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Review

Progress in particle resuspension from rough surfaces by turbulent flows

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ABSTRACT

This article deals with the resuspension phenomenon whereby particles adhering on a wall surface can be re-entrained by a flowing fluid. This is an area where significant progress has been achieved over the last years from an experimental, theoretical and numerical point of view. A first purpose of the present work is to report on the advances that have clarified our understanding of the physics of particle resuspension. It will be seen that new pictures have emerged about the physical processes involved in particle resuspension and, correspondingly, that new models have been proposed. A second purpose of the review is to put forward a general framework that allows both experimental analysis and new modelling ideas to be developed in terms of the fundamental interactions at play. These interactions are made up by the particle–fluid, particle–surface and particle–particle forces which are, in turn, related to the three specific fields of fluid dynamics, interface chemistry and surface roughness. Such a separation is helpful to highlight the actual physical processes while emphasising their relative importance in different situations and to provide useful guidelines for the necessary modelling efforts. In particular, it is stressed that new models which capture particle motion along a wall and simulate the complete particle dynamics represent an improvement over more classical static approaches. It is proposed that these new approaches be pursued and brought to higher levels of maturity.

In this paper, attention is first focussed on the case where only a single layer of particles is sticking on the surface and, thus, can be re-entrained. A detailed review of the experimental works brings out the essential mechanisms and particle resuspension is shown to result from a balance between particle–fluid interactions and particle–surface interactions influenced by surface heterogeneities (roughness). The numerical models which have been proposed are then thoroughly discussed with respect to a new hierarchy of modelling approaches which is introduced. The present paper also outlines the mechanisms of multilayer particle resuspension which is still an open subject and where our present understanding remains preliminary. In this situation, resuspension is shown to be also governed by particle–fluid and particle–surface interactions but with the addition of particle–particle interactions (through cohesion forces or impaction). Finally, suggestions about the areas that still need to be addressed as well as about the issues that remain to be improved are addressed.

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1. Introduction

The present review deals with the issue of particle resuspension, a field where much progress has been made experimentally, theoretically and numerically since the detailed review of Ziskind [1].

1.1. The resuspension phenomenon

Resuspension (also referred to as re-entrainment, removal or detachment) corresponds to the process where particles sticking on a surface are reentrained away from the surface. Depending on the field, resuspension can either be required so as to limit surface fouling (for instance dust accumulation on solar cells [2]) or has to be avoided when deposited particles are hazardous materials (such as radioactive particles in nuclear power plants [3] or contaminant particles in hospitals). The resuspension phenomenon has thus been extensively studied in a wide range of fields which are illustrated by the following examples.

- Re-entrainment of sediments (particles with sizes ranging from a few tens of micrometres to a few millimetres) is a key issue in sediment dynamics [4] and also in soil resuspension [5].
- Dust resuspension is a matter of concern for the environment since a release of road dust (particulate matter with diameters smaller than 10 μm) greatly impacts pollution levels [6] and, also, since resuspended dust can be carried by winds [7] (sometimes leading to the formation of sand dunes in desert).
- Resuspension of airborne particles is investigated both for indoor environment [8] (including ventilation systems [9,10] or walking-induced resuspension [11]) and for outdoor environment (e.g. industrial pills and pesticide applications [9]) due to their potential threat on human health.