Plastics Topics – Static electricity and plastics

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1. Introduction

Most people are familiar with the effects of ‘static electricity’ and plastics through such simple demonstrations as a plastic comb being used to pick up small pieces of paper or of rabbit fur being attracted to an acrylic rod. Despite this, there are a number of fundamental misconceptions about static electricity (starting with the name) and many people are not familiar with the problems that it can create in the use of plastic products.

One of the first and largest misconceptions about static electricity is in the name. Static electricity is no more ‘static’ than conventional electricity and in both cases, electrons move and are responsible for charges. What is being created in the case of so-called ‘static’ electricity is a charge imbalance due to the movement of electrons and if it involves movement of electrons then how can it be static? This charge imbalance is as free to move as ‘conventional’ electrical current - all electrical phenomena are due to movement of electrons and it is not logical to divide this up into static and conventional electricity any way.

It is often said that static electricity is caused by friction but this is also not true, static electricity is caused by contact between materials (which may or may not involve friction) and electron transfer between materials so that there is a charge imbalance on both of the materials. High levels of friction will increase electron transfer and increase charge imbalance but friction is not the root cause of the charge imbalance – charge imbalance can occur by simple contact of two materials.

Despite these common misconceptions, ‘static electricity’ is not simply a laboratory curiosity nor is it always a bad thing. As with many other phenomena it is only uncontrolled static electricity that is bad and controlled static electricity is a vital tool for many industrial processes such as:

- Electrostatic precipitation is a key method for removing particles from exhaust gases of power stations, steel mills and chemical factories. Electrostatics is one of the key techniques for pollution control and the removal of smoke or dust particles from exhausts.
- If you print this document using a laser printer or an ink-jet printer then the quality of the print will depend on finely controlled application of electrostatics. Equally if you copy this document with a photocopier then you will use another application of electrostatics.
- If you use coated and painted steel or aluminium then electrostatics will probably have been used in the powder coating or electrostatic painting process.

The use of electrostatics is almost endless and it is one of the most important and yet under acknowledged technologies in use today – silent, controllable and cost effective. Equally, when uncontrolled the discharge of electrostatic charge imbalances can be both dangerous and cause many problems in industry such as explosions in grain elevators, utility tunnels and chemicals tanks.

Charge imbalances are not a simple laboratory curiosity.

2. Charge imbalances and static electricity

Understanding charge imbalances is quite easy. All matter is composed of atoms, whether the atoms are included in polymer molecules or in other arrangements, and all atoms are made up of positively charged protons and neutrons in the nucleus (at the centre) and ‘clouds’ of negatively charged electrons around the nucleus in distinct layers (orbits). For a standard neutral atom, the number of electrons is the same as the number of protons. If an atom has more electrons than protons, it is negatively charged and if it has more protons than electrons then it is positively charged. The strength of the attachment of the electrons to the atom varies with the material – some materials have their electrons more tightly bound to them than others. The ‘triboelectric series’ (see below) is a rough measure of how tightly bound the electrons in a given material are. A material that is high up the series will generally give up electrons easily to become positively charged and a material that is low in the series will generally capture electrons and so become negatively charged.

The relative position on the series of two substances will give an indication of what will happen when they come into contact under ideal conditions. The higher material in the series will give up electrons to become positively charged and the lower material in the series will capture electrons to become negatively charged. As a general rule, the greater the distance the materials are apart in the triboelectric series then the greater will be the number of electrons transferred and the greater will be the charge imbalance created.

Triboelectric series	
Human skin	Loses electrons. Becomes positively charged. + ve.
Asbestos	
Rabbit fur	
Cellulose Acetate	
Glass	
Human hair	
PA (Nylon)	
Wool	
Lead	
Silk	
Aluminium	
Paper	
Cotton	
Steel	Gains electrons. Becomes negatively charged. -ve.
Wood	
Hard rubber	
Copper	
Silver	
Brass	
PS	
Polyacrylonitrile fibres (e.g., Orlon™)	
PMMA (Acrylic)	
Vinylidene Chloride Copolymers (e.g., SARAN™)	
PUR (Polyurethane)	
PE (Polyethylene)	
PP (Polypropylene)	
PVC	
PCTFE	
Silicon	
PTFE	
Silicone Rubber	

The Triboelectric series

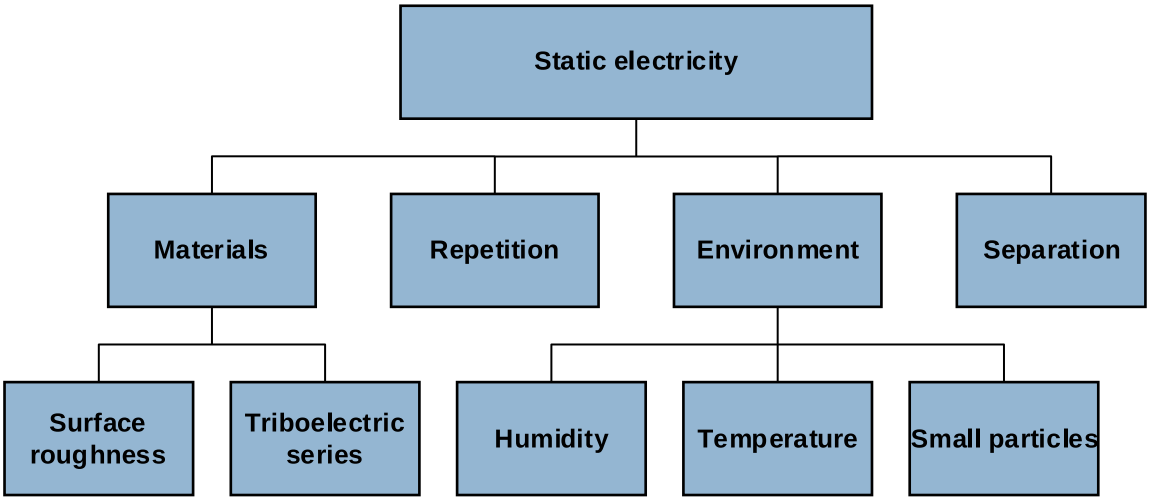
A simple example of this would be combing your hair on a dry day with a plastic comb (generally PP or PE). Human hair is significantly higher in the triboelectric series than PP or PE so the hair will give up electrons to become positively charged and the comb will gain electrons to become negatively charged. Like charges repel one another and the individual strands of hair will therefore repel one another - another 'bad hair day' that is simply the result of charge imbalance or static electricity. Fortunately, water molecules can disrupt the transfer of electrons due to their shape and their own electrical properties (they provide a low resistance path for charges to recombine) and simply moistening the hair before combing will reduce or remove the charge imbalance effect and reduce the 'fly-away hair' effect.

The charge transfer mechanism begins with the basic effect of adhesion. When two materials come into contact, they form a bond, which may be very weak, between each other. If the materials are far apart on the triboelectric series, then this adhesion effect can lead to electron transfer. If the materials are then separated the charge imbalances can remain and static electricity is created.

It is common to think that friction is the cause of static electricity but it is simply the adhesion that causes electron transfer, high friction loads increase the transfer but do not cause it. Equally repeated contact and separation, as happens in many industrial processes (such as roller conveyors) can lead to large charge imbalances and high static effects if the atmosphere is dry.

3. Factors affecting the amount of static electricity generated

The triboelectric series gives a broad indication of the amount of charge imbalance resulting from the contact of two materials but this is not the only factor and the general factors influencing the amount of charge imbalance are shown below:



Factors affecting the amount of static electricity generated

Materials

The materials effect is dependent on two factors, the relative position of the materials in the triboelectric series (as explained in Section 2) and the surface roughness of the materials. Surface roughness is important because when flat surfaces come into contact, they have more actual contact area available for electron transfer than do rough surfaces in contact and therefore more electrons can be transferred. This is one of the reasons that applying pressure to two contacting materials together will give more charge imbalance – the pressure increases the contact area.

Repetition

Repetitive movements such as rubbing or rolling will tend to increase the amount of charge imbalance on the two materials in contact.

Environment

The environment affects charge imbalances in three ways:

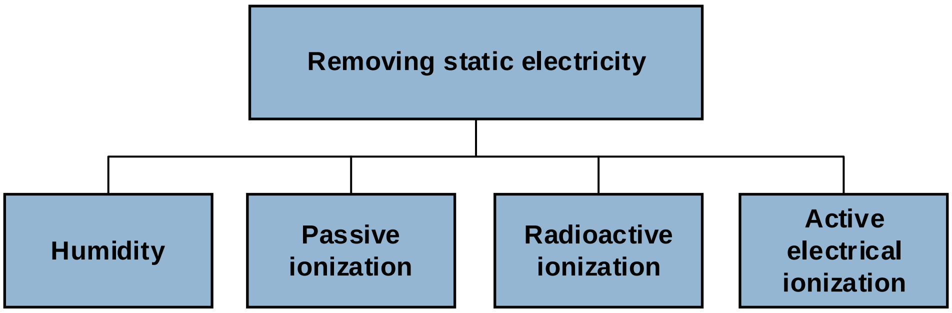
- The presence of atmospheric moisture or humidity decreases the amount of charge imbalance because water molecules provide a low resistance path for the charge imbalance to 'leak' away.
- High temperatures increase electron movement and make it easier for electrons to become separated and for charge imbalances to be created. When high pressures and repetitive motions are used then the temperature at the adhesion interface can also rise quite dramatically and the increased surface temperature makes charge imbalances higher. In some cases, as a material cools down it will generate charge imbalances and this is particularly important for injection mouldings which can be neutral when moulded but acquire a surface charge as they cool.
- Small particles such as dust and smoke can reduce the amount of charge imbalance by becoming charged themselves.

Separation

Simply separating two materials after they have been in contact can generate a charge imbalance. The amount of charge will vary with the materials but will also increase with the speed of separation because rapid separation reduces the time available for the electrons to balance at the separating surfaces. This can lead to concerns with processes such as PVC or other films running over PTFE coated rollers. The rapid contact and separation can lead to high charge imbalances being created on the roller and on the film.

4. Removing static electricity

Controlling charge imbalances in conductors is relatively easy, the conductor can be simply grounded to earth to remove the charges but insulators need to be controlled by other methods. The main methods used are shown below:



Removing static electricity

Humidity

As noted above, a humid atmosphere will allow the charges to leak way but this is not always a fully controllable method of static elimination. Anti-static additives for many plastics use humidity to control charge imbalances. The additives have a low solubility in the plastic and migrate to the surface of the product. Once there, they interact with the atmospheric moisture to allow charges to move across the surface and reduce any charge imbalance present.

Passive ionization

In this method a conductor, generally in the form of a brush or other sharp tipped object, is brought close to the charged product. The fine tip of the conductor concentrates the charges in a small area and ionizes the gas molecules in the gap between the conductor and the charged product. The ionized gas molecules are attracted to the oppositely charged product to neutralize the product. This method is good for reducing the charge imbalance but cannot completely eliminate the imbalance.

Radioactive ionization

This method uses small radioactive sources to ionize the gas molecules which can then neutralize the product. The radioactive source generally used is polonium (probably now more famous for being used to poison Russian émigrés in London).

Active electrical ionization

These are small fans with a high voltage AC (or pulsed DC) source that is supplied to small corona points to produce large amounts of ionized air molecules. The relevant ions are then attracted to the charged surface to neutralize the product. This method can be used to completely eliminate the imbalance.

The choice of the method to be used is complex and specialist advice on the particular Application is recommended.

5. Electrostatics and plastics

One of the advantages of plastics is their high electrical resistance and this makes them ideal for many electrical applications. Unfortunately, the length of time taken to discharge any charge imbalance is directly related to the resistance of the material. This means that, after acquiring a charge, a plastic product can maintain the charge for a very long time. This can present problems long after the static charge was acquired and give unpredictable behaviour in plastics products.

Equally, the voltage on a charged material is related to the charge by the formula:

V = Q/C where Q is the capacitance of the material and C is the charge present.

Plastics generally have low capacitances and therefore even a relatively small charge imbalance can create a high voltage in a plastic product, voltage levels of 100,000 volts are not unusual when dealing with plastics and static. These high levels of voltage are the cause of many of the problems associated with plastics and static as they will attract dust and dirt, cause operator shocks and cause products to behave unpredictably.

Typical concerns with charge imbalances and plastics are:

- Injection moulding and dust attraction – The temperature, separation and cooling effects can lead to high charge imbalances being created in injection mouldings. This can result in significant dust attraction as products cool (you may have noticed the smear of dust on some polypropylene products) and operator shocks when the operator discharges to earth. Active electrically ionized air is often used to solve this concern.
- Injection moulding and small products – The trend towards micro-moulding and much smaller injection mouldings can lead to concerns if the mouldings become charged. The charges can often be high enough to cause mouldings to stick together or repel (depending on the charge acquired) and small moulding are particularly sensitive.
- Charging of plastic films – Industrial concerns can be significant if plastics films pick up charge imbalances as they are processed. This can be caused by rapid movement over plastic-coated rollers that are far apart on the triboelectric series from the material being processed. The result will be unpredictable behaviour of the film as it is processed.
- Charging of plastic films – Once they are processed, most films are stored in rolls before further processing. Rapid unwinding of the rolls can lead to charging by separation and again unpredictable behaviour of the film as it is processed into the final product.
- Nested plastic buckets or chairs – When plastic products are nested (stacked inside one another) it is possible for a charge imbalance to be created when they are separated. This is due to the fact that plastics are not necessarily homogeneous materials and the surface of the nested buckets can become contaminated (through static electricity again) with dust and dirt. When the products are separated, the movement can lead to charge imbalances between the products and in the case of buckets, if they contain liquids then they can act as a capacitor leading to explosions from capacitive sparks.
- Fabrics – The use of many plastics for fibres used in seat covers and clothing makes charge imbalances a common occurrence in seating and car applications. Sliding on the seat and then touching a metal car body can produce annoying shocks.

6. Summary

Static electricity is sometimes seen as a quaint demonstration for small children but the reality is that it is both a serious tool for society and, when uncontrolled, a serious concern for industry. Understanding the causes and remedies are essential to the control of charge imbalances in the plastics processing industry.