DUST EXPLOSION IN THE COUNTERCURRENT INDUSTRIAL SPRAY DRYING TOWER


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Abstract: The three-dimensional simulation of dust explosion in the countercurrent spray drying tower was performed. Two sets of CFD calculations of dust explosion in the tower were carried out to reflect distribution of wet and dry powder zones in spray dryer. Dust was replaced with a flammable gas-air mixture. In the calculations the following parameters of dust explosion were analyzed: the reaction progress, maximum and average gas temperature, velocity and pressure. Results of calculations allow to determine position and parameters of venting devices which should be installed to minimize the risk of damages of the dryer construction.

Keywords: dust explosion modeling, spray drying, industrial tower

INTRODUCTION

The three-dimensional simulation of dust explosion in a closed volume is still one of the most challenging applications of CFD technique. A typical approach to solve the problem of dust-air explosion is to replace dust with a flammable gas-air mixture (Zimont et al, 1998). This approach requires determination of the content and proportions of a flammable gas-air mixture to reflect changes of pressure, temperature and velocity like for a dust-air mixture (Skjold et. al, 2006). At the first step of this part of the project, a set of experiments was carried out to find properties of the explosive gas-air mixture. Finally, the mixture of methane-air, containing 0.052 mass fraction of methane, was found appropriate to simulate the behavior of the dust and to be applied in the calculations. 3D calculations were carried in a counter current industrial spray dryer. Lower part of the tower was cone-shaped with a diameter increasing from 0.5m to 5.2m. The dryer height was 25m, diameter in the bottom part 0.5m, in the cylindrical part 4.5m and at the top 5.3m.

Air flow field in the tower was previously found and described in the first part of the project (Podyma et al, 2010). According to the procedure typically applied in the calculation of gas explosions, all air inlets and outlets were "virtually" closed giving the closed system of solid walls in which the explosion took place. This assumption does not affect the accuracy of calculations as the explosion process is quick and air flow does not influence the propagation of pressure and temperature waves.

The above assumption reduces significantly the time of calculation and first of all makes the calculations more stable and easy to converge. Additionally, as the main goal of the calculations was to predict the most extreme conditions which can occur in the dryer, i.e. maximum pressure, maximum and average air temperature and velocity, when the above parameters achieved maximum values, the calculations were stopped because further continuation would not bring any valuable information useful for safety analysis of the system performance. At the first step of CFD calculations a numerical mesh filling volume of the analyzed object must be developed. Test calculations prove that a mesh consisting of tetrahedral elements will be the most suitable to solve this problem. Finally, if dust ignition starts in the axis of the tower, propagation of the explosion will be axisymmetrical which allows us to divide the spray dryer into 4 quarters and perform calculations in one fourth of the space of the tower. Due to this assumption we may increase a number of elements in the mesh which makes the calculations more accurate in a reasonable calculation time. During data postprocessing the quarters were "glued" and a 3D picture of dust explosion development was presented.
The model of dust explosion

The explosion process was calculated with the application of two combustion models: Spark Ignition Model (SIM) and Burning Velocity Model (BVM). Ignition of the process was described with the use of the Spark Ignition Model. (Zimont et al, 2001).

Gas mixture distribution in a drying Tower

CFD calculations were carried out for two different methane concentrations in the tower:

1. Spray dryer filled uniformly, constant mass fraction of methane in the gas mixture
2. Spray dryer filled with variable mass fraction of methane in the gas mixture

The first case reflects a classical approach to solve explosion problems and potentially describes the most drastic damages in the system occurring in the explosion.

We should remember, however, that in the spray dryer we may observe an area with reduced gas temperature and high material moisture content which substantially decreases the probability of explosion. To reflect this case methane content distribution in the gas mixture along the dryer height was assumed.

The methane content in the gas mixture along the height of the dryer changed from 0.052 to 0.031 was assumed arbitrarily.

RESULTS

Distribution of pressure in the spray dryer

Results of CFD calculations of the maximum pressures during the explosion of detergent in the spray dryer for constant and variable gas mixture concentration are presented in Fig. 1.

For constant gas mixture concentration in the spray dryer ($y=0.052$) maximum value of pressure during process of methane-air combustion achieved 6.3 bar after about 1.7 sec (Fig. 1.) and was similar to the average pressure which was equal to 6.1 bar.

For the case of variable methane mass fraction, the maximum pressure achieved 5.3 bar (Fig. 1.) was similar to the average pressure which was equal to 5.1 bar. There is a clear difference between both cases in terms of maximum pressure which could be achieved during the combustion process (6.3 bar and 5.3 bar) as well as in terms of time for completion of the combustion process 1.7 sec and 2.5 sec respectively, which is a result of different methane content in the tower.

Like for the reaction progress after about 0.5 sec from the beginning of the combustion process to 1.4 sec, a faster increase of pressure was reported for variable gas mixture concentration than for constant gas mixture concentration despite a lower methane content which is a result of lower turbulent burning velocity in this time period. After 1.4 sec the pressure decreases for both maximum and average values due to a smaller content of methane.

Analysis of the results show that in the whole dryer maximum pressure is achieved at any point due to a quick propagation of shock wave in the system.

Calculation results confirm a quick nature of the process, pressure is practically identical in the whole dryer for any time step.

Table 1 gives the most important process parameters: reaction progress, maximum and average temperature, maximum and average velocity, maximum and average pressure and process time.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Constant methane mass concentration</th>
<th>Variable methane mass concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction progress</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Velocity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>88.4 m/s</td>
<td>61.0 m/s</td>
</tr>
<tr>
<td>Average</td>
<td>30.5 m/s</td>
<td>25.0 m/s</td>
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<tr>
<td>Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>6.3 bar</td>
<td>5.3 bar</td>
</tr>
<tr>
<td>Average</td>
<td>6.1 bar</td>
<td>5.1 bar</td>
</tr>
<tr>
<td>Process time</td>
<td>1.7 s</td>
<td>2.5 s</td>
</tr>
</tbody>
</table>
Fig. 2. Change of temperature contours along the spray dryer for different time steps for constant methane mass concentration: a) 0.40[s], b) 0.80[s], c) 1.20[s], d) 1.60[s]

Fig. 2. visualize temperature changes in during dust explosion in the dryer for constant methane mass concentration. In this case after ca. ~0.9 sec a maximum temperature ~2080K is reached in almost the entire tower.

SUMMARY

Two sets of CFD calculations of dust explosion in the tower were carried out at constant gas concentration and variable concentration in the dryer. The variable gas concentration reflected the situation of reduced gas temperature and high material moisture content encountered in the upper part of the drying chamber which substantially reduced the probability of explosion. The CFD calculation show that dust explosion is developing from the ignition point mostly to the upper part of the tower. The temperature, velocity and reaction profiles follow the same upward pattern. This indicates that a venting device should be installed above the hot air inlet which generates the highest risk of ignition.

The drying chamber above the first nozzles level is filled with moist, hardly explosible dust. The distance above the hot air inlet to the first nozzle level seems to be the best space to install the venting device. However, in the case of explosion, the area close to venting will be exposed to flames and parts of the construction could be lifted by blast.

The drying tower with the length/diameter ratio ~5.5 should be considered as an elongated enclosure. For that type of enclosure the application of two venting devices, one close to each end, is advised.

REFERENCES


