MODELLING OF VENTED CORN STARCH DUST EXPLOSION USING OPENFOAM

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Introduction

Dust explosion is a constant threat to the industries which deal with combustible powders such as pellets producers, food industry, metal industry, pharmaceuticals and additive industries. It is a complicated chemical and physical process, when very fine combustible particles well mixed with air in a confined equipment are ignited, resulting in a violent and explosive combustion. Once the dust explosion occurs, the generated high-pressure waves, hot flames and extremely radiative heat may cause loss of life and severe economic consequences. Statistics shows that there is one serious dust explosion every day in Europe alone [1].

This work is part of a project which aims at developing a well-verified and well-validated numerical tool based on the OpenFOAM platform for studying dust explosions in the process industry. A dust explosion process resembles the turbulent burning of a gas cloud for very fine organic dust particles with high volatile content [2, 3]. Therefore, to simulate dust explosions within the framework of the present project, a so-called Flame Speed Closure (FSC) model of premixed turbulent combustion has been implemented into OpenFOAM [4]. Note that the FSC model has been quantitatively validated against a wide set of experimental data obtained by various research groups from various gaseous flames under a wide range of substantially different conditions [5-7]. In a previous work [4], implementation of the FSC model into OpenFOAM was verified and the model was validated against Leeds experimental data [3] obtained in well-defined laboratory conditions. In the present work, the tool is applied for simulating a large-scale industrial vented dust explosion and the first results are reported.

Experimental and numerical setups

Corn starch vented explosion experiments were carried out at Rembe Research and Technology Center during 2017 and 2018 with an aim of studying the effect of vent geometry on the vent efficiency [8, 9]. An 11.5 m³ explosion vessel utilized in those experiments can be equipped with a round, a square, or a rectangular opening with an area of 0.5 m², at one end of the vessel. The vent opening is covered with a layer of 70 µm aluminium foil with a static activation pressure of 0.1 ± 15% bar. The corn starch dust was injected into the vessel from two attached 20 l containers at approximately 20 bar pressure. After an ignition delay time of around 800 ms for corn starch, the dust-air cloud was ignited by a pair of pyro-technique ignitors with a total ignition energy of 10 kJ. The reduced explosion overpressure \( P_{\text{red}} \) inside of the vessel was measured by two pressure detectors mounted on the wall of the vessel; see Figure 1.

![Figure 1: 2D drawing of dimensions of Rembe explosion vessel and the computational domain.](image)

Two sets of computational meshes used for the simulations. The first mesh is used for simulating dust explosion before the rupture of the vent panel, whereas the second mesh covers the volume of the vessel and a volume outside of the vessel to capture the venting process. The explosion is simulated in two stages. The first finer-resolved simulation is stopped when the pressure inside the vessel reaches a critical pressure. Then, the saved results are mapped to the second mesh with the pressure and temperature outside of the vessel equal to 1 atm and 273 K, respectively. The mapped fields provide initial conditions for the second simulations performed for the entire computational domain. Only a half of the vessel and a half of the outside volume are simulated to save computational time by assuming symmetry with respect to the vertical plane. The CAD geometry of the vessel was provided by Rembe as stp files, and the files were read in an open source 3D CAD modelling tool FreeCAD [10]. The detailed geometry of the vessel was obtained in FreeCAD, and the geometry of the vessel shell was exported in a stl file in the ASCII format. The geometry is then imported into the OpenFOAM, and the computational mesh was generated using a so-called snappyHexMesh tool in OpenFOAM.

Results and discussions

Table 1 shows evolution of the computed fields of the mean temperature at different time instants before the rupture of the vent panel. Figure 2 (a) compares the measured (solid line) and computed (dashed line) explosion overpressures at the measurement point P2 in Figure 1. Note that the measured explosion overpressure is an averaged value of two test
trials, because the simulation is based on the Reynolds-Averaged Navier-Stokes approach which deals with averaged flow and flame characteristics. Note also that this simulation was stopped when the vent panel ruptured, i.e. at an overpressure of around 0.1 bar or around 0.1 s after the start of ignition. During this time interval the measured and computed results are hardly distinguishable in Figure 2 (a). Even if the results obtained at overpressure less than 0.1 bar are zoomed in Figure 2 (b), agreement between measured and computed curves is encouraging.

Table 1: Mean temperature fields computed at different time instants

<table>
<thead>
<tr>
<th>Time [ms]</th>
<th>Mean temperature fields</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>4</td>
<td><img src="image2.png" alt="Image" /></td>
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<tr>
<td>6</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>8</td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
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Scale [K] 280 1800

![Image](figure2a.png)  ![Image](figure2b.png)

(a) overpressure vs time  (b) a zoomed-in version of (a)

Figure 2: Comparison between the simulated and measured explosion overpressure.

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References