INVESTIGATION INTO THE CAUSE OF AN EXPLOSION DURING THE DRYING OF POROUS NITROCELLULOSE POWDER

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The investigation into the cause of an explosion in a propellant factory in the Netherlands is described. A combination of an analysis of the hazards involved in the particular process and a thorough study of the properties of the relevant porous nitrocellulose propellant led to the hypothesis that incorrect operation of the equipment caused the formation of electrostatic charges followed by spark ignition of the propellant. This hypothesis was substantiated by the results of model studies and it was possible to discard other theories.

INTRODUCTION

On December 8th, 1972 a violent explosion occurred in a propellant factory in the Netherlands involving approximately 2500 kg of a porous nitrocellulose gunpowder. The building was completely destroyed and the damage in the neighbourhood was considerable. Also, two workers were killed and one was seriously injured.

Several agencies took part in the investigation of the explosion, including the Factory Inspectorate (Ministry of Social Affairs). The latter asked the Technological Laboratory TNO to conduct a thorough technical investigation into the cause of the explosion.

The production of porous nitrocellulose propellants

Porous nitrocellulose propellants are manufactured by mixing the normal constituents of smokeless gunpowder (for instance 98% of nitrocellulose and 2% of a stabilizer) with a certain amount of potassium nitrate in the presence of organic solvents. The solvents are then partially removed and the resulting mass is processed into its final form, in the present case small rectangular flakes (1.4 x 1.4 x 0.27 mm). Later on these flakes are extracted with hot water until the potassium nitrate content has dropped below 0.1 %; in this way a porous material is obtained. The porosity will depend on the amount of potassium nitrate originally used.

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The next step is the removal of the water by means of hot air (approximately 60°C) in aluminium containers which may contain 350-400 kg of the wet porous propellant. The explosion occured in a drying building with a capacity of six containers; however, one unit was defective so that only five containers were dried during the night preceding the accident.

The type of propellants involved in the explosion

The five containers mentioned above each contained approximately 350 kg of a medium porosity propellant which must have been well-dried at the moment of the explosion. Two other containers had been fetched by two workers from the extraction building; these contained a slightly less porous propellant with a water content of 27 per cent. Therefore 1750 kg of the dry propellant and 700 kg of the wet propellant were present in or near the drying building; practically no propellant grains were retrieved after the explosion.

Short description of the drying process

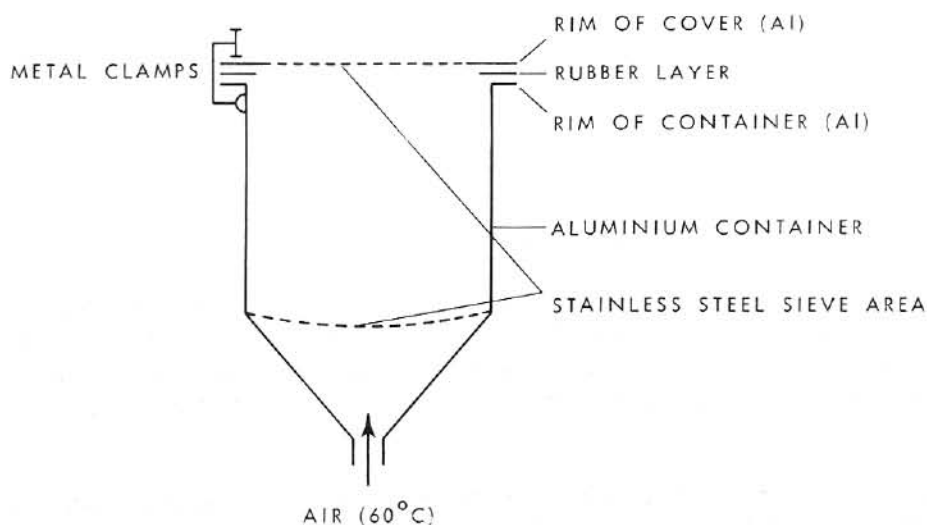The basic concept of the drying process is exemplified in Fig.1.

RIM OF COVER (Al)

METAL CLAMPS — RUBBER LAYER

RIM OF CONTAINER (Al)

ALUMINIUM CONTAINER

STAINLESS STEEL SIEVE AREA

AIR (60°C)

Fig.1 Setup of the drying process

The container with the propellant is connected to a source of hot air thermostatted at 60°C. The air leaves the container through its cover which basically consists of a flat aluminium ring with a large stainless steel sieve area in the middle. The cover is attached to the container by means of clamps; leaking is prevented by a thin rubber layer between cover and container. When the contents of a certain container are dry, the air flow is disconnected and the cover is lifted about ten centimeters by means of a hoisting device. The cover being fixed in this position the container can now be removed by means of a manually operated hydraulic lift car which carries the containers just a few centimeters above the floor.

The situation in the drying building

The situation in and around the drying building (building 7) is shown in

Fig.2. The two drying rooms - each with three units' capacity - were open on the northern side and had a light roof construction. The thickness of the walls does not show in the Figure; for instance, the southern side of the building consisted of a 1 metre brick wall.
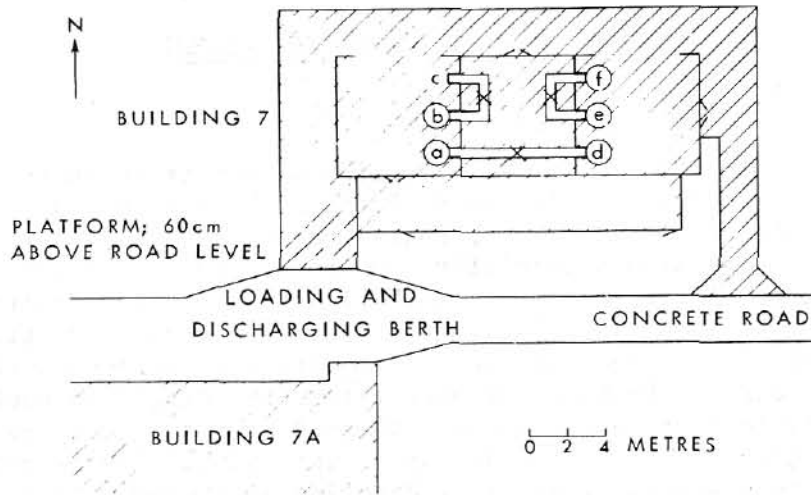

Fig.2   Situation in the drying building before the explosion

Only three hot air generators were present in the central part of the building, each being connected with two containers by means of $\emptyset$ 33 cm tubes. The two drying rooms were therefore connected by means of such a tube.

The containers with the wet propellant are transported from the extraction building to the drying building on a flat cart pulled by a small diesel tractor. This cart takes two containers, and one cartload had been fetched half an hour before the explosion took place; it was parked along the S-W platform which had the same height. To facilitate the exchange procedure in the drying building it is started by disconnecting one dry vessel and just putting it a few metres backwards by means of the hydraulic truck (presumably container d).
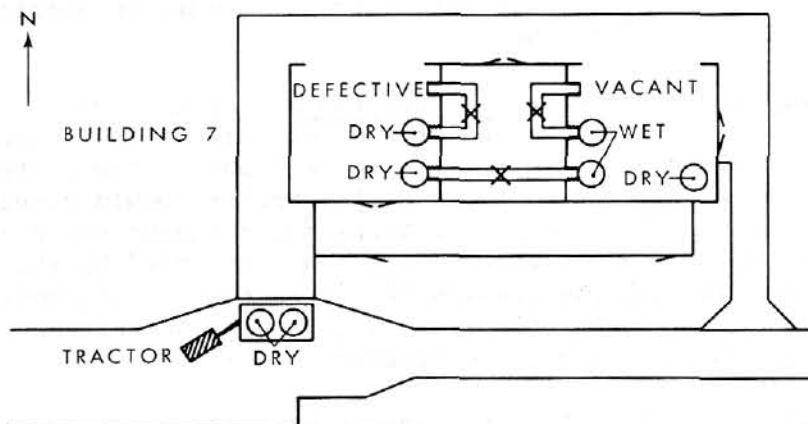

Fig.3   Situation in the drying building at the moment of the explosion

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A wet container is fetched and connected to the now vacant drying unit and a second dry container (for instance e) is carried to the vacant position on the transport cart outside; the second wet vessel is taken inside, etcetera. This procedure will result in the situation shown in some detail in Fig.3. The exact time of the explosion in relation to the usual work schedule suggests that this situation was actually reached at the moment of the explosion.

ASSESSMENT OF THE PROCESS HAZARDS

Hazards already eliminated

The most common hazards involved in dealing with nitrocellulose propellants had already been accounted for in the accepted working procedure for the drying building. The small amount of fine propellant-dust deposited on the floor during the drying process was always carefully removed and the floor was wetted before the actual exchange of the containers took place (to prevent ignition by friction of the nylon weels of the hydraulic lift truck). The generators providing the hot air had a safe design and were well-thermostatted; moreover, the temperature was checked and found to be 60°C one hour before the explosion took place (stabilized nitrocellulose propellants can withstand prolonged heating at 60°C). The containers were grounded since the dry propellant particles will get electrostatically charged in a stream of dry air. Handling of the propellant itself was reduced to a minimum, since the containers were neither filled (with the wet propellant) nor emptied (when dry) in or near the drying building.

Remaining hazards

Transportation risks. The containers were transported over the factory grounds on top of a flat cart connected to a diesel tractor with a certified spark catcher. A manually operated hydraulic lift truck was used to remove the wet containers on arrival at the platform of the drying building in order to replace them by dry ones. Especially the latter operation incurs some risk, since the lift truck with the container might be pushed too far over the surface of the flat transport cart before the hydraulic pressure is reduced. In this way the container with dry propellant may tumble sideways from the 60 cm high transport cart onto the concrete road.

To establish the probability of this hypothesis a reconstruction was essential, as well as an assessment of the impact and friction sensitivity of the propellant. The spark sensitivity is not relevant in this connection since the containers were made from aluminium.

Incorrect handling of the containers inside the building. Almost certainly the explosion took place when the exchange of two wet and two dry containers was (nearly) finished. The wet containers were to be found in the eastern drying room and it was common practice that one of the workers would enter the other drying room in order to make some preparations for the next exchange. Probably this also happened on the day of the explosion as supported by the retrieval of parts of one human body from the remains of the western drying room. It is quite well possible that this man not only started to sweep and wet the floor, but that he already disconnected two dry containers as well.

A simple analysis of the actual disconnecting procedure shows that two actions have to be performed in the correct order. First the closing of the hot-air valve (and disconnecting the flexible air inlet from the container) and secondly the removal of the clamps, which keep the cover attached to the container, followed by hoisting the cover ten centimeters to be fixed in that position.

The small dry porous propellant particles are extremely light and will partially be blown out of the container when the cover is hoisted before the air valve is closed. Any worker will almost certainly react by dropping the cover back on top of the container, which again necessitates the determination of the shock and friction sensitivity of the dry propellant.

Another - less obvious - point is the fact that the cover is no longer grounded when the metal clamps are removed, since only the container itself is grounded and an insulating rubber layer is present between cover and container. Under normal conditions this does not matter too much, but with the air-flow still on it may result in a dangerous situation as the electrostatically charged propellant particles will be blown against the insulated cover, that might obtain a charge as well. This had to be verified by model studies and the amount of charge on an insulated cover of an authentic container had to be estimated in order to establish whether a spark discharge from the cover to the vessel would have sufficient energy to ignite the propellant.

Other hazards. Naturally it is not impossible that something was wrong with the product itself. Most chemical and physical properties had to be determined in order to see whether the product was sufficiently stable to undergo heating at 60°C during the drying period and to see whether any hazardous impurities were present.

EXPERIMENTAL RESULTS

Chemical composition. Two types of propellants were involved in the explosion. Analyses showed that both the dry and the wet propellant (with 27% of water) had a satisfactory chemical composition with no impurities present.

Stability. The thermal stability of the samples was cheched by means of a special calorimetric test in which the heat production due to exothermal decomposition of the sample was determined for the drying temperature of 60°C. The stability was more than adequate as supported by the results of a number of older stability tests like the Dutch weighing test.

Deflagrability and detonability. The dry propellant sample is, of course, easily ignited and will deflagrate if there is no confinement. The wet sample however, could not even be ignited by a certain amount of burning black powder. Therefore it is evident that the two containers with the wet propellant must have detonated during the explosion in the factory. The detonability of both the dry and the wet sample was verified by means of a tube test in which the sample was initiated by a 200 g PETN booster under a certain degree of confinement (the steel tube is 118 cm long, has an inner diameter of 5 cm and a wall thicknes of 1 cm). The shock wave propagated through the substance with a measured velocity of more than 3 km/sec in both samples.

The deflagration-detonation transition. In the preceding paragraph it was established that both wet and dry porous propellants can be detonated when initiated with a booster charge but that only the dry ones will deflagrate. Since incorrect handling of these materials may only start a deflagration, it is almost certain that the accident started with the ignition of the contents of a container with the dried product. The deflagration (fast explosive burning) of this propellant should undergo a transition into a detonation under the conditions of confinement in the container in order to explain the sympatic detonation of the two containers with the wet product.

First this deflagration-detonation transition was studied in the same tube

as mentioned earlier, the initiator (booster charge) being replaced by a squib (thermal ignition). A rapid build-up to a full detonation was observed. Extensive field trials have been carried out in the past year in order to check whether the transition would also take place in the life-size aluminium containers when the substance is ignited by a squib in the middle of the propellant mass. This was shown to be the case and the hazards inherent to the production of porous propellants should once more be stressed.

Reconstruction to establish transporation hazards. A possible source of ignition just outside the drying building is provided by the fact that a container filled with dry propellant might have fallen sideways from a height of 60 cm onto the concrete road. Reconstruction using a container filled with a material with similar characteristics (oats) resulted in the actual fall of the container.

Assessment of the impact and friction sensitivity. If the aluminium container with the dried product did fall on the concrete road, possibly with a small amount of propellant between the upper rim and the concrete surface, this will only have resulted in ignition if the propellant were sufficiently sensitive to impact and/or friction. The properties of both the original samples and those of a finely ground dry sample (propellant dust;< 150 micron) were studied by means of standardized apparatus of German design. The friction sensitivity was low in all cases; the impact sensitivity was not to be neglected, but additional, more realistic studies in which the combined action of impact and friction was simulated showed that ignition is not to be expected in the case of a falling container.

This eliminates the theory of the falling container, so that the source of ignition must have lain inside the drying building. This is supported by an analysis of the damage pattern of the explosion. A few possibilities for an ignition inside the building have been summarized earlier, but most of these can be ignored as well because of the low impact and friction sensitivities. Actually only one theory remains and this one is strongly supported by the facts in the following chapter. Sabotage and acts like cigarette-smoking are neglected since they are considered to be very unlikely.

THE MOST LIKELY CAUSE OF THE EXPLOSION

Introduction

The only remaining hypothesis is the one in which a worker removes the metal clamps that keep the cover attached to a drying container filled with the dry propellant, while forgetting to disconnect the air inflow. A thin foam-rubber layer is present between cover and container to prevent leaking. When the clamps are removed the cover is no longer grounded, since only the container itself is connected the earth. How this incident may result in an explosion is shown in the following sections.

The formation of electrostatic charges on the propellant grains

A batch of 50 g of the dry porous propellant sample was saturated with water and dried again in a small model in which the drying process was simulated. A few grams of the resulting product were transferred to a specially designed meter which indicated that the sample had an electrostatic charge of approximately 0.1 nC/g. It should be emphasized at this point that the dry propellant had not yet been treated with graphite.

The formation of electrostatic charges on an insulated cover

The electrostatic charge on the dry propellant grains being established it was also studied whether these charged particles could effectuate the development of a charge on an insulated cover by being blown against it. Details on the electronic test setup are beyond the scope of the present paper; it was found that the cover of the model vessel was charged at a rate of approximately 2 nC/s. Assuming that the charging current is proportional to the surface area of the cover it can be calculated that the cover of an authentic aluminium container will be charged at a rate of 0.2 µC/s.

Spark sensitivity of the dry propellant

The dry (not yet graphitized) propellant should have a certain sensitivity towards sparks in order to account for a possible ignition. An apparatus similar to that of the Bureau of Mines (Pittsburgh, USA) was used. The dry propellant grains (small rectangular flakes) were hardly sensitive towards capacitive sparks, the minimum ignition energy being 2 J. When ground to a powder (< 150 micron) the sensitivity was much larger with a minimum ignition energy of only 10 mJ.

Ignition in the authentic container

The drying process always produces a certain amount of propellant dust and it is likely that some of it collects on those places where the foam rubber layer between the rims of the cover and the container is locally damaged. In a most crucial experiment some propellant dust was deliberately put on such places of an authentic container which was otherwise empty. The container was grounded and the (insulated) cover was given a potential by means of a high-voltage generator. As expected the sparks from the cover to the container appeared exactly at those same damaged positions; ignition was observed when the applied potential exceeded 6.7 kV.

Several other parameters have also been determined and/or calculated, the more interesting ones being the energy of the sparks (15 mJ, which is in good agreement with the minimal ignition energy of the propellant dust) and the amount of charge on the cover before the sparks are formed (4.7 µC). This means that the cover may get sufficient charge in approximately 20 seconds, since it has been established that the rate of charging by collisions of charged particles against the cover was 0.2 µC/s.

Propagation of the explosion

The dry propellant in one of the two containers in the western drying room (Fig.3) was almost certainly ignited by a spark on the top rim of the container. The propellant mass in the container itself resembled a fluid bed due to the drying air; presumably this will have facilitated a deflagration - detonation transition. The second vessel will come to a detonation as well and the presence of the Ø 33 cm tube between the two drying rooms enables a sympatic detonation of the containers in the eastern drying room. The two containers with the dried product standing outside on the flat transport cart were probably hit by high velocity fragments and detonated as well. The damage observed on the surface of the concrete road suggests that one container exploded in upright position and the other one while falling after being blown away by the blast of the explosion inside the building. All seven containers were completely fragmented and the building was destroyed including the southern 1 metre brick wall. An account of the damage on the factory grounds and in the nearby village

is beyond the scope of this paper.

CONSEQUENCES FOR PLANT DESIGN

Considering the cause of the present explosion the following conclusions regarding plant design can be drawn.

When processing electrostatically charged materials one should always ground the several parts of the equipment when there is even the remotest chance that they might become disconnected due to incorrect handling.

When a building consists of several compartments in which explosive materials are processed one should never make a connection between these rooms (for instance by means of a tube), since a sympathic detonation should be prevented in the case of an accident in one room.

A remote-control operation is of course ideal and is currently being installed in the new drying buildings.

Acknowledgement