

CHAPTER 2 BASICS OF EXPLOSION PROTECTION

The determination of the amount of time that an explosive mixture will be present in an area is the basis of "area classification."

2.1 NORTH AMERICAN CODE DEFINITIONS

Hazardous Locations are defined as:

premises, buildings, or parts thereof in which there exists the hazard of fire or explosion due to the fact that

a) highly flammable gases, flammable volatile liquid mixtures, or other highly flammable substances are manufactured or used, or stored in other than original containers;

b) combustible dust or flyings are likely to be present in quantities sufficient to produce an explosive or combustible mixture, or it is impracticable to prevent such dusts or flyings from collecting in or upon motors or other electrical equipment in such quantities as to produce overheating through normal radiation being prevented, or from being deposited on incandescent lamps;

c) easily ignitable fibers or materials producing combustible flyings are manufactured, handled, or used in a free open state; or

d) easily ignitable fibers or materials producing combustible flyings are stored in bales or containers but are not manufactured or handled in a free open state."

Hazardous Locations shall be classified according to the nature of the hazard, as follows:

a) Class I locations are those in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive gas atmospheres;

b) Class II locations are those which are hazardous because of the presence of combustible or electrically conductive combustible dusts;

c) Class III locations are those which are hazardous because of the presence of easily ignitable fibers or flyings, but in which such fibers or flyings are not likely to be in suspension in air in quantities sufficient to produce ignitable mixtures."

Worldwide there have been many spectacular examples of human failure when working in hazardous areas which have resulted in explosions and fires causing the loss of life and destruction of installations. Two such examples are the Piper Alpha oil and gas production platform installed in the British Sector of the North Sea and Flixborough near Scunthorpe in Lincolnshire, England. In both examples, a massive release of flammable material was ignited by either electrical or mechanical energy.

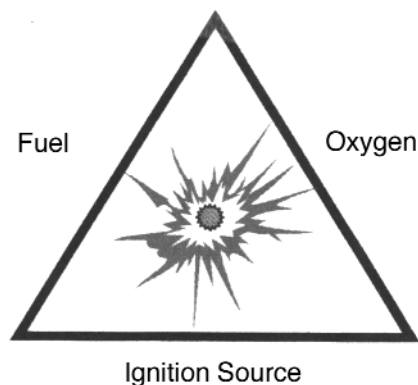


Ignition of flammable materials causes catastrophic results.

A literal interpretation of the Hazardous Location definition might lead to classifying areas that are accepted as being unclassified and therefore the definitions must be applied with a degree of knowledge and experience. For example, part (a) of the Hazardous Location definition could lead to the conclusion that the fuel supply to gas furnaces in homes would require the area around the furnace to be classified. However, as the pressure of the gas is very low relative to the rating of the piping, and the installation of the piping can be done only by qualified persons, the possibility of a release of sufficient gas to create an "explosive gas atmosphere" is so low that the area is not classified. Rules in other codes such as the Building Codes or the Natural Gas and Propane Installation Codes contain additional information that may also affect whether an area should be considered a Hazardous Location. It is important that the decisions regarding the determination as to whether or not an area is a Hazardous Location are made only by individuals who are familiar with all the codes, standards and principles that apply.

2.2 THE HAZARD TRIANGLE

For an area to be classified as a Hazardous Location there must be the possibility that the conditions for an explosion or fire may exist as the result of some abnormal occurrence. To better understand what these conditions may be, an understanding of the combustion triangle is a fundamental requirement.



All three elements must be present for an explosion to occur.

For an explosion to take place, all three sides of the triangle, satisfying the following conditions, must be present:

- There must be a supply of oxygen present. In most situations this is applicable as a result of the oxygen content in the air (21%).
- There must be sufficient fuel present in the air to form an ignitable mixture. The fuel may be in the form of a gas, vapor, mist or dust.
- There must be a source of ignition with sufficient energy to ignite the fuel-air mixture. For electrical equipment this may be from an arcing or sparking device or from a hot surface. There may be sources of ignition other than electrical equipment, such as hot exhaust surfaces from internal combustion engines. These devices do not fall within the scope of the North American electrical codes and are normally covered by other codes and standards such as Occupational Health and Safety.

The basic approach to design in a Hazardous Location is to ensure that all three sides of the triangle do not exist simultaneously. If any one side of the triangle is not present, an explosion cannot occur. Protection against explosions will therefore require control or elimination of one or more sides of the triangle.

2.2.1 THE OXYGEN SIDE

In most situations there is sufficient oxygen present in the air (21%) to meet the conditions for an explosion. In some situations however, oxygen may be excluded by blanketing an enclosed area with another gas to ensure there will not be sufficient oxygen present. The blanket gas is normally an inert gas, such as nitrogen, or in some cases it may even be a flammable gas such as methane.

2.2.2 THE FUEL SIDE

If avoiding the use of flammable substances is not possible, the fuel side of the triangle is removed by enclosing the gas or dust in piping, or vessels in the case of gas, vapors or flammable liquids, or in enclosed ducts in the case of dust. Of course there is always the possibility that flammable materials could be released in sufficient quantity to form an explosive mixture as a result of a malfunction of equipment. In some situations an explosive mixture may be present frequently or continuously as a result of normal operations such as the interior of vented fuel storage tanks or the interior of paint spray booths.

The determination of the amount of time that an explosive mixture will be present in an area is the basis of “area classification,” which is discussed in more detail in Chapter 3.

2.2.3 THE IGNITION SIDE

The electrical equipment installed in Hazardous Locations forms the ignition side of the triangle. The various designs used for electrical equipment ensure there will not be a simultaneous occurrence of all three sides of the triangle. The specific design of an electrical device for use in a Hazardous Location will depend on the amount of time it will be exposed to flammable

concentrations of flammable material. In other words, the design must be suitable for the classification of the area in which it is installed.

Overall the design of equipment for the different “Zones” or “Divisions” is based on ensuring the probability of the simultaneous occurrence of a flammable gas (or vapor, mist or dust) concentration and an ignition source from equipment is so low that in practice it does not happen. It has been suggested in a number of industry papers that the probability of an ignition occurring once every hundred years is so low that in practice it will not happen. Probabilities at this level (approximately 1 in 1,000,000) are similar to those done for the catastrophic failure of piping or vessels.

2.3 IGNITION SOURCES—GASES & VAPORS

Ignition sources can occur by various mechanical means, but for the purpose of this publication we consider only electrical sources of potential ignition.

The most important characteristics of flammable substances in regard to ignition are:

- Upper Flammable Limit
- Lower Flammable Limit
- Flash Point of the flammable material
- Auto-Ignition Temperature
- Vapor Density

2.3.1 UPPER & LOWER FLAMMABLE LIMITS

There are a number of characteristics of gases and vapors that are important for the classification of a Hazardous Location and the application of equipment within the Hazardous Location.

- **LOWER EXPLOSIVE LIMIT (LEL)**—is the lowest percentage by volume of gas (or vapor) in a gas-air mixture that will form an ignitable concentration. Below that concentration there is insufficient gas or vapor in the mixture and the gas-air mixture is *too lean* to be ignited.

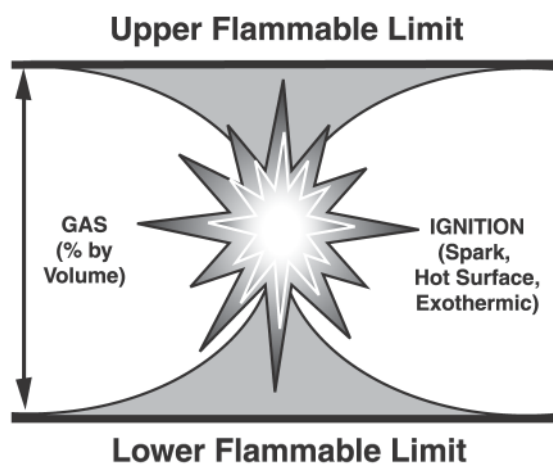
Class I Group	Substance	Flammable Limits Percent by Volume	
		Lower	Upper
C IIB	Acetaldehyde	4.0	60
D IIA	Acetic Acid	4.0	19.9 @ 200°F
D IIA	Acetic Anhydride	2.7	10.3
D IIA	Acetone	2.5	13
D IIA	Acetone Cyanohydrin	2.2	12.0
D IIA	Acetonitrile	3.0	16.0
A IIC	Acetylene	2.5	100

Complete table is contained in Appendix I.

- **UPPER EXPLOSIVE LIMIT (UEL)**—is the highest percentage by volume of gas or vapor in a gas-air mixture that will form an ignitable concentration. Above that concentration there is too much gas or vapor in the mixture and the gas-air mixture is *too rich* to ignite.

If the percentage of gas is below the lower limit, the mixture is too lean (insufficient fuel) to ignite. The mixture is too rich (insufficient oxygen) if the percentage is above the upper limit. Some gases, such as methane, are ignitable over a relatively narrow range of 5% to 15%. Methane is frequently used in the form of natural gas to provide a low-pressure gas blanket over liquid in a tank to ensure an ignitable mixture is not formed. The presence of the natural gas blanket ensures the mixture in the tank will always be above the UEL.

Other gases are ignitable over a relatively large range, such as acetylene (2.5 to 100%) and hydrogen, which is ignitable from 4% to 75%. As hydrogen is a very light gas, it is often used in large turbine generators to reduce the friction loss of the rotor. Because of the extremely large explosive range of hydrogen, great care must be taken to ensure concentrations within the generator do not enter the explosive range as the result of the introduction of air. Refer to Appendix I NFPA 325 M-1991, Fire Hazard Properties of Flammable Liquids, Gases & Volatile Solids, for the complete listing of gases and vapors.



The mixture of gas and air must be between the Upper and Lower Flammable Limits for a fire or explosion to occur.

Liquids that are stored or used below their flash points will normally not require the area in which they are stored to be classified as a Hazardous Location.

2.3.2 FLASH POINT OF THE FLAMMABLE MATERIALS

Flash point is the minimum temperature of a liquid at which sufficient vapor is given off to form an ignitable mixture with air, near the surface of a liquid. Liquids with a flash point below 37.8°C (100°F) are defined as flammable liquids, whereas liquids with a flash point above 37.8°C are defined as combustible liquids. Liquids which are stored or used below their flash points will normally not require the area in which they are located to be classified as a Hazardous Location. However liquids that are stored or processed under pressure, which may be released in the form of a mist, may be ignitable at temperatures below their flash points.

Flammable limits are normally given at 25°C; an increase in temperature widens the flammable limits.

As a general rule, 12°C below flash point results in a flammable vapor concentration of 50% of the lower flammable limit. See Appendix I, "Gases & Vapors – Hazardous Substances Used in Business & Industry."

Class I Group	Substance	Flash Point	
		°F	°C
C IIB	Acetaldehyde	-38	-39
D IIA	Acetic Acid	103	39
D IIA	Acetic Anhydride	120	49
D IIA	Acetone	-4	-20
D IIA	Acetone Cyanohydrin	165	74
D IIA	Acetonitrile	42	6
A IIC	Acetylene	gas	gas

Complete table is contained in Appendix I.

2.3.3 AUTO-IGNITION TEMPERATURE

The ignition temperature of a gas, sometimes referred to as "auto-ignition" temperature, is the lowest surface temperature which will ignite the flammable atmosphere (independent of any externally heated element). This becomes important when determining the temperature rating, or T-rating, of an enclosure or component. Published values of ignition temperature are determined by injecting a gas sample into a heated flask to determine the minimum temperature at which ignition takes place.

Class I Group	Substance	Auto-Ignition Temp.	
		°F	°C
C IIB	Acetaldehyde	347	75
D IIA	Acetic Acid	867	464
D IIA	Acetic Anhydride	600	316
D IIA	Acetone	869	465
D IIA	Acetone Cyanohydrin	1270	688
D IIA	Acetonitrile	975	524
A IIC	Acetylene	531	305

Complete table is contained in Appendix I.

Actual ignition temperatures are affected by many variables such as the percentage of gas or vapor in the mixture, the size and shape of the heated surfaces, wind and convection currents. The published ignition temperature values are usually accepted as being the minimum ignition temperatures. Further information regarding ignition temperatures can be found in the following documents:

- API Publication 2216—*Ignition Risk of Hydrocarbon Vapors by Hot Surfaces in the Open Air*
- NFPA 325-1994—*Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*
- NFPA 499-1997—*Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*

2.3.4 VAPOR DENSITY

The vapor density of a gas sometimes referred to as “relative vapor density,” is the weight of a volume of a vapor or gas with no air present compared to the weight of an equal volume of dry air at the same normal atmospheric temperature and pressure. Vapor densities greater than 1.0 indicate the vapor or gas is heavier than air and will tend to settle towards the ground. Vapor densities less than 1.0 indicate the vapor or gas is lighter than air and will tend to rise.

Class I Group	Substance	Vapor Density (Air Equals 1.0)
C IIB	Acetaldehyde	1.5
D IIA	Acetic Acid	2.1
D IIA	Acetic Anhydride	3.5
D IIA	Acetone	2.0
D IIA	Acetone Cyanohydrin	2.9
D IIA	Acetonitrile	1.4
A IIC	Acetylene	0.9

Complete table is contained in Appendix I.

When selecting hazardous area electrical apparatus, ensure that the gas grouping is appropriate to the area classification and that the temperature classification of the equipment is not higher than the auto ignition temperature of the surrounding gas or vapor.

Minimum Ignition Current (MIC) is determined in a laboratory and provides comparative values for the purposes of grouping only. Gases in the higher gas groups will ignite with lower currents, and as a result, intrinsically safe circuits for these groups will be restricted to lower currents than in the lower groups. For the IEC, gases and vapors are subdivided according to the ratio of their minimum igniting currents (MIC) to that of laboratory methane.

Most zone equipment is rated IIC for the most severe gas groups. The exception to this would be light fittings or other large electrical apparatus such as enclosures or motors where it is cost effective to design the apparatus with flat joints. These carry a IIB designation. Most North American equipment is rated for Groups C and D, which account for 85 to 90% of hazardous area applications. Enclosures which meet the higher explosive pressures of hydrogen are rated for Group B. It is rare to find areas or equipment classified as Group A except for intrinsically safe apparatus.

Zone 2 equipment does not always carry a Group marking. If the Zone 2 equipment does not produce sparks or arcs, such as terminal boxes, the equipment is suitable for all gas groups. The label on the product does not have to designate the gas group. However, in all cases, the T-number must be identified.

2.4 GAS GROUPING

Individual gases and vapors have distinct characteristics. One possible approach to equipment design would be to design equipment for each specific gas. That approach is not practical since it would greatly increase the cost of equipment and make the manufacturing process a virtual nightmare. In order to simplify the manufacturing and equipment selection processes, gases are divided into groups with similar characteristics based on two main factors:

- The requirements for constructing an “explosionproof” or “flameproof” enclosure to contain an explosion of the gas or vapor, and
- The minimum current (amperage) required to ignite the gas or vapor. This is the basis for gas grouping relative to intrinsically safe circuits.

The North American Division system groups gases into four Groups; A, B, C and D, where A is the most critical group. The IEC system groups the gases into only three Groups; A, B and C, with C as the most critical group

Explosionproof or flameproof enclosures are constructed to withstand an internal gas explosion without damage to the enclosure and to cool the hot gases produced by the explosion as they exit the enclosure along the flame paths. The gases in the most critical gas groups (i.e. Groups A, B or IIC) require longer **flame paths** to cool the gas and sometimes thicker walls to contain the increased pressure of the internal explosion. The main factor in grouping gases for the design of explosionproof enclosures is the **Maximum Experimental Safe Gap (MESG)**. MESG for a given gas is the maximum gap or opening (expressed in mm), for a 25 mm-wide flame path, which does not propagate an explosion of that gas.

2.4.1 NORTH AMERICAN VS IEC PRACTICES

The North American Division system groups gases into four groups while the IEC system groups the gases into only three groups. Table 2.4.1 shows a comparison of the two systems, a typical gas for each group and the MESG and MIC for each of the gases.

Table 2.4.1
Comparison of North American and IEC Gas Groupings

Typical Gas	MESG		MIC		Grouping	
	NA (mm)	IEC	(mm)	IEC*	NA	IEC
Acetylene	0.25	<0.5	60	>0.8	A	IIC
Hydrogen	0.28	<0.5	75	>0.8	B	IIC
Ethylene	0.65	0.5-0.9	108	0.45-0.8	C	IIB
Propane	0.97	>0.9	146	<0.45	D	IIA

* For the IEC gases and vapors are subdivided according to the ratio of their minimum igniting currents (MIC) to that of laboratory methane.

The IEC gas groupings are divided into **Group I** for mining and **Group II** for surface industrial applications. Equipment approved for use in Group IIC is also safe to use with Groups IIB and IIA gases. Equipment approved for use in Group IIB is also safe to use with Group IIA gases. Under the North American system of gas grouping, there is not an official hierarchy as in IEC. Equipment is marked only in accordance with gas groups for which it has been tested. For example, equipment tested with group B, C and D gases would be marked “B, C, D.”

Equipment tested only with group B gas would be marked "B" only. In practice however, the North American system is unofficially treated as if a hierarchy similar to IEC existed.

2.5 TEMPERATURE CLASSIFICATION

The selection of electrical equipment for use in hazardous areas must ensure that the maximum surface temperature of any part of the apparatus exposed to the potentially explosive atmosphere, does not exceed the auto ignition temperature (i.e., the temperature at which the substance when heated will ignite spontaneously).

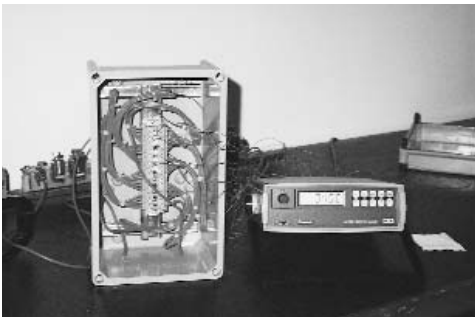
Temperature classifications according to the North American and IEC 79-0 standards are detailed in Table 2.5.

Table 2.5
T-numbers for North America and IEC

Temperature Classification	North America	Maximum Surface Temperature IEC
T1	450°C	450°C
T2	300°C	300°C
T2A	280°C	-
T2B	260°C	-
T2C	230°C	-
T3	200°C	200°C
T3A	180°C	-
T3B	165°C	-
T3C	160°C	-
T4	135°C	135°C
T4A	20°C	-
T5	100°C	100°C
T6	85°C	85°C

The reference ambient temperature of 40°C will be assumed unless otherwise stated on the apparatus labeling. Normal test requirements also assume that the tested equipment is suitable for lower ambient temperatures of minus 20°C.

The **T-Classification** allocated to Certified Electrical Apparatus is based on normal temperature at the most difficult operating conditions. For example, the most onerous condition for an increased safety, Ex-e, terminal box would be an enclosure fitted with the maximum permitted number of terminals with every terminal carrying its maximum rated current and maximum cable lengths connected to each terminal.



An example of the temperature test conducted on an Ex-e terminal enclosure.

Increased Safety Ex-e terminal boxes normally have T6 Temperature Classification, i.e. 85°C maximum surface temperature if routine tested, or 80°C if only type tested, at an ambient of 40°C. Apparatus with a T6 Classification has a very high degree of safety and can be used for all temperature classes. (The only listed gas in the temperature class T6 (85°C) is Carbon Disulfide.)

It is important to evaluate the maximum operating temperature of cables connected to electrical equipment, particularly if the cable is PVC insulated. They normally have a maximum operating temperature of 70°C. This is also in conformance with the IEC standard IEC 60079-0. To make full use of the maximum operating temperature of T6 classified equipment, cables with a 95°C rated insulation should be used.

The minimum concentrations of dust that will explode are normally two or three orders of magnitude above acceptable concentrations for workers.

2.6 IGNITION SOURCES—DUSTS

Some air suspended dusts will explode if ignited from a source with sufficient energy. Materials that can create dust explosions include:

- Natural organic materials (grain, linen, sugar)
- Synthetic organic materials (plastics, organic pigments, pesticides)
- Coal and peat
- Metals (aluminum, magnesium, iron, zinc)

2.6.1 MINIMUM EXPLOSIVE CONCENTRATION

For air suspended dust to explode it must be present in quantities at or above the **Minimum Explosive Concentration (MEC)**. The MEC of dust is defined as:

- The minimum concentration of dust in air that will explode when ignited, expressed in grams per cubic meter (g/m³) or in ounces per cubic foot.

Typically, the minimum concentrations of dust that will explode are normally two or three orders of magnitude above acceptable concentrations for workers and are normally present only inside process equipment such as coal pulverizers, enclosed conveyor transfer points, silos, grain elevators, etc. For example a glowing 25-watt incandescent bulb cannot be seen through a 2-meter dust cloud exceeding 40 g/m³, whereas the MEC for coal dust is in the range of 60 g/m³. While dust concentrations approaching these levels are not normally present in working areas, accumulations of dust, when disturbed, may result in temporary concentrations of dust above the MEC. The accumulation of layers of dust on heat-producing electrical equipment, such as motors, can prevent the release of heat from the equipment and may create temperatures hot enough to ignite the dust layer. The burning dust if disturbed can simultaneously create an ignitable dust cloud and an ignition source, resulting in a dust explosion. Thus, one of the best methods to avoid dust explosions is to enforce good housekeeping rules.



Good housekeeping measures of eliminating dust deposits are important in Class II locations.

Most sparks that occur from the operation of electrical equipment have sufficient energy to ignite most dust clouds.

2.6.2 MINIMUM IGNITION TEMPERATURE

The **Minimum Ignition Temperature (MIT)** for dust is defined as:

- The minimum temperature required, at normal atmospheric temperatures in the absence of spark or flame, to ignite a dust layer or a dust cloud.
- For most dusts the “layer ignition temperature” is significantly lower than the cloud ignition temperature. Tables providing the ignition temperatures for dust will typically provide the lower of the layer or cloud ignition temperatures. In the IEC Series there are definitions for minimum ignition temperature of dust clouds and dust layers.

Class II, Group F	Minimum Cloud or Layer Ignition Temp.	
	°F	°C
Asphalt, (Blown Petroleum Resin)	950	CI 510
Charcoal	356	180
Coal, Kentucky Bituminous	356	180
Coal, Pittsburgh Experimental	338	170
Coal, Wyoming	–	–
Gilsonite	932	500
Lignite, California	356	180
Pitch, Coal Tar	1310	NL 710
Pitch, Petroleum	1166	NL 630
Shale, Oil	–	–

See Appendix II “Dusts—Hazardous Substances Used in Business & Industry”

2.6.3 DUST EXPLOSIONS

Dust explosions are categorized as primary and secondary explosions. Primary explosions normally occur within equipment where a dust cloud is ignited by some ignition source. Secondary explosions are created by the dust entrained in the blast wave from the primary explosion. The heat from the primary explosion ignites the entrained dust, resulting in further explosions. Often multiple secondary explosions do more damage than the primary explosion.

The **Ignition Sensitivity** of dusts is a measure of the amount of energy required to ignite the dust. Many dusts are capable of being ignited by relatively low-energy sources, such as static electricity. As static electricity can be created by the relative motion of dust in enclosures, grounding and bonding of transport equipment is of critical importance where dust is transported.

The **Explosion Severity** of dusts (also referred to as explosion violence) is a measure of the maximum explosion pressure and the maximum rate of pressure rise and is equal to the maximum rate of pressure rise in a standard test volume. Dusts with high explosion severity include wheat grain, lignin, peat, milk powder, soybean, maize starch, rice starch, wheat starch, brown coal, charcoal, asphalt, cellulose, polyethylene, polyurethane, acetylsalicylic acid, dimethylaminophenazone, aluminum powder, magnesium, manganese, zinc, sulfur, fly ash, etc.

The **Minimum Ignition Energy (MIE)** of a dust cloud is a measure of the amount of spark energy to ignite it. In general most dust clouds require more energy to ignite than do gases and vapors, however most sparks that occur from the operation of electrical equipment have sufficient energy to ignite most dust clouds.

Other factors that influence the ease of ignition of dusts are:

- **Particle size**—Dust clouds composed of smaller particles will ignite more easily than dust clouds with larger particles.
- **Moisture content**—Increasing levels of moisture in dust will increase the ignition temperature of the dust.
- **Makeup of the dust cloud**—Dusts which are not combustible, such as rock dust, can change the ignitable makeup of a dust cloud. This principle is often used in coal mines where noncombustible dust is spread over the coal dust to prevent the occurrence of dust explosions.

For questions or comments, please contact the author at paul.babiarz@crouse-hinds.com