Static Electricity in Industry: Preventing Explosions of Dusts and Volatile Fluids

An Online Continuing Education Course for Engineers

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Introduction

Static electricity is an imbalance of electric charges within or on the surface of a material. The charge remains until it is able to move away by means of an electric current or electrical discharge. Static electricity is named in contrast with current electricity, which flows through wires or other conductors and transmits energy.

A static electric charge is created whenever two surfaces contact and separate, and at least one of the surfaces has a high resistance to electrical current (and is therefore an electrical insulator). The effects of static electricity are familiar to most people because people can feel, hear, and even see the spark as the excess charge is neutralized when brought close to a large electrical conductor (for example, a path to ground), or a region with an excess charge of the opposite polarity (positive or negative). The familiar phenomenon of a static shock–more specifically, an electrostatic discharge–is caused by the neutralization of charge.

Causes of static electricity

Materials are made of atoms that are normally electrically neutral because they contain equal numbers of positive charges (protons in their nuclei) and negative charges (electrons in "shells" surrounding the nucleus). The phenomenon of static electricity requires a separation of positive and negative charges. When two materials are in contact, electrons may move from one material to the other, which leaves an excess of positive charge on one material, and an equal negative charge on the other. When the materials are separated they retain this charge imbalance.

Contact-induced charge separation

Electrons can be exchanged between materials on contact; materials with weakly bound electrons tend to lose them while materials with sparsely filled outer shells tend to gain them. This is known as the triboelectric effect and results in one material becoming positively charged and the other negatively charged. The polarity and strength of the charge on a material once they are separated depends on their relative positions in the triboelectric series. The triboelectric effect is the main cause of static electricity as observed in everyday life, and in common high-school science demonstrations involving rubbing different materials together (e.g., fur against an acrylic rod). Contact-induced charge separation causes your hair to stand up and causes "static cling" (for example, a balloon rubbed against the hair becomes negatively charged; when near a wall, the charged balloon is attracted to positively charged particles in the wall, and can "cling" to it, appearing to be suspended against gravity).

Pressure-induced charge separation

The piezoelectric effect is the generation of an electric charge in certain nonconducting materials, such as quartz crystals and ceramics, when they are subjected to mechanical stress, such as pressure or vibration. (The piezoelectric effect also refers to the generation of vibrations in such materials when they are subjected to an electric field. Piezoelectric materials that are exposed to a fairly constant electric field tend to vibrate at a precise frequency with very little variation, making them useful as time-keeping devices in electronic clocks that are used in wristwatches and computers).

Heat-induced charge separation

Heating generates a separation of charge in the atoms or molecules of certain materials. Pyroelectricity is the ability of certain materials to generate a temporary voltage when they are heated or cooled. The change in temperature modifies the positions of the atoms slightly within the crystal structure, such that the polarization of the material changes. This polarization change gives rise to a voltage across the crystal. Note that all pyroelectric materials are also piezoelectric. The atomic or molecular properties of heat and pressure response are closely related.

Charge-induced charge separation

A charged object brought close to an electrically neutral object causes a separation of charge within the neutral object. Charges of the same polarity are repelled and charges of the opposite polarity are attracted. As the force due to the interaction of electric charges falls off rapidly with increasing distance, the effect of the closer (opposite polarity) charges is greater and the two objects feel a force of attraction. The effect is most pronounced when the neutral object is an electrical conductor as the charges are more free to move around. Careful grounding of part of an object with a charge-induced charge separation can permanently add or remove electrons, leaving the object with a global, permanent charge. This process is integral to the workings of the Van de Graaff generator, a device commonly used to demonstrate the effects of static electricity.

Energies Involved

The energy released in a static electricity discharge may vary over a wide range. The energy in joules can be calculated from the capacitance (*C*) of the object and the static potential *V* in volts (V) by the formula $E = ½CV^2$. One experimenter estimates the capacitance of the human body as high as 400 picofarads, and a charge of 50,000 volts, discharged during touching a charged car, creating a spark with energy of 500 millijoules. Another estimate is 100 to 300 pF and 20,000 volts, producing a maximum energy of 60 mJ. IEC 479-2:1987 states that a discharge with energy greater than 5000 mJ is a direct serious risk to human health. IEC 60065 states that consumer products cannot discharge more than 350 mJ into a person.

The maximum potential is limited to about 35–40 kV, due to corona discharge dissipating the charge at higher potentials. Potentials below 3000 volts are not typically detectable by humans. Maximum potential commonly achieved on the human body range between 1 and 10 kV, though in optimal conditions as high as 20–25 kV can be reached. Low relative humidity increases the charge buildup; walking 20 feet (6.1 m) on vinyl floor at 15% relative humidity causes buildup of voltage up to 12 kilovolts, while at 80% humidity the voltage is only 1.5 kV.

As little as 0.2 millijoules may present an ignition hazard; such low spark energy is often below the threshold of human visual and auditory perception.

Typical ignition energies are:

- 0.017 mJ for hydrogen
- 0.2-2 mJ for hydrocarbon vapors
- 1–50 mJ for fine flammable dust
- 40–1000 mJ for coarse flammable dust.

The energy needed to damage most electronic devices is between 2 and 1000 nanojoules.

A relatively small energy, often as little as 0.2–2 millijoules, is needed to ignite a flammable mixture of a fuel and air. For the common industrial hydrocarbon gases and solvents, the minimum ignition energy required for ignition of vapor-air mixture is lowest for the vapor concentration roughly in the middle between the lower explosive limit and the upper explosive limit, and rapidly increases as the concentration deviates from this optimum to either side.

Aerosols of flammable liquids may be ignited well below their flash point. Generally, liquid aerosols with particle sizes below 10 micrometers behave like vapors, particle sizes above 40 micrometers behave more like flammable dusts. Typical minimum flammable concentrations of aerosols lay between 15 and 50 g/m^3. Similarly, presence of foam on the surface of a flammable liquid significantly increases ignitability. Aerosol of flammable dust can be ignited as well, resulting in a dust explosion; the lower explosive limit usually lies between 50 and 1000 g/m^3; finer dusts tend to be more explosive and require less spark energy to set off.

Simultaneous presence of flammable vapors and flammable dust can significantly decrease the ignition energy; a mere 1 vol.% of propane in air can reduce the required ignition energy of dust by 100 times. Higher than normal oxygen content in the atmosphere also significantly lowers the ignition energy.

Types of Electrostatic Discharge

There are four common types of electrostatic discharge (ESD) that need be considered from the point of view of ignition hazard. These are sparks, brush discharge, propagating brush discharge and cone discharge. (Corona discharges may occur but are considered non- hazardous and are therefore not discussed here).

Sparks

Spark discharges are responsible for the majority of industrial fires and explosions caused by static electricity. Spark discharges will occur from conductive objects, surfaces and personnel, which are ungrounded and have become charged to an electrostatic potential. The energy (E) in a spark is expressed in Joules or more commonly millijoules (mJ) and can be calculated from the formula E=VCV2 where C is the capacitance of the object and V is its potential. With the correct equipment both C and V can be measured and E can be calculated.

Flammable hydrocarbon vapors are extremely sensitive to spark ignition. A number of hydrocarbons have minimum ignition energies of 0.2 millijoules. A spark of this energy is often below human perception in terms of sight and sound.

In a plant, sources of spark energy will comprise ungrounded metal fixtures and fittings. They may also include personnel if their footwear and flooring are insulating, mobile and non-fixed items such as trolleys, metal drums, ancillary equipment, gauging equipment and hand tools. Once identified, this hazard can usually be simply remedied by providing a permanent conduction path to ground.

Brush Discharges

Electrostatic brush discharges occur from charged non-conductive surfaces such as plastics and may even occur from highly charged non- conductive liquids such as hydrocarbon solvents and fuels. The incendivity (igniting power) of a brush discharge depends on a number of factors but energy content is limited to a theoretical maximum of 4 millijoules. Furthermore, since the theoretical limit of 4mJ applies to brush discharges they only represent an ignition hazard with flammable gases and solvents over part of their flammable range.

Generally for brush discharges to present an ignition hazard, the following conditions must apply:

- the charged surface has a potential of 20kV or greater
- the polarity of charge on the surface is negative
- a flammable atmosphere exists at the point of discharge
- the energy content of the brush is greater than the minimum ignition energy of the flammable atmosphere.

The energy content of the brush will be dependent not only on the surface potential but also on the area of surface contributing to the discharge. Normally, since there is a maximum charge density that can be established on any surface, an area in excess of 100 cm^2 is required to produce an ESD with sufficient energy to ignite a flammable hydrocarbon vapor (with some exceptions). It is doubtful that brush discharges can ignite flammable dusts and no such incidents have been observed.

Important differences exist between brush discharges and sparks. The first is that since only part of a charged insulator contributes to the brush it is possible to obtain many discharges from a single large charged surface. Secondly, because of the low mobility of charge carriers, in an insulator, it is impossible to remove the charge by simply connecting to ground. The discharges themselves also vary significantly in the way the energy is released with brushes producing lower currents and consequently lower temperatures.

Propagating Brush Discharges

Propagating brush discharges (PBD's) can occur when an insulati… material of up to around 8mm thickness has become highly polarised wit… e, i.e. positive charge on one face and negative charge on th… occur where large areas of insulating sheets ar… eneration (note that both of these conditions are … sheets are in the form of a lining or layer, with … ation is a Teflon or glass-lined reactor vessel.

A photograph of a pr… this case the discharge has occurred during … al ignition of the fuel can be observed. This typ… us.

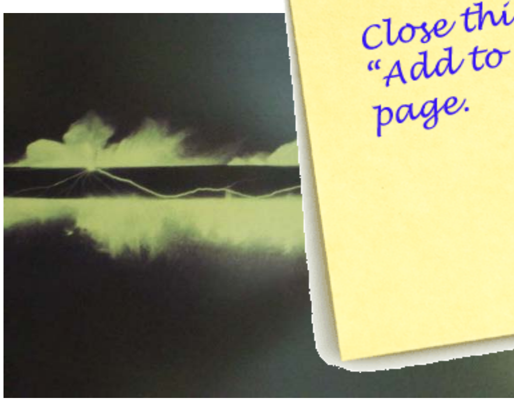

***Figure 1.** Propagating brush discharge from a plastic pipe conveying diesel fuel (photo courtesy J. F. Hughes, University of Southampton)*

Cone discharge

Cone discharges are sometimes referred to as 'bulking brush discharges' and occur across the surface of bulked powder in storage silos, containers and hoppers. They can also occur deep within the powder heap. Conditions for cone discharges are a charged powder of resistivity exceeding 10 ohms. In grounded metal silos the discharges travel radially towards the silo wall across the surface of the powder cone during filling and may have an effective energy of up to 20mJ.