EVIDENCE OF COLLISION-INDUCED EFFECTS IN PARTICLE RESUSPENSION

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TITLE

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RESUME

Nos travaux portent sur la remise en suspension de billes de verre microscopiques formant initialement un dépôt monocouche sous l'action d'un écoulement turbulent. Avec une couverture de surface intermédiaire, ici fixée à environ 10 %, nous avons expérimentalement identifié deux mécanismes de détachement distincts. Pour des vitesses d'écoulement relativement faibles, quelques particules faiblement adhérentes se mettent en mouvement sur la paroi puis entrent en collision avec les particules voisines, ce qui entraîne une remise en suspension en cascade. À des vitesses d'écoulement plus élevées, la plupart des particules individuelles sont mises en suspension via leur interaction avec l'écoulement turbulent. L'évolution de la fraction de particules restant sur la surface en fonction de la vitesse d'écoulement présente un fort caractère bimodal, qui n'a pas été rapporté jusqu'à présent.

ABSTRACT

This study addresses the resuspension of microscopic glass particles from a monolayer bed into a turbulent gas flow. With an intermediate surface coverage, here set to about 10 % of the field of view, we report two distinct detachment mechanisms. At relatively low flow velocities, few loosely adhering particles move on the wall to eventually collide with neighboring particles resulting in a clustered resuspension. At higher fluid velocities, mostly individual particles resuspend due to their interaction with the turbulent flow. The resuspension curve, showing the remaining particle fraction as a function of the flow velocity, exhibits a strong bimodal character, that has not been reported so far.

MOTS-CLÉS : écoulements multiphasiques, particule, resuspension, paroi, propagation de collision / **KEYWORDS:** multiphase flow, particle, resuspension, collision-propagation

1. INTRODUCTION

1.1. General context

Resuspension refers here to the physical process by which a bed of solid particles initially at rest on a wall surface is re-entrained by a turbulent flow. Particle resuspension is ubiquitously present in natural and industrial environments (Henry & Minier, 2014). In fact, resuspension occurs in a number of atmospheric flows (it is then referred to as dry resuspension). Examples include pathogens detaching off indoor and outdoor surfaces, microplastics, soot, minerals in arid environments, radioactive particles and terrestrial ones during Mars explorations. Resuspension can also occur in liquid flows and is then referred to as wet resuspension. For instance, resuspended debris in water include organic pollutants, heavy metals and microplastics entrapped in sediment beds.

1.2. Objectives

Modelling resuspension is a challenging task owing to its complexity and multiscality (Henry & Minier, 2014). In practice, numerical concepts describing the resuspension at the particle scale, that is in the micron to millimetre size, exist. However, such models have been designed to treat two limit cases: monolayer or multilayer deposits. In the monolayer case, the inter-particle distance L is implicitly assumed to be much greater than the particle diameter d_p ($L \gg d_p$), such that each resuspension event can be treated independently. In the multilayer case where particles sit on top of one another ($L/d_p \rightarrow 0$), resuspension events involve either single particles or clusters of particles depending on the local deposit structure and inter-particle cohesion forces. Yet, a unified description of particle resuspension from monolayer to multilayer deposits is still missing.

The present work bridges the gap by addressing the very special case where the inter-particle distance becomes comparable to the particle diameter ($L \sim d_p$). Such investigations raise exciting questions because of the anticipated competition between the two triggering mechanisms: individual resuspension due to the turbulent flow or collision-induced resuspension (Matsusaka, 2015 ; Rondeau et al, 2021).

2. METHOD & RESULTS

2.1. Methodology

The measurement of particle resuspension in a wind channel is detailed in (Banari et al, 2021). Spherical particle beads (made of Barium-titanate glass) with a diameter of 40 µm are initially sprinkled over the substrate, resulting in a monolayer deposit with a surface coverage typically around 10 %. The substrate is then placed in a wind channel (far enough from the channel entranced that the turbulence is fully developed). The airflow is then increased in a stepwise manner. For each value of the flow rate, the number of particles remaining on the substrate is monitored using a high-speed and high-resolution camera (together with image processing techniques). Within seconds, the number of particles remaining reaches an equilibrium and the flow rate is then increased again.

2.2. Results

We provide the first direct experimental evidence of inter-particle collisions in the case of a monolayer deposit (with a surface coverage as low as 10 %, i.e. a ratio between interparticle spacing and particle radius $L/d_p \sim 5$). Such collision-propagation effects induce a bi-modal character in the measured resuspension rate instead of the typical sigmoid shape reported in previous experimental investigations of purely monolayer deposits (Barth et al, 2014). Quantitative numerical simulations endorse these observations by including a simple collision component to the course of events leading to resuspension. The model, despite its relative simplicity, further highlights the subtle role played by local clustering regions, where particles are much closer to each other resulting in significant collision-propagation effects (Banari et al, 2021).

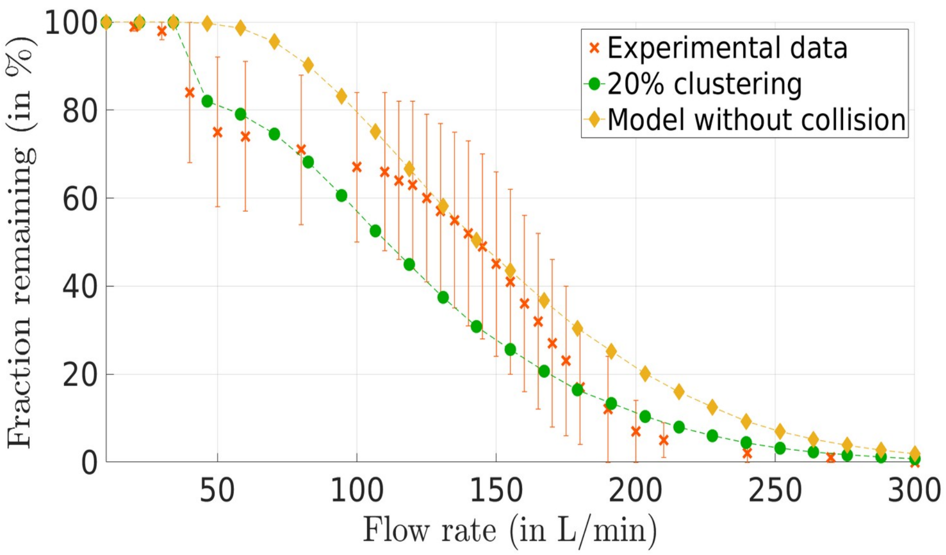

Figure 1. Comparaison entre les simulations et les données expérimentales

3. CONCLUSION

The present study provides direct evidence of the recent idea that monolayer resuspension actually results from three underlying mechanisms: direct-lift off, rolling/sliding motion and inter-particle collisions. These findings call for the development of refined resuspension models that account for such collision-propagation effects. However, such sophisticated models require a more systematic analysis of the experimental data in order to shed light on the phenomenology of collision-propagation (including shielding effects, average distance and time between collisions, outcome of collisions, role of elastic or inelastic collisions).

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