STATIC HAZARDS USING FLEXIBLE INTERMEDIATE BULK CONTAINERS FOR POWDER HANDLING

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FIBC use is increasing rapidly owing principally to improved handling efficiency and product quality improvement. However, selection of the proper FIBC has many aspects, of which safety is paramount. Numerous accidents have occurred when emptying flammable powders from FIBCs, both with and without flammable vapors additionally present. Owing to the mode of operation and speed of emptying, not only is there a high probability of static generation but also a high probability of one or more operators being in the flash fire zone should ignition occur. Apart from the flash fire produced by a dust cloud and/or flammable vapors displaced from a receiving vessel, a flame may in some cases propagate into the FIBC, which might then explode. This paper discusses the FIBC selection problem, a series of case histories, and available literature. Since no FIBC loading incidents are known, the paper will focus on emptying. In particular it should be appreciated that the potential for operator grounding error and sudden nemesis can be very high.

INTRODUCTION

FIBCs are flexible, rectilinear containers constructed of woven plastic with a suitable liner. The typical FIBC is made of woven polypropylene with a polyolefin liner, and has a capacity of 300-500 kg. Various designs exist for the basic container and grounding arrangements (if any), and larger capacities are also available. FIBCs are often discarded after first use, both for quality reasons and possible degradation of grounding elements. Examples of the latter include the erosion of aluminized conductive liners by product flow and spout flexion, and the breakage of metallic filaments during loading and handling cycles. FIBCs are fully collapsible for easy storage and once used can be folded again, hence the name "Flexible Intermediate Bulk Container".

It was known in the 1970s that plastic containers for powders could be hazardous due to formation of capacitor-like layers of charge across the walls during filling. The countercharge on the outside wall might appear, for example, via static discharges to a metal support frame. Blythe and Reddish [1979] described the formation of propagating brush discharges across the 5 mm thick wall of a polyethylene tote bin being filled with coarse (1 mm radius) polypropylene granules. The bin's dimensions were 1x1x2 meters, therefore it had about twice the volume of a typical 300-500 kg FIBC. A severe electric shock of the order 1 Joule could be experienced by an employee reaching into the bin and shorting the capacitor formed across the plastic walls. While not relevant in this instance, these and less energetic (brush) discharges could also represent an ignition hazard. This case does not translate directly to typical FIBCs, which have thinner walls and are usually smaller. However, 1000 kg FIBCs are available with similar or even larger dimensions, as described by Dahn et al [1991].

FIBC advantages include more efficient handling with an associated benefit in improved product quality. Typically 300-500 kg of product can be transferred in about 30 seconds or less from a single FIBC. This has obvious setbacks in terms of static generation, and less obvious setbacks in terms of displacing flammable vapor from a receiving vessel or entraining air into its inerted vapor space. An operator typically stands next to the FIBC during emptying, first to untie the strings and later to shake out residual powder. Should ignition occur the operator is likely to be in a flash-fire zone. Furthermore, a dust deflagration of residual fines could propagate into the

FIBC, which might explode. The situation could be exacerbated if flammable vapor enters the FIBC during unloading; failure to untie the top vent of the FIBC could be a contributing factor here.

There have been a number of fires involving FIBCs of various designs. One repeated course of events has been that within a few weeks or months of changing from bag transfer to FIBC transfer a fire has occurred, often with burn injuries to one or more operators. It is essential to recognize the differences between FIBC and smaller volume transfers from bags or fiber drums. For a start the following check list might be considered:

- Have the ignition properties of the powder (such as its ignition energy) been determined?
- Could degradation of the product during handling and storage affect its ignition properties?
- Will the customer handle or empty the FIBC in a flammable atmosphere?
- If safe design requires a thin-walled 100% plastic FIBC, will this provide an adequate moisture barrier for the product?
- Is there the possibility of wet patches on 100% plastic FIBCs acting as spark sources?
- If safe design requires a more expensive conductive or antistatic FIBC instead of 100% plastic, will this still be cost effective versus bags or fiber drums?
- Will a conductive or antistatic FIBC contaminate the product with carbon or metal?
- Could the product cause degradation of the conductive elements (residual acid etc)?
- Can a conductive or antistatic FIBC be supplied with a suitable 100% polyolefin or other compatible lining and still be safe?
- Was the FIBC design and any limitations on use developed from proper testing?
- Is there adequate quality control to ensure the FIBC can be properly grounded?
- Is the grounding point well marked and robust?
- Does the conductive or antistatic FIBC have conductive slings to mitigate operator grounding error?
- What are the FIBC recycling problems associated with metallic elements versus other types?

In keeping with CMA "Responsible Care" objectives, suppliers of products in FIBCs should attempt to give guidance on handling practices where appropriate. For example, if a customer is pouring from a 100% plastic FIBC into a flammable solvent, and proper inerting practices are not being used, there is a high probability of an accident plus litigation in the near future. Customers should be made aware of the absolute necessity to ensure proper grounding is used where flammable atmospheres might be present. If minimum safe practices cannot be established, suppliers should consider refusing to supply in FIBCs.

Terms Used

(1) 100% Plastic FIBC. Collapsible, rectilinear plastic containers typically holding 300-1000 kg of powder and available in a variety of styles. The typical design comprises a bi-directional polypropylene weave plus a facing of polypropylene or polyethylene film of specified thickness on one or both sides. The containers are fitted with reinforced plastic slings for hoisting. While they may be nitrogen purged prior to filling, they cannot be grounded and in common with other FIBCs, powder flow during emptying may entrain ambient air into inerted equipment

(2) Antistatic FIBC. Fabric usually contains conductive threads or aluminized surfaces that are electrically connected to one or more grounding connections. Conductive threads may run in the warp or weft direction, or both. Antistatic FIBCs have also been produced with topical antistatic coatings or with ungrounded systems of isolated conductive threads, which limit charge accumulation by corona discharge and have an intrinsically low capacitance.

(3) Fully Conductive. FIBCs that contain sufficiently high loadings of conductive material (typically carbon black) to render the plastic everywhere conductive (typical fillers are discussed by Whitaker 1989). To avoid product contamination, thin non-conductive linings such as 100% polyolefin might be incorporated if testing reveals this to be safe.

(4) Flammable. In this paper the term means "capable of deflagrating as a suspension in air, whether a gas, vapor or powder".

Types of Static Discharge

For an illustration of the effective energy levels of the following types of discharge, see Figure 1.

Figure 1: Effective Energy Levels. Materials at Risk of Ignition, and Types of Ignition Source
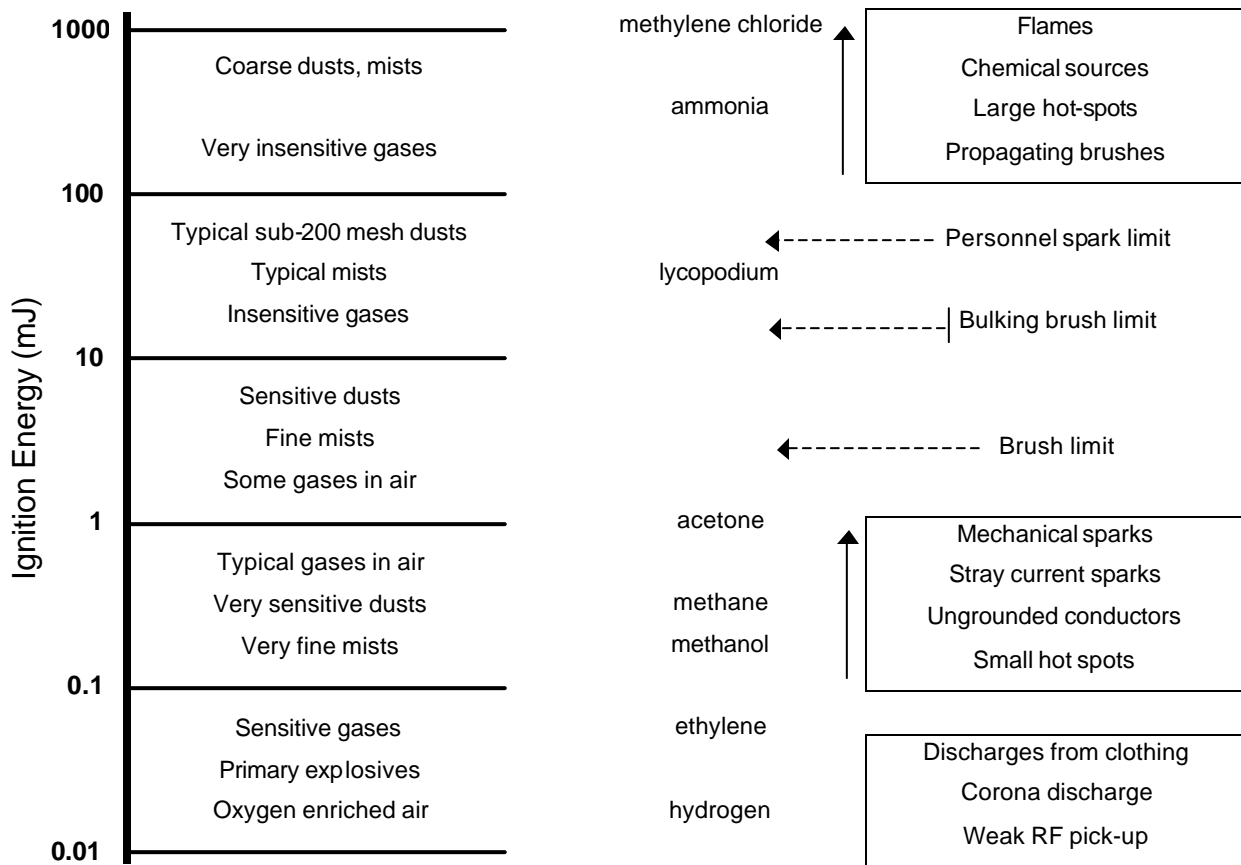
(1) Corona Discharge

Corona discharges are formed in the divergent field between a charged surface and a conductor having a radius of curvature less than about 3 mm. They consist of a rapid succession of weak pulses and have a very low effective energy. In FIBC operations, corona represents a safe means of dissipating charge. Only very sensitive materials should be at risk of ignition.

(2) Brush Discharge

Brush discharges are formed in the divergent field between a charged surface and a conductor having a radius of curvature more than about 3 mm. They can be formed by rubbing (tribocharging) a plastic surface or by introducing charged material into a plastic container. Brush discharges have been shown to carry effective energies up to about 4 mJ in so far as they can ignite gas-air mixtures with MIEs up to this level [Glor 1981]. Neglecting primary explosives and other sensitive materials that would not be transported in FIBCs, powder ignition by a brush discharge in air has never been reported. It is believed that powder ignition may be possible in the presence of flammable gas concentrations at a fraction of the gas LFL (nominally at 1O-20% LFL). Thus, hybrid mixtures where the gas concentration is below its LFL may be at risk. This includes powders that may desorb solvents or slowly decompose in storage.

Note: A number of authors have raised the possibility of ignition of "sensitive" powders by these discharges, although experiments to demonstrate this have been uniformly negative [Britton 1988]. Recently Schwenzfeuer and Glor [1993] ignited sulfur dust by rerouting the charge from a brush discharge through a spark gap contained in a Hartmann ignition tube. However, although this secondary spark dissipated less energy than the total available from the original brush discharge, its characteristics (such as energy density) were radically changed. The ignition process resembled a practical case reported by Britton and Kirby [1989], in which a likely scenario involved charge collection from some type of brush discharge and subsequent sparking from a poorly grounded cable support. Thus, there is still no indication that any powder that would be handled in FIBCs should be directly at risk from brush discharges, provided no flammable gas or vapor is present.

(3) Bulking Brush Discharge (Also known as Conical Pile, Maurer or Cone Discharge)

This is the large discharge type seen during silo filling and results when the dispersed, charged powder "bulks" in the container and its charge is concentrated. Infrequent surface flashes up to several feet long are observed in large containers being filled with granules or pellets having a bulk resistivity above 10^{10} Ohm-m. [Glor 1987]. Bulking brushes are believed to have an effective energy up to about 10 mJ (depending on the test method used to establish MIE for the dust concerned) and are believed responsible for fine dust explosions in grounded silos. This finding is based on analyses of silo explosions where ungrounded objects and other ignition sources could be confidently eliminated. A rule of thumb might be that dusts with MIEs less than lycopodium (*lycopodium clavatum spore*) should be considered at risk from these discharges. This approach avoids some of the problems associated with the variety of MIE test methods currently in use. Britton [1992] reviewed published MIE values for lycopodium varying from 2 mJ up to about 50 mJ depending on the test equipment used and ignition probability involved. In view of such differences for a dust having almost constant characteristics, reference to a maximum "effective energy" of bulking brush discharges can be misleading.

Bulking brush discharges have not been reported in small containers of the size of 300-500 kg FIBCs, and a bulking volume above 1 m^3 (35 ft^3) has been theorized to be needed [Rogers 1991, Bruderer 1992]. Dahn et al [1991] believe such a discharge might have occurred during FIBC filling at high rates of charging. However, this was inferred rather than observed, and the FIBCs investigated by Dahn et al. were unusually large, reported to be 2.6 meters high by 1.6 meters square (2000 lb capacity). A further consideration is that the phenomenon is only observed with relatively coarse powder above 100 microns [Glor 1987], and such particles would normally be too large to have a MIE less than 10 mJ. For ignition one would need to advocate unusually high charging rates during FIBC filling and the powder to contain mostly coarse particles plus an easily ignited fine

fraction. FIBCs significantly larger than 1 m^3 might pose an ignition risk to sensitive powders via this phenomenon, although no case histories are available.

(4) Propagating Brush Discharge

This is a very energetic discharge (effective energy of the order 1000 mJ) produced when an electrical double layer (capacitor) is produced across an insulating surface. It has been theorized that it might be produced during FIBC filling, should the charge on the inner bag wall attract an opposite sign of charge onto the outer wall (for example via corona discharge to a nearby conductor). Charge continues to accumulate on either side of the wall until the insulating wall breaks down under the resulting electric field. This causes massive lateral discharge to the puncture point. Alternatively, the discharge may be initiated by mechanical stress to the wall or by approach of a discharge electrode. It has been theorized that the discharge could also occur on the FIBC spout during emptying. The author has found little evidence for the production of such discharges in FIBCs except as reported by Blythe and Reddish [1979] and inferred by Maurer [1992] from an examination of pinholes and powder patterns on used FIBCs.

The phenomenon is affected by the rate of charging, the duration of charging, the dielectric strength of the wall and the wall thickness. Experiments by Glor [1989b] have shown that if a plastic layer has a breakdown voltage less than 4 kV, propagating brushes cannot be produced.

(5) Spark Discharge

Sparks will ignite powders depending on the stored energy and the MIE of the powder. Hybrid mixtures are particularly at risk from small sparks. Sources of sparks are ungrounded operators and equipment, ungrounded FIBCs, and grounded FIBCs that have a discontinuity in their grounding elements. Sparks may be possible from power electrical sources such as fork lift trucks and hoists. They may occur directly from the surface of charged conductive powder in a plastic FIBC. This may be due to an inherent powder bulk resistivity less than 1×10^6 O.m [Rogers, 1991] or might possibly take place from damp product. Finally, wet patches on the surface of a plastic FIBC might give rise to sparks via induction charging (see Incident "B" below).

SUMMARIES OF SOME RECENT INCIDENTS

(Caution: In no case is a completely definitive account available and therefore the incidents are discussed in terms of "scenarios" rather than "causes". All of the following FIBC incidents occurred in the U.S. between 1988 and 1991).

(Incident A.1: 1988)

An antistatic FIBC was used to transfer a vinyl resin to a 6000 gallon mixing tank containing a xylene-MEK mixture. The FIBC was woven polypropylene with a 1 mil internal polypropylene coating. It was equipped with thin conductive wires running lengthwise through the spout and connected to a bare stranded aluminum wire and alligator clip. The FIBC was hoisted above the tank using a forklift and the resin was dumped through a circular port on a hinged tank cover.

The tank was inerted at 15 SCF/min with combustion gas (mainly CO_2) introduced through a flow meter. There was no independent venting of displaced vapor and the tank lid was not gas tight.

The operator reported that the ground wire was missing from the FIBC but he proceeded to unload the FIBC anyway. The hinged portion of the tank lid was open allowing solvent vapor to escape freely into the operating area.

Accounts at this point differed as to whether the fire occurred immediately or after the FIBC was about three-quarters empty. In any case, the operator was standing a few feet from the tank and turned away when he observed a flash. The side of his head was singed, the back of his neck was burned and he received 2nd degree burns on his right arm. The flash was outside the tank and the tank contents did not catch fire. The operator was disciplined for failure to follow safety procedures. After the second fire (A.2) he voluntarily quit owing to apprehensiveness of the job.

The source of ignition was assumed to be a spark from the ungrounded FIBC during emptying. Since it was known that the vinyl resin had a very high MIE in air, it could be assumed that flammable vapor was a major contributor to the ignition process. Although the operator was not grounded, he was not considered a likely source of a spark owing to his location. Since the operation involved making lacquer for can coatings, antistatic shoes would probably have been ineffective owing to the possibility of a film of lacquer on the floor around the tank.

FIBCs had been used at this location since January 1988. Between this incident and the next (October) some 70-80 batches were produced without problem using six FIBCs per batch.

(Incident A.2: 1988)

This incident was similar to the previous one except that the FIBC was designed with an internal conductive aluminum liner bonded to the polypropylene in the spout. This was connected to an external grounding tab to which a grounding clip was to be connected by the operator.

The FIBC was suspended over the tank as before, and after applying the grounding clip the discharge spout was pushed through the port in the tank manway so that it extended 10-12 inches inside the tank. The draw cord was then cut to open the spout and release vinyl resin into the tank. The FIBC was not opened at the top to vent the contents and prevent drawing vapor into the FIBC. On this occasion, flow was delayed and the operator "puffed" the FIBC to free the flow. Within 10 seconds of flow a flash fire occurred. Failure to vent the FIBC was not believed a contributing factor as there was no fire or explosion inside it.

The operator was standing close to the FIBC but not touching it. He received 2nd and 3rd degree burns to stomach and face and entered a burn unit. Although the 165°F sprinkler heads above the tank were not actuated, pallets of vinyl resin bags had their outer paper layers singed at a distance of 20-30 feet from the tank. Although the hinged lid was closed, there was again no provision for venting either the purge gas or the air entrained into the tank by the powder flow. A significant displacement of flammable vapor therefore took place into the operating area.

It was reported that the grounding connection had been properly made, although this could not be completely ascertained. The grounding clip was unavailable for examination but it might have been disabled by lacquer accumulation. A FIBC manufacturing error causing loss of continuity could not be ruled out since the FIBC involved was destroyed in the fire.

(Incident B: 1989)

An organic herbicide formulation comprising 6-8 micron particles was supplied in 1000 lb, 100% plastic FIBCs by a supplier. The FIBC was lifted by hoist and set over a dump station to flow by gravity through a 15 foot long, 18 inch diameter steel chute into a weigh bin with an attached dust collector.

Generally the FIBC needed to be beaten with a rod to loosen the material so it would flow out of the FIBC. In the subsequent step the active ingredient was charged to a liquid mix vessel. There were no flammable liquids involved.

An employee started dumping a FIBC and as he turned away heard a mild roar and on turning saw the FIBC emptying extremely fast. As it emptied completely he saw a mushroom cloud of smoke around the FIBC and then a wall of flame traveling very fast towards him. A second employee some 20 feet away heard a rumble and on turning saw a fireball engulfing the dumping station area. He was knocked to the floor by the pressure wave. A third employee some 40 feet away heard a loud bang and saw a wall of flame 1O-15 feet high rolling towards him. Two other employees on the floor below observed the events.

The first two employees were seriously injured, one with second degree burns over 22% of his body and the other being released some hours later for outpatient care. Another employee was briefly hospitalized as a precautionary measure for possible smoke and dust inhalation. Losses were also incurred due to flash fire damage to equipment and utilities, plus structural damage to the building walls and ventilation ductwork due to overpressure.

A possible scenario was that the FIBC may have been wet due to rain entering the supplier's truck. This may have created a conductive patch on the FIBC capable of yielding sparks. For further discussion of incident scenarios, see Incident "C" where the same material was involved.

(Incident C: 1989)

The same herbicide powder as in case (B) was being discharged from a 100% plastic FIBC through a dump station directly into a weigh bin. There were no flammable liquids involved. A deflagration occurred after the FIBC emptied at an unusually high flow rate. Other factors resembled Incident B.

Owing to the presence of rupture panels on the dust collector and possibly other factors there was no overpressure damage as in Incident B.

An initial scenario involved some ungrounded baghouse component. There was also some suspicion that the herbicide batches in this and Incident "B" were unusually fresh (days rather than months between synthesis and consumption) and that this might explain unusual behavior. For example, the observed high flow rates plus an unusually low MIE might create the right conditions for static ignition. Since the herbicide was subject to decomposition, the possibility of gas evolution and hybrid mixture ignition was raised.

(Incident D: 1990)

A 3000 gallon toluene mixing vessel was inerted with nitrogen and the metered toluene flow was started. Shortly after midnight an operator began dumping the first of several 1500 lb FIBCs of resin into the open manway (before the introduction of FIBCs they had used 50 lb bags). The FIBC was hung from a frame on a davit over the manway and was designed with special grounding straps. The bottom had a 14 inch chute extended into the 20 inch manway which was opened with a quick release tie that allowed FIBC emptying in 20-30 seconds.

A statement by one of the injured employees says that he saw static sparks at the bottom end of the FIBC as it flopped around while unloading and then he found himself on fire.

Two loaders sustained second and third degree burns of the face and body. Site damage included bowing of masonry walls and a section of the roof directly over the vessel was blown out and a roof fire

burned for 45 minutes. Minor fire damage was sustained by wiring and transfer piping, and many windows in the room were broken.

Investigation could not ascertain the condition of the ground connection on the FIBC owing to fire damage, although employees stated the connection had been properly made.

The apparent source of ignition was static discharge between the FIBC and the manway due to improper ground connection or a faulty grounding system.

FIBC use was suspended pending evaluation and OSHA investigation. The company involved developed the following recommendations to prevent reoccurrence:

a) Require a fixed continuous alarmed monitoring system for assuring an oxygen free atmosphere in the vessel.
b) Entrance nozzles for solvent charging into vessels should be oriented in the opposite quadrant from the open manway to prevent venting of vapors from the manway
c) Assure continuity of the ground connection between the FIBC and the vessel with an indicating ground connection system.
d) Revise batch operating procedures to require completion of solvent additions and reconfirmation of the inert gas pad before starting other additions.
e) Be certain that the procedures list any safety concerns involved with each operating step.
f) Provide a properly sized ventilation system for displaced vapors from solids charging additions.
g) Use a closed system when uniformly feeding solids into the vessel.

(Incident E: 1991)

A company was in the process of reworking sixty 960 lb, 100% plastic FIBCs filled with product which had fallen out of viscosity specifications in inventory. To rework the material it was first transferred from the FIBCs into 41 gallon fiber drums. To empty a FIBC it was hoisted on a track and moved over a row of seven fiber drums on the concrete floor of the loading room. While one operator worked the hoist a second held two vacuum hoses near the top of each fiber drum to minimize dust leakage into the room. A third operator regulated flow from the FIBC. Forty FIBCs were successfully emptied and repackaged into fiber drums.

At the time of the incident the 7th fiber drum was being filled and the FIBC was being "puffed" to shake out residual powder. After sensing vibrations and heat, the three operators observed the material on fire in the fiber drum. The flame propagated into the FIBC via the spout and all three operators received 1st degree burns on the hands and face, plus singeing of hair. <u>There were no flammable vapors involved</u>.

Owing to several potential sources of ignition in the area it was not possible to identify the ignition source with certainty. It was clear that "puffing" the FIBC when almost empty created a cloud of fine dust particles and it was noted that humidity was low at the time of the incident. The operators and fiber drums were not grounded and a spark may have occurred between the operator holding the vacuum hoses and the ungrounded top chime of the fiber drum. The vacuum hoses were non-conductive and the operators reported previous shocks from these hoses. Finally, the hoist controls were not of intrinsically safe design for a flammable dust environment.

(Incident F: 1991)

Three people were injured in a dust explosion during unloading of an additive from a 2000 lb FIBC. A preliminary account indicated that all three were in serious condition and were undergoing skin grafting. <u>There were no flammable vapors involved.</u>

It is believed but unconfirmed that the FIBC was of the antistatic type, containing some type of grounding element. An initial scenario under investigation involved the absence of proper grounding at the time of the incident. No further information is available.

LITERATURE SUMMARIES

The following literature summaries are given chronologically.

<u>Petino and Grelecki [1986]:</u>

Emptying tests were made with polyethylene prills from several designs of FIBC, the objective being to select the design giving the lowest apparent spout potential as inferred from an electric field reading (3M "703" static meter). Grounded, aluminized linings proved best but FIBC use beyond one dispensing operation was not recommended owing to lining wear. The aluminized lining was most effective when applied to the bottom and spout.

<u>Britton [Union Carbide Unpublished 1989]:</u>

A series of FIBC emptying tests was run under very dry conditions (about 10% relative humidity) inside a large darkroom. Two grades of vinyl resin and three FIBC designs (100% plastic plus two antistatic types) were used. Image intensified photography plus electrostatic and weight-time measurements were carried out as FIBCs were emptied. It was found that with granular vinyl resins very little charge was generated owing apparently to their excellent flow properties, allowing "rat-holing" of the product through the spout. This allowed very little triboelectrification.

The highest electric fields during pouring from 100% plastic FIBCs (100 kV/m) were less than simply hoisting the FIBC from the floor (200 kV/m). Maximum charging took place during low flow rates such as when shaking out a nearly-empty FIBC. Polarity reversals occurred owing to change of contacted surface during flow as the FIBC distended.

The only observed discharge (spark type) occurred when ground connections were deliberately not made on antistatic FIBCs. A potential of about 10 kV was attained on the conductive elements within seconds of flow when grounding was not present on some of the FIBCs examined, a lack of continuity was found from the conductive elements to the grounding point provided on the FIBC.

It was recommended that 100% plastic FIBCs be used for powders in air since grounding arrangements are unnecessary and might fail, producing spark hazards. In the presence of flammable gases, vapors and hybrid mixtures, 100% plastic FIBCs might be hazardous owing to brush discharges. In this case a completely conductive FIBC was preferred provided there was the assurance of proper grounding. Ideally, a closed and inerted powder addition system was recommended both to maintain receiving vessel inerting and to prevent flammable vapor from entering the work area. No recommendation was made regarding a maximum breakdown voltage for the wall material (see Glor 1989b), since at this time there was no evidence that propagating brush discharges could be produced during practical FIBC operations.

Glor [1989a]:

Brush discharges can normally be avoided by keeping the surface resistivity of the plastic below 10^{11} Ohm. In the range 10^9-10^{11} Ohm brush discharges may be avoided under all humidity conditions without the need for grounding. However this only holds for plastic bags up to the size of bin liners for standard 55 gallon drums. In the case of FIBCs the greater charging rate requires a lower surface resistivity of $< 10^8$ Ohm, and this is less than the 10^9 Ohm criterion at which grounding should be used. To prevent brush discharges from FIBCs they must have a ground resistance less than 10^8 Ohm and be grounded.

Figure 1: Glor's Criterion for Propagating Brushes (Schematic)
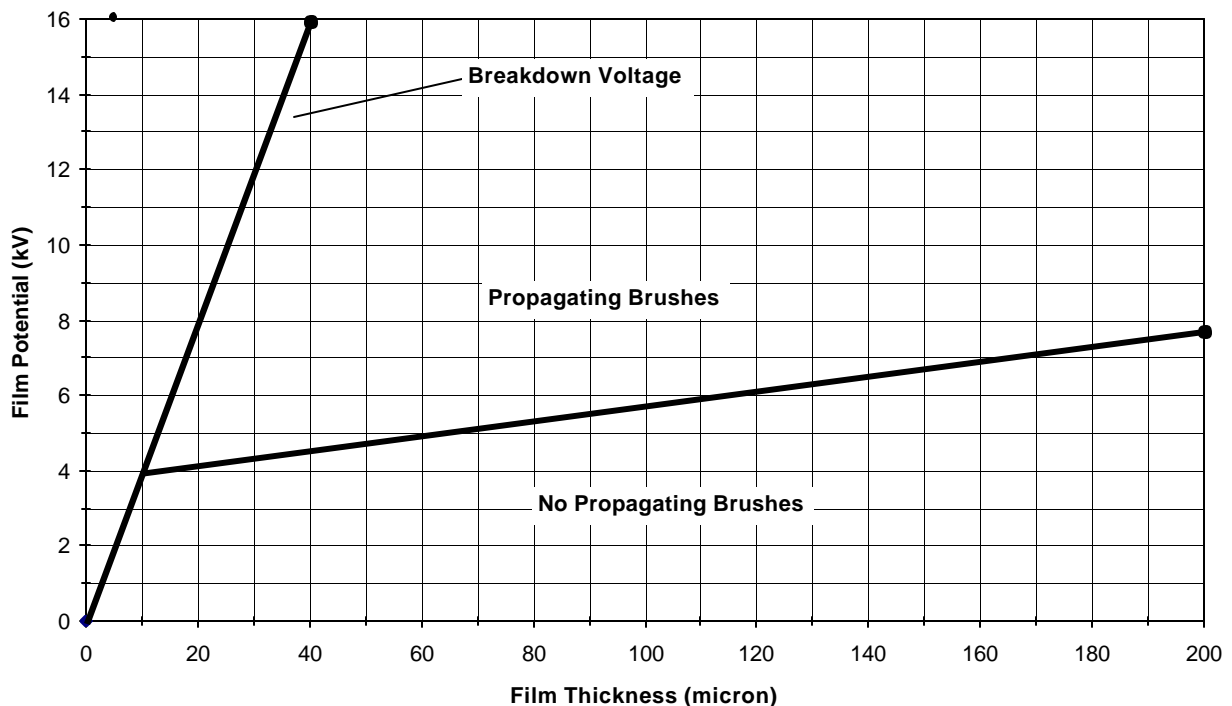
In the past it had been recommended that no more than 50 kg of powder be charged at one time to a vessel containing flammable liquid. This was to prevent discharges from a charged floating pile of powder. The criterion is reasonable for bag additions, which are normally 25 kg per bag. However, it is impossible to load only 50 kg or less from a FIBC so it is recommended the receiving vessel be nitrogen inerted. This must account for air entrained with the powder. Since the FIBC will be in a Zone 1 area of the plant (roughly Class 1, div 1) the 10^8 Ohm resistance criterion given above still applies for an inerted receiving vessel.

Glor [1989b]:

A number of previously published Ciba-Geigy studies were reviewed. The most important contribution was the delineation of conditions required for formation of propagating brush discharges. It was stated that these discharges have been observed from the wall of a FIBC while being filled with highly charged bulk material (possibly in reference to the paper by Blythe and Reddish [1979] as discussed above).

Glor's criterion for propagating brush discharges has become well known in Europe and has been applied to a variety of situations. Figure 2 shows the derived relationship between film potential and layer thickness for propagating brush production. Also shown is the breakdown voltage with respect to film

thickness. Clearly the film potential cannot be above its breakdown voltage. In all cases, propagating brushes could not be produced at film potentials less than 4 kV, so if 100% plastic FIBCs are selected to have wall breakdown voltages less than 4 kV, they are immune to the propagating brush phenomenon. This is independent of the actual wall thickness shown in the figure.

Practical Note: Application of the 4 kV Criterion

With reference to the avoidance of propagating brush discharges using Glor's 4 kV criterion described above, this can be impractical for products that are sensitive to moisture and other degradative effects. A 4 kV breakdown voltage requires that the liner thickness be limited to about 1 mil and this will not usually be sufficient to provide a good moisture barrier. Since the spout receives the highest charging and is folded in shipment, it would appear possible to apply the 4 kV criterion only to the spout in such cases. However, this is not usually amenable to the FIBC manufacturing process.

A related problem is whether the 4 kV criterion should be rigidly adhered to, or whether it might safely be exceeded in some cases. It has been observed that there is a transition region over which the discharges are weak [Luttgens 1992] and therefore not an ignition risk for many powders in air. It is easier said than done to call for testing in this "gray area", since the author is unaware of any direct observations of propagating brush discharges during emptying of FIBCs, whatever their wall thickness. The effective energy of discharges produced from fabric samples under laboratory conditions would be hard to determine and the relevance would in any case be questionable were unrealistic charging methods employed.

A third problem is that the 4 kV criterion is not usually given with respect to a test method for breakdown voltage. Not only must the test employ a uniform field but this must be impressed over a prescribed area of fabric. Also, the value will vary with position and a representative sample must be taken. Since the FIBC outer layer is a weave, it might be considered necessary only to test the inner liner. This is because a fabric containing regular air gaps such as pinholes will not support high surface charge densities and hence the conditions necessary for propagating brushes. However, if tested in series (as used in the FIBC) the two layers will give a higher breakdown voltage than the liner alone, due in part to the additional spacing. If the criterion is used as part of a FIBC specification it is essential to specify the exact test conditions.

The test recommended by Ciba-Geigy [private communication from R. Bruderer] is a variant of DIN 53481 except that in this application DC rather than AC power is used. Ciba-Geigy use a FUG Model HCN 35-35000 high voltage generator, although any suitable DC generator can be used. Test geometry is however critical.

The sample is placed on a circular base (ground) electrode of 75 mm diameter. The upper base perimeter has a radius of curvature of 3 mm, contacting the sample. The high voltage electrode comprises a 25 mm diameter electrode, having a total weight of 674 gm bearing on the sample and the lower perimeter having a radius of curvature of 3 mm (these rounded edges prevent sharp edge contact with the specimen and promote uniform electric fields). The high voltage is exerted across the test sample for a period of 10-20 seconds to determine if breakdown occurs (a suitable current indicating device may be used).

A 20 cm x 20 cm sample no more than 3mm thick is required to check the breakdown voltage. Based on Ciba-Geigy experience, FIBCs constructed with polypropylene-fabric strips with a thin inner coating will meet Type B requirements (see classification under Bruderer 1992) provided the FIBC is not equipped with an additional isolated inner bag or thick linings.

The spark discharging behavior was investigated for 1 m^3 FIBCs constructed of 100% polypropylene or polypropylene containing conductive threads. Since the latter FIBCs are not uniformly conductive, the mechanism of charge reduction by threads was considered to be a combination of conduction, induction and corona discharge. That is, a charge located near to a thread may go to ground via conduction across the fabric to the thread, while a charge located further away is impeded by the high resistance of the fabric but its effect can still be neutralized by inducing an opposite sign of charge on the thread (induction). If the inductive effect is great enough, the thread will lose charge by corona discharge even if the thread is not connected to ground. It was found that although the corona effect can limit the voltage on ungrounded FIBCs of this type, 2-3 kV is needed to induce corona discharge and the FIBC potential always stays above this range whatever the thread weave design.

Two designs using conductive threads were tested. In one case the threads circumscribed the FIBC spaced at 20 mm intervals and were not interconnected. Thus, the FIBC was not designed to be grounded. In the second case the threads were interconnected at the FIBC seams and grounding was required. Measurements showed that the capacitance of single threads was 32 pF and that of the interconnected threads was 259 pF. This latter value is greater than the typical capacitance of a person (100-200 pF).

Ignition tests showed that the 100% polypropylene FIBCs could give brush discharges capable of igniting common solvent vapors in air (Circular fabric specimens 20 cm in diameter were charged negatively and brush discharges drawn from them using grounded electrodes of various diameters).

Sparks from single isolated threads could ignite hydrogen in air above 2 kV but methane in air was not ignited at up to 5.5 kV. It was concluded that common solvent vapors (with MIEs similar to methane) would not be ignited by brush or spark discharges from FIBCs containing isolated threads. This is because during powder emptying trials, a maximum of only 3.5 kV could be generated on such FIBCs due to corona discharge losses. 3.5 kV is far too low for brush discharges and less than the 5.5 kV needed for sparks capable of igniting methane-air. This implies there would be no hazard from using this ungrounded type of FIBC in most flammable gas/vapor atmospheres.

Sparks from interconnected thread matrices could ignite methane in air above 5 kV and powder emptying trials showed up to 6 kV could be generated on the ungrounded thread system. Hence this type of FIBC could not safely be used ungrounded in typical flammable vapor atmospheres.

Rogers [1991]:

The paper first reviewed the different types of discharge possible from FIBCs and suggested that 10 mJ is the maximum effective energy of a bulking brush discharge (no reference to MIE test method). This area of the paper was in broad agreement with other contemporary opinion. Next the benefits and hazards of antistatic FIBCs were discussed. Items:

Early designs of antistatic FIBCs involved systems of metal threads woven into the fabric. These introduced additional hazards by occasionally breaking and forming spark gaps. Polypropylene threads coated with an antistatic showed degradation over time and the coating could leach into the product causing contamination. Another design using a thin metallic foil lining was shown in tests to be prone to breakage of the lining during folding, leading to large isolated conductive areas and generating hazardous spark discharges. The most effective type of FIBC was stated to be a polypropylene type containing conductive threads. However, there are a large number of variations on this basic design.

The several modes of charge neutralization by conductive threads was discussed. The discussion was very similar to that made by Wilson [1989].

ICI conducted tests on a particular design of FIBC using conductive threads and showed that provided charging was not large, a flammable gas with MIE of 0.2 mJ could not be ignited even if the FIBC was ungrounded. "Large" charge densities were considered to occur during milling of polymeric material or in pneumatic conveying. The weave of the conductive thread was crucial in obtaining this result, and the threads had to protrude above the surface of the fabric. This finding was compared with previous work by Wilson and others. The importance of allowing for grounding failure was highlighted, suggesting this be provided via the filling or emptying equipment rather than by manual attachment. The ICI work was later reported in the Journal of Electrostatics [Nelson et al. 1993].

In summary, certain FIBC designs containing conductive threads might be used safely without grounding but only if a specific number, spacing, resistance, capacitance and weave design is adopted. The latest available report [Nelson et al. 1993], implies that further full-scale testing is yet required to verify this.

Ebadat and Cartwright [1991]:

Experiments were carried out with 100% polypropylene FIBC and two types of FIBC containing conductive threads. The scope of test work and results practically duplicated Wilson [1989] although the latter is neither referenced nor discussed.

Dahn et al [1991]:

Experiments conducted in a 100% plastic FIBC of dimensions 2.6 m high by 1.6 m square showed that during loading with 2200 lb of high resistivity powder there was a sudden drop in the field strength above the powder heap when the FIBC was about half full. This was taken as evidence for a bulking brush discharge, since the field was being measured above the center of the heap. Some theoretical evidence was also cited that the FIBC radius was great enough to allow this phenomenon to occur. In separate "inclined chute" tribocharging experiments, the powder was shown to have an unusually high charge-to-mass ratio (2 µC/kg) compared with other powders tested (typically 0.2-0.6 µC/kg).

The conclusions in this reference understate the experimental result with respect to bulking brush discharges. The conclusion might have been made that it appears possible for bulking brush discharges to appear during loading of large FIBCs at high rates of charging. This would suggest that ignition might be possible during loading of easily ignitable powders or for coarse powders containing an easily ignitable fines fraction.

The recommendation was made that even grounded FIBCs should not be used in the presence of flammable solvents or vapors.

Figure 3: Glor-Bruderer Classification

Product ╲ Area		Flammable powder only	Gas or vapor present
	A	B	C
Flammable powder only	B	B	C

A: No special requirements

B: Breakdown voltage < 4 kV

C: Ground resistance < 100 M ?

Bruderer [1992]:

This paper was similar to the earlier one by Glor [1989b] with some additional material. A revised version was later published [Bruderer 1993].

1) Bulking brush discharges are unlikely if the powder bulk is limited to a nominal 1 m^3 (35 ft^3).

2) Propagating brush discharges will not develop if the breakdown voltage of the bag wall does not exceed 4kV. This has been confirmed in a number of tests.

3) All powders having MIE less than 10 J (10000 mJ) are considered explosive.

4) Flammable vapor atmospheres are expected if a liquid is present with a flash point below 55°C.

5) Powders in FIBCs must have solvent contents less than 1wt%.

With reference to Figure 3, type "A" FIBCs (with no grounding elements and unlimited wall breakdown voltage), are applicable only for non-explosive powders (such as pellets or metal oxides) in non-flammable environments. Type "B" FIBCs with the 4 kV maximum breakdown voltage are suitable in "powder only" environments.

The universal type "C" FIBC contains a maximum overall ground resistance of 100 MO from any point to ground, including the slings. It requires at least one clearly marked grounding tab. The solvent concentration of the powder must be limited to 1 wt% or less.

Luttgens [1992]:

This paper discussed propagating brush discharges as a major powder ignition hazard of FIBCs. Electrically conductive FIBCs should have a resistance to ground less than 10^8 Ohm from every point. The measurement uses a 5 cm diameter circular electrode. In the case of 100% plastic FIBCs, ionization above the loaded powder can transfer charge to the inner walls and various mechanisms (including ionization) can transfer an electrical countercharge to the outside of the fabric, creating an electrical double layer (capacitor) across the wall. In this way a large part of the charge transferred to the FIBC resides in the wall double layer.

Descriptions were given of pinholes and powder patterns found on used FIBCs that were indicative of propagating brush discharges. Melted material on the inner side of the pinholes was further indication of electrical breakdown. This type of discharge as considered the only realistic ignition source for powders and the pinholes were further considered to be a source of contamination for sterile powders. Spark discharges from people were not considered energetic enough to ignite powders.

(the author does not share this last opinion with Dr. Luttgens)

If the wall has a breakdown voltage of 4 kV or less, propagating brush discharges will not occur. 4 kV is capable of puncturing a 30 micron film of polyethylene, therefore this thickness of polyethylene is safe for lining the porous outer weave of polypropylene FIBCs. If the breakdown voltage exceeds 4 kV slightly (for example, poor quality control in liner thickness) no danger of powder ignition will arise since the discharges are weak close to their minimum triggering voltage.

Where FIBCs are used in flammable gas/vapor atmospheres, two approaches can be used to avoid brush discharges:

1) Antistatic treatments on both sides of the fabric
2) Weaving conductive threads in the warp and filling

If FIBCs of either type are reused, these systems can be compromised. Antistatic treatments can wear away, dissolve or contaminate the product. Conductive threads may break and create an increased danger of spark discharges. It is the responsibility of the user to ensure that FIBCs are electrostatically safe and are grounded reliably.

A selection protocol for FIBCs in terms of product and environment is given which is much the same as the Glor-Bruderer Criteria given above. The only additional caveat is in the case of Shaped Flexible Liners, which will always be too thick to meet the 4 kV criterion and must therefore be conductive.

Wurr [1992]:

This paper advocated a particular FIBC design (ECOTAINER LF) by Wurr's company (EUREA). It opened by reviewing the shortcomings of topical antistatic treatments, which restricted FIBC use to one round trip. The traditional problem of breakage of conductive threads was considered, and a partial solution was given to increase the tensile strength by spinning steel fibers into yarns of polyester or polyamide. These threads were then woven into the warp or weft. However, this introduced a recycling problem since the FIBC contained metal.

A highly elastic conductive polypropylene (PP) thread was advocated to avoid these problems. The elasticity (>40%) of the carbon black loaded threads exceeded that of typical polypropylene FIBC fabrics (18-22%). The threads were woven into warp and weft with a lattice below 20 cm^2, which met the "conductive" provisions of DIN 53482 (resistance tested with 5 cm diameter electrode so that this electrode will always touch a conductive thread). Additional threads ensured a completely conductive system including the spout and slings. The design included test certificates for every FIBC and well marked ground connections. The $< 10^8$ Ohm resistance to ground was found to be achieved from every point on the FIBC. Tests showed 10^4 Ohm typical.

For (FDA) food grade products, where contact with carbon black is prohibited, tests showed that a 20 micron white polyethylene lining was able to dissipate static in this type of FIBC. EUREA conducted

tests to prove that multiple trips (70 cycles with overload capacity) did not cause degradation of the conductive properties of the carbon loaded PP threads.

Published Codes of Practice

Recommendations regarding FIBC use have been published by the British Standards Institution in BS 5958 (1991). The Standard sets powder MIEs below which personnel grounding should be employed, and below which 100% plastic FIBCs should not be used for powder handling in air. These MIE limits are respectively 100 mJ and 25 mJ using the test method described in BS 5958. The former restriction is very conservative, since personnel are unlikely ever to be such energetic ignition sources. In the latter case, the Standard is saying that discharges occurring during use of 100% plastic FIBCs may ignite powders with MIE less than 25 mJ. The author assumes this is in reference to the possibility of bulking brushes during FIBC filling, since powder ignition by brush discharge (such as from the bag surfaces) has not been demonstrated. Owing to the diversity of FIBC designs and the development of new concepts such as corona-limited thread voltage, the broad attempt to describe FIBC limitations in BS 5958 is of little practical use.

Multi-Company Test Program

Gibson [1992] invited US companies to become involved in a European Test Program on FIBC design and use (Gibson is a consultant to the UK Board of Trade and Industry and the British Material Handling Board). A proposal was issued to the EEC for funding of a FIBC test program. This had the support of UK and European FIBC Manufacturers Associations.

The proposal recognized that 70-80% of powders used in industry are combustible and that the FIBC is capable of generating a relatively large cloud. Ignition of this might cause more destructive secondary explosions. It is rarely possible to apply normal explosion prevention techniques to FIBC emptying operations, and instead, ignition sources must be eliminated.

The test program objectives were to determine the static hazards associated with FIBC construction and use, and to prevent unnecessary restrictions on use. FIBCs offer advantages over drums and sacks with respect to toxicity and environmental protection. The test program was said to be more valuable than those of individual manufacturers because the latter are limited to specific products and would not lead to guidelines. The research program would lead to guidance on safe FIBC design, quantify risk levels in actual operation and lead to International Guidelines and Standards. Four topic areas for study were proposed:

- construction methods for FIBCs
- incendivity of discharges from FIBCs
- static levels generated in industrial operations
- preparation of guidelines for safe construction and use of FIBCs

CONCLUSIONS

General FIBC Design Considerations

(1) A problem with several designs of antistatic FIBC is possible failure of the grounding system, which may lead to sparks in the region of the spout. This is extremely hazardous when loading to a flammable atmosphere, since sparks may be produced in the flammable zone at the filling port. Failures may be due to manufacturing defects, operator error or disabling of the grounding clip by non-conductive accumulations such as lacquer or gums. This problem may be mitigated by extending the antistatic region to the slings, so that with proper installation the FIBCs will be

automatically grounded via the hoisting system. It is necessary to ensure that rubber tires on fork lift trucks and similar ground discontinuities are thoroughly evaluated in advance, and a positive ground indicator system might be considered. A grounding criterion recommended by Ciba-Geigy is a maximum resistance of 100 megohm to ground from any point on the FIBC (using prescribed test electrode).

- Antistatic FIBCs containing a metalized film (such as a vacuum aluminized polypropylene liner) have special advantages in reducing transmission of moisture and vapor. However, loss of grounding is particularly severe owing to the relatively high capacitance of the system and minimal charge dissipation via corona discharge as occurs with fine conductive threads. Also, partial application of the film (spout only, or spout plus floor only) does nothing for the static properties of the remaining FIBC walls.

- Antistatic FIBCs containing systems of conductive threads are proving most popular in Europe. With certain isolated thread designs, charge on the fabric is limited by corona discharge even though the thread system is not grounded. This has been found to greatly reduce potentials, although the discharge cannot be sustained below 2-3 kV and the potential becomes self-limiting at somewhat above this value. There is some evidence that common solvent vapors in air will not be ignited by certain isolated thread designs, although hydrogen and other sensitive gases may be ignited. With interconnected thread designs, the FIBCs require grounding in flammable gas/vapor atmospheres.

- Large and obvious grounding instructions should be printed on the FIBC wall so that operators will not connect grounding clips to metal rings or other attachments on sling systems, et cetera, as has been reported to have been done [private communication from R. Mancini].

(2) Fully conductive FIBCs are superior to most antistatic types since discontinuities in the internal grounding arrangement should not be possible. Conductive plastic can readily be applied to the slings to give a completely conductive system. Operational grounding problems remain, but are somewhat less likely owing to electrical continuity of the slings and hoist system. Should manual grounding be required, a very robust and well marked terminal should be provided. For critical use in flammable atmospheres, a positive ground indicator system might be considered.

- Two problems with fully conductive FIBCs are compatibility (and possibly FDA approval) of the conductive additive and cost. The former might be addressed by a compatible, thin inner lining provided testing shows this to be safe. While the latter may be reduced by multiple use, this might adversely impact product quality.

(3) In many applications, smaller FIBCs (300-500 kg) should be safer than larger FIBCs (up to about 1000 kg). The latter introduce the possibility of bulking brush discharges during loading, whether the FIBC is grounded or not. Other problems such as dust clouds, air entrainment and FIBC explosions may be magnified by the greater capacity.

(4) All types of FIBC have the capacity to entrain significant quantities of air with the powder during emptying. This can produce locally flammable volumes in inerted containers and also displace flammable vapor from the container, especially if the tank vent pipe is undersized. Ideally, when flammable atmospheres are present, use of an intermediate hopper and rotary valve such as described by ESCIS [1988] should be considered. The latter system may be equipped with a separate inert gas supply.

Operator Grounding

(1) Ungrounded operators using 100% plastic FIBCs are at particular risk of becoming charged by induction from the large adjacent area of charged plastic. Note that electric fields in excess of 1000 kV/m have been reported in the vicinity of large FIBCs of this type [Dahn 1991]. This can create a risk of powder ignition due to sparks from the operator to ground (note that 100% plastic FIBCs must not be used in flammable gas/vapor environments). There is no general agreement as to the MIE of powders at risk. British Standard 5948 recommends personnel grounding for powders with MJE less than 100 mJ. Shell recommends this be done if the MIE of a powder is unknown or is less than 50 mJ [Walmsley 1992]. The author believes the 50 mJ criterion is more reasonable owing to the very conservative assumptions adopted by the British Standards committee.

(2) Operators should be grounded in flammable gas/vapor environments whether FIBCs are used or not. The zone for which grounding is mandated can be specified in the same way as electrical classification, and other areas defined for through traffic.

(3) The best type of personnel grounding system depends on the type of operation, since if poor housekeeping or lacquer results in contaminated floors, conductive or antistatic footwear will not work. For clean environments, devices such as the Legge "Heelstat" have proved successful since unlike antistatic shoes they do not have to be worn exclusively by one person. The "antistatic" grounded operator should have a total resistance to ground in the range 10^5-10^8 Ohm (including flooring). Lower resistances in the "conductive" range ($< 10^5$ Ohm) are only necessary for sensitive gases and could introduce a personnel shock hazard from powered equipment should a fault occur. Most devices for grounding the wrist or leg have a built-in 1 megohm resistor to avoid such shocks.

Vacuuming

(1) Vacuuming is often used to empty FIBCs. It is recommended that conductive vacuum hoses be used to avoid both ignition of flammable powders and personnel nuisance shocks. These hoses are made from conductive plastic and are not prone to giving shock hazards or incendive discharges from the fabric, which can occur with non-conductive hoses. Although there is no ignition hazard with pellets in air, conductive hoses might be specified to avoid nuisance shocks.

Powders in Flammable Gas/Vapor Atmospheres (including solvent-wet powders)

(1) It can be unsafe to use FIBCs of any type in the presence of flammable gases and vapors unless the flammable atmosphere is properly controlled. 100% plastic types give brush hazards which cannot be avoided, plus the possibility of bulking brushes and even propagating brushes. Their inductive effect on ungrounded conductors and people in the vicinity (spark hazards) is greater than other types of FIBC. They may also give spark hazards if they have wet patches on the fabric. Antistatic and conductive FIBCs can be grounded to prevent static discharges. However, any manufacturing defect or operational error in establishing grounding could be disastrous. Ignition, fire and operator injury have unacceptably high probabilities for a single failure, particularly when the FIBC discharges to a flammable liquid tank.

(2) The hazards could in principle be substantially mitigated by using conductive FIBCs that are grounded via conductive slings. Alternatively or additionally, ground indicators might be used on an independent manually-applied ground. Thorough training of personnel and testing of the grounding system would be essential. This introduces the problem of advising customers on safe FIBC use.

(3) Experiments by Wilson [1989] suggested that a certain antistatic FIBC design incorporating isolated conductive threads separated by 20 mm would successfully suppress brush discharges while being incapable of storing enough spark energy on the threads to ignite common solvent vapors in air, even though the FIBC is ungrounded. However, this conclusion was based on emptying tests yielding a particular charging rate which could be partially neutralized by corona discharge from the threads. At some higher charging rate, a higher voltage might have been generated, and the generality of the result is uncertain.

(4) Experiments by ICI [Rogers 1991, Nelson et al. 1993] support those of Wilson. There is evidence that certain antistatic FIBCs containing isolated threads may be intrinsically safer provided that precise design features are adopted for thread number, spacing, resistance, capacitance and weave, and that abnormally sensitive gas mixtures are not involved. Recent development of conductive (carbon black loaded) polypropylene threads has improved the reliability of antistatic FIBCs from the standpoint of thread breakage. EUREA claims a reliable design which can meet FDA requirements owing to a thin virgin PE lining.

Powders in Air Only

(1) Because of the potential for grounding error, it is better to select a 100% plastic FIBC for handling dry powders alone. This eliminates spark hazards from the FIBC itself. Brush discharges from the fabric cannot ignite powders and are not a problem. There remain problems due to bulking brushes from the product during loading, propagating brushes during unloading, and miscellaneous spark sources.

(2) There may be a certain size of FIBC above which powder ignition may be possible during loading via the bulking brush discharge phenomenon, with no flammable gas/vapor present. This possibility has not previously been recognized with respect to FIBC size, which is normally not considered a variable. Until more is known, it is assumed that this possibility does not exist for FlBCs below about 1.5 m^3 volume (up to about 500 kg) and might appear as FIBC capacity increases to about 1000 kg. It is relevant only to ignition of fine particles with MIE nominally less than that of lycopodium (clavatum) or coarser powders containing a significant fines fraction with a MIE nominally less than that of lycopodium. As discussed in the text, this approach avoids some of the problems associated with the variety of MIE test methods currently in use.

- Since this phenomenon only occurs due to bulking of large piles of charged powder, ignition during large FIBC (> 1.5 m^3) filling with sensitive powders could be carried out after inflating the FIBC with nitrogen rather than air. Subsequent emptying of sensitive powders to an inerted system could subsequently be made. Note that there are no known case histories of ignitions via this mechanism.

(3) Provided bulking brush discharges are avoided by using smaller FlBCs, hazards may still exist due to propagating brushes and sparks, which can both ignite powders in air. The former may be avoided by specifying a maximum 4 kV breakdown voltage for the FIBC wall. Sparks may be avoided by operator and equipment grounding, and storing FlBCs dry so that wet patches cannot act as spark sources.

- A specific test method is required for applying the 4 kV criterion. The criterion as usually stated in the literature does not make it clear how to conduct the test. Also, while some authors apply the criterion only to the FIBC liner (assuming the outer weave to be porous), reference is usually given to the FIBC wall (outer weave plus liner).

- The 4 kV criterion cannot be applied rigorously to powders which require superior moisture barriers, since the liner thickness is usually limited to about 1 mil. Owing to the appearance of weak discharges for somewhat greater breakdown voltages it might be possible to use thicker liners, but this is presently a "gray" area since the effective energy of such discharges is difficult to assess experimentally.

- On the subject of propagating brush discharges from FIBCs, it is significant that such discharges have not been reported following any of the large number of experimental powder emptying tests that have been made. This suggests that the discharge rarely occurs. A further point is that the existing evidence for such discharges (as discussed) lies in the observation of pinholes in the spouts of used FIBCs. It must be established whether these were indeed due to propagating brushes and not tiny thin spots in the spouts allowing breakdown at some lower voltage, perhaps 2-4 kV. If the phenomenon does not in fact occur,, a major area of concern with 100% plastic FIBCs can be dismissed.

Non-Flammable Powders

(1) These comprise pelletized and some coarse granular combustible materia ls, plus any powder identified as non-combustible. For air transfer they should normally be handled in 100% plastic FIBCs.

(2) These powders may give a static hazard in flammable gas/vapor atmospheres in the same way as flammable powders. The essential difference is that the gas/vapor needs to be above its LFL, rather than some fraction of it Also, personnel charging and shock hazards are similar.

(3) A possible hazard of coarse granule and pellet handling in air is personnel shock from the sides of a 100% plastic FIBC, particularly during or soon after filling. If this occurs it might be remedied by using the 4 kV criterion for wall breakdown voltage. Other measures such as the internal discharge electrode described by Blythe and Reddish [1979] would normally be impractical owing to the lack of an available opening once the filling spout is clamped.

Product Quality Impact of Static

(1) If the breakdown voltage of a liner is exceeded a static discharge can produce a pinhole. The appearance of pinholes in FIBC liners might have a significant impact on product quality, particularly for products that are hygroscopic or otherwise sensitive to moisture. Pinholes might also be formed during filling of plastic lined fiber totes.

(2) Where this phenomenon is suspected, examination of used container liners might be carried out. If pinholes are found, testing might be done to address their effect on moisture permeation rate or other measure. Possible remedies might include modifications to the filling system to reduce triboelectrif ication, increasing liner thickness or use of a suitable neutralization system close to the loading point.

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