Polydispersed Initiation of a Dust Suspension in a Partitioned Structure

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Extended abstract :

Dust explosions often have in the past created dramatic situations and consequences[1]. These phenomena are actually the subject of advanced studies[2]. However, if different works have tried to improve the present knowledge on safety, it remains difficult to predict the explosive properties of a reactive dust suspension in partitioned industrial or agricultural plants. A simple simulation initially developed as part of a novel study on ignition and combustion of classical propulsive powders has been presented in order to predict the main characteristics of these explosions in a closed or a vented vessel[3]. A calculation methodology allows to adapt the numerical simulation to the transmission of the explosion from one compartment to another adjacent compartment by the means of the hot flow through the shared orifice and finally to generalise this methodology to a complex multi-partitioned structure. The aim of this work is to study the effects induced by a multi-source ignition on the flammability of a dust suspension and more particularly the pressure history in a partitioned structure with a wide energy range ($E_{ign} \leq 20000$ J). Simulated predictions have been compared with results of various experimental works available for dust suspensions.

The combustion of the dust grains (solid fuel) results from collisions between particles of the gaseous phase and those of the solid phase[3]. The reactive system is composed of molecules in gaseous phase and active molecules. The energy flux brought to the solid fuel leads to its degradation by the active molecules and to the dissociation by the other molecules in the gaseous phase. All those phenomena contribute to the destruction of the dust grains[3].

The combustion of the dust suspension takes place in a closed partitioned vessel which may be fitted with a vent. In the course of the ignition process, a little amount of solid fuel is initially destroyed. The destruction of the fuel molecules implies the formation in the reactive mixture of active species. These species induce a destruction energy flux which contribute to

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develop the reaction and to increase the internal energy and the temperature in the mixture. Then, the reaction is ignited. However, in some cases, the deactivation of reacting species, by collisions on the dust grains, collisions on the wall or energy release in the gaseous medium may become a predominant phenomenon and the reaction may not go on. This situation may correspond to particular initial thermodynamic conditions or eventually a too weak initial destruction of the solid fuel. Ignition appears therefore as the essential element in the development of the reaction. Several hypotheses such as the initial amount of fuel burnt, the time variation linked to this destruction, the creation of a hot point in the mixture or the initial increase in the internal energy are susceptible to influence the reaction conditions. Even though these different factors give similar global evolutions, their introduction at different steps in the model also confers them a specific behaviour. The last assumption has been more particularly envisaged to obtain reactions in a range of low dust concentrations with high ignition energies and it seems to be adapted to a multi-source ignition which remains essentially dispersed inside the structure.

The various adjacent compartments in the vessel are connected by inner openings with a variable surface which allow the propagation of the reaction and the progressive establishment of a thermodynamical equilibrium[4]. The initial thermodynamic characteristics of the medium are determined (pressure P_o , temperature T_o) or may be calculated (internal energy, total number of gaseous molecules) from oxygen-nitrogen-fuel amounts in the vessel. The evolution of the active or gaseous species is based on the chemical kinetics of the reaction and takes into account collisions on the dust grains, collisions on the wall or in the gaseous medium[3].

The knowledge of the chemical process and the amount of transferred molecules[4] allows to know by successive time steps, the number of molecules and the mass of each species remaining in each compartment. The numerical integration of equations gives the access for the whole structure to thermodynamic factors and to the calculation of the time evolution of the pressure, the rate of pressure rise and the regression velocity of the dust grains. The model behaviour is tested as an example with cornstarch and a grain size such as $D_g = 10$ µm. The indicated numerical value corresponds to a medium distribution value, which is representative of experimental results[3].

Figure 1 presents experimental and theoretical curves relative to a cornstarch-air mixture in the case of the time evolution of the pressure and the rate of pressure rise. The experimental curves are due to Senecal[5] for a large spherical vessel volume such as $V_o = 1900\ l$ and a cornstarch concentration $\Delta = 1$ kg/m^3 corresponding to a very rich mixture ($\Delta_{sto} = 0.253$ kg/m^3).

The theoretical characteristics of this explosion are then $P_{max} = 807$ kPa and a Bartknecht's K_{st} factor such as $K_{st} = 24.95$ MPam/s. The experimental values given by Senecal[5] in the same conditions lead to $P_{max} = 810$ kPa and $K_{st} = 24$ MPam/s. The rise times are also quite comparable with values around 130 ms for the pressure and 100 ms for the rate of pressure rise. A good correlation between both series of curves may be observed.

The influence of the vessel volume or the fuel concentration are also interesting parameters to compare with experimental data. Figure 2 shows the time evolution of the pressure for different vessel volumes between 200 and 5 000 l in order to get a wide study range in the conditions of a rich mixture of cornstarch such as $\Delta = 1$ kg/m^3. It is noticeable that the same value of the maximum pressure $P_{max} = 807$ kPa is practically obtained for the different volumes[1]. The maximum of pressure is therefore independent of the vessel volume.

This result is in accordance with Bartknecht's experiments[1]. Furthermore, it can be observed that the smaller the vessel volume is, the quicker P_{max} can be reached in about 0.11 to 0.15 s.

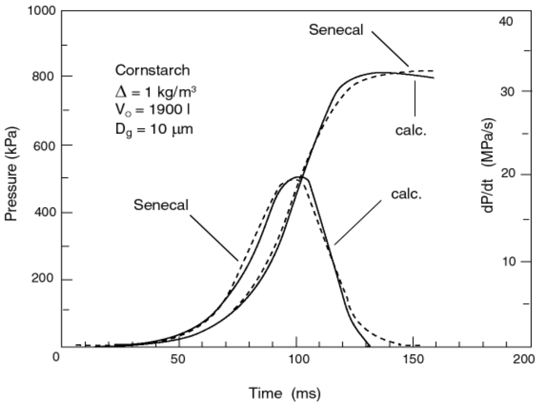

Fig 1 Pressure and rate of pressure rise vs time.

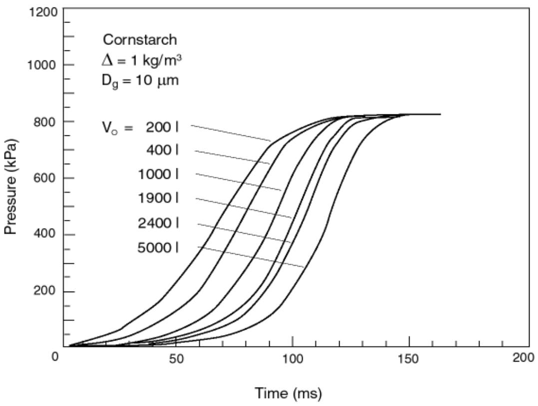

Fig 2 Pressure vs time for different vessel volumes.

The time evolution of the pressure is obtained in figure 3, for varied cornstarch concentrations extending from lean mixtures to rich mixtures ($\Delta_{sto} = 0.253$ kg/m^3). For rather rich mixtures ($\Delta \geq 0.8$ kg/m^3), the maximum pressure decreases and the rise time becomes longer. On the contrary, for lean mixtures the increase of the concentration leads to a progressive increase of the maximum pressure and to a very important decrease of the rise time when curves are close to stoichiometric conditions. Stoichiometry appears to be the most favourable environment to get explosive conditions. It can be noticed that according to the model, these conditions still exist on a wide enough concentration range between 0.25 and 0.8 kg/m^3 and show the transition between lean and rich mixtures. The continuity of conditions close to stoichiometry in relatively rich mixtures is experimentally verified for dust suspensions[1].

It is also interesting to study the model behaviour in the case of vented explosions. In order to verify the model validation, the theoretical predictions have been compared with experimental results due to Bartknecht[1].

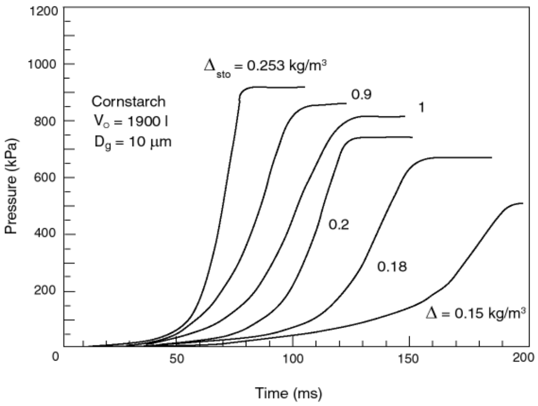

Fig 3 Pressure vs time for different concentrations.

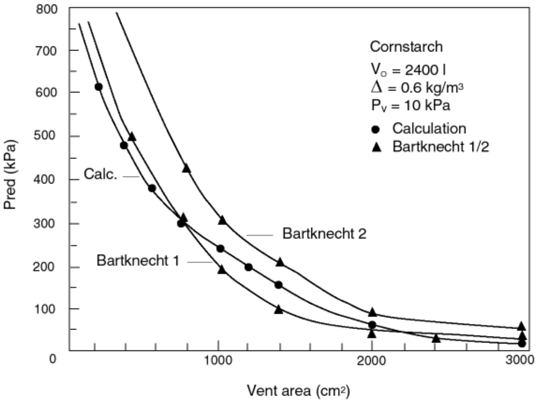

Fig 4 Evolution of the reduced maximum explosion pressure with the vent area.

Figure 4 shows the evolution of the reduced maximum explosion pressure as a function of the vent area for a static venting pressure P_v = 10 kPa in a large vessel volume such as V_o = 2 400 *l* and a relatively rich mixture with a concentration $\Delta = 0.6$ kg/m^3. The theoretical curve is obtained plotting the different values of P_{red} calculated for each vent opening.

The experimental curves have been obtained for slightly different initial conditions linked to the choice of the K_{st} factor for the closed explosion, such as K_{st}^{1} = 20.6 MPa.m/s for the lower curve and K_{st}^{2} = 31 MPa.m/s for the upper curve. The general trend of the curves has the aspect of a decreasing hyperbola with a very good correlation between experimental and theoretical data.

A slight inflexion for the theoretical curve in a range of intermediate vent areas is noticeable. The theoretical curve is very close to the lower experimental curve for slight vent openings and remains bounded by both experimental curves for intermediate vent areas. Finally, for large vent areas, the reduced pressure strongly declines and tends towards a residual pressure close to experimental values. The model validation may be completed with numerous other examples and different dusts in closed or vented one-compartment vessels[3]. It appears therefore interesting to study the influence of a variable polydispersed ignition on the pressure evolution in a partitioned vessel composed of nine identical compartments (3x3) such as V_{ok} = 1000 *l* and $1 \le k \le 9$, for a cornstarch concentration near the stoichiometric conditions. All the adjoining compartments are connected by a small inner opening a = 100 cm^2.

Figure 5 gives the time evolution of the pressure for a same two-source ignition in compartments 1 and 3 which define two corners of the structure. The first part of the figure corresponds to an intermediate ignition energy E_{ign} = 1000 J. The reaction expands around the ignition areas and leads to the formation of a progressive overpressure. The maximum of pressure reached varies between 800 kPa in the corners and 1100 kPa in the furthest symmetric area corresponding to compartment 8. The picture obtained is quite similar to the case of a single ignition in a corner of the structure and in the same conditions with the corresponding overpressure around 300 kPa .The second part of the figure corresponds to a strong ignition energy E_{ign} = 20000 J. A decrease of the rise times and a marked strengthening of the maximum pressure close to 1050 kPa may be noticed in the ignition compartment without big modification in the intermediate regions. It can be noticed that, for a high ignition energy, the pressure pilling phenomenon is completely mitigated in the furthest part of the structure in comparison with the ignition compartment.

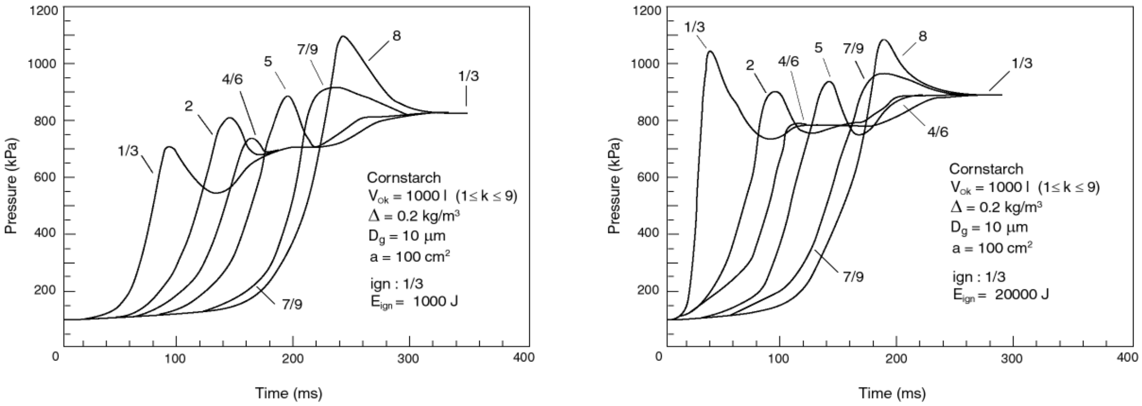

Fig 5 Pressures vs time for different locations and ignition energies.

Figure 6 shows the time evolution of the pressure for a same three-source ignition in compartments 1,3 and 7 which define three corners of the structure. The first part of the figure corresponds to an intermediate ignition energy $E_{ign} = 1000$ J. The figure shows the formation of a progressive overpressure which varies between 800 kPa in the corners and 1050 kPa in the furthest symmetric area corresponding to compartment 9. The main result is that there is no significant reduction of the overpressure when the number of ignition sources located in various points of the structure increases.

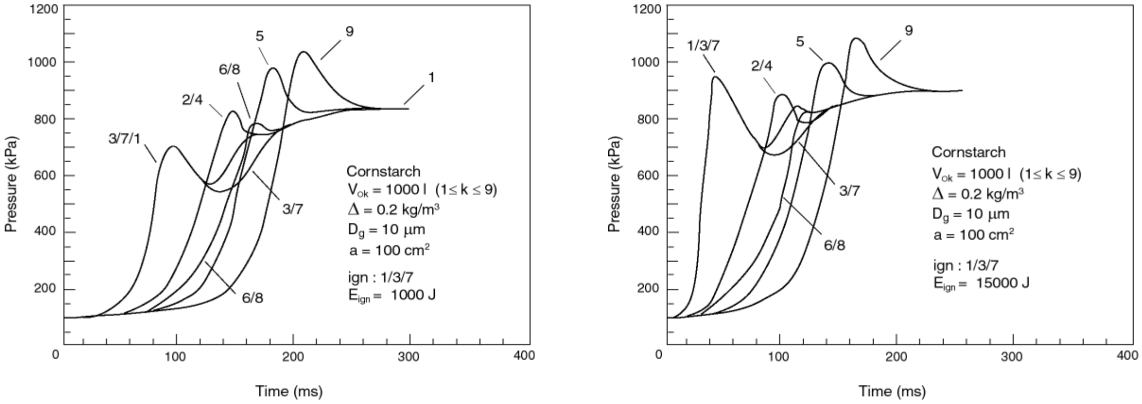

Fig 6 Pressures vs time for different locations and ignition energies.

The second part of the figure corresponds to a strong ignition energy $E_{ign} = 15000$ J. The pressure evolution is practically the same as previously except a strong increase in pressure in the ignition compartment without other global effect on the whole structure.

Figure 7 shows the time evolution of the pressure for a same four-source ignition in compartments 1,2,4 and 5 localised in a corner of the structure. In the first part of the figure, we have chosen an intermediate ignition energy $E_{ign} = 1000$ J. As previously, the figure shows the formation of a progressive overpressure which varies between 820 kPa in the ignition area and 1050 kPa in the furthest part corresponding also to compartment 9.

Despite a choice of multiple sources relatively dispersed in the vessel the reduction of the overpressure remains limited around 230 kPa.

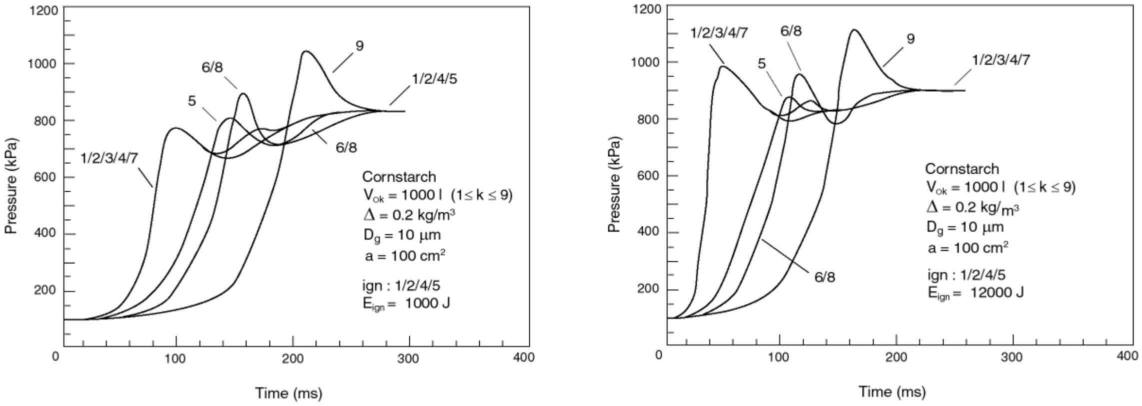

Fig 7 Pressures vs time for different locations and ignition energies.

The second part of the figure corresponds to a strong ignition energy E_{ign} = 12000 J. The pressure evolution is similar to the previous one, but the higher energy supply is dissipated in the form of a pressure increase, essentially in the ignition area with a slight decrease of the overpressure.

These evolutions are verified for all polydispersed ignitions and similar data may be observed if the ignition compartments are fitted with vents, but the pressures obtained are therefore reduced[1].

Finally, all the cases observed lead to the following results:

- in the case of a single or a polydispersed ignition, a noticeable overpressure progressively forms with a maximum in the furthest part of the structure corresponding to a pressure pilling phenomenon.
- except in the ignition compartments where the pressure is as much higher as the ignition energy is stronger, the maximum pressure reached does not practically depend on the nature, the location or the energy supply of the initiation.

Comparable results are obtained with other dust suspensions. Some interesting differences may be observed with gaseous substances[6] which gives to dust suspensions a specific behaviour. The partitioning effect is more important than for gaseous mixtures[6] and there is no global evolution of the pressure increase in all compartments for high ignition energies or for a multi-source initiation. The description presented for a dispersed ignition in partitioned systems seems to be globally in good agreement with experimental data and it seems interesting to verify this evaluation by studying more complex multi-partitioned structures.

References

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