Partitioning effect on a dust exposion

J.M. Pascaud

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J.M. Pascaud
Université d'Orléans
63, avenue de Lattre de Tassigny
18020 BOURGES Cedex, France

Fax : 02.48.23.80.23
Net : Jean-Marc.Pascaud@bourges.univ-orleans.fr

Abstract :

The aim of this work is to verify the partitioning effect on the chain propagation of a dust explosion and the formation of overpressures inside a partitioned vessel. A calculation methodology, particularly interesting in the field of the risk assessment is developed to simulate 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 basic characteristics of the model have been developed for the ignition and the combustion of propulsive powders and adapted to dust suspensions with appropriate parameters linked to simplified kinetics. A simple representation of the combustion phenomena based on energy transfers and the action of specific molecular species is presented. The model allows the study of various parameters such as the initial thermodynamical conditions, the size of the inner openings or the vent areas and finally the location of the ignition energy and of overpressures inside the structure. The calculations have been compared with experimental data available for usual dust suspensions and indicate correct preliminary tendencies.

Keywords : dust suspensions; overpressures; compartments; pressure pilling

INTRODUCTION

Over the last past years, a simple modelling 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. The model has been adapted to the explosion of dust suspensions (Pascaud,1998). Dust explosions often have in the past created dramatic situations and consequences (Field,1982) or (Nagy,1983) and the risk of a dust explosion exists in each agricultural process which implies handling or stocking of pulverized combustible material. These phenomena have been the subject of very advanced studies (Lee,1987), (Tai,1988) and more recently Di Benedetto(2007) . However, if different works have tried to improve the present knowledge on safety (Klemens,1985), it remains difficult to predict the explosive properties of a reactive dust suspension in partitioned industrial or agricultural plants. The physical processes involved in the ignition and the propagation of the combustion of dust suspensions in such structures are generally complex (Di Benedetto,2007) and the theoretical predictions often remain limited with long calculation times. It has been experimentally verified for gaseous mixtures that very important overpressures went on in all the adjoining areas of the ignition compartment for a multi-partitioned vessel (Hu,2005) or (Fairweather,1998). We envisage now, to clarify the existence of such phenomena in the case of dust explosions. The aim of this work is to verify the model validation for usual dust suspensions such as cornstarch, cellulose or aminophenazone and to extend

the study to the chain propagation of a dust explosion inside a partitioned vessel. The reaction mechanisms and the energy transfers are explained by the action of specific molecular species (active molecules). The model requires the knowledge of some parameters linked to simplified kinetics, to energy transfers and to thermal exchanges (Pascaud,1998). The pressure venting, due to the vent breaking may be calculated from thermodynamical characteristics given by the model and taking into account the mass rate of discharge of the different products via the vent (Pascaud,1998).
We intend to develop a calculation methodology allowing to adapt our simple numerical simulation to the case of 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 representative of real cases (Sochet,2000). The model particularly permits to study in each compartment the time evolution of the pressure, the rate of pressure rise and to clarify the various regimes observed for different vent breaking pressures in a vessel considered as a perfectly well-stirred reactor.
The proposed development allows the study of varied initial conditions which may differ for the various compartments, the influence of different parameters such as the vessel volume, the concentration of dust suspensions in a rich or a lean mixture, the venting effects or the vent sizes between the compartments and finally the existence of overpressures.
In order to validate the model, theoretical predictions have been compared with results of various experimental works available for dust suspensions (Bartknecht,1978).

MODELLING ELEMENTS

General hypotheses :

We consider that the combustion of the solid fuel (dust suspension) may be described by collisions between particles of the gaseous phase and those of the solid phase. The elastic collisions, only characterized by kinetic energy transfers are the most numerous. The reactive system is composed of molecules in gaseous phase and active molecules (Pascaud,1998). The active molecules are highly energetic particles which principally provide a new gaseous molecule by interaction on the solid. This phenomenon leads to increase the elastic collision rate.
The next assumptions summarise the different interactions envisaged by the model.
The energy flux brought to the solid 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 solid destruction (Pascaud,1998). The model takes into account the efficiencies of the active molecules, the supplementary energy supply due to collisional interactions leading to a progressive destruction of the solid fuel, the energy release of the active molecules in the gaseous medium and the dissipative phenomena due to active or gaseous molecules on the vessel wall and by thermal losses (Pascaud,1998). The combustion of the solid fuel takes place in a closed partitioned vessel. The initial conditions are supposed to be homogeneous in the vessel. The various adjacent compartments are connected by inner openings with a variable surface which allow the propagation of the reaction and the formation of a progressive thermodynamical equilibrium in the vessel. Each compartment is considered as a perfectly well-stirred reactor which may be fitted with a vent. The vent breaking is obtained when the pressure in the medium reaches the static venting pressure P_v (Bradley,1978).The initial thermodynamical 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 solid fuel, collisions on the wall or in the gaseous medium (Pascaud,1998).

Chemical kinetics :

Among the products which can be obtained with $C_x H_y O_z N_t$ solids, we only consider :

- gaseous molecules $X_i = CO_2, CO, H_2O, O_2, N_2$ and H_2.

- active molecules $X_i^* = CO_2^*, CO^*$ and H_2O^*.

The destruction reaction of the solid fuel with the oxygen of the air is considered with oxygen in excess, but without solid carbon. Hence equation (R) :

$$C_xH_yO_zN_t + m\,O_2 \rightarrow \alpha\,CO_2^* + (x-\alpha)\,CO^* + (z+2m-2r-x-\alpha)\,H_2O^* + \left(\frac{y}{2}+x+\alpha+2r-z-2m\right)H_2 + r\,O_2 + \frac{t}{2}N_2 \qquad (R)$$

For initial determined conditions, it is possible to calculate the concentration Δ of the dust suspension and the amount m of oxygen necessary to the combustion. The conditions corresponding to the stoichiometry Δ_{sto} may be deduced from the previous equation. The coefficients of the global chemical equation remain positive only for well-defined concentrations. Then, the chemical reaction has to be adapted to take into account particularities of rich and lean mixtures.

- kinetics of lean mixtures $\Delta \le \Delta_{sto}$:

The reaction is considered without hydrogen molecules and without CO^*. This last condition is equivalent for stoichiometry to the absence of oxygen in excess and expresses the continuity of the chemical equation system. Hence :

$$r = \frac{z}{2} + m - \frac{y}{4} - x \qquad \alpha = x$$

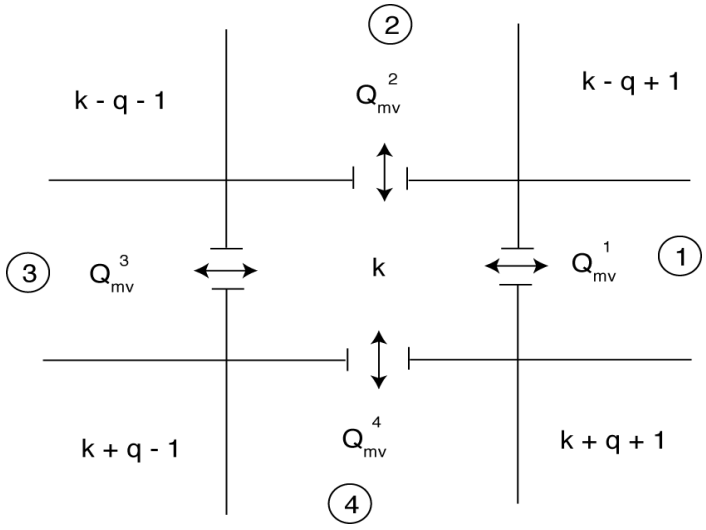
- kinetics of rich mixtures $\Delta \ge \Delta_{sto}$:

In the case of rich mixtures the reaction is considered without oxygen in excess and without H_2O^* to equilibrate the equation with positive coefficients. Hence :

$$r = 0 \qquad \alpha = z + 2m - x$$

Pressure venting and thermodynamical factors :

In the general case, the considered structure defines a volume composed of several compartments represented as rectangular surfaces. The adjacent compartments are connected by inner openings with variable dimensions. The reaction expands in compartments corresponding to a given initial ignition.



The difference of pressure with adjacent compartments leads to a transfer of matter towards these compartments and particularly to a supply of active molecular species . The destruction energy

flux due to these molecules progressively increases as well as the internal energy. These processes initiate the reaction. Similar phenomena occur in all the adjoining areas. The reaction goes on and a thermodynamical equilibrium is obtained.
The position of the various compartments in the considered area is linearly described.
A matrix location may also be used. For a central compartment k, four transfers of matter are envisaged with the adjoining areas. For a compartment on the side, there is no transfer with the outer environment.
The characteristics of each compartment (thermodynamical conditions, surface, volume and configuration of inner openings) are initially introduced in the calculation code. The transfer of matter between a reference compartment k and an adjacent compartment l occurs when the pressures are different in both compartments ($P_k \neq P_l$). In this case, the total mass rate of gaseous substances may be calculated by the standard orifice equations due to Bradley(1978).

The following development is relative to a reference compartment k.

i) if $P_k > P_l$ (flow from k to l) :

Two possible regimes exist, depending on whether the discharge velocity through the vent is subsonic or sonic (Bradley,1978). Both regimes depend on the critical pressure P_c given by :

$$P_c = P_l \left(\frac{\gamma + 1}{2} \right)^{\frac{\gamma}{\gamma - 1}}$$

- if $P_k < P_c$ the regime is subsonic :

$$Q^s_{mv} = -C_d A^s_{vk} \left[\frac{2\gamma \rho_k P_k}{\gamma - 1} \left(\frac{P_l}{P_k} \right)^{2/\gamma} \left(1 - \left(\frac{P_l}{P_k} \right)^{\frac{\gamma - 1}{\gamma}} \right) \right]^{1/2}$$

- if $P_k \geq P_c$ the regime is sonic :

$$Q^s_{mv} = -C_d A^s_{vk} \left[\gamma \rho_k P_k \left(\frac{\gamma + 1}{2} \right)^{\frac{1+\gamma}{1-\gamma}} \right]^{1/2}$$

The previous equations give the mass rate of discharge Q^s_{mv} for each possible transfer s. The signs are imposed by the reference compartment. Supplies are assumed to be positive and losses negative.

In these formulas :
ρ_k is the specific mass and P_k the absolute pressure in the compartment k.
P_l is the absolute pressure in the compartment l.
A^s_{vk} is the inner vent area corresponding to the transfer s.
C_d is the coefficient of discharge.

The value of the coefficient of discharge $C_d = 0.6$ is generally used. This value is consistent with many theoretical (Fairweather,1982) and experimental (Palmer, 1966) results. Furthermore, the previous formulas may be applied both to burnt or unburnt gaseous products with a γ coefficient such as $\gamma = \frac{C_p}{C_v}$.

Finally, the variation of internal energy corresponding to the transfer of gaseous or active molecules may be written in the assumption of a polytropic evolution :

$$(\frac{dU}{dt})_v^s = \left[C_{vg}^k \, (\frac{dN_{gv}}{dt})_k^s + C_{va}^k \, (\frac{dN_{av}}{dt})_k^s \right] . (T_k - T_o)$$

The calculation of the specific heat capacities of the gaseous phase C_{vg}^k or of the active phase C_{va}^k takes into account the specific heat capacities of the reaction products and the time evolution of the molar composition in compartment k.

ii) if $P_k < P_l$ (flow from l to k) :

The critical pressure P_c is then :

$$P_c = P_k \left(\frac{\gamma + 1}{2} \right)^{\frac{\gamma}{\gamma - 1}}$$

- if $P_l < P_c$ the regime is subsonic :

$$Q_{mv}^s = C_d A_{vl}^s \left[\frac{2\gamma \rho_l P_l}{\gamma - 1} \left(\frac{P_k}{P_l} \right)^{2/\gamma} \left(1 - \left(\frac{P_k}{P_l} \right)^{\frac{\gamma - 1}{\gamma}} \right) \right]^{1/2}$$

- if $P_l \geq P_c$ the regime is sonic :

$$Q_{mv}^s = C_d A_{vl}^s \left[\gamma \rho_l P_l \left(\frac{\gamma + 1}{2} \right)^{\frac{1+\gamma}{1-\gamma}} \right]^{1/2}$$

The inner vent area is the same for both compartments and then $A_{vk}^s = A_{vl}^s$.
The corresponding variation of the internal energy may be written :

$$(\frac{dU}{dt})_v^s = \left[C_{vg}^l \, (\frac{dN_{gv}}{dt})_l^s + C_{va}^l \, (\frac{dN_{av}}{dt})_l^s \right] . (T_l - T_o)$$

iii) Vent opening (outer flow)

The reference compartment k may in some cases be fitted with a vent
The vent breaking is taken into account by the calculation code when the overpressure in the medium reaches the static venting pressure P_v. If the vent opens when the mixture ignites, the venting pressure corresponds to the initial pressure P_o in the vessel.
The critical pressure P_c is defined by :

$$P_c = P_a \left(\frac{\gamma + 1}{2} \right)^{\frac{\gamma}{\gamma - 1}}$$

where P_a is the pressure of the outer ambient medium.

- If $P_k < P_c$ the regime is subsonic :

$$Q_{mv}^{ext} = - C_d A_{vk} \left[\frac{2\gamma\rho_k P_k}{\gamma - 1} \left(\frac{P_a}{P_k} \right)^{2/\gamma} \left(1 - \left(\frac{P_a}{P_k} \right)^{\frac{\gamma-1}{\gamma}} \right) \right]^{1/2}$$

- If $P_k \geq P_c$ the regime is sonic :

$$Q_{mv}^{ext} = - C_d A_{vk} \left[\gamma\rho_k P_k \left(\frac{\gamma + 1}{2} \right)^{\frac{1+\gamma}{1-\gamma}} \right]^{1/2}$$

where A_{vk} is the vent area.
In the absence of vent, there is no outer flow and we have $Q_{mv}^{ext} = 0$.

Then, the loss of internal energy may be written :

$$\left(\frac{dU}{dt}\right)_v^{ext} = \left[C_{vg}^k \left(\frac{dN_{gv}}{dt}\right)_k^{ext} + C_{va}^k \left(\frac{dN_{av}}{dt}\right)_k^{ext} \right] . (T_k - T_o)$$

It is possible to calculate at each time and for the whole structure the mass transfers and the variation of the internal energy due to the various molecular transfers inside the structure and with the outer environment . We obtain for the compartment k :

$$Q_{mv}^k = \sum_s Q_{mv}^s + Q_{mv}^{ext}$$

$$\left(\frac{dU}{dt}\right)_{vk} = \sum_s \left(\frac{dU}{dt}\right)_v^s + \left(\frac{dU}{dt}\right)_v^{ext}$$

We can also consider that the ratio of the mass rate Q_{mvi}^k of each species i (active, gaseous or solid) to the total gaseous mass rate Q_{mv}^k is equal to the ratio of corresponding masses remaining in compartment k (Yao,1974). Various solutions relative to burnt or unburnt products have been proposed by many authors and have been detailed by Bradley(1978) . Hence :

$$\frac{Q_{mvi}^k}{Q_{mv}^k} = \frac{m_{ik}}{m_k}$$

The mole number of each species i transferred between compartment k and the environment is therefore :

$$\left(\frac{dN_{iv}}{dt}\right)_k = N_{ik} \frac{Q_{mv}^k}{m_k}$$

where N_{ik} is the mole number of species i in compartment k.

The knowledge of the chemical process and the amount of transferred molecules allows to know by successive time steps, the number of molecules and the mass of each active, gaseous or solid species remaining in each compartment.
The internal energy U_k can be obtained (Pascaud,1998) taking into account the energy release due to collisions in the reactive mixture, the global thermal transfer with the surrounding environment and the variation of energy due to the various molecular transfers inside the structure or the outer environment.
We deduce thermodynamical factors in compartment k :

$$T_k - T_o = \frac{U_k}{C^k_{vg} + C^k_{va}} \qquad \text{and} \qquad P_k = \frac{N_k R T_k}{V_k}$$

RESULTS

We intend in a first place, to compare experimental and theoretical results obtained for usual dust suspensions and then, to study the influence of various parameters such as the vessel volume, the solid concentration, the venting and the partitioning effects. Finally, different elementary cases with 3 or 9 compartments will be analysed in order to validate the model predictions. A generalisation to more complex structures may be envisaged afterwards.

Modelling and experimental results :
The model is applied to various solid fuels with different physico-chemical characteristics and different grain sizes such as D_g = 10 μm for cornstarch, D_g = 35 μm for cellulose and D_g = 8 μm for aminophenazone. The indicated numerical values correspond to medium distribution values, that are representative of experimental results (Pascaud,1998).
Figure 1 presents experimental and theoretical curves relative to a cornstarch-air mixture in the case of the time evolution of the pressure. The experimental curve is due to Senecal (1989) for a large spherical vessel volume such as V_o = 1900 *l* and a cornstarch concentration Δ = 1 kg/m^3 corresponding to a rich mixture (Δ_{sto} = 0.254 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 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. A good correlation between both curves may be observed.

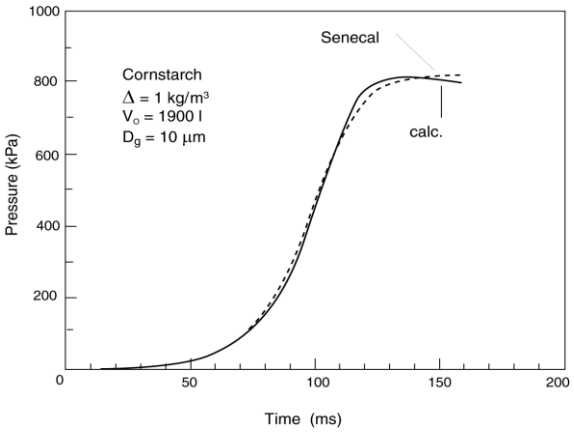


Fig 1 Pressure of explosion vs time.

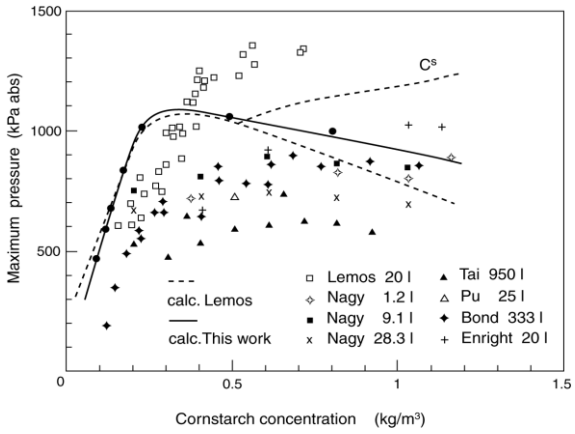


Fig 2 Maximum pressure vs cornstarch concentration. Experiments and calculations.

The maximum pressure calculated from the model (full line) is given in figure 2 as a function of the concentration in the case of cornstarch. This evolution is compared to various experimental results indicated in the figure and to another theoretical simulation (dotted line) calculated by the means of

the Quatuor code matched by Lemos (1991). This code gives the calculation of the product properties of a chemical reaction for ideal conditions (homogeneous mixture, adiabatic reaction and a complete thermodynamical equilibrium). It cannot predict the time evolution of the pressure and does not take into account the losses at the wall.
Two hypotheses are considered in the calculation :
- All the combustion products are only gaseous substances.
- Solid carbon is also a combustion product.
For lean mixtures, the maximum pressure predicted by our model progressively increases towards an approximately constant level for intermediate concentrations ($0.25 \leq \Delta \leq 0.5$ kg/m^3). Then, the maximum pressure decreases for rich mixtures. These results seem to be in good accordance with experimental data whose mean evolution is comparable with the model.
Furthermore, we observe a very good correlation of our model with the Quatuor code for concentrations such as $\Delta \leq 0.5$ kg/m^3. For higher values, our result appears as intermediate between both hypotheses of the Quatuor code. Similar results may be obtained with other solid fuels like cellulose or aminophenazone.
Figure 3 shows the time evolution of the pressure and the rate of pressure rise for a vessel volume such as $V_o = 2400$ *l* and a cellulose concentration $\Delta = 0.6$ kg/m^3. The theoretical characteristics of the explosion are then $P_{max} = 903$ kPa and $K_{st} = 23$ MPa m/s.
Experimental results due to Bartknecht(1986) in the same conditions lead to $P_{max} = 900$ kPa and $K_{st} = 20.2$ MPa m/s.

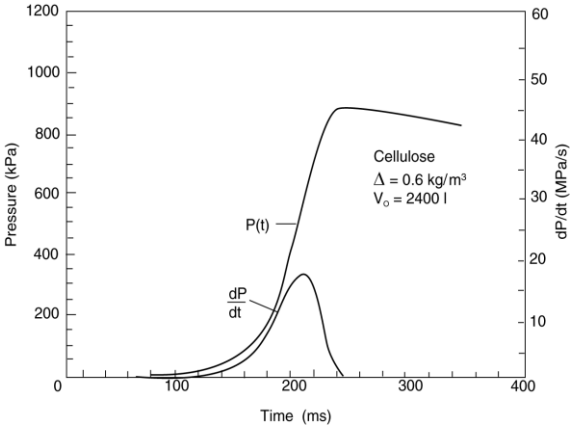


Fig 3 Pressure and rate of pressure rise vs time.

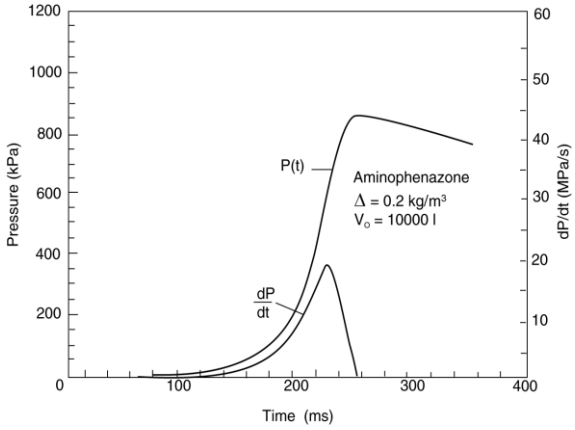


Fig 4 Pressure and rate of pressure rise vs time.

The time evolution of the pressure and the rate of pressure rise for a vessel volume such as $V_o = 10\ 000$ *l* and a concentration $\Delta = 0.2$ kg/m^3 of aminophenazone are presented in figure 4. The theoretical characteristics of the explosion are $P_{max} = 870$ kPa and $K_{st} = 38$ MPa m/s. Bartknecht's experiments(1986) give in the same conditions $P_{max} = 890$ kPa and $K_{st} = 30.1$ MPa m/s. The good agreement between theoretical predictions and the experimental results represents a quite correct validation of the model for varied usual dust suspensions.

Applications and existence of a partitioning effect :
The influence of the vessel volume or the fuel concentration are also interesting parameters to compare with experimental data.
Figure 5 shows the time evolution of the pressure for different vessel volumes between 500 and 10 000 *l* in order to get a wide study range in the conditions of a rich mixture of aminophenazone such as $\Delta = 0.2$ kg/m^3. It is noticeable that the same value of the maximum pressure $P_{max} = 870$ kPa is practically obtained for the different volumes. The maximum of pressure is therefore independent of the vessel volume. This result is in accordance with Bartknecht's experiments(1978). Furthermore, it can be observed that the smaller the vessel volume is, the quicker P_{max} can be reached in about 0.14 to 0.24 s.

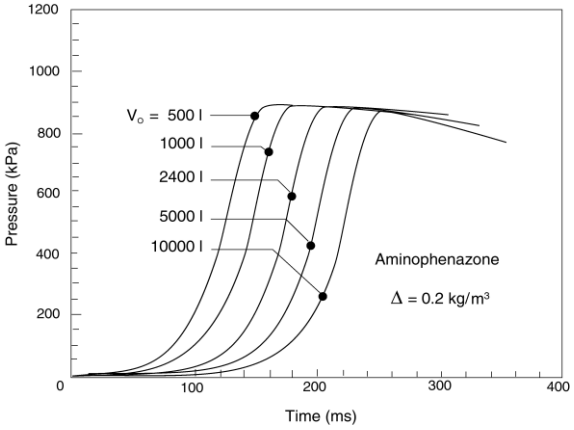


Fig 5 Pressure vs time for different vessel volumes.

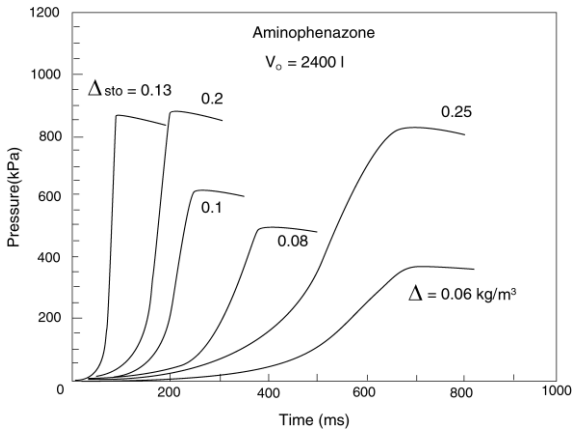


Fig 6 Pressure vs time for different concentrations.

The time evolution of the pressure is obtained in figure 6, for varied concentrations of aminophemazone extending from lean mixtures to rich mixtures (Δ_{sto} = 0.13 kg/m^3). For rather rich mixtures (Δ = 0.25 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 0.13 and 0.2 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 (Bartknecht,1978).

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(1986) about aminophenazone.

Figure 7 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 = 10 000 *l* and a slightly rich mixture with a concentration Δ = 0.2 kg/m^3.

The theoretical curve is obtained plotting the different values of P_{red} calculated for each vent opening. The general trend of the curves has the aspect of a decreasing hyperbola with a very good correlation between experimental and theoretical data.

The model validation may be completed with numerous other examples and different dusts in vented or unvented one compartment vessels (Pascaud,1998).

So, we intend now to study dust-air explosions inside a multi-partitioned structure. Different elementary cases with 2 compartments are analysed in order to test the partitioning effect and the model predictions.

The existence of overpressures in the adjoining areas of the ignition compartment has been experimentally observed in industrial installations with interconnected vessels. After ignition in the first vessel, the flame is accelerated when it enters the second one and becomes very turbulent. According to Bartknecht(1978), for identical combined vessels, the maximum explosion pressure in the second vessel may be increased by approximately 10 %. This value may be modified and strongly increased when the explosion propagates from the larger vessel into the smaller one.

On the contrary, the propagation of a flame in a tube composed of different compartments by the means of obstacles (large vent areas) increases the turbulence in the mixture but does not lead to the formation of significant overpressures (Pu,1988).

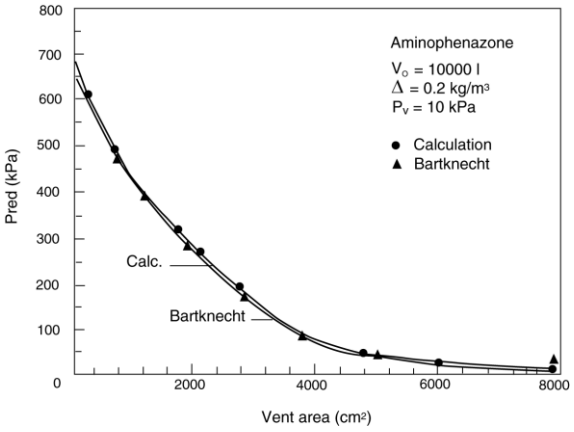


Fig 7 Evolution of the reduced maximum explosion pressure with the vent area.

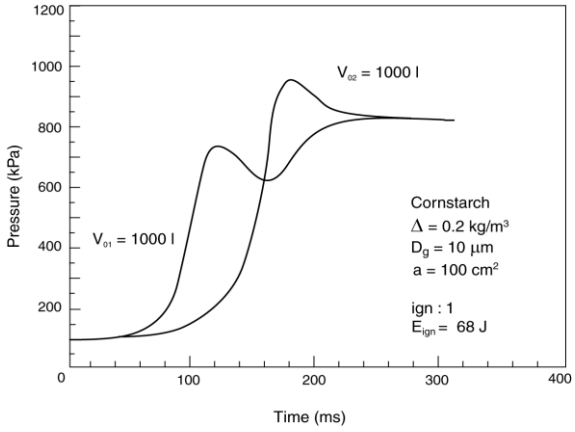


Fig 8 Pressure vs time in both compartments.

In fact, very few quantitative data are available about dust explosions in partitioned vessels and between these different results, the partitioning effect leading to a pressure pilling phenomenon seems interesting to investigate by the simulation. So, we consider a set-up composed of a cylindrical vessel with a global volume such as V_o = 2000 *l*. A vertical steel plate allows to define two compartments with respective volumes such as $V_{o1} = V_{o2}$ = 1000 *l*. Both compartments are connected by a small inner opening positioned in the centre of the plate. Several plates may be envisaged corresponding to various inner openings. The thermodynamical conditions are supposed to be homogeneous in the vessel. The combustion of the dust-air mixture may be carried out in both compartments by the means of a central ignition corresponding to 68 J.

Figure 8 gives the time evolution of the absolute pressure in each compartment for a small inner opening a = 100 cm^2 in the case of a cornstarch-air mixture near the stoichiometry.

The ignition occurs in the first compartment and induces there a quicker pressure rise. This effect involves a molecule transfer towards the adjacent compartment, which modifies the concentrations in the reactive mixture and therefore, the maximum pressures reached. At the end of the reaction, a thermodynamical equilibrium is obtained in the mixture and the pressure evolution is shared by both compartments.

It can be observed that the maximum pressure obtained is higher in the adjacent compartment than in the initial one, where ignition occurs . The effective overpressure ΔP = 150 kPa is stronger than Bartknecht's experimental results (1978) for comparable volumes (about 10% of overpressure) but remains consistent with results obtained by Hu(2005) for gaseous mixtures in partitioned vessels.

Furthermore, the maximum pressure reached at the end of the reaction nearly corresponds to the value obtained in a closed vessel with a single compartment such as V_o = 2000 *l*. The observed phenomena do not depend on the mixture which may be rich, lean or stoichiometric.

It is therefore interesting to study the evolution of the maximum pressure in similar conditions, but for dissymmetric volumes. These evolutions are plotted in the figures 9 and 10 for vessel volumes such as V_{o1} = 5000 *l* and V_{o2} = 1000 *l* .

The ignition may occur in the first or in the second compartment. In both cases and as previously, an overpressure appears in the compartment adjacent to the ignition compartment but both behaviours however remain very different.

The overpressure is very strongly marked when it occurs in the small compartment. In this case, the effective overpressure ΔP = 340 kPa is increased by approximately 40 % in comparison with the ignition compartment with rise times close to 180 ms. Similar data with sometimes more important overpressures have been observed by Bartknecht (1978) for comparable interconnected volumes. Experimental data depend strongly enough in this case on the inner opening and on the turbulence created by the propagation of the flame front. The volume effect created in these conditions is maximum and can lead to the destruction of the vessel structure.

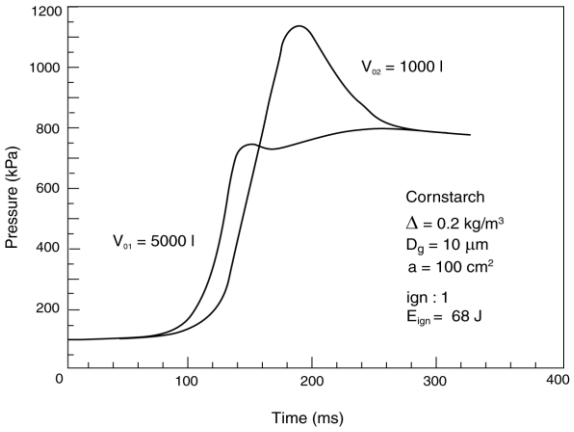


Fig 9 Pressure vs time in both compartments and different locations of the ignition energy.

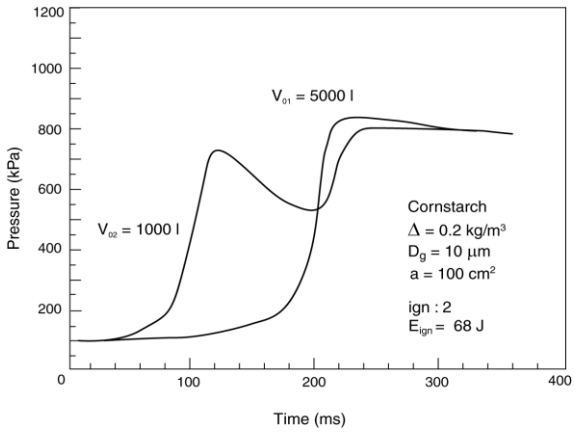


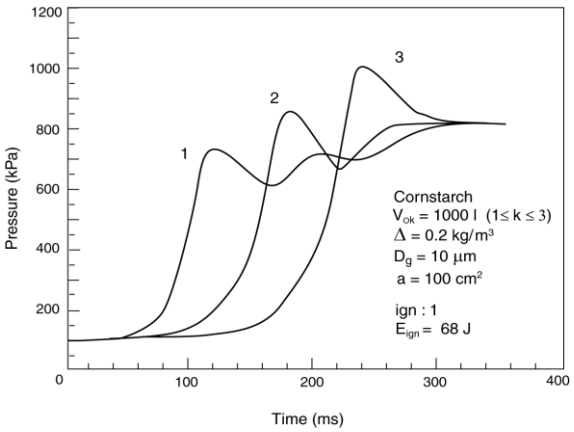
Fig 10 Pressure vs time in both compartments and different locations of the ignition energy.

On the contrary, when ignition occurs in a small compartment (V_{o2} = 1000 *l*), the initial reaction, limited by the number of available molecules is quickly slowed down by the molecular transfers and the overpressure increases faster in the adjacent compartment than in the initial one. The rise time in the large compartment is delayed and the effective overpressure remains very limited (ΔP = 50 kPa). Similar results are obtained by Bartknecht (1978) with an effective overpressure of the order of 7 to 8 %. Finally, more complete studies show that the delay is all the shorter since the mixture is close to stoichiometric conditions. These different examples clearly show the existence of a partitioning effect but also the influence of a volume effect in each compartment.

Applications to simple multi-partioned structures :

We present afterwards, the study of a few simple multi-partitioned structures in order to test the model behaviour for cornstarch explosions in varied situations.

Figure 11 shows the time evolution of the absolute pressure in each compartment of the vessel for initial conditions near the stoichiometry. The global volume is composed of three identical compartments (1x3) such as V_{ok} = 1000 *l* with $1 \le k \le 3$. The inner opening between each compartment is a = 100 cm^2.



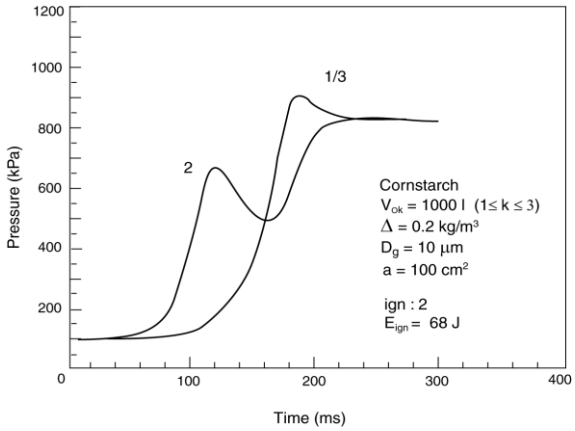


Fig 11 Pressure vs time in a simple partitioned structure and different locations of the ignition energy.

The first part of the figure corresponds to a side ignition, in the first compartment. It can be noticed, that the successive adjacent compartments are the aim of a progressive overpressure.

The intermediate maximum pressures are about 740 kPa in the first compartment, about 870 kPa in the second and about 1000 kPa in the last one.

But the final overpressure remains more limited (about 25 %) between the furthest compartments which corresponds to $\Delta P = 200$ kPa. The overpressure is also delayed in each one of the successive compartments between 120 and 240 ms, which characterises the propagation of the reaction in the mixture. These phenomena generalise the experimental results obtained for two compartments with an amplification of the pressure pilling.
The second part of the figure shows a central ignition in the second compartment. On account of the symmetry, the pressure evolution is identical in the compartments 1 and 3. In these compartments adjacent to the central compartment, a more reduced overpressure may be noticed around 100 kPa. The final rise times are close together between 180 and 200 ms with an initial delay in the side compartments.
Figure 12 starts the same kind of study again, with a more developed structure composed of nine identical compartments (3x3) such as $V_{ok} = 1000\ l$ and $1 \le k \le 9$. All the adjoining compartments are connected by a small inner opening $a = 100\ cm^2$.

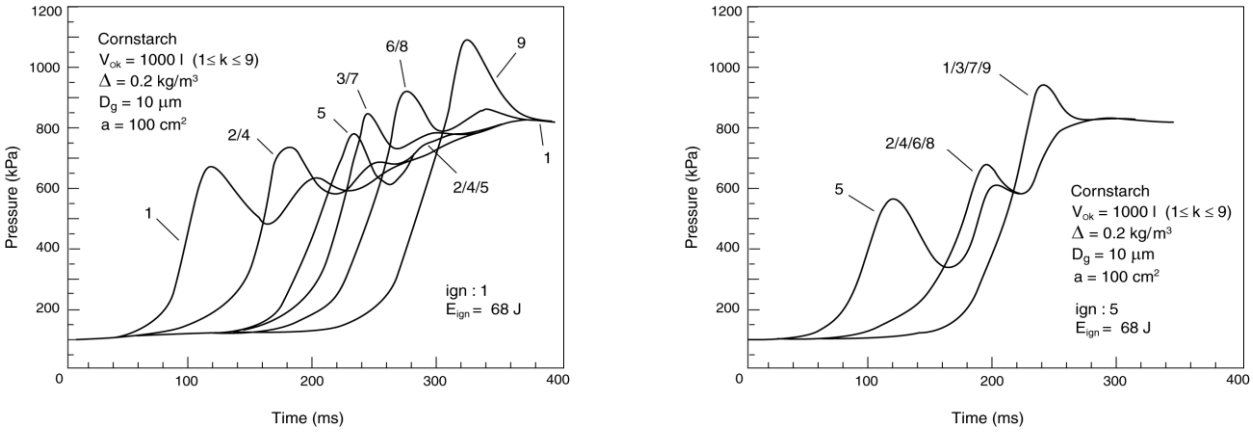


Fig 12 Pressure vs time in a simple partitioned structure and different locations of the ignition energy.

The first part of the figure corresponds to an ignition in compartment 1 which defines one of the corners of the structure. The reaction progressively expands in the adjoining areas with a delay time and leads to the formation of a progressive overpressure.
On account of a possible symmetry in the thermal exchanges and the transfers of matter in the course of the reaction, the maximum pressure in each compartment corresponds to relatively close rise times between 320 and 360 ms. The pressure is the same in the symmetrical compartments in comparison with the ignition compartment.
The maximum pressure reached varies between 800 kPa in the first compartment, and 1100 kPa in the furthest compartment (about 35 %), which confirms the amplification of the pressure pilling in the course of the propagation.
The second part of the figure, corresponds to a central ignition in compartment 5.
The pressure evolution due to the symmetry is the same in different compartments.
A reduced overpressure about 100 kPa exists between the corners of the structure and the central compartment for final rise times comprised between 250 and 280 ms.
All the cases observed indicate two kinds of situations :

- in the course of a central ignition, the overpressure remains limited and the maximum pressure in each compartment does not sensibly differ from the pressure obtained in the global volume without partitioning.
- in the course of a side ignition, a very important overpressure progressively forms with a maximum in the furthest part of the structure.

The location of the ignition compartment considerably influences the thermodynamical evolution of the mixture and the possible destruction of the structure. The partitioning effect is still more noticeable than for gaseous mixtures (Hu,2005).

Comparable results are obtained with the other dust suspensions. The description proposed for partitioned systems seems to be globally in good agreement with experimental data and it seems possible to adapt the simulation to the description of complex multi-partitioned structures.

CONCLUSION

The previous results show a correct adaptation of the model to the description of closed or vented explosions for usual dust suspensions inside a partitioned vessel. The propagation of a hot flow calculated by the means of the standard orifice equations, through the inner openings seems to be representative of real simple cases and it seems possible to extend this methodology to complex multi-partitioned systems. Experimental and theoretical results essentially show that in all cases, an overpressure appears in the adjoining areas to the ignition compartment. The overpressure is particularly important when it occurs in a rich mixture and a small compartment and the partitioning effect appears to be even more important than for gaseous mixtures.
So, it seems possible with the model to calculate the time evolution of this overpressure and to localise its effects in each part of the structure to adapt useful protection conditions in the field of the risk assessment. The proposed development shows the model representativeness for varied conditions such as the thermodynamical conditions in rich or lean mixtures, the location of the ignition energy, the venting effects and the calculation of overpressures. The validation will have to be clarified by more detailed experimental data integrating the previous factors and by studying more complex structures.

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