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Static Electricity and the Pharmaceutical Industry

By Ian Pavey – Senior Process Safety Consultant
Chilworth Technology Ltd, Beta House, Chilworth Science Park, Southampton, SO16 7NS, UK

Introduction

There is no doubt that static electricity costs the pharmaceutical industry dearly. The cost can often be measured in terms of production rates, yields, and down time in a wide range of operations. Unfortunately when static leads to damage to plant, environmental damage, injury to personnel, or even loss of life, the cost, in human terms at least, may be quite immeasurable.

Hardly anyone in the process industries is unaware of static electricity and some of the problems it causes. Indeed, electrostatic phenomena feature in some of the earliest recorded scientific observations. And yet, 4500 years later the feeling that it is unpredictable and dealing with it is a "black art" is still a commonplace misconception. At the same time, electrostatics is playing an increasingly important role across the whole gamut of process industries - and none more so than pharmaceuticals. As we shall see, in many respects, the pharmaceutical industry is particularly vulnerable.

However, the fact is that electrostatics is now better understood than ever before. This article will explain briefly where the charge comes from and how it leads to a number of different types of problem with references to specific operations where static has proved to be a hazard. With understanding comes logical solutions so the article also explains the basics of a systematic approach to dealing with the problems described, which can often readily be extended to other situations once the fundamentals are properly understood.

Legislation, Standards and Guidelines

Legislation in the general area of process safety has often appeared rather vague. It is clear that there is an obligation on the part of employers to run an operation, which does not put their staff (or the public) at risk. Unfortunately national legislation has often fallen short of indicating exactly and unambiguously how this should be done.

However, over the next few years European Member states will be adopting a new and far reaching directive in this area (ATEX 137) which leaves little room for discussion or misinterpretation.

Employers will be obliged to identify and classify areas where flammable atmospheres could occur, including dust handling areas. Also, strategies to control and avoid potential ignition sources must be devised. Inevitably this will require the detailed knowledge of the flammability characteristics of all materials, including ignition sensitivity. In addition, plant will have to be designed to safely control the consequences of an explosion. This will require a knowledge of the severity of any explosion as a result of materials being. At last the need to properly know your process materials, which safety experts agree is crucial, will be enshrined in law.

For many years British Standard BS5958 and Germany's ZH1/200 have stood out as general guidance for industry on the avoidance of hazards due to static electricity. Recently a CENELEC Technical Report (R044-001:1999) has been published. Entitled "Safety of machinery: Guidance and recommendations for the avoidance of hazards due to static electricity" it discusses a wide range of processes and situations. It is certainly a great help in standardising the advice given by those already expert in the area although realistically, working from a document such as this with no previous experience may be a little like learning to drive with reference to the Driver's Manual which comes with a new car! In theory it should be possible but the process is fraught with risks along the way. Indeed, this latest document still has to use the phrase "expert advice should be sought" within its pages.

Static Charge Generation

The two most important ways in which unwanted electrostatic charge is acquired are induction charging and tribo-charging. It is crucial that the principles of each are understood in order to recognise where charge may be produced, which is an essential precursor to dealing with it.

Tribo-Charging

Whenever two different materials contact one another electrons will move across the interface so that one becomes negatively charged (excess electrons) and the other positively charged. If the two materials are good conductors (such as metals) all the exchanged charge will flow back through the last point of contact when they are separated. However, if at least one of the materials is a poor conductor this will not happen and the charge which was exchanged during the contact will be carried away on separation.

It is extremely important at this stage to dispel one very common misunderstanding. Only one of the two contacting materials must be a poor conductor for both to carry charge away on separation. Furthermore, if the good conductor (a metal, perhaps) is well earthed charge will still cross the interface and the poor conductor will still carry away charge when they separate. The only difference is that the charge the metal acquired will be lost to earth almost instantly. All too often it is thought earthing plant solves all electrostatic problems. The reality is that although earthing plant is vital, it is not the whole answer.

The magnitude of charge acquired by tribo-charging depends on various factors but in general the more energetic the process the greater will be the charge generated. Table 1 illustrates this by giving typical charge levels acquired by powders undergoing some very common processes.

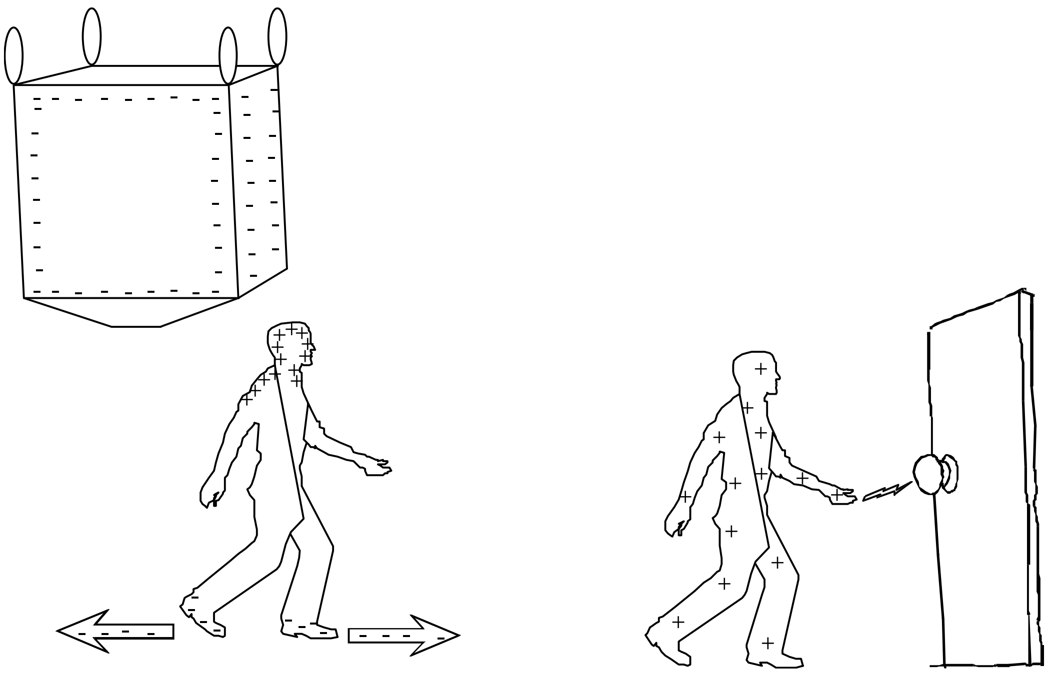
Process	**Charge:Mass Ratio (μC/kg)**
Sieving	10^{-3} to 10^{-5}
Pouring	10^{-1} to 10^{-3}
Scroll Feed Transfer	1 to 10^{-2}
Grinding	1 to 10^{-1}
Micronising	10^{2} to 10^{-1}
Pneumatic Transfer	10^{3} to 10^{-1}

Table 1. Typical Powder Charge Following Common Processes

Induction Charging

All but the most insulating of materials will charge by induction. When exposed to an electric field (such as when in the vicinity of a charged object) opposite charges within the material will tend to separate - either being attracted towards, or repelled from, the nearby charge. Any local excess of charge at a point of contact will then leak away according to just how conducting the material is and how good is the contact. This will leave behind an overall excess of the opposite sign of charge.

In order to clarify this point a typical example of how this may occur in practice is shown in Figure 1. Figure 1(a) illustrates a person (a very good conductor) near to a big bag (FIBC) containing a highly charged product (plastic pellets, perhaps). The separated charges are shown, as is the negative charge leaking away via shoes and floor. Figure 1(b) shows the person now moved away from the vicinity of the FIBC, carrying a net charge, and consequently receiving a small shock on opening the door.



(a) (b)

Figure 1. Induction Charging

Material Assessments

In tribo-charging the precise nature of the two surfaces is very important in determining the level of charge acquired. For a material to be moderately charged it often means that there is only one electron too many or too few for every billion (10^9) molecules, or more. This means that very low levels of impurity, or seemingly insignificant variations in materials, may have a very dramatic effect on their charging properties. As a result, when assessing potential problems this disproportionate effect leads to a need to look at all but the simplest of materials on a case by case basis, often by carrying out measurements under carefully controlled laboratory conditions to assess the propensity for charging in a particular situation.

No material is a perfect insulator so that even as charge is being generated it will also be dissipated by conduction. The actual charge which will be observed will therefore be the result of the dynamic equilibrium between charge generation and dissipation rates. The rate of charge dissipation depends on the conductivity of the material and, just as various factors affect charge generation, this too can vary. Especially important is the relative humidity of the air around the material. Minute quantities of water adsorbed on to a surface from the surrounding air can have an enormous effect on conductivity, dissipation rate and hence detected charge levels.

Static Discharges

Hazards (as opposed to problems) due to static almost invariably arise because sparks, or discharges, are able to ignite flammable materials. In fact, several types of electrostatic discharge have been identified, each with characteristic energies.

For example, a brush discharge will occur from an insulating surface. The energy in a brush discharge is relatively low; often below the limit of perception if it is to a person in a typical working environment. Nevertheless, a brush discharge will ignite many common solvent vapours.

A capacitive discharge (or spark) dissipates energy, E, according to the relationship:

$$E = \frac{1}{2}CV^2$$

where C is the capacitance of the conductor on which charge was stored, and V the voltage to which it was raised. Capacitance is dependent upon geometry and location, but simplistically increases with the size of the object. Assuming a potential of 10kV (easily attainable) Table 2 shows capacitances and spark energies available from some common objects.

Object	**Typical Capacitance (pF)**	**10kV Spark Energy (mJ)**
Small metal items (eg scoop)	10 - 20	0.5 - 1
Small containers (eg bucket)	10 - 100	0.5 - 5
Medium containers (eg drum)	50 - 300	2.5 - 15
Human body	200 - 300	10 - 15
Large plant (eg reaction vessel)	100 - 1000	5 - 50

Table 2. Capacitances and Spark Energies for Some Common Objects

Other types of discharge are corona, cone and propagating brush discharges. Each has a characteristic energy range associated with it. Corona occurs from sharp points and is a low energy type of discharge, even compared with brush discharges. Cone discharges occur across the conical surface of powder, and especially granules and pellets, as they collect in hoppers, silos and other containers. These are more energetic than brush discharges and can ignite common solvent vapours and some dusts. Propagating brush discharges are the most energetic of all. They arise when charge accumulates on two sides of a thin insulating layer. A practical scenario where a propagating brush discharge can occur is on an insulating plastic liner used inside a fibreboard drum.

Systematic Hazard Assessment

We have seen the ways in which charge may be generated. Whether or not it actually happens in a particular situation will be a matter for prediction from laboratory measurements or direct measurements on plant.

If charging occurs we have seen how it could lead to different types of discharge. The energy which might be available from such discharges can be predicted according to its type and, in some cases, specific measurements on site.

In general, the risk is ignition of a flammable material: solvent vapour, permanent gas or dust. Whether or not this could occur will simply depend on a knowledge of its sensitivity to ignition (or Minimum Ignition Energy) and comparing that with the potential discharge energy. For many simple materials ignition energies are published in the literature. For special materials determination of Minimum Ignition Energy is a routine test for laboratories such as Chilworth Technology's. Photograph 1 shows a small dust explosion initiated by a spark of known energy as part of the series of tests carried out to determine Minimum Ignition Energy.

Photo 1: Minimum Ignition Energy test.

Avoiding Hazardous Situations

With the risk, and the mechanism for its arising, properly understood there are a number of options for avoiding the hazards, although in practice one option often stands out as the most appropriate.

It may be possible to avoid charging in the first place by altering the process or operating conditions in some way. Alternatively, charging may have to be accepted and charge accumulation prevented. There is no excuse for allowing charge to accumulate on conductors; they can always be earthed. However, as we saw earlier, although earthing the plant is crucial and will prevent charge accumulation there, it will generally have no effect at all on the material inside which is being processed.

In the end, it is sometimes the case that if the desired process is to be carried out charging cannot be avoided, the risk of discharge cannot be avoided and a flammable material is at risk of ignition from the discharge. If this is the case the only option will be to avoid ignition by inerting.

Incidents from the Pharmaceutical Industry

It was stated at the beginning of this article that the pharmaceutical industry was particularly vulnerable to electrostatic hazards and problems. In the light of the foregoing discussion it is now possible to explain and justify that statement.

Plant is often deliberately and necessarily operated under low humidity conditions. For many materials this means they are at their least conductive and therefore most susceptible to charging.

Materials are mostly organic, and often chemically very active. Experience in Chilworth Technology’s test laboratories is that, increasingly, pharmaceutical products are amongst the most sensitive to ignition.

In common with most other processes ever higher speeds are required to maximise the plant capacity and minimise cost. As discussed earlier, higher transfer speeds, and more energetic processes in general, lead to higher levels of charge.

The cleanliness and low cost of plastics as containers themselves, liners for other containers, liners for plant, or plant materials means that there seems to be no stopping their increasing use. These, of course are the very materials which will lead to many of the problems discussed earlier.

Often floors (and walls) are finished with materials eminently suitable for washing down and maintaining cleanliness but with little thought to their conductivity. People and objects moving around on an insulating floor have no means of dissipating charge and will become charged.

Many of these problems arise in other industry sectors. However, few others bring them all together in the way the pharmaceutical industry does. The consequences can be graphically illustrated with a few real examples from Chilworth Technology’s archives of incident investigations. Some of the hazards are so obvious with hindsight that it is difficult to see how they could have been missed - yet they were. Others require considerable insight even when the concepts are fully explained.

Dust Explosion - Sieving

Operators were scooping powder from an FIBC to the sieve unit. The fines product from the sieve were dropped into a stainless steel bin. One day there was an explosion and fire in the bin accompanied by thick black smoke. Fortunately the operators were unhurt and able to evacuate the room before returning to extinguish the fire. Following a detailed analysis of the incident and measurement of relevant variables an explanation for the incident was found.

The bin was on insulating wheels. Although an earthing lead was provided it was not used. A simulation experiment demonstrated that the powder would be charged by the sieving operation, and carry charge into the bin. The powder was found to have a Minimum Ignition

Energy of 15mJ. Given the measured capacitance of the bin, and the rate of charge accumulation in the bin based on the experimentally determined powder charge, it would have taken a little over half a minute to reach the point where a discharge would be sufficiently energetic to ignite the powder. All the ingredients were there but why did the incident actually occur this time. It turned out that as the bin filled the centre of gravity moved until it was able to rock forward about its larger central wheels. When placed in just the right (wrong!) position this caused it to contact the main body of the sieve. To avoid dust in the room as a whole the bin had been covered with a plastic sheet. This caused a concentrated dust cloud to escape where the sheet was draped over the sieve outlet - exactly where the spark occurred on this one occasion when the bin rocked and made contact with a good earth after it had acquired sufficient charge to provide an incendive discharge.

Seemingly insignificant changes had been made to working practices, until all the ingredients for the incident were in place. It then simply needed the bad luck of coincidentally bringing them all together at once. And the solutions were simple enough. Improve the bin earthing, preferably by the use of conducting wheels. Provide local dust extraction so that concentrated dust clouds are avoided.

Reactor Charging Explosion

A 4500l vessel had been washed with acetone and left to dry overnight. The next day drums of a powder intermediate were manually tipped into the vessel via an open manway. After drum number six was added there was an explosion and a fireball enveloped the operators. This incident did cause serious injury and resulted in lost production, compensation payments and, less tangibly, loss of workforce confidence.

The investigation found the powder in this case to have an ignition energy of between 1 and 5 mJ. Trials showed that the morning after an acetone wash the concentration of acetone vapour could be about 50% of the lower explosible limit. Clearly the acetone on its own would not ignite, but it could contribute to a hybrid flammable mixture together with the flammable powder. It was found that the operators footwear and gloves were both insulating. This identified two possible isolated conductors - the drums and the operators. Simulation experiments showed 10kV could be attained by the drum during emptying. Given its capacitance this meant that a 10mJ spark could have been produced from the drum (or indeed from the operator). Clearly this was the source of ignition.

In this case a number of solutions are possible. The vessel could be inerted and double valves or flap valves used. Local dust extraction may also have improved the situation. However, probably the most important recommendations, whether or not the others were implemented, was to provide dissipative footwear and gloves and an earth clip for the drum.

Ignition of Hexane Vapour

A hexane-laden powder was being transferred by two operators from a centrifuge buggy lined with a woven cloth “buggy bag” into plastic lined fibreboard drums. When most of the powder had been removed one of the operators grabbed the “buggy bag” on one side and pulled it from the supporting hooks. The ignition occurred as a flash fire on the “buggy bag” which immediately spread to the nearby fibreboard drums.

All conducting plant, and the operators were well earthed in this case. However, the buggy bag and the drum liners were insulating. The powder was found to be very insulating, and hexane known to be. Although not discussed earlier, insulating liquids can generate charge in a special case of tribo-charging - known as a streaming current. The insulating process materials, “buggy bag” and liners provided the means for charge generation. In this case hexane has an ignition energy of only 0.24mJ. That means a brush discharge from an insulating surface, in this case the “buggy bag”, was the most likely cause of the ignition.

The recommendations here were to change the final wash solvent to, preferably a non-flammable liquid but, at least a conducting one. In addition all insulating plastics were banned from the area.

Electrostatic Discharges over Toluene

An operator observed blue flashes in a stirred vessel containing toluene as the solvent. Although under nitrogen this observation was, to say the least, disconcerting.

A special probe was constructed and installed on site in order to carry out measurements during a trial run in which operational parameters could be varied. It was found that below a certain temperature the level of charge rose dramatically, falling away again as the temperature was raised. This temperature was coincident with the temperature at which solute started to come out of solution.

It is well known that a multi-phase liquid system charges very much more highly than a single phase. The problem was solved by ensuring the temperature never dropped below the experimentally-found transition temperature.

Vacuum Dryer Incidents

A vacuum dryer had suffered several product decompositions at the end of the drying cycle leading to over-pressurisation of the vessel and, in some cases, loss of containment.

Chilworth Technology undertook a wide-ranging research project and discovered that the product was susceptible to acquisition of high charge levels. However, the key was in showing that an electrostatic phenomenon known as the Paschen effect could occur in charged powders – a fact hitherto unreported. This meant that relieving the vacuum could cause electrostatic discharges that, in turn, could initiate the decomposition.

The solution was to limit the level of vacuum used. This ensured that breaking the vacuum at the end of the cycle no longer caused discharges as a result of the charge gained during drying.

Conclusions

The pharmaceutical industry is particularly susceptible to electrostatic problems in general, and hazards in particular. However, a proper understanding of the relevant phenomena and appropriate physical property information allows a systematic approach to defining operational practices and plant designs to minimise the risk.

Incidents, such as those described earlier, can be effectively and systematically investigated. However, the direct and indirect costs of allowing any avoidable incident to occur can be very significant and it is clearly much better to undertake an expert assessment of a plant and its operations prior to any incident. Then, by adopting appropriate recommendations, the risks can be minimised or avoided altogether.

Best of all would be to consider the full implications of potential static hazards (alongside other hazards assessments) before the plant is even off the drawing board. Increasingly companies recognise this themselves, but it is probably true to say that many have had to learn the hard way.

About the Author

Ian Pavey, M.Phil, BSc (hons), M.Inst.P, C.Phys, graduated from Bath University with a BSc in Chemical Engineering. After acquiring some practical experience of electrostatic hazards while working as a process development engineer, he gained an M.Phil. in applied electrostatics and thereafter specialised in electrostatic applications, problems and hazards. Ian worked for ICI for 11 years on projects involving electrostatic process research and development. Now Ian is currently working as Principal Electrostatics Specialist.

Whilst at Chilworth Technology Ltd, Ian has been responsible for a variety of problem solving and research projects where electrostatics is involved. These have included powder and liquid handling problems and applications. Ian has led multi-national research projects under EC Framework programmes, including one investigating powder handling and processing problems caused by static electricity in industrial processes, and one aimed at developing new tests for anti-static footwear. Ian is a member of the Static Electrification Group of the Institute of Physics, and a past member of the group's committee.

During 25 years working in the field of electrostatics, Ian has published numerous articles covering subjects from new electrostatic applications to powder handling problems to fundamental research leading to new understanding of hazardous situations. In addition, he is a named inventor on a number of patents in areas from electrostatic sprays for agricultural purposes to electrostatic fibre production for liquid crystal displays.

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