Ignition risks from static electricity – problems solved?

M. Glor
Swiss Institute for the Promotion of Safety and Security, WRO-1055.5.23
CH-4002 Basel, Switzerland
martin.glor@swissi.ch

Abstract. In the past the biggest advances in our ability to assess electrostatic ignition risks have repeatedly come about through painstaking investigations into explosions that have occurred. This paper offers a general overview of the present state of knowledge in the individual subject areas and the questions that still remain unanswered. In particular, it addresses the handling and processing of flammable liquids and dusts together with the design of equipment, process plant and containers. In addition, the open questions concerning the occurrence, characterization and incendivity of electrostatic discharges are discussed. The paper concludes by examining how the knowledge gained is applied in industrial practice.

1. Introduction and general background
Throughout the twentieth century the ignition risks from static electricity in the process industries were constantly on the increase due to the growing use of petroleum products coupled with a steady rise in production volumes. Ignition risks result from a variety of causes. Because of the very poor electrical conductivity of most petroleum products, whether in liquid, solid or finely divided form, a strong electrostatic charge tends to accumulate. In addition, when organic solvents and powders are used, a potentially explosive atmosphere can be created. To make matters worse, the space charge field and the charge-to-mass ratio are boosted by the increasingly large quantities being processed and the tendency for product transfer speeds to become ever greater.

Looking back over the last fifty years, it can be seen that the greatest advances have always been made in the aftermath of serious incidents involving explosions in a wide variety of industrial sectors. This applies not only to the countless explosions that have occurred while filling vessels with hydrocarbon fuels, or emptying or transferring their contents, but also to the tanker explosions that happened while the cargo tanks were being washed with sea water, the numerous explosions in various chemical industry processes and the silo explosions in the food and plastics industries.

This paper provides an overview of the major achievements in the field by outlining the milestones reached and the questions still open in the individual areas involved in assessing the risks of ignition from static electricity. The well-known schematic diagram in Fig. 1 serves as a general basis for this overview, as it has repeatedly proved to be a useful orientation when investigating incidents involving explosions as well as when evaluating the risks in existing and projected plants and processes.

When addressing the questions still open and the problems yet unsolved in electrostatics, it is necessary to differentiate between the various factors involved in explosion protection but at the same time adopt a holistic approach. On the one hand there are unanswered questions of purely scientific interest and those that are also of scientific interest but have a definite practical significance as well. On the other hand, among the questions with practical implications there are those that can be solved...
in practice by taking very conservative precautions or primary explosion protection measures such as blanketing with an inert gas. In safety engineering it is a well-established fact that the more that is known about the properties of the product and the plant, the less is the expenditure on protective measures. The decision as to whether an electrostatic problem is solved by scientific investigations, or whether very conservative precautions or primary explosion protection measures are taken, nowadays hinges almost exclusively on considerations of cost-effectiveness. Additionally, it is important to point out that today it is very often not the state of knowledge in general that is lacking, but rather that those responsible in the process industries lack the necessary knowledge and therefore fail to put it into effect by applying the protective measures needed.

2. Liquids

In the mid-twentieth century, various companies in the petroleum industry carried out extensive research and investigations into the ignition risks from static electricity when transferring and processing hydrocarbon fuels. This resulted in safe filling velocities being specified for various vessel sizes and geometries and piping cross sections [1-4]. The results have also been incorporated in company internal guidelines and in national and international directives and codes of practice [5-7].

In the late 1960s a number of serious explosions occurred in tankers when their cargo tanks were being cleaned with sea water at a pressure of 12 bar. As a result, detailed investigations were carried out into the jetting of liquids in large volumes and the ignition risk that this posed. In the course of this work the falling water slug theory was postulated as ignition mechanism and subsequently verified experimentally [3, 8].

Open questions still exist, for example, in the following areas:
- Safe filling velocities for non-conductive liquids other than hydrocarbon fuels
- Safe filling velocities when using plastic piping
- Safe filling velocities for multiphase systems (e.g. suspensions)
- Special risks (extremely high charge-to-mass ratio) when handling liquids that are slightly conductive, especially ethyl acetate and similar products
- High pressure cleaning (up to 500 bar) of vessels with volumes less than 100 m³ using water or non-conductive liquids.

The uncertainties that these questions raise are resolved at the present time in practice by applying measures of primary explosion protection or using electrically conductive piping.

3. Dusts

Towards the end of the twentieth century, interest focused primarily on the ignition of dust clouds by static electricity. Ever lower minimum ignition energies for dusts were determined, with values even falling into the range associated with gases and vapours. This resulted in the likelihood of dust clouds being ignited by electrostatic discharges being reassessed upwards [9]. Initially, lightning-like discharges in the highly charged dust clouds were held to be responsible for the many inexplicable

![Fig. 1: Schematic representation of the charge separation process possibly leading to ignition of an explosive atmosphere](image-url)
explosions occurring in silos. Experimental work then showed, however, that discharges of this type in silos of industrial dimensions are improbable [10]. Subsequently, extensive projects to carry out fundamental investigations into the ignition of dust clouds in silos and large vessels were initiated [11, 12], which resulted in the phenomenon of cone discharges being discovered and examined in detail [13].

In the case of highly combustible dusts with a minimum ignition energy of 1 mJ or less, the question repeatedly arose in the past as to whether they could be ignited by low-energy brush discharges. Despite numerous tests in various laboratories [14, 15], to date no one has succeeded in igniting pure dusts by means of brush discharges. This is the current state of knowledge, although it must be admitted that it is always difficult to prove by experiment that a phenomenon does not exist.

To assess the risk of igniting dusts with static electricity, several questions still require further investigation, for example the following:

- The occurrence and equivalent energy of cone discharges in non-conductive silos and vessels
- The occurrence and equivalent energy of cone discharges in silos and vessels that do not have a symmetrically cylindrical geometry
- The minimum surface area necessary for the occurrence of propagating brush discharges
- Assessment of the risk of propagating brush discharges (occurrence of high surface charge densities) in various transfer operations

4. Plants and containers

When the various materials of construction for plant and equipment are selected, there are today virtually no more uncertainties regarding their properties if considered purely in terms of static electricity as an ignition risk. Questions and problems that arise in practice in this connection are mainly due to other requirements relating to safety and quality. These typically concern corrosion protection, mechanical strength, compatibility with solvents, ageing characteristics, occupational safety and hygiene, and product contamination. In addition, of course, profitability considerations must be numbered among those factors that lead to a conflict of interests with the requirements dictated by static electricity.

One unsolved problem that can be cited in this connection is that there are to date no materials that can conduct or dissipate static electricity, are lightweight yet stable, are transparent and resistant to solvents, are approved by the regulatory authorities (e.g. FDA) and, above all, are inexpensive.

The same considerations and unsolved problems apply to a wide variety of container types. There is a growing trend towards the use of RIBCs (rigid intermediate bulk containers) for handling liquids on a large industrial scale. An RIBC consists essentially of an inner container made of plastic (usually polyethylene) and a metal exterior, either a wire mesh cage or a sheet metal enclosure. When RIBCs are used for flammable liquids, they must comply with requirements for preventing dangerous charge accumulations; otherwise there is a risk of ignition due to electrostatic discharges [16]. The problem that is as yet unsolved is that, as mentioned above, the ideal container material does not yet exist, and the exact requirements and test methods for appropriate “compromise solutions” are not yet available. Projects to address this problem are under way (see Section 6).

Rather more progress has been made with practical solutions for large containers for combustible bulk solids – the well-known FIBCs (flexible intermediate bulk containers), otherwise known as big bags. These are normally made from a fabric of woven polypropylene ribbons and can give rise to both brush discharges and propagating brush discharges. Depending on the intended application (presence of potentially explosive dust, solvent vapour or gas atmospheres), varying requirements are stipulated for the FIBCs. These requirements and test methods are described in the standard IEC 61340-4-4 [17].

Open questions also exist concerning the use of liners and the associated requirements.
5. Discharges

5.1. Types of discharge

The characterization of the incendivity of discharges is one of the most critical points when assessing the ignition risks from static electricity. For this reason it has been helpful in the past to distinguish between the different types of discharge. So far this approach has a proven track record. Firstly, the type of discharge to be expected can be predicted with a high degree of reliability on the basis of the electrical properties and the geometrical arrangement of the charged objects and their surroundings. Secondly, differing incendivities can be assigned to the different types of discharge, and their parameters can be described. However, if a more differentiated picture is called for, especially of the discharges originating from non-conductive objects and products, one encounters many unsolved problems.

5.2. Energy

Exact quantification of the energy released in a discharge is possible only for a spark discharge. As is generally known, the energy released in this case is equated with the energy stored in the capacitor prior to the discharge. With discharges originating from non-conductive surfaces, objects or products, only some of the accumulated charge and hence only a proportion of the stored energy is released in the discharge. The detailed discharge mechanism is therefore the deciding factor in estimating this proportion of the energy. In the case of discharges such as brush or corona discharges, the local electric field, which initiates the discharge, is itself weakened by it. The discharge ceases, and only a small proportion of the accumulated charge and energy is transferred. On the other hand, with discharge mechanisms that strengthen the local field after they have been initiated, such as propagating brush and cone discharges, the discharge continues to take place and the transfer of charge and energy released are considerably greater.

It is still not yet possible to measure the energy released in discharges originating from non-conductive objects or products with simple means. Attempts are therefore being made to use the charge transferred in a discharge, which can be measured relatively easily, as a measure of the energy released. According to the laws of physics, this energy is calculated by integrating the product of the charge and its potential. However, as the potential always depends on the accumulated charge, the relationship between the transferred charge and the energy released is not straightforward (e.g. it is not simple proportionality). Nevertheless, this method has proved itself in practice in assessing the incendivity of brush discharges originating from smooth non-conductive surfaces (see Section 5.3).

5.3. Incendivity

Two different questions must be answered when assessing the incendivity of a discharge: 1. What is the magnitude of the total energy converted in the discharge? 2. Is the knowledge of the total energy released in a discharge sufficient to assess its incendivity?

The question concerning the energy of discharges and the unsolved problems associated with this have been discussed in Section 5.2. Since direct determination of the energy is very difficult, except in the case of spark discharges, the opposite pragmatic approach has been taken in the past: the energy of the various types of discharge has been deduced from ignition tests on potentially explosive atmospheres of a known minimum ignition energy [18]. The discharge energy measured in this way is termed the equivalent energy. The second question is therefore the same as asking whether the equivalent energy is identical to the energy released in the discharge. To date, however, this question cannot be answered satisfactorily. Even in the case of spark discharges, where it is possible to calculate the energy converted using basic physics, the question still cannot be answered, because the minimum ignition energy is itself determined by means of spark discharges.

Although a comparison between the equivalent energy of a discharge and the minimum ignition energy of a potentially explosive atmosphere has to date as a rule been a proven method for assessing
the ignition risk in practice, the ignition process does not depend solely on the discharge energy integrated over space and time, but also on the spatial and temporal distribution of the energy. An example of this is provided by the contradictory results obtained for the equivalent energy of brush discharges determined with gases and vapours and their incendivity compared with dusts of a lower minimum ignition energy [14, 15]. A better understanding of the ignition mechanisms, also taking into account the power densities in the various discharges, would be very desirable and helpful.

Major efforts are being made today to establish a correlation between the charge transfer in discharges originating from insulating surfaces and the incendivity of the discharges. Such a correlation would greatly simplify matters, since a measurement of the charge transfer can be carried out relatively simply. It was possible to establish a correlation of this type for brush discharges originating on smooth, non-conductive surfaces and the ignition of substances in Gas Groups IIA, IIB and IIC [19]. The data gathered so far have not yet shown any satisfactory results for fabrics of the type used in the manufacture of FIBCs.

6. Standards, directives and codes of practice

The introduction of the explosion protection Directives 94/9/EC and 1999/92/EC (otherwise known as ATEX 95 and ATEX 137) in Europe with their special reference to so-called “non-electrical ignition sources” – to which static electricity also belongs – has led to an increased awareness of the ignition risks from static electricity on the part of both process plant manufacturers and plant operators. This in turn has given rise to increased activity in the fields of standardization, directives and codes of practice.

Apart from the fact that many standards and directives are still in preparation, a major problem exists in attempting to harmonize the test methods, requirements and marking conventions. This is also due in no small measure to the fact that standardization at IEC level is taking place not only in technical committee TC 101, comprising experts from the electronics and process industries, but also in technical committee TC 31, which is mainly made up of experts in electrotechnical explosion protection.

The following new publications and projects in the field of international standardization relating to ignition risks from static electricity are worthy of mention:

- IEC 61340-4-4 First Edition 2005-10: “Standard test methods for specific applications – Electrostatic classification of flexible intermediate bulk containers (FIBC)”
- Project team for IEC 61340-4-6: “Standard test methods for specific applications - Test methods for the electrostatic properties of intermediate bulk containers (IBC)”
- Project team for IEC 61340-6-1: “Performance and design requirements for IBC”
- Incorporation of the existing CENELEC Technical Report CLC/TR 50404 “Electrostatics - Code of practice for the avoidance of hazards due to static electricity” in an IEC TR “Avoidance of hazards due to static electricity” by a joint working group (JWG) from TC 31 and TC 101

7. Conclusions

As can be seen from the foregoing, the problems as yet unsolved tend today to be less a matter of scientific/technical questions than of putting current knowledge into industrial practice, solving conflicts of interests between safety and economic considerations and harmonizing directives and standards. In these areas there are still many unsolved problems, and action needs to be taken.

The decision to tackle the remaining scientific/technical questions will in the future still be made on the basis of cost-benefit analyses in industry. As long as the adoption of very conservative precautions or primary explosion protection measures such as inerting are estimated to be more cost-effective in individual cases than accurate research into the ignition risks from static electricity, scientific investigations will be dispensed with.

However, precisely because it will be possible for ever fewer experts to be active in research and development, the preservation of scientific knowledge and experience represents a serious challenge
for the future. This challenge will become more accentuated and topical due to the resiting of manufacturing and development activities in locations where there is less experience in this field.

References
[1] N. Gibson and F.C. Lloyd, Journal Physics D Applied Physics 3 (1970) 563.
[2] H. Krämer and K. Asano Journal of Electrostat. 6 (1979) 361-371.
[3] W.M. Bustin and W.G. Dukek, “Electrostatic Hazards in the Petroleum Industry”, Research Studies Press Ltd., 1983.
[4] H.L. Wamsley, Journal of Electrostat. 26 (1991) 127-173.
[5] CENELEC Technical Report CLC/TR 50404 „Electrostatics - Code of practice for the avoidance of hazards due to static electricity”, June 2003.
[6] BGR 132 „Vermeiden von Zündgefahren infolge elektrostatischer Aufladungen”, Hauptverband der gewerblichen Berufsgenossenschaften, Fachausschuss „Chemie“ der BGZ, 2004.
[7] Shell Safety Committee “Static Electricity- Technical and Safety Aspects” June 1988
[8] J.M. van de Weerd, Journal of Electrostat. 1 (1975) 295-309.
[9] M. Glor, Journal of Powder Technology 135-136 (2003) 223-233.
[10] P. Boschung, W. Hilgner, G. Lüttgens, B. Maurer and A. Wimer, J. Electrostat., 3 (1977) 303.
[11] A.G. Bailey, Inst. Phys. Conf. Ser. No. 85 (1987) 1-13.
[12] B. Maurer, M. Glor, G. Lüttgens and L. Post, Journal of Electrostat., 23 (1989) 25.
[13] M. Glor, Journal of Loss Prevention in the Process Industries, 14 (2001) 123-128.
[14] Ø. Larsen, J.H. Hagen and K. van Wingerden, Journal of Loss Prevention in the Process Industries, 14 (2001) 111-122.
[15] M. Glor and K. Schwenzfeuer Journal of Electrostat., 63 (2005) 463-468.
[16] G.P. Ackroyd and S.G. Newton, Loss Prevention Bulletin IchemE 165 (2002) 13.
[17] L.G. Britton, P. Holdstock and R.J. Pappas, Process Safety Process 24 (2005) 213-222.
[18] N. Gibson and F.C. Lloyd, British Journal of Appl. Physics., 16 (1965) 1619.
[19] U. von Pidoll, E. Brzostek an H.-R. Froechtenik, IEEE Transactions on Industry Applications 40 (2004).