Electrostatic Ignition Hazards from Flexible Intermediate Bulk Containers (FIBCs) with Materials of Minimum Ignition Energies Down to 0.12 mJ

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***Abstract*—The use of flexible intermediate bulk containers (FIBCs), or "big bags" as they are commonly known, is becoming widespread in a variety of industries, including chemical, pharmaceutical, and foodstuffs. Typically, FIBCs, roughly cubic in shape and constructed from woven polypropylene, are used to store and transport powdered or granular material in loads of between 300–1000 kg. In many cases, FIBCs are used in the vicinity of sensitive flammable atmospheres which may arise from the presence of dispersed combustible dusts or solvent vapors. Over the years, there have been a number of serious fires and explosions (particularly during the discharging of the bag contents) which have been attributed to static electricity. As a result, various "antistatic" FIBC designs have been produced containing intrinsic features aimed at minimizing the risk of electrostatic ignition. This paper presents the results of a rigorous assessment of a variety of FIBC designs with regard to electrostatic ignition hazard in flammable atmospheres of minimum ignition energy 0.12, 0.25, and 1.5 mJ. (The minimum ignition energy of methanol, a common industrial solvent, is 0.14 mJ.) The study involved setting up a test rig to enable the FIBCs to be filled and emptied under controlled conditions of relative humidity. During these operations, the electrostatic activity in terms of surface potentials, electric field, and electrostatic discharge energy was carefully monitored. Incendiary discharges were quantified by using a calibrated propane/oxygen/nitrogen gas probe. The findings of this paper indicate which of the designs can be safely used in various industrial processes without risk of ignition.**

***Index Terms*—Electrostatic discharge, electrostatic ignition, flexible intermediate bulk containers, gas-probe ignition, .**

I. Introduction

POWDERED granular or pelleted materials can produce large amounts of static electricity. Electrostatics is a surface phenomenon, and for a given mass of powder the total surface area and, therefore, the propensity to generate and store charge is very high.

In industrial situations involving standard flexible intermediate bulk containers (FIBCs), there are primarily three ways in which potentially hazardous levels of electrostatic charge can be generated.

When filling an FIBC, product transferred to the bag is often in an electrostatically charged condition. Bulking the product within the bag can intensify the volume charge density, resulting in a high electric field radiating from the bag walls. Emptying product from the bag will also generate charge due to triboelectrification (frictional charging) between the product and the bag wall. Finally, cleaning, rubbing, or simply handling the outside surface of the bag may generate relatively high levels of static charge.

Once electrostatic charge has been generated or accumulated by any of the mechanisms described above, a situation can arise in which discharges can occur.

There are a number of different forms of electrostatic discharge possible from standard FIBCs. These are as follows.

1) Brush Discharges: These are low-energy discrete electrostatic discharges which can occur from insulating surfaces such as the bulked product or the bag wall. The maximum discharge energy is around 4 mJ.

2) Cone Discharges: These can occur across the surface of the bulking material in the bag. Cone discharges can be more energetic than brush discharges and their limiting energy is dependent on the dimensions of the bag being filled as well as the particle size of the product. Pellets can produce cone discharges of higher energy than fine powders.

3) Propagating Brush Discharges: This type of discharge can occur when ions are created at powder bulking. Some of these ions are repelled toward the bag wall and can accumulate there, often causing opposite charge to appear on the outer bag surface. Propagating brush discharges can have an equivalent energy content of up to 1 J and can readily ignite solvent vapors and powder clouds.

Under certain conditions, other electrostatic discharge mechanisms may also appear.

- An electrically insulating bag (standard polypropylene) which has become contaminated with a conducting substance such as water, may also be capable of producing spark discharges from the contaminated area to any nearby earth.
- Conducting objects, including personnel, which are in the vicinity of a charged bag and are not properly grounded can also become electrostatically charged by induction

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and depending on their proximity to other grounded objects could produce "secondary" spark discharges.

The energy stored on a conducting object depends on its capacitance and the square of the voltage to which it is raised, and it is easy to envisage spark energies of a few tens of milliJoules for conducting patches on insulating bags, people, and moveable objects in the area.

If the bag receiving the powder is made from a conducting material which is connected to earth, then brush and propagating brush discharges from the bag fabric are no longer possible. External bag contamination and external object charging by induction are also no longer relevant. If the bag is not earthed or becomes disconnected from earth, then energetic spark discharges can occur under certain conditions.

When an FIBC is emptied, a process which could take as little as 15 s, electrostatic charging mechanisms will again be present. The bag walls—in particular, the bag cone and chute—can charge by triboelectrification, and the powder too will acquire net charge, but only where individual particles contact the bag.

If the powder was highly charged before emptying began, then the removal of the powder (and charge) may expose an oppositely charged bag fabric—such charge being previously masked. This mechanism could apply both to conducting and insulating FIBCs.

As a consequence of the above, a number of approaches have been taken to reduce or eliminate the electrostatic hazard associated with the use of FIBC's in sensitive flammable atmospheres [1]–[3].

II. Samples Under Test

From the point of view of electrostatic ignition hazard, FIBCs can be categorized into four distinct types by mode of construction:

- Type A which have no special safety precautions;
- Type B where the wall fabric has a breakdown voltage of 4 kV or less;
- Type C having interconnected conductive threads or fabric which are earthed;
- Type D with conductive threads that are not interconnected and, it is claimed, do not require earthing; this type may also have a partially conductive coating.

During this study, electrostatic ignition tests were performed on types A, C, and D. The type-C bag tested here comprised interconnected metallic threads spaced 15–20 mm apart. Previous tests had indicated that this design was safe for use in flammable atmospheres down to 0.25 mJ when earthed [4]. The type-D bag under test had also been subjected to electrostatic testing [5] and was claimed by the manufacturer to be safe for use in such atmospheres *without* an applied earth.

The tests performed are detailed in the following sections of the paper. Conclusions from this study as to the suitability of the bags for various sensitive flammable environments are also given.

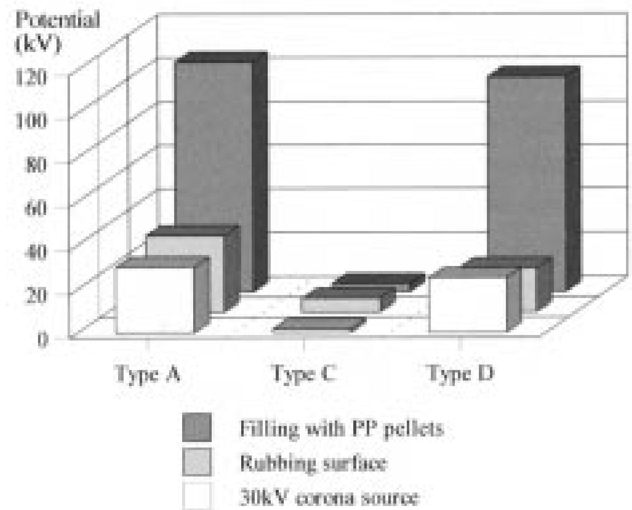

Fig. 1. Electrostatic potentials developed on FIBC surface by various charge-generation mechanisms.

III. Electrostatic Charging of FIBCs, Surface Potentials, and Electric Field

Three methods of charging the sample bags were used in order to obtain data on maximum surface potentials. They were as follows:

1) corona discharge from an array of fine wire filaments taken to −30 kV; the corona was applied to the outside of the bag;
2) rubbing the outer bag surface with a variety of fabrics;
3) filling the bag with electrostatically charged polypropylene pellets via an industrial pneumatic conveying system.

A. Corona Charging

Each of the samples was in turn supported on a metal test frame and corona was applied to the outer surface of the test samples using a voltage of −30 kV applied to an array (brush) of fine filaments. Electrostatic charge retained on the surface of the bag was then quantified using a static monitor.

In the case of the plain type-A bag (nonantistatic), this was an effective way of applying a high level of surface charge. The type-D bag could also be effectively charged in this way when supported in the test frame unearthed.

In both cases, electrostatic discharges could be obtained from the bag surface after the application of charge (see Sections III-D).

With the type-C bag, the electrostatic potentials developed on the exterior surface were found to be relatively low and independent of the applied corona voltage. The corona charging test for the type C bag was extended to an applied voltage of −60 kV in order to fully evaluate this "self-limiting" property. Fig. 1 shows the voltages developed on the bag surface. Despite applying a 60-kV corona voltage, the surface potential was limited to around 1.5 kV. No electrostatic discharges could be obtained at any time with the grounded type-C bag.

This self-limiting of the FIBC's surface potential during corona charging was almost certainly due to the ionic current from the corona source flowing directly to the conductive threads in the bag weave. It illustrates that corona charging is not a suitable method of simulating the electrostatic charging of the bag in use since both the rubbing and filling operations produced significantly higher potentials (as indicated below).

B. Electrostatic Charge Generated by Rubbing

Fig. 1 also shows how the grounded type-C bag can acquire electrostatic charge by vigorous rubbing of the outer surface using a variety of textiles. In this case, surface potentials of up to 6.3 kV could be produced (with a 50/50 acrylic–cotton cloth). The values of potential obtained during this trial were found to be dependent on the bag type, which part of the bag was rubbed, and the textile material used in the rubbing operation. No electrostatic discharges were obtained with the grounded type-C bag as a result of charging in this way.

As expected, the plain polypropylene bag (type A) could be charged to a considerably higher level of around 35 kV by this method. The unearthed type-D bag could also be highly charged by rubbing the outer surface, resulting in potentials as high as 20 kV.

It is considered that rubbing the bag material in this way is a more efficient charge generator than a corona source, particularly in the case of the grounded type-C bags. Rubbing of the surface enables electrostatic charge to be produced on the bag material between the conductive threads, whereas corona ions tend to be deflected away from these regions directly to the threads and then to earth.

C. Filling the Bags with Polypropylene Pellets

Here, the bags were suspended and filled with 4-mm-diameter polypropylene pellets via a pneumatic conveying system at an industrial test site. As each pellet carries an electrostatic charge which builds up as the pellets are bulked together in the bag, this process is an efficient way of generating charge and results in extremely high surface potentials on nonantistatic bags.

The earthed type-C bag performed extremely well in these trials, giving surface potentials during and after filling of up to around 3.8 kV (see Fig. 1).

The plain polypropylene type-A bag gave very high surface potentials of the order -100 kV or greater. The unearthed type-D bag also gave similarly high potentials of around -100 kV. Types A and D both gave rise to numerous energetic brush discharges during these tests.

D. Electrostatic Charge Transfer from Brush Discharges from the Bag Surface

Measurement of the electrostatic charge transferred in a spark or brush discharge (in nanoCoulombs) is an established technique which gives an indication of the incendivity of the discharge.

With the bag samples under test charged by the methods described in Sections III-A–III-C, electrostatic discharges were promoted from the outer surface of the bag by an approaching probe incorporating a 15-mm-diameter ball electrode held at virtual earth. In the event of a discharge to the electrode from the bag surface, the total charge transferred was recorded via a capacitor and high impedance buffer onto a digital storage oscilloscope.

A rough equivalent in terms of discharge energy was then obtained from the empirical relationship determined by Glor *et al.* and Gibson *et al.* [6], [7]. This equivalent energy value was compared to the minimum ignition energy of the flammable atmosphere being considered.

With the grounded type-C bag samples, no discharges were achieved during the corona charging and rubbing trials. The pellet filling trials, however, did produce some intermittent brush discharges of very low energy in the range 5–15 nC, equivalent to an energy content of less than 0.1 mJ.

The type-D bag produced significantly more energetic discharges ranging from maxima of 60 nC in the rubbing trials to 300 nC in the filling trials. These charge transfer values are equivalent to around 0.3–3.0 mJ of energy.

This level of discharge energy would normally be sufficient to ignite many hydrocarbon vapors and perhaps even sensitive dusts. The nature of the discharge from the type-D bag under test, however, was observed to be relatively slow, with a rise time measured at around 30 ms. The increased discharge time was due to the partial conductivity of the bag surface. As to whether these discharges constitute an ignition hazard was answered in the ignition trials which are detailed in the next section of this paper.

The type-A bags produced energetic discharges with all three charging methods. During the pellet filling trials, electrostatic charge transfers of as high as 400 nC were recorded.

IV. Gas Ignition Tests

Ignition trials using a "gas probe" were performed under controlled humidity conditions by erecting a tented enclosure around the FIBC and pneumatic conveying rig and incorporating an industrial dehumidifier unit. In this regime, the relative humidity was maintained at 38%–45%.

The gas probe comprises an acrylic tube terminating in a chamber filled with small polypropylene beads. An earthed metal ball electrode of 15.8-mm diameter is mounted such that it slightly protrudes from the chamber. A propane–air mixture is fed in along the tube to the vicinity of the electrode. Electrostatic discharges are promoted from the bag to the electrode by the approaching probe. If the discharge energy exceeds the minimum ignition energy of the localized gas mixture, ignition may result.

The most sensitive propane–air mixture that can be ignited with an electrostatic discharge is around 0.25 mJ [8]. In order to achieve lower ignition energies, for example, 0.12 mJ, it is necessary to increase the concentration of oxygen relative to the other gases.

For a flammable atmosphere of 0.25 mJ the relative gas proportions by volume are as follows:

$$\begin{aligned}
\text{propane concentration} &= 5.5\% \\
\text{oxygen concentration} &= 19.8\% \\
\text{nitrogen concentration} &= 74.7\%.
\end{aligned}$$

TABLE I
SUMMARY OF BAG PERFORMANCE IN RESPECT TO ELECTROSTATIC DISCHARGE AND IGNITION

FIBC	Description	Maximum discharge[1] (nC)			Gas probe ignition (bag surface)		Gas probe ignition (isolated metal)[2]		
		Corona	Rubbing	Filling	0.25 mJ	0.12 mJ	1.5 mJ	0.25 mJ	0.12 mJ
Type A	Plain polypropylene weave (non-antistatic)	-	-	400	yes	yes	-	-	-
Type C	Polypropylene weave with earthed interconnected metal threads	0	0	12	no	no	no	no	no
Type D	Polypropylene weave with non-grounded conductive threads and partially conductive coating	120	60	300	no	yes	yes	yes	yes

Notes: [1]Charge transferred in electrostatic discharge from bag surface for the three charging generation mechanisms
[2]Metal clip resting against bag surface. Capacitance measured at 4.0 picoFarads.
Dash (-) in any column indicates no data obtained for this test condition.

In order to obtain a mixture with a minimum ignition energy of below 0.25 mJ, it is necessary to increase the ratios of both the oxygen and the propane to the total mixture.

For a flammable atmosphere of 0.10–0.12 mJ, the relative gas proportions by volume are as follows:

$$\begin{aligned} \text{propane concentration} &= 6.5\% \\ \text{oxygen concentration} &= 24.5\% \\ \text{nitrogen concentration} &= 69.0\%. \end{aligned}$$

The ignition tests performed were undertaken with gas mixtures of ignition energies 0.25 mJ (standard propane–air mixture) and 0.12 mJ (oxygenated propane–air).

Prior to the electrostatic ignition tests on the FIBCs at the lower ignition energy level of 0.12 mJ, the gas probe was calibrated using a low-energy precision spark generator specifically designed for this project.

Using this generator, it was possible to produce electrostatic discharges from a fraction of a milliJoule up to 1.5 mJ in energy content. Care was taken to adopt a discharging potential high enough to avoid quenching effects between the spark generator and the gas probe electrode. Using the gas mixture prescribed for a flammable atmosphere of 0.10–0.12 mJ, it was possible to obtain ignitions down to energy levels of 0.12 mJ discharges from the spark generator.

The test procedure on the bags was as follows.

1) The bag was filled with 4-mm-diameter charged polypropylene pellets using a pneumatic conveying system.
2) The gas ignition probe was presented to the outer surface of the bag.
3) A minimum of 20 approaches of the probe were made to different points on the bag surface.
4) All ignition events were recorded.

In the case of the type-C bags, all samples were earthed as required in normal use. The type-D bags were not earthed.

In addition to direct electrostatic discharges from the bag surface itself, the phenomenon of secondary electrostatic discharges influenced by the potential and electric field from the external bag surface was also investigated.

These tests involved using the gas probe to measure spark incendivity both directly from the bag and from secondary discharges from a small metal clip measuring just a few square centimeters in contact with the bag.

In the case of the type-C bag, maximum potentials recorded on the outer surface of the bag reached -2.2 kV. There were no gas probe ignitions at 0.12 mJ from the bag surface during any of the bag filling or emptying operations.

The type-D bag produced potentials of around 100 kV during both filling and emptying and produced one gas probe ignition at 0.12 mJ directly from the bag surface. No direct ignitions were produced at 0.25 mJ.

Gas-probe ignition tests obtained from discharges from the small metal clip in contact with the external bag surface produced no ignitions at 0.12 mJ from the type-C bag. With the type-D bag, however, numerous ignitions were obtained with the 0.25 mJ gas mixture during both bag filling and emptying operations.

As a result of these findings, further ignition tests were undertaken on the type-D bag with a desensitized gas mixture. By reducing the propane content in air from 5.5% to 3.3%, a gas mixture of minimum ignition energy 1.5 mJ was produced. This was checked using the calibrated spark gap as earlier described. Despite this relatively high ignition energy, ignitions could still be obtained from the clip when resting against the surface of the type-D bag.

It was not possible to extend the ignition trials to encompass spark energy levels in excess of 1.5 mJ as there was no means of calibrating the gas probe at higher ignition energy levels. A calculation of available spark energy from the clip is possible, however, by taking into account the clip capacitance (4 pF) and the bag voltage ($\simeq$100 kV). This gives a spark energy value of around 20 mJ for the type-D bag. The same calculation for the type-C bag yields a spark energy of 0.08 mJ (based on a maximum recorded voltage of 6.3 kV during the rubbing trials).

The results from the gas ignition trials are tabulated together in Table I.

V. Summary of Results and Conclusions from the Study

When considering the hazard due to electrostatic discharges directly from the external surface of an FIBC, the results from this study have corroborated earlier findings on the type-C bag by demonstrating its safe use with materials and atmospheres exhibiting an ignition energy of 0.25 mJ or greater. In addition, the study has also demonstrated that this type of bag is an appropriate choice for use in atmospheres where the minimum ignition energy may be as low as 0.12 mJ. Methanol, a commonly used industrial solvent with a minimum ignition energy of 0.14 mJ, is an example of such a material.

The mode of construction of the type-C bag produces a Faraday-cage effect which reduces the electrostatic potential on the outer surface of the bag. Consequently, this has the effect of reducing the electric field in the space around the bag which might otherwise give rise to hazards from "secondary" discharges as the result of personnel and objects becoming charged by induction or through contact.

The type-D FIBC was subjected to the same tests but produced fairly high potentials and relatively energetic electrostatic discharges from the bag surface. These surface discharges were found to be nonincentive when tested with the 0.25-mJ gas mixture, but did ignite a 0.12-mJ mixture on one occasion during the gas-probe trials.

When unearthed, the type-D design does not produce a Faraday-cage or "shielding" effect. The consequence of this is that nearby personnel, objects, and even contamination present on the outer surface of the bag can become highly charged and give rise to "secondary" electrostatic spark discharges which present an ignition hazard when in the presence of flammable vapors and dust clouds.

This was borne out in the ignition tests performed during this study when it was shown to be possible to ignite flammable gas mixtures with electrostatic discharges from a small object in contact with the bag.

Many FIBC operations involve emptying the bag contents into a vessel containing solvent vapors. These vapors are then displaced by the FIBC contents, often producing an optimum flammable concentration around the outside of the bag. The Faraday-cage or shielding effect produced by the earthed type-C bag ensures that this region is not influenced by the electrostatic activity within the bag. This does not apply to unearthed "antistatic" type-D bags and, therefore, the risk of secondary electrostatic discharge and subsequent ignition remains a possibility.

Very small objects such as the metal clip investigated during this test program will often be overlooked when earthing procedures are applied in environments containing flammable atmospheres. Despite its small size, such an object can theoretically, in the case of the unearthed bag, produce an electrostatic spark discharge of up to 20 mJ. A spark of this energy can ignite virtually all flammable hydrocarbon vapors and gases and many common industrial dusts, such as powder coatings, metal powders, and some foodstuffs [9].

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