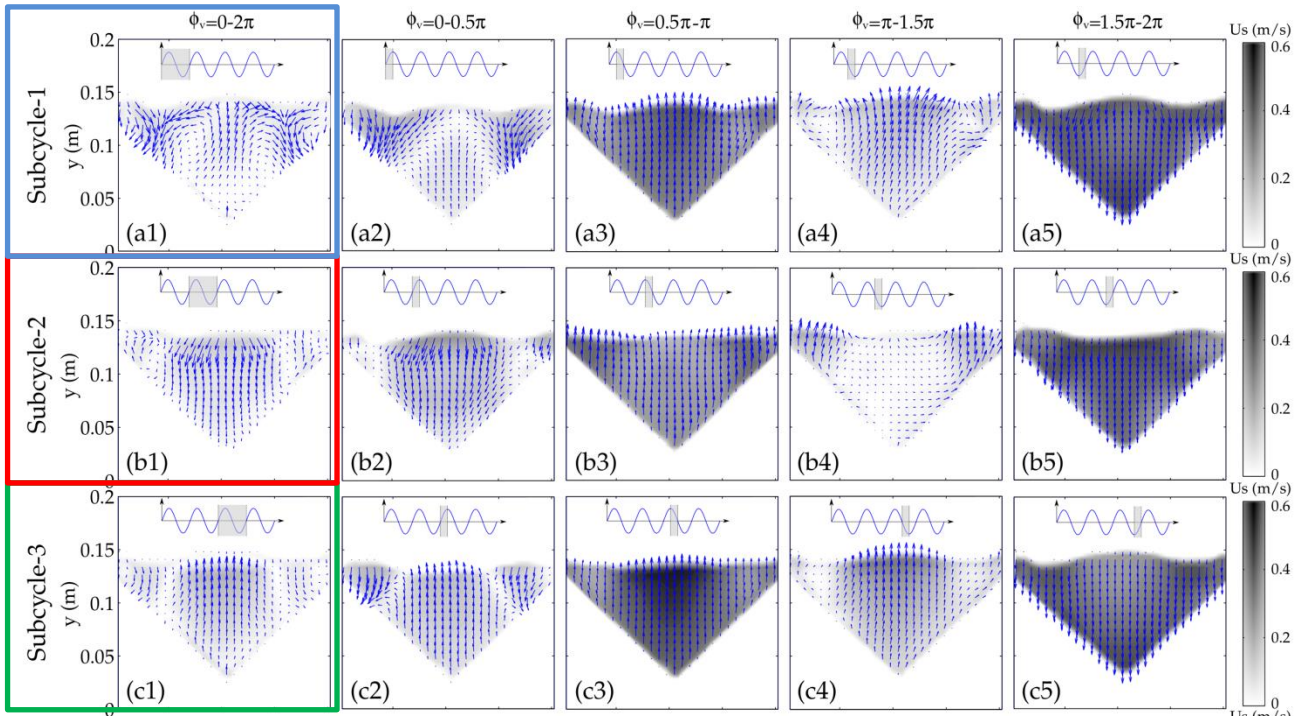

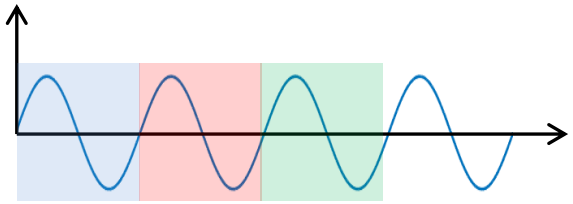

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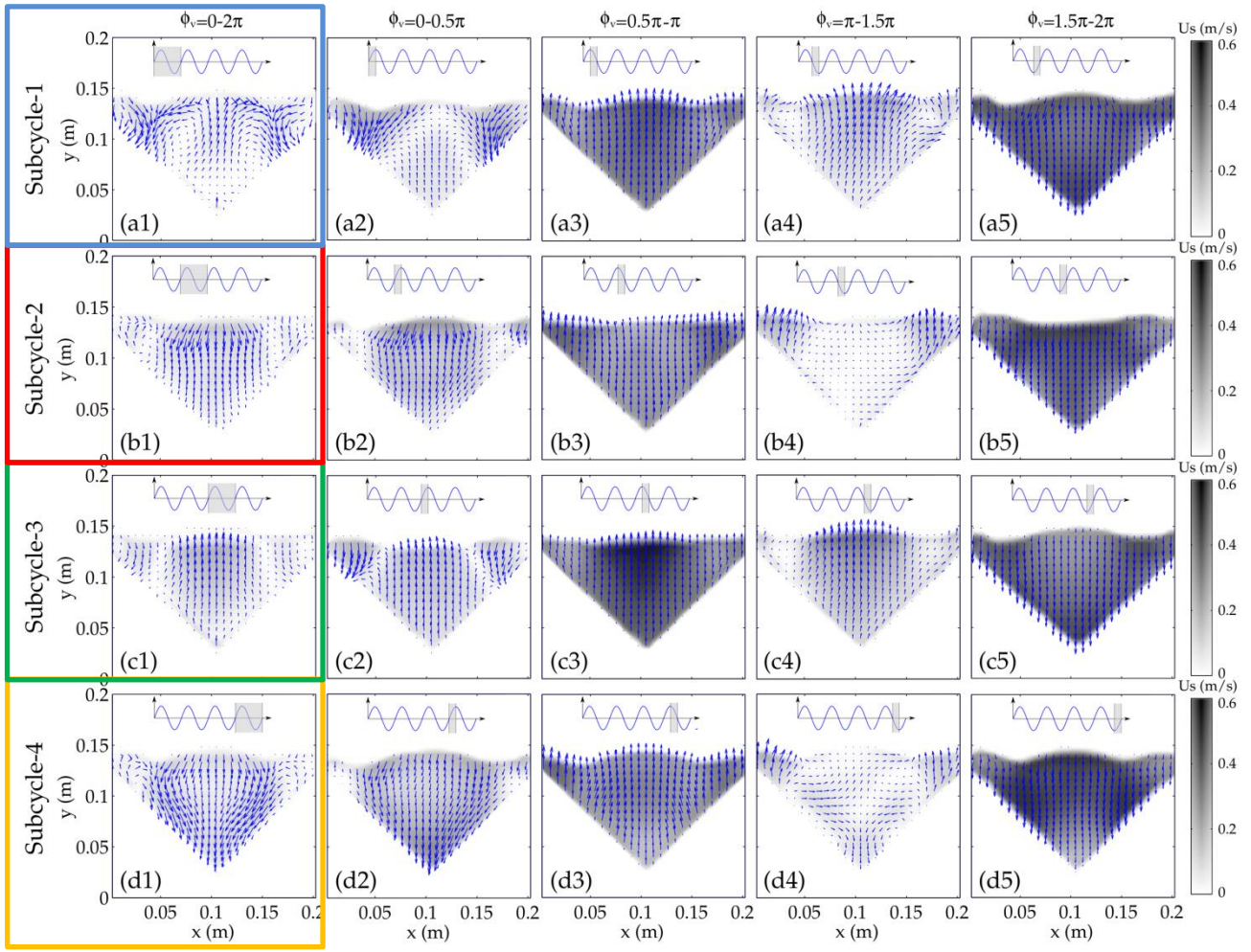

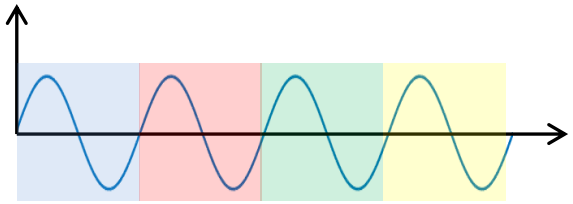

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- Two regions: close to the lateral walls and center.
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Conclusions

- Gas injection through the inclined walls of the bed change the way particles behave in a fluidized bed of triangular shape.
- Different patterns, including tilting, *f*/2 and *f*/4 surface waves were observed.
- The gulf stream circulation of particles in the triangular bed could be reversed when injecting gas through the inclined walls.
- Several subcycles of vibration appear when gas is injected. The average particle motion after a whole cycle leads to the reversal of the gulf stream circulation.

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Segregation of equal-sized particles of different densities in a vertically

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)