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Numerical simulation of hybrid dust/gas explosion experiments in the standard 20-L sphere

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HIGHLIGHTS

- The CFD code DET3D has been extended to cover also hybrid dust/gas combustion events.
- The paper describes numerical simulations of dust/gas explosion experiments in the standard 20-L sphere with DET3D.
- Special emphasis is given to a good reproduction of the explosion indices and of the pressure decay after the explosion.
- The simulated experiments use aluminium-dust in combination with hydrogen/air gas mixtures.
- The same approach can also be used with other dust species, e.g. graphite, tungsten or beryllium.

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ABSTRACT

During the last years, the CFD code DET3D, originally developed for the simulation of pure gas explosions [1], has been extended to cover also hybrid dust/gas explosions, using the Crebcom combustion model [2]. The paper gives an overview of the model development in this regard and, in particular, of the validation calculations using experiments performed at the Karlsruhe Institute for Technology (KIT) in the standard 20-L Dustex sphere [3]. The code has been used to simulate explosions with various dust species (graphite, tungsten, aluminium, beryllium) distributed in a wide range of $H_2/O_2/N_2$ gas mixtures but, because of its relevance for fusion safety, the paper will concentrate on the numerical simulation of experiments involving aluminium dust in H_2/air gas mixtures.

Special emphasis in the simulations is given to a sufficiently accurate reproduction of the explosion indices (i.e. maximum pressure and maximum pressure rise rate) of these dust/gas mixtures, as well as of the pressure decay after the pressure peak due to heat loss of the burnt dust/gas mixture to the shell of the sphere.

1. Introduction

During the last years, the CFD code DET3D, originally developed for pure gas explosions [1], has been extended to cover also combined dust/gas explosions. It is the purpose of the present paper to report on the validation phase of this code extension.

The model development and validation phase of the code consisted in the numerical simulation of a large set of dust explosion experiments performed in a standard 20-liter sphere (DUSTEX) at the Karlsruhe Institute of Technology (KIT). The model approach taken was to treat the dust just as another gas species, but with zero partial pressure, and to use the Crebcom [2] combustion model. The simulated dust/gas explosions consisted in $H_2/O_2/N_2$ gas mixtures at various compositions with the following dust species added: (a) Graphite, (b) Tungsten, and (c) Aluminium. In addition, a set of beryllium-dust/air explosions performed in the Idaho National Laboratory 20-L sphere [4] was also simulated.

This DET3D code development is part of a larger program at KIT, dealing with the experimental and computational simulation of dust/gas explosions which, on its part, is motivated by the safety issues discussed in connection with nuclear fusion facilities such as ITER and DEMO, see e.g. [5]. In order not to overload the paper and since it can serve as a non-toxic substitute for Be-dust in nuclear fusion safety studies (cf. [3]), the paper will concentrate on the Al-dust/H_2/air explosion simulations. But it should be remarked that other dust species can be treated by the same modeling approach.

The paper starts with a description of the DET3D code in Section 2, and then gives a general overview of the Dustex experimental setup and the numerical simulation approach in Section 3. Detailed simulation results are presented in the ensuing sections: First for

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Fig. 1. The 20-L Dustex sphere.

the 'pure' mixtures, i.e. Al-dust/air in Section 4, and H_2/air in Section 5, and then for the hybrid Al-dust/H_2/air mixtures in Section 6. The paper ends with some concluding remarks in Section 7.

2. Description of DET3D

DET3D was originally developed as a fast CFD tool for simulating gaseous (especially hydrogen–air–steam and hydrogen–oxygen) detonations in complex 3-dimensional geometries. In the context of the work on the ITER safety simulations, this application area was extended to also cover dust–gas explosions by using a continuum

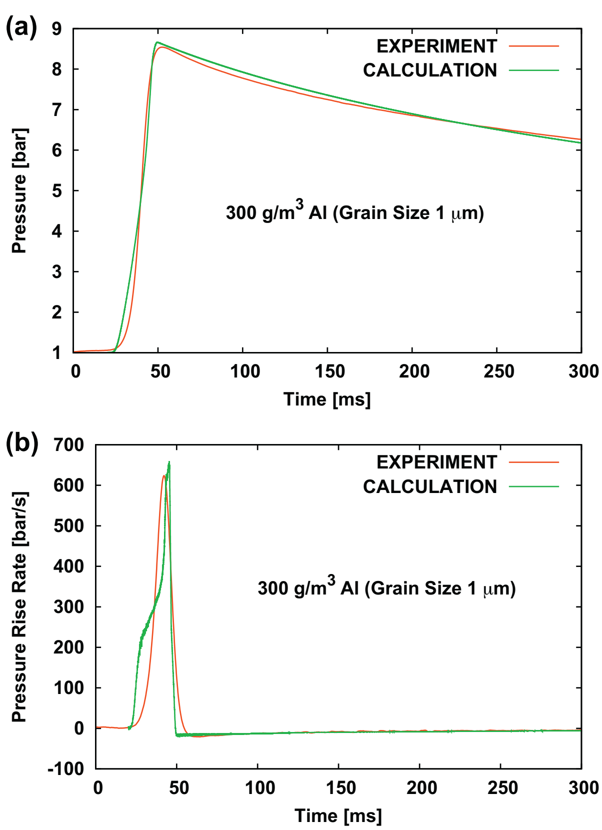

Fig. 2. Al-dust/air explosion in the Dustex sphere. Aluminium-dust density is 300 g/m^3, grain size is 1.0 μm. Shown are comparisons of experimental and DET3D-calculational results for: (a) pressure, and (b) pressure rise rate.

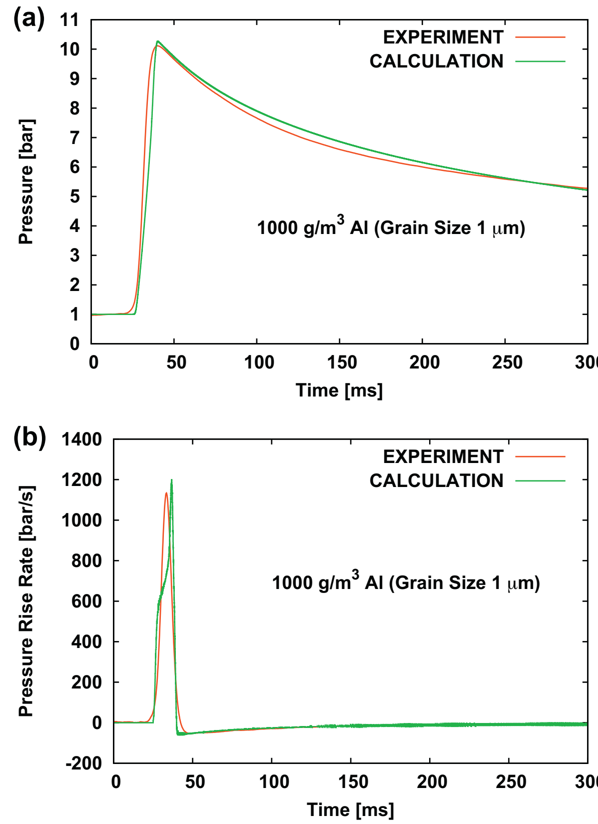

Fig. 3. Al-dust/air explosion in the Dustex sphere. Aluminium-dust density is 1000 g/m^3, grain size is 1.0 μm. Shown are comparisons of experimental and DET3D-calculational results for: (a) pressure, and (b) pressure rise rate.

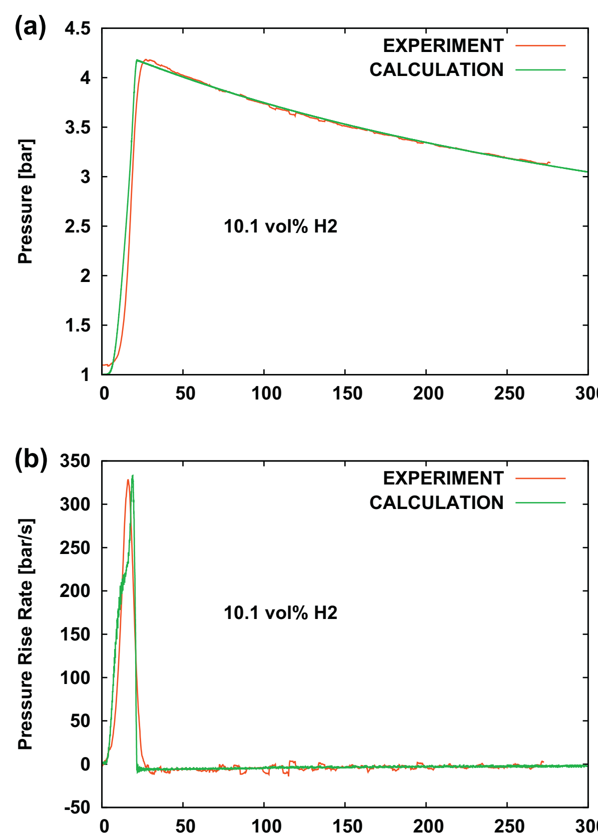

Fig. 4. H_2/air explosion in the Dustex sphere with 10.1% H_2. Shown are comparisons of experimental and DET3D-calculational results for: (a) pressure, and (b) pressure rise rate.