



Explosion Prevention and Blast Mitigation

An Online Continuing Education Course for Engineers

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Credit: 2 Hours / 2 PDH / 2 CPD

Explosion Prevention and Blast Mitigation

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Introduction

The purpose of this course is to provide engineers with an overview of explosive conditions, environments, and methods to mitigate the risk and/or result of an explosion within such environments. Specifically, upon completing this course, you should have a rudimentary understanding of the following:

- Basic chemistry and classifications of explosions
- Hazardous area classifications
- Intrinsically safe systems and components
- Combustible vapor and gas detection instrumentation and systems
- Blast venting and containment methodology
- Hazard and Operability Analysis (HAZOP) reviews

The intent of this course is to limit the discussion of explosions to those that are accidental in nature. The course is not intended to be used as a design reference, design guide, or as a primary source of information on the topics covered. If you will be involved in the design, specification, or installation of any of the equipment or instrumentation discussed, it is important that you, at a minimum, consult the relevant standards and guidelines referenced throughout this course.

The author of this course has over forty-five (45) years of engineering experience, including instrumentation and control systems, and most recently, nineteen (19) years of forensic engineering experience, which includes fire and explosion investigations for the private sector and in assistance to the ATF. In addition to being a licensed engineer in twelve (12) states, the author is a certified fire and explosion investigator (CFEI) and member of the NFPA (National Fire Protection Association), IAAI (International Association of Arson Investigators, and NAFI (National Association of Fire and Explosion Investigators).

Basic Chemistry and Classification of Explosions

An explosion is generally defined as a violent and destructive sudden release of energy leading to a rapid increase of pressure. For our discussions, the energy can be either physical or chemical. A third type of energy, radioactivity, will not be covered in this course.

Physical Explosions

Physical explosions are generally considered to involve a release of physical energy, such as the bursting of a pressure vessel, rupture of a liquid containing vessel—which is sometimes referred to as a “BLEVE” (pronounced BLEV-ee)—an acronym standing for **boiling liquid expanding vapor explosion**, or a steam explosion caused by molten metal such as aluminum coming into direct contact with water.

An example of the latter investigated by the author was an aluminum castings plant in which water came into direct contact with a large quantity of molten aluminum. The resulting explosion intense enough to blow a large section of the metal roof above off of the building. Fortunately, no one was seriously injured. Damages to the structure and equipment were substantial.

An example of a BLEVE type of explosion would be a steam boiler explosion in which steam pressure within the steam drum exceeded the maximum allowable pressure of the drum (a pressure-rated vessel), and the pressure relief valves failing to open and limit the maximum pressure.

Safety valves or pressure relief valves are sized by the boiler manufacturer to open or release at a pre-set pressure that is below the maximum pressure rating of the steam drum and reclose after the pressure has returned to normal. In many locations, government regulatory agencies require annual inspections of the boilers and testing of the pressure relief valves in accordance with the National Board Inspection Code (NBIC) to ensure they are properly functioning (opening at their design pressure setting). The NBIC is updated every two years.

An excerpt from the NBIC states that “Pressure relief devices are used to provide a means of venting excess pressure which could rupture a boiler or pressure vessel. A pressure relief device is the last line of defense for safety. If all other safety devices or operating controls fail, the pressure relief device must be capable of venting excess pressure.”

Most pressure relief devices fall under one of the following types:

- **Pressure Relief Valve** – A device designed to open and release pressure during emergency or abnormal over-pressurization conditions and reclose after the pressure is reduced.
- **Safety Valve** – A device typically used for steam or vapor service. It pops fully open during over-pressurization and recloses once the pressure drops to a value consistent with blowdown requirements specified by governing codes or standards.
- **Relief Valve** – A device typically used for liquid service. It operates automatically by opening farther as pressure increases beyond the initial opening pressure. It recloses once the pressure drops below the opening pressure.
- **Safety Relief Valve** – A device that has the combined operating characteristics of both a safety valve and a relief valve and can be used in either type of application.
- **Temperature and Pressure Safety Relief Valve (T & P Valve)** – A device most commonly used on domestic, potable water heaters. In addition to its pressure-relief function, it has a temperature-sensing element that causes the device to open at a predetermined temperature regardless of the pressure.
- **Rupture Disk** – A one-shot, non-reclosing device. The disk remains open upon actuation (rupturing) and is typically found on pressure-rated vessels when a spring-loaded pressure relief valve is inappropriate due to the operating conditions or environment that may foul or inhibit a relief valve's operation.
- **Pilot Operated Pressure Relief Valve** – A pressure relief valve within which the relief disk is held closed by system pressure. Pressure is controlled by a pilot valve actuated by system pressure.

Additional information pertaining to pressure relief devices, including installation requirements, can be found in the following publications and sources:

- National Board Inspection Code (NBIC)
- ASME Sections I, IV, VI, VII, VIII and X
- ASME CSD-1
- Device Manufacturer's Installation, Operation, and Maintenance Documentation

An example of a BLEVE explosion occurred in the central boiler facility at a tape manufacturing plant. The relief valves had not been inspected and tested for years and, at some point, no longer functioned as designed. The relief valve failed to open on the steam drum of the coal-fired boiler when a controller failed, allowing pressure in the drum to exceed its maximum pressure rating. When the steel steam drum ruptured violently, it split wide open and the pressure released was sufficient to kill the boiler operator on duty and propel the drum, which weighed well over a thousand pounds through the wall of the boiler house and across a parking lot, where it hit and partially collapsed one end of a warehouse. From there, it continued across the parking lot at a lower altitude, clipping a guard rail along a nearby public roadway, and landed in a wooded lot approximately a quarter-mile from the boiler house. Had the drum traveled in the opposite direction, it would have entered the tape plant, which had approximately 300 employees in it at the time. Had a car been traveling along the public roadway where the guardrail was struck, it would have easily penetrated the passing vehicle, and potentially, more lives would have been lost. As terrible a tragedy as it was, it could have been far worse.

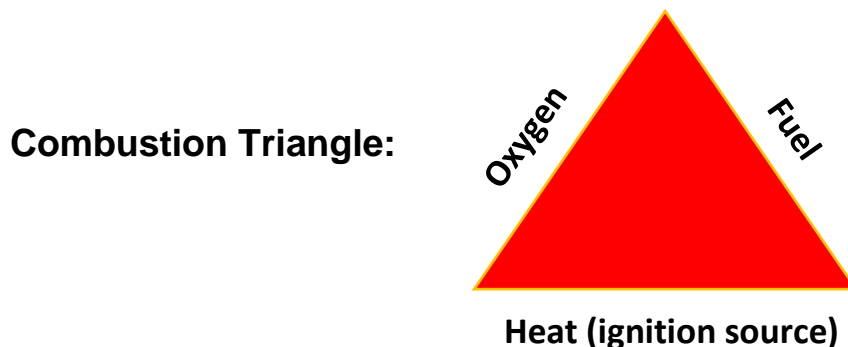
Properly sized and functional pressure relief devices are critical in mitigating the risk of a physical explosion.

Chemical Explosions

Chemical explosions are generally considered to be, as the name suggests, explosions caused by some type of chemical (dust, gas, vapor) reaction, either by decomposition or combination reaction. Both decomposition and combination result in an exothermic reaction (release of heat). An example of two or more chemicals in combination to produce an exothermic reaction would be potassium nitrate, carbon, and sulfur to produce gunpowder or fireworks.

Typically, in an explosion event, there will be an ignition of some type of highly reactive material that ignites or detonates, producing a rapidly expanding outward destructive force (shock wave) from its epicenter that results in the formation of an expanding fireball and debris field. Often the substance or material ignited is either a gas, highly volatile solid material, or dust.

Similar to fire, there are three basic components, often referred to as a triangle, that must all be present at the same time in order for combustion/ignition to occur: 1) oxygen, 2) a fuel, and 3) an ignition source (heat). The optimum mixture to produce an explosion is referred to as the stoichiometric proportion. A fire may not result in an explosion, and an explosion can occur without a fire.



Air, which is 16% oxygen by volume, is typically the oxygen source for an explosion event. In the absence of oxygen, combustion (ignition) does not occur.

Heat sources that provide ignition of the fuel can be any source that produces sufficient localized heat energy to ignite the fuel that it's in contact with, such as an electrical arc (including static electricity), an open flame, or a hot surface. The autoignition temperature of the fuel is the lowest temperature of a hot surface capable of igniting the fuel-air mixture.

Fuels in an explosive environment can consist of a solid, gas/vapor, or dust. The intent of this course is not to go in-depth into the various explosive materials, as there is sufficient information related to the various types of substances that can produce an explosion to warrant a separate course. Examples of each of the three classifications mentioned are shown below:

Solid Explosive Materials

As previously mentioned, this course is limited to accidental sources of explosions and therefore does cover explosives or pyrotechnics.

There are a few chemical substances capable of producing their own oxygen once ignited. They tend to make good solid fuels for rocketry.

Self-reactivity of some solid materials can occur when exposed to a shock or increase in temperature or pressure. Materials in this group tend to be very chemically unstable. Depending on the material, they can react vigorously and, in some cases, explosively under conditions of mechanical shock, such as a hammer blow or even slightly elevated temperature or pressure. Materials that fall into that category include:

- acetylides
- ammonium perchlorate
- azides
- diazo compounds
- fulminates
- hydrogen peroxide solutions (in high concentration)
- many organic peroxides
- nitro compounds
- nitrate esters
- some types of epoxy compounds

(Source: Canadian Centre for Occupational Health and Safety (CCOHS))

Information contained on MSDS (Material Safety Data Sheets) includes the volatility or reactivity of the substance referenced and should be consulted whenever uncertain about the chemical nature of the substance in question.

Explosive Gas/Vapor

In the right mixture or concentration of air (oxygen) and a combustible gas/vapor, an explosion can result if ignited. Examples of such gases and/or vapor are:

- natural gas
- propane
- butane
- propylene
- gasoline
- coal gas
- acetone
- isobutane
- ethylene

Gases and vapors behave differently than solids and dusts. Depending on its density, the gas or vapor will be heavier or lighter than air, which determines whether it collects at a high or low point within a space. If the gas or vapor displaces enough air, there will be insufficient oxygen present for ignition to occur. The concentration at which a gas or vapor is sufficient to result in an explosion is defined by the upper and lower explosion limits.

The Lower Explosive Limit, or LEL, is the lowest concentration of gas or vapor that will burn or explode if ignited. The Upper Explosive Limit, or UEL, is the highest concentration of gas or vapor that will burn or explode if ignited. The LEL and UEL are referred to as the “flammability limits” or “explosive limits” and have been determined by research for most gases and vapors. That important data can be found in the NFPA Handbook.

Gas / Vapor	Lower Explosive Limit (LEL)
Butane	1.8% volume
Ethane	
Ethylene	
Gasoline	
Propane	
Propylene	
Acetone	
Isobutane	

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A type of explosion known as ordinary propagation occurs when a fuel (such as ordinary propane) is ignited, the burning rate may increase and the shock wave may be strong enough to cause an explosion.

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