3.3 Explosions

3.3.1 Definitions

The word explosion is used to cover all processes characterized by a sudden flow of material (usually consisting mostly of hot gases) out from one point.

There are two main types of explosion, depending on how the sudden flow has been caused:

Explosions as a result of physical processes

- stored energy in the form of pressure x volume is suddenly liberated,

- external energy is suddenly supplied to a solid or liquid substance, transforming it into gas.

- energy is suddenly supplied to a gas, which increases its pressure,

Examples of explosions caused by physical processes: pressure vessel explosions, steam explosions.

Explosions as a result of chemical reactions

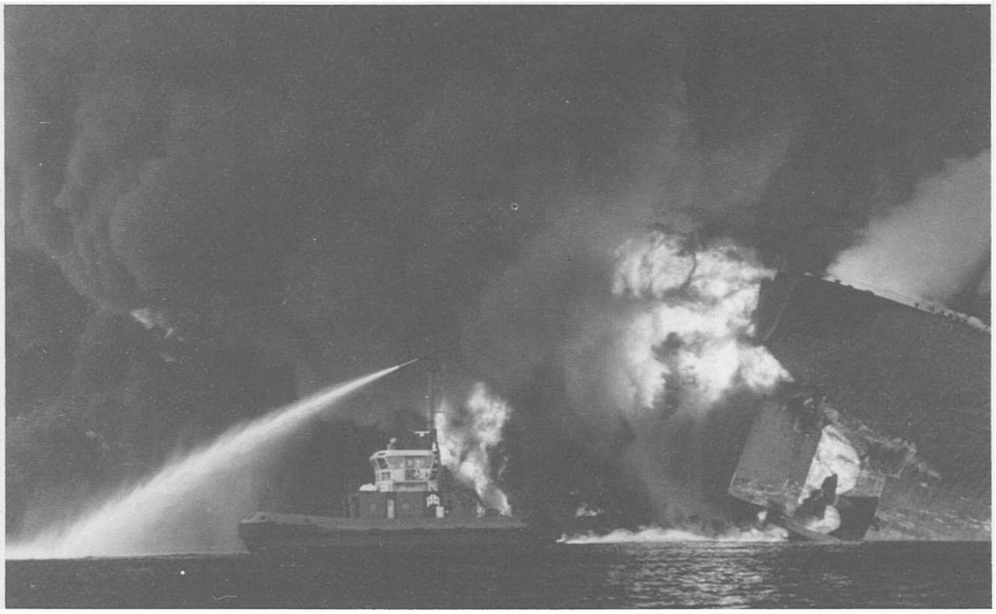
These are caused when reactions that give out heat provide the energy for the flow of material. There are three ways for this to take place. In each case the substances concerned must be present in the right proportions and well mixed.

- Heat explosion
The reaction mixture has roughly the same temperature throughout. The liberation of energy takes place at the same time throughout the mixture. Example: rapid uncontrollable chemical processes.

- Deflagration
The liberation of energy takes place in a thin layer which has a high temperature, the rest of the volume having the same temperature as the surroundings The next layer to react is warmed up by the conduction of heat through the mixture. The speed of deflagration is low - mm/s for solids and liquids, m/s for gases. The speed of deflagration depends on pressure (increasing with increased pressure). The deflagration is started by a localized pulse of heat.

- Detonation
The liberation of energy takes place in a thin layer which has a high temperature, the rest of the volume having the same temperature as the surroundings. The next layer to react is hit by a shock wave and warmed up by compression heat in gases or deformation heat in solids. The speed of detonation depends on the movement of the shockwave through the reactants and is therefore high - km/s for all materials. The speed of detonation does not depend on the surrounding pressure. The detonation is started by a localised shock.

In certain circumstances a deflagration can turn into a detonation (eg in the cases of large quantities, porous solids or obstacles creating turbulence in the flame front in a gas).



Fire resulting from explosion on board an oil tanker, Genova, 1991.

3.3.2 Hazards

3.3.2.1 Explosions Caused by Physical Processes

Pressure vessels and processing equipments for compressed gases are latent bombs. Faults in materials, corrosion or being struck by another object can cause the wall of a vessel to rupture, with a consequent explosion. The force of the explosion is determined by the energy stored - that is P x V / (k-1), where P is pressure (Pa), V is volume (m3) and k is the cp/cv for the gas.

Pressure vessel explosions cause damage as a result of the pressure wave and flying debris.

Liquids at a temperature exceeding 100oC can cause steam explosions. If water (or any other liquid with the same or lower boiling point) finds its way into the hot liquid there will be an explosive production of steam. The steam produced has a far greater volume than the original water (several thousand times the volume!). Steam explosions can occur at foundries and in cellulose production (soda vessels). The force of the explosion is determined by the temperature of the hot liquid and its heat capacity as well as the volume of the liquid that boils.

Steam explosions cause damage as a result of the pressure wave as well as fire and burns caused by the escape of the hot liquid.

Explosions caused by external energy (usually electrical) can take place in a solid, liquid or gas. If sufficient energy is supplied, it will cause a solid substance already in gas form greatly to increase its pressure. There is always the risk of this kind of explosion when there is a short circuit in a large oil or gas-cooled transformer.
Damage is caused by the pressure wave and flying debris.

3.3.2.2. Explosions Caused by Chemical Reactions

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It is possible to cause explosions with any kind of heat-producing (exothermic) chemical reaction.

Exothermal processes in industry

There is always the risk of an explosion when an exothermal process is being used in the chemical industry All it needs is a fault in the regulation of quantities in the process or in the cooling system.

The easiest way to recognise equipment for exothermal processes is that it includes a cooling system of some kind, usually water cooling, which is meant to keep the temperature within certain limits

The force of an explosion is determined by the total amount of energy liberated, which is given by the quantity of the reaction. The damage is mostly due to the pressure wave and flying debris.

Unintentional mixtures of air and fuel

Explosive mixtures are created when:

1. inflammable gases are mixed with air

2 inflammable liquids with a low boiling point evaporate in air

3. inflammable liquids at a high temperature escape into air

4. inflammable liquids at high pressure are ejected into air

5. combustible solids in a powder form whirl round in air

1-3 give gas mixtures, 4-5 aerosols.

The mixtures are only explosive within a certain interval of the fuel/air ratio, depending on the substance in question.

The energy content of the mixture is greatest when there is exactly enough oxygen present in the air to burn the fuel completely. This is usually called the stoichiometric concentration and lies about halfway between the limits of the explosive mixture. The stoichiometric concentration for combustible aerosols is about 100 g/m3, the lower boundary being about 1/3 of that.

Deflagration of a fuel/air mixture in a closed space produces a pressure of about 7 bars (1 bar = 1.033 atmospheres at stoichiometric concentration and atmospheric pressure). Detonation in similar conditions produces about 20 bars.

Deflagration in an open space does not produce such a high pressure (as long as the fuel/air cloud is not very large). However detonation in the open produces the same pressure as in a closed space.

Damage is caused by the effects of heat and pressure, but flying debris can also cause damage (eg. glass from broken windows).

Latent hazards, in the same order as the five types of mixtures given above:

1. Compressed or condensed inflammable gases (eg. LPG, natural gas, acetylene. hydrogen, ammonia, ethylene)

2. Inflammable liquids with boiling points under 100oC in tanks and processing equipment (eg. ether, alcohol, acetone, petrol)

3. Inflammable liquids in processes where the temperature is at or above the boiling point of the liquid at atmospheric pressure.

4. Inflammable liquids in processes at high pressure.

5. All finely divided combustible solids that can be caught up in the air when handling (loading/unloading, regulating quantity) - eg flour, sugar, starch, aluminium powder.

The greatest risks are for powders in large quantities, as in silos, and with certain energy-rich substances such as aluminium.

The hazards in 1-4 above arise from: the inadvertent release of fuel caused by faults in components; corrosion; equipment being struck by another object, or human error.

Substances that can break down and give out energy

There is a number of chemical compounds which, on being given initial energy (from heat, friction or being struck), can break down explosively. Many are classed as explosives - but not all! Special permission is needed to produce or obtain substances designated as explosives. However, many commonly used substances can cause explosions but are not classified as explosives. These include: peroxides (hydrogen peroxide and organic peroxides); aluminium salts with an oxygen carrying group such as a nitrate, chlorate, perchlorate, chromate, dichromate, etc; and metal complexes of the form metal-amine-nitrate (or chlorate, perchlorate, chromate, dichromate, etc). Of these, hydrogen peroxide, ammonium nitrate and ammonium perchlorate are handled in the largest quantities.

An explosion causes damage as a result of heat and pressure effects and fires often occur.

Mixture of an oxidizing agent and combustible material

An explosion can be caused when a solid or liquid oxidizing agent is mixed with fuel. The greatest energy is released if there is a stoichiometric mixture. It is easy to get an energy content of 5- 10 MJ/kg, i.e.as much as conventional explosives!

Common solid oxidizing agents are peroxides, nitrates, chlorates, perchlorates, chromates and dichromates

Common liquid oxidizing agents are perchloric acid, nitric acid, hydrogen peroxide, tetranitromethane.

The fuel can be more or less any combustible organic substance, metal, alloy, sulphur or sulphur compound.

The most common hazard is a combination of a liquid oxidizing agent and solid combustible material, or vice versa, which are handled or stored near each other.

The hazard leads to an explosion if an inadvertent release leads to the two materials coming into contact. This could be the result of a fault in equipment, corrosion, equipment being struck by another object or human error.

The damage from this kind of explosion is the same as that caused by conventional explosives

3.3.3 Consequences

People are injured in explosions due to the effect of pressure, flying debris and heat.

The parts of the body most sensitive to pressure are the ear drums, lungs and stomach/intestines. The ear drum is damaged at an excess pressure of 35 kPa Lungs are damaged at about 70 kPa, 300 kPa putting life in danger. The severity of injuries to the lungs and stomach/intestines also depends on the length of exposure and rate of increase in pressure.

If the pressure is suffcently high and long-lasting a person can be knocked over. Serious injuries (eg fractured skull) come with an impulse density of about 380 Pa x s (380 Ns/m2)

Injuries from flying glass are also common Pieces of glass weighing between 0.2 and 2 g penetrate skin if they have a speed of 65-80 m/s, and penetrate the stomach wall at 70-155 m/s.

Explosions caused by chemical reactions also cause **injuries from the heat radiation generated.** About half of the energy liberated takes the form of heat

Burns to the hands and face are caused by the following amounts of energy:

first degree burns	50- 80 kJ/m2
second degree burns	120-200 kJ/m2
third degree burns	200-350 kJ/m2

(The lower value is for short, intensive exposure - of about 1 s - the higher for longer exposure - about 10 s)

Due to their large surface areas buildings can stand exposure only to relatively low pressures if they are to be left undamaged. Windows are damaged at as little as 1 kPa. Limited damage to windows, doors and external surfaces occurs if the pressure exceeds 5 kPa and impulse density is greater than 100 Pa x s. Serious damage (i.e.only a quarter of the building left standing) occurs at 40 kPa and 400 Pa x s.

Explosions that take place indoors nearly always lead to serious damage for this reason. Note that people cope much better with exposure to pressure than buildings do!

When heat is generated there is the risk of easily combustible materials, such as paper, curtains etc, being set on fire. This takes place if the energy level is at 200-350 kJ/m2, the level producing third degree burns

Establishments for communications and the supply of electricity, water, etc, are specially attractive targets for sabotage.

In wartime the likelihood of explosions increases greatly Most weapons cause a great deal of damage where they land, as well as throwing out shrapnel, which can penetrate steel at a distance of several hundred metres.

Pressure vessel explosions and fuel/air explosions would often occur when an industrial area is attacked.

After an attack there would still be a high risk of explosions, for example from delayed action or unexploded bombs. Bomb disposal must be done by trained experts

3.3.4 Examples of Serious Explosions

A bomb explosion in the railway station at Bologna, Italy, caused the roof to collapse, killing 85 people It is the worst explosion of modern times, though there have been many other accidents with explosives. Here are some other examples·

Longview,Texas, USA,1971

On February 1971 a preassure ethylene gas pipe broke in a plant near Longview, Texas and the vapour cloud found a source of ignition and exploded. The explosion broke numerous other pipes and caused the release of many thousands of pounds of ethylene. The larger vapour cloud which resulted ignited and exploded violently. Four people were killed and 60 were treated in hospital.

Bantry Bay, Eire, 1979

On 8 July 1979 a small explosion took place at the oil terminal at Bantry Bay. An oil tanker was unloading oil. Later there was a large explosion accompanied by a fireball. Missiles from the explosion travelled up to six miles. All 42 members of the crew were killed, together with 8 other people, mostly terminal operators.

Henderson, USA,1988

An explosion, caused by a fire, devastated a rocket fuel factory in Henderson near Las Vegas, USA, 1988. Ammonia, ammonia perchlorate and hydrochloric acid were being handled in the factory.

In addition to the two deaths, about 350 workers and Henderson residents were hurt The main injuries were cuts and abrasions, from flying glass and debris, and bruises and sprains from being knocked down by the shock waves.

The blast damaged more than 50 % of the buildings in Henderson, forcing shops, offices and schools to close. The damage was initially estimated at more than $70 million, $ 23 million of which was uninsured.

3.3.5 Hazard Analysis Methods

It is necessary to know the amount of energy released and the distance from the object in question. Approximate values for the danger area for the most common kinds of explosions are given below. Only the effects of pressure are considered and it is assumed that the explosion takes place outdoors.

For more precise estimates a computer program is needed, which takes account of geometry, the strength of the object in question, shrapnel, heat effects etc.

Pressure vessel explosions

Estimated energy released $E = P \times V/(k-1)$
where: P is gas pressure (Pa)
V is volume in m3
k is cp/cv for the gas

Examples of values for k:

air	1.40
ammonia	1.32
argon	1.67
nitrogen	1.40

oxygen	1.40
carbon dioxide	1.31
hydrogen	1.41

Estimate the corresponding amount of explosives in kg by dividing E by 5 000 000 (5 x 10^6). Then estimate for the radius of the danger area for people and buildings (see diagram 3.3.1).

Explosions of solid or liquid substances or mixtures of an oxidizing agent and fuel

Go directly to the diagram in 3.3.1, using the quantity in kg of substance or mixture in question

The diagram is for explosives with an energy content of 5 MJ/kg If the actual energy content of the substance is known, multiply the quantity in kg by the factor (actual energy /5)

Fuel/air explosions

Calculate the amount of explosives in kg corresponding to the explosive effect of the mixture

kg = 0.02 x M x Q

where: M = kg inflammable substance released in air

Q = heat from combustion of the substance in MJ/kg (if this is unknown, use the value 50 MJ/kg)

The estimated amount of kg should be doubled for hydrogen, ethylene, acetylene.

See diagram 3.3.1 for the radius of the danger area for people and buildings

FOA

Explosion shock wave damage

Diagram
3:3:1