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Modelling of dust lifting using the Lagrangian approach

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Abstract

The subject of this paper is dust lifting behind shock waves, a process that is important for the formation of explosive dust clouds in air. While Eulerian–Eulerian has been the standard numerical technique for such simulations, the Eulerian–Lagrangian technique has been used in this paper, making it possible to take into account more physical phenomena, such as particle–particle and particle–wall collisions. The results of the simulations are shown mainly graphically, as snapshots of particle positions at given times after the passing of the shock wave. The results show that the collisions, and the coefficient of restitution assumed for them, is important in determining the mobility and lifting of dust behind shock waves. The results also show that the idea of a horizontally travelling shock wave is an oversimplification: the strong pressure gradient at the surface results in a series of reflected waves generated at the surface and travelling into the gas phase.

Keywords: Dust lifting; Explosion; Two-phase flow; Shock waves; Lagrangian model

1. Introduction

Dust lifting behind shock waves is a process that is especially interesting for engineers and researchers dealing with safety problems connected with dust explosions. Organic, metal or other

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kinds of dust can become hazardous when they are mixed with air and ignited. Such materials are present in many branches of industry and they constitute a potential danger for both people and equipment.

In practice dust is lying in deposits, for instance in processing units or in coal mines. The dust can easily be entrained by a pressure wave that may be generated intentionally or by accident. The latter case is unexpected and can lead to the creation of a dangerous mixture, and this type of occurrence has therefore been the subject of much research. Most of this research has been experimental, see for instance Fletcher (1976), Kauffman et al. (1992), Lebecki et al. (1995) and Lebecki et al. (2000). In those experiments a dust layer was lying at the lower wall of a channel and a primary explosion was generated with the object of creating a strong pressure wave. The wave propagated over the dust deposit and as a result the dust was entrained, dispersed and finally ignited.

This type of experiment is usually expensive and difficult to carry out, especially when accurate measurements are required. Therefore it has become popular to perform numerical simulations of such processes in recent years. One of the early studies was that of Butler et al. (1982) in which the interaction of a shock wave with a porous bed was modelled. The model used by Butler et al. was the basis of models used later by other researchers.

In the following years, other publications appeared, which were devoted specifically to the topic of the solid phase lifting behind a shock wave: Kuhl et al. (1989), Ben-Dor and Rayevsky (1991), Collins et al. (1994), Klemens et al. (2000), Thevand and Daniel (2002) and many others. The wider problem of modelling two-phase flows, with and without combustion, for safety applications have been a topic of many publications: Miura and Glass (1982), Dushin et al. (1993), Samuelsberg and Hjertager (1996), Boiko et al. (1997), Boiko and Poplavski (1997), Rose et al. (1997), Smirnov et al. (1997), Tu (1997), Mathiesen et al. (2000), Ibsen et al. (2000) and many others.

This paper is devoted to modelling dust lifting from a solid surface behind shock waves. In most of the publications mentioned above the main simulation method has been the so-called Eulerian approach, where the solid phase is treated as a continuum, penetrating and interacting with the gas phase and described by nearly the same equations as the gas phase. Both phases are coupled by a set of interphase interaction mechanisms, such as drag and lift force, heat and mass exchange and chemical reaction.

Not many attempts have been made to use the Lagrangian approach where the particles are treated as points that move in the computational domain interacting with the moving gas. Two-way coupling needs to be considered for this kind of process, since the particles act on the gas by changing its momentum significantly. Simulations using this approach are not easy to perform even nowadays due to the huge numbers of particles in real applications. On the positive side, this kind of simulation is very realistic from the physical point of view and many physical phenomena can be considered that cannot be accounted for in the Eulerian approach. An example is collisions between the particles: this is challenging and problematic for Eulerian models.

Summarizing: it is not possible to use the Lagrangian approach for simulation of dust lifting in large-scale domains covering real industrial facilities. However, using this approach for a smaller domain makes it possible to analyse the fundamental processes and seek the mechanisms responsible for entrainment of solid particles from a deposit.