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Günter Lüttgens, Sylvia Lüttgens,
and Wolfgang Schubert

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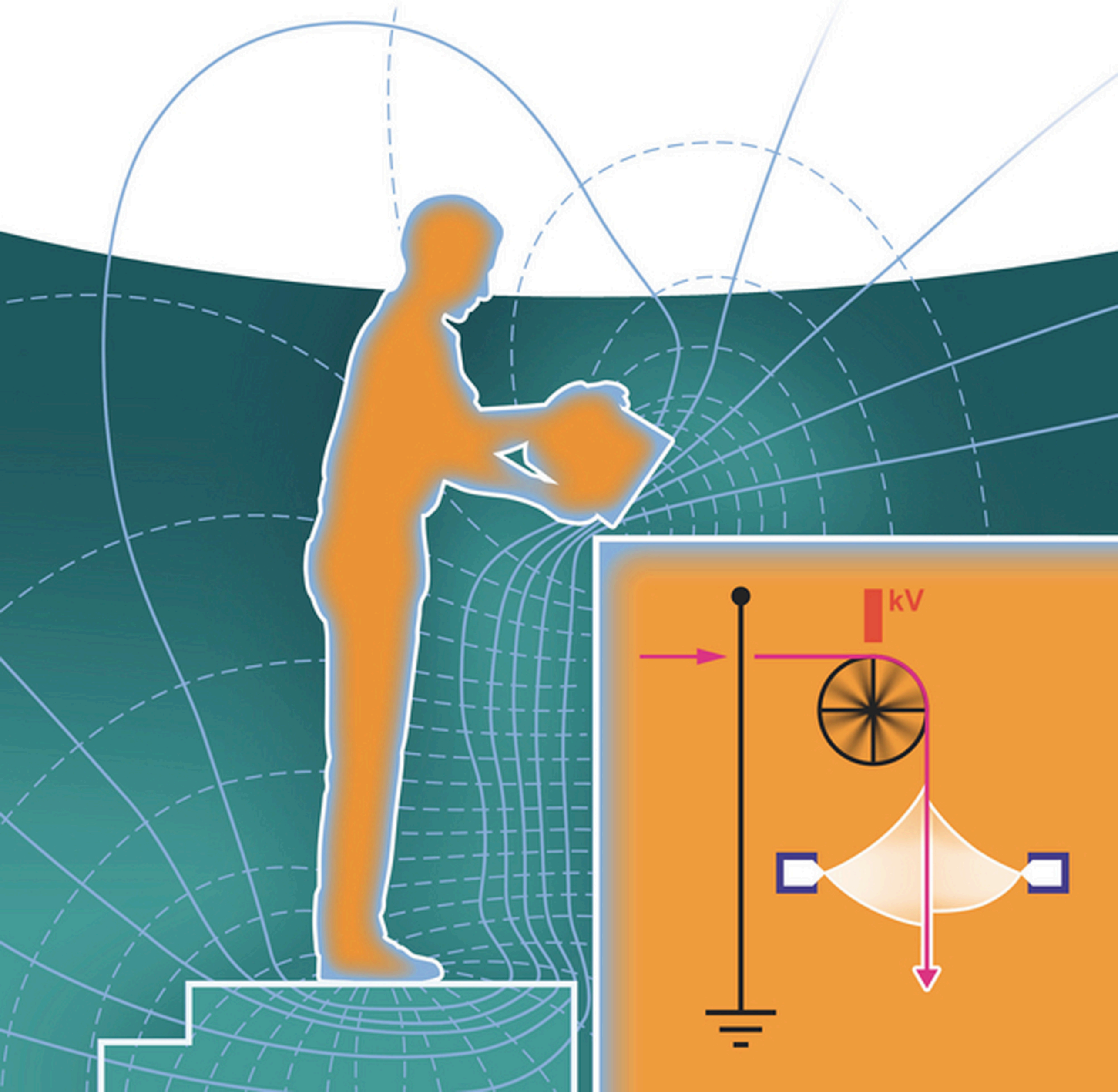
Understanding, Controlling, Applying



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About the Authors

Günter Lüttgens was born in Berlin, 1933, and holds a master's degree in electrical engineering. Since graduation he mainly worked in the chemical industry in the field of electrostatics. He was primarily responsible for laboratory research, as well as plant safety, in the area of fire and explosion prevention. In 1998, he was nominated by IEC as an expert for electrostatic test methods. For more than 25 years he gave lectures on static electrification and safety measures together with his wife Sylvia. He published several articles and specialist books. In 2013, he received the International Fellow Award by the European Working Party (EFCE) as a researcher and teacher in the field of "Static Electricity in Industry."

Sylvia Lüttgens was born in Geroda, 1946, was graduated a teacher, and tried to direct the interest of her students to Music and English. Then she learned about static electrification and that it could be the cause for many a fire or an explosion. So she has been working together with her husband Günter, carrying out experimental lectures (up to 2015) in seminars about electrostatics, giving practical proof of the theory. Besides, she is publishing articles and writing specialist books on this topic.

They actually compiled the first encyclopedia on static electricity 15 years ago, and the third edition was published in 2013.

Wolfgang Schubert was born in 1952. He studied print technology in Leipzig and is a trained printer. He became self-employed in 1997 having previously worked in various managerial roles in the print industry and in sales and marketing for manufacturers of roll- and sheet-fed printing presses. Since then he has also been working in the specialized field of electrostatics, in sales and marketing and also in further education. He has coauthored the specialist publication *Static Electricity.*

In May 2016, he was publicly appointed and inaugurated by the Leipzig Chamber of Commerce and Industry (IHK) as an expert in the fields of printing processes, printing presses, printability, runnability, and packaging printing. He also works as an expert in the field of electrostatics.

Opening Remark

Minds of Felix – our faithful companion

May I introduce myself; I am Felix the electrostatics specialist dog (see Figure 6.1 in Section 6). When my humans are carrying out seminars, I silently lie under the tables with the experimental devices until Sylvia prepares the one in which a plastic tumbler is flung into the air by an explosion in an explosion tube (see Section 6.11.1). Then, I run for the tumbler and noisily chew it apart, which makes the audience laugh.

When my humans Sylvia and Günter are working at the computer, I often lie on the sofa watching them. When I have had enough of it, I fetch my teddy and place it in front of them. Then, they throw it somewhere, and I have to find it. This happens several times but then I take my teddy and jump back onto the sofa again. My humans think I am doing this because I am bored, but this is not true! I feel sorry for them that they have to sit in front of the computer with lots of paper, clattering the keys, writing this specialist book. So I have to offer them some variety. I know what this is all about, and I am definitely responsible for my pack.

Felix

Preliminary Remarks

In this specialist book, Videos and PowerPoint Presentations are referred to.

The Videos are indicated with "V" and listed at the end of the relevant chapters and may be downloaded from www.wiley-vch.de/xxx.

For better comprehension, at different places animated PowerPoint Presentations are referred to with the symbol (💻). The letter T stands for theory and P for practice.

These presentations may be requested from the authors:
G. & S. Lüttgens: elektrostatik@elstatik.de
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Preface

It gives me a great pleasure to preface this excellent reference book for engineers and technicians. Sylvia Lüttgens, Günter Lüttgens and Wolfgang Schubert are well known for their very didactic manuals, excellent presentations and so well prepared demonstrations such way that rather complicate phenomena seem simple.

This reference book on Electrostatic Hazards for engineers and technicians is, in my knowledge, the first one with very clear explanations, describing step by step the phenomenon with very didactic concepts and perfect pedagogic demonstrations.

Electrostatic Hazard is a very worrying problem in a lot of industrial processes, using liquids, granular material, powders, or foils etc. It concerns a wide range of industries: Chemical, Petroleum, Pharmaceutical industry, as well as the agricultural sector and electric power plants.

Indeed, in recent decades many industrial processes increasingly use electrically insulating materials. These materials such as polymers have emerged with the petroleum products industry and have played a growing importance in industry because of their lower costs like metals and their easier processing, manufacturing and use. This has partly led to the fact that these materials and products brought about electrostatic hazards and nuisances and have become an important concern. When speaking about electrostatics, everyone has in mind the spark which we sometimes feel by touching the door of a car after being parked; or small pieces of paper attracted to a plastic wall that has been rubbed before. In fact, electrostatic charging in general is the study of electrical phenomena when the charges are not moving ("static"). However, at present, the so-called electrostatic phenomena are those involving electrification processes whereby often charge accumulation due to the use of insulating materials and product takes place.

The electrostatic hazards are sources of dangers of electric discharges due to electrostatic phenomena. Under certain conditions, these discharges lead to ignitions causing fire or explosions. Electrostatic nuisances cause degradation of an industrial process due to electrostatic effects. Precondition for this is that the generated charge will be accumulated.

Charge generation is, in principle, related to contact of material and separation thereafter as, e.g., friction, flow, transfer of solids, or liquids. The accumulation is the result of the storage or collection of such products or liquids in unearthed containers.

Unfortunately electrostatic hazards may result in fatal accidents, injuries, often serious, especially burns, property damage, often important or significant in that case, for example, of fire extension to nearby facilities.

This reference book has a very logical and scientific methodology, making these interrelations very clear and useful for engineers and technicians. Indeed, it starts with the situations with the Risk Assessment, explaining precisely when and where such risks come into being. Then the basics of Static Electricity are presented, developing all the concepts and equations which are needed to understand the different phenomena. In another chapter the metrology, needed to understand the different situations, is presented. The processes of the different gas discharges are then exposed as well as different methods to prevent electrostatic disturbances. One important subject of the book is the presentation of very didactic descriptions of demonstration experiments and of case studies.

It would fall short of that goal to hold static electricity accountable only for dangers and nuisances, however, electrostatic mechanisms are used in many applications where one would not expect them as there are: photocopying techniques, car body lacquering etc. Widely used is static electricity in improvements of many different scopes of application like wetting, drying, printing etc. Therefore one chapter is dedicated especially to that task to motivate the curious reader to improve other technologies with the help of static electricity.

Finally a very useful mathematic toolbox is given at the end of the book, making an easy understanding of all equations needed to comprehend the different processes.

Each chapter provides a complete bibliography of what was stated.

And in the good end, I have spent a pleasant time to read this very educational and didactic reference book that I strongly recommend to any engineer and technician who wants to learn on Electrostatics.

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Poitiers, France
October 2016

1

Basics of Fire and Explosion: Risk Assessment

If static electricity was really static, as one may assume by its name, then it could be ignored. Only when it becomes more dynamic does it appear to be interesting and extend in our awareness from harmless electric shocks, sometimes felt when leaving a car, to the possibly fatal lightning strokes of a thunderstorm (for the latter, there is detailed information given in www.lightningsafety.noaa.gov).

However, our intention in this book is to demonstrate that the obviously weak electrostatic discharges are more or less capable of igniting combustible materials, thus causing hostile fire and casualties. It is probably because of its unpredictability that static electricity is often incorrectly blamed as a cause of fire and explosion when no other plausible explanation is at hand. So it seems logical to start with basics on fire and explosion.

1.1 Basic Considerations on Fire and Explosion (💻T1)

In which way do fire and explosion differ from one another?

Common to both is the manifestation of a flame, which always indicates a fast combustion of fuel/air mixtures in the gaseous phase. The chemical reaction, depending on the combustion heat of the fuel, leads to an increase in temperature.

Fire is characterized mainly by a stationary burning flame in an open atmosphere, for example, a lighted candle. Therefore the reaction heat spreads into the surroundings without increase in pressure.

However, when an ignition occurs in a combustible atmosphere within an enclosed space, for example, a drum, a flame front runs through the entire space, starting from the ignition source. Under atmospheric conditions, the flame front extends at a speed of 10 m/s. Therefore the heating effect of the flame causes a pressure increase of about 10 bars, which diminishes during subsequent cooling. It is decisive that this short time pressure increase may cause a devastating damage called explosion.

The exothermic reaction of fuel in air occurs between the tiniest particles, that is, the molecules of fuel and oxygen. This is the case when prevailing fuel gas forms the required gaseous phase. With flammable liquids, this molecular fuel/oxygen

Static Electricity: Understanding, Controlling, Applying, First Edition.
Günter Lüttgens, Sylvia Lüttgens, and Wolfgang Schubert.

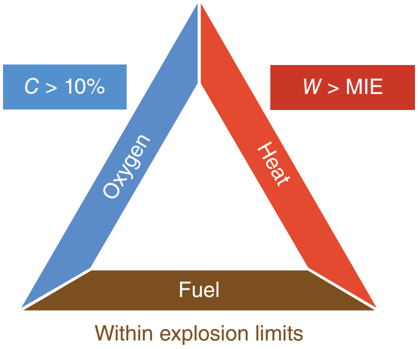


Figure 1.1 Danger triangle.

mixture can easily be achieved by vaporization of the liquid. However, for solid fuels (dusts, but not metal dusts), it is necessary to break their chemical bonds so that hydrocarbon molecules are set free to react with oxygen. Therefore a considerable part of the ignition energy is used for melting, vaporizing, or cracking the dust particles to gaseous hydrocarbons. This is the reason why much more energy is always needed to ignite flammable dusts than is necessary to ignite flammable gases and vapors.

On the contrary, at metal dusts an oxidization at the particle surface takes place, which is exothermic as well.

Basically a fire or an explosion will occur when the following components coincide with time and volume, which is known as the “danger triangle” (see Figure 1.1):

- Fuel
- Oxygen
- Ignition source (heat)

This danger triangle is used worldwide mainly to show that three components are required to cause a fire, and if one of them is missing, combustion will not occur. Looking more into details, it is necessary to meet the additional conditions for each component.

1.1.1 Fuel

In this context fuel stands for the material that causes an explosive atmosphere. Although it is necessary to distinguish between gaseous, liquid, and solid fuels, a common feature between them is that combustion is sustained only within a certain explosion range, which is determined by the lower and upper explosion limits. For flammable liquids, the lower explosion limit is characterized by the so-called flash point (see Figure 1.2). Between the lower and the upper explosion limits, an explosive atmosphere always prevails.

1.1.2 Heat

In this context heat stands for the thermal energy needed to start an ignition, also called an ignition source (see Figure 1.4).

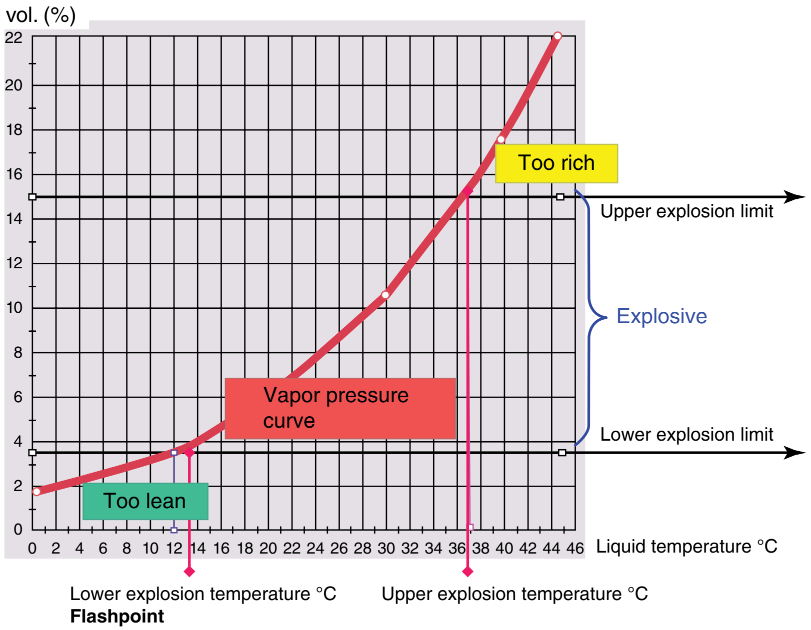


Figure 1.2 Vapor pressure/temperature curve of ethanol.

1.1.3 Oxygen

For all fuels, a minimum oxygen concentration (MOC) in air is necessary below which combustion cannot occur.

1.1.4 Inerting Process

It is worth mentioning the "MOC," which is defined as the threshold of oxygen concentration below which combustion is impossible. It is expressed in units of volume percent of oxygen and is independent of the concentration of fuel (see Table 1.1). But it is to be noted that the MOC varies with pressure and temperature and is also dependent on the type of inert gas.

1.1.5 Heat versus Oxygen

It has to be pointed out that there is an interrelation between the oxygen concentration and the energy of the ignition source: the higher the oxygen concentration, the lower the need for ignition energy and vice versa.

1.2 Explosive Atmosphere

1.2.1 Explosion Limits with Flammable Liquids

In preventing fire and explosion in general, explosion limits are important. This can be explained by a simple experiment in which some lamp kerosene is poured

Table 1.1 Threshold of oxygen concentration for some gases and dusts with two kinds of inert gases (volume percent oxygen).

Gas or dust	Nitrogen/air	Carbon dioxide/air
Ethane	11	14
Hydrogen	5	5
Isobutane	12	15
Methane	12	15
n-Butane	12	15
Propane	12	15
PE-HD	16	—
PE-LD	16	—
Paper	14	—
PMMA	16	—
PP	16	—
PVC	17	—

into a small coquille: when a lighted match is dipped into the liquid, it becomes extinguished. Obviously lamp kerosene is fuel!

However, when this experiment is repeated after the lamp kerosene is heated up to 45 °C, the lighted match causes an ignition, and the liquid continues to burn at its surface.

The explanation for the behavior of the lamp kerosene in the aforementioned experiment has to do with the vapor pressure of the liquid. Depending on the temperature of the liquid, a certain vapor pressure, and hence vapor concentration, is developed above the surface of the liquid. Figure 1.2 shows the vapor pressure temperature curve for ethanol and the relation between the vapor concentration at the surface of the liquid and its temperature. As ethanol is indicated by a flash point of 12°C the above mentioned experiment would lead to a flame already at room temperature.

By using the curve, temperatures can be assigned to the lower and upper explosion limits of a liquid. The temperature related to the lower explosion limit is called the flash point (°C) and is a simple and reliable way of defining the danger of flammable liquids in view of their ease of ignition. Liquids at a temperature lower than their flash point cannot be ignited. Therefore, the flash point ranks as the most important data when using flammable liquids and is listed in safety data sheets, for instance, indicating that they will not burn at room temperature.

In the example for ethanol, the explosion danger exists only within the explosion range, which is limited by the lower explosion temperature (12 °C) and the upper one (37 °C). After ignition, the flame spreads through the entire volume without any further fuel or air access. Also, it has to be taken into consideration that ignition is not possible above the upper explosion temperature. The fuel/air mixture is, so to speak, too rich, because of a lack of oxygen. This effect is used, for example, in gasoline tanks for cars. They will never explode but may burn down when there is a leakage (access to air).

Below the lower explosion limit, the average distance between fuel molecules to each other in air is too large; hence, by means of radiation from the ignition source, no sufficient energy can be transferred to continue the ignition (the decrease of energy by radiation follows the square of the distance). Above the upper explosion limit, the concentration of fuel molecules is so high that there is no enough oxygen between them for a reaction to take place.

In this context, it has to be stated that all vapors of flammable liquids show a higher density than air; thus they will always accumulate at the bottom of a vessel.

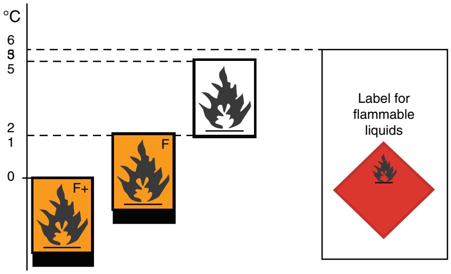
1.2.1.1 Classification of Flammable Liquids

Until 2009 the classification for flammable liquids depicted in Figure 1.3 was valid.

In 2009 flammable liquids were classified as hazardous substances and so have been covered in the United Nations Globally Harmonized System (GHS) of Classification and Labelling of Chemicals (UN 2013) [1].

The aim of the GHS is to have the same criteria worldwide for classifying chemicals according to environmental and physical hazards (see Table 1.2).

Now flammable liquids (see Table 1.3) are being classified according to their flash point (TF) and initial boiling point (TIBP).



- Flammable: TF < 55 °C and > 21 °C
- Highly flammable: TF < 21 °C [F]
- Extremely flammable: TF < 0 °C [F+] and TIBP < 35 °C

Figure 1.3 System of flammable liquids (up to 2009).

Table 1.2 Criteria for flammable liquids.

Category	Criteria
1	Flash point < 23 °C and initial boiling point ≤ 35 °C
2	Flash point < 23 °C and initial boiling point > 35 °C
3	Flash point > 23 °C and ≤ 60 °C
4	Flash point > 60 °C and ≤ 93 °C

Table 1.3 Flammable liquids, classification, and labeling.

Hazard category	Pictogram	Signal word	Hazard statement	Hazard statement codes
1		Danger	Extremely flammable liquid and vapor	H224
2		Danger	Highly flammable liquid and vapor	H225
3		Warning	Flammable liquid and vapor	H226
4	No pictogram	Warning	Combustible liquid	H227

Note: Aerosols should not be classified as flammable liquids.

1.2.2 Explosion Limits with Combustible Dusts

In contrast to gases and vapors, mixtures of solid fuels (combustible dusts) and air are inhomogeneous because of the effect of gravity on particles; for example, with dusts in air, the particle distribution is not constant with reference to time and space. In terms of safety, the explosion limits for dust/air mixtures are not as critical as those for vapor/air and gaseous/air mixtures.

For most combustible organic dusts, the lower explosion limit ranges between 20 and 50 g/m^3. However, there are a few very sensitive dusts with a lower explosion limit down to 10 g/m^3. For instance, a few millimeters of combustible dust settled on the floor may present an explosion hazard in the entire room when swirled up by a draft of air. To determine an upper explosion limit is difficult as it ranges in concentrations of 1 kg/m^3 and above.

1.2.3 Metal Dusts

Finely dispersed airborne metallic dust can also be explosive in so far as the metal itself tends to oxidize.

In contrast to the aforementioned organic dusts, transfer into the gaseous phase is not necessary to ignite metal dusts because they react exothermally directly at their surfaces with the oxygen in air.

1.3 Hybrid Mixtures (💻 P7)

An increased ignition danger always exists when powder products are combined with combustible gases or vapors because the ignition energy of the latter is lower on most occasions. Furthermore it has to be taken into consideration that hybrid mixtures are already combustible when the concentration of the dust as well as that of the gas is lower than their respective explosion limits. The needed energy to ignite hybrid mixtures is always lower than that of the pure dust cloud. Hybrid mixtures are to be expected, for example, when the powder is wet with flammable solvents.

1.4 Allocation of Explosion-Endangered Areas and Permissible Equipment (💻 P6)

In the ATEX 137 "Workplace Directive," the minimum requirements for improving the safety of workers potentially at risk from explosive atmospheres are laid down.

The plant management must divide areas where hazardous explosive atmospheres may occur into "zones." The classification given to a particular zone and its size and location depends on the likelihood of an explosive atmosphere occurring and its persistence if it does.

An explosive atmosphere can be divided into zones according to IEC 60079-10-1 and 60079-10-2 [2]:

Zone 0: Area in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapor, or mist is present continuously or for long periods or frequently

Zone 1: Area in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapor, or mist is likely to occur in normal operation occasionally

Zone 2: Area in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapor, or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only

Zone 20: Area in which an explosive atmosphere in the form of a cloud of combustible dust in air is present continuously or for long periods or frequently for short periods

Note: Areas where piles of dust are present but where dust clouds are not present continuously, or for a long period, or frequently are not included in this zone.

Zone 21: Area in which an explosive atmosphere in the form of a cloud of combustible dust in air is likely to occur occasionally in normal operation

Zone 22: Area in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but if it does occur will persist for a short period only

1.5 Permissible Equipment (Equipment Protection Level)

An equipment category indicates the level of protection provided by the equipment to be used according to zones (💻 T6).

Here, areas in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapor, or mist prevails are indicated with the letter G (gas). Correspondingly, areas in which an explosive atmosphere in the form of a cloud of combustible dust in air exists are indicated with the letter D (dust).

1.5.1 Classification of Equipment Protection Level That Is Currently in the Introductory Stage

As already discussed, explosive atmospheres are divided into zones based on the probability that such an atmosphere will occur. But experience has shown that in some situations, a risk assessment would give the plant operator more flexibility. On this account and to facilitate a dependable risk assessment approach to make equipment selection easier, "equipment protection levels" (EPLs) have been introduced. EPLs identify and characterize all equipments according to the ignition risk they might produce.

According to IEC60079-0:2011 [3], equipment for use in explosive atmospheres is classified into the following EPLs (with distinguishing signs such as M for mining, G for gases, and D for dusts).

EPL Ma: Equipment for installation in a mine susceptible to firedamp, having a "very high" level of protection, which has sufficient security that it is unlikely to become an ignition source in normal operation, during expected malfunctions, or during rare malfunctions, even when left energized in the presence of an outbreak of gas

EPL Mb: Equipment for installation in a mine susceptible to firedamp, having a "high" level of protection, which has sufficient security that it is unlikely to become a source of ignition in normal operation or during expected malfunctions in the time span between there being an outbreak of gas and the equipment being de-energized

EPL Ga: Equipment for explosive gas atmospheres, having a "very high" level of protection, which is not a source of ignition in normal operation, during expected malfunctions, or during rare malfunctions

EPL Gb: Equipment for explosive gas atmospheres, having a "high" level of protection, which is not a source of ignition in normal operation or during expected malfunctions

EPL Gc: Equipment for explosive gas atmospheres, having an "enhanced" level of protection, which is not a source of ignition in normal operation and which may have some additional protection to ensure that it remains inactive as an ignition source in the case of regular expected occurrences

EPL Da: Equipment for explosive dust atmospheres, having a "very high" level of protection, which is not a source of ignition in normal operation, during expected malfunctions, or during rare malfunctions

EPL Db: Equipment for explosive dust atmospheres, having a "high" level of protection, which is not a source of ignition in normal operation or during expected malfunctions

EPL Dc: Equipment for explosive dust atmospheres, having an "enhanced" level of protection, which is not a source of ignition in normal operation and which may have some additional protection to ensure that it remains inactive as an ignition source in the case of regular expected occurrences