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TESTING THE SUITABILITY OF FIBCS FOR USE IN FLAMMABLE ATMOSPHERES

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ABSTRACT

Flexible intermediate bulk containers are used in several industries -- including the chemical, pharmaceutical, and food processing industries -- for convenient handling of bulk solids and powders. While the electrostatic hazard posed by FIBCs is well known, little full-scale experimental work has been performed to quantify this hazard.

In this paper, experimental work conducted to evaluate the suitability of a new type of FIBC for use in common industrial flammable atmospheres is described. As a part of this work, two other FIBC types were evaluated for comparative purposes. Testing included determination of electrostatic discharge incendivity and measurement of charge transfer, surface potential, and charge density.

The primary outcome of this work has been to provide the viability of a new type of FIBC for use in flammable atmospheres without the need for electrical grounding. However, consequent outcomes include a move towards a quantification of the electrostatic hazard posed by FIBC use and a better understanding of the mechanism characteristic of discharges from charged FIBC surfaces.

1. INTRODUCTION

Companies use flexible intermediate bulk containers (FIBCs or "bulk bag") to transport and store bulk solids and powers, including raw materials, in-process materials, and products. The use of FIBCs has increased greatly in recent years, primarily because of their convenience. FIBCs make it possible for operators to move large quantities of material easily and efficiently around the work area using hoists or forklift trucks. In contrast, paper and plastic sacks, fiberboard and metal drums, and metal tote bins may require more handling time and often prove unwieldy. FIBCs are also collapsible and thus take up less space in the work area after their contents have been discharged.

Despite these advantages, even wider use of FIBCs has been hampered by concerns about potential electrostatic hazards. The polypropylene fabric from which FIBCs are typically made are insulating materials in electrostatic terms and, as such, have a propensity to generate and accumulate static charge during materials handling operations. FIBCs can become charged during filling due to receipt of material charged during upstream handling and during emptying as material slides against the outlet spout and other inside surfaces. When exposed to grounded plant or personnel, charge accumulated on insulating FIBC surfaces can produce electrostatic discharges capable of igniting some flammable atmospheres.

A number of approaches have been taken to eliminate or control the electrostatic hazard associated with FIBCs [References 1-3]. These approaches can generally be categorised as attempting to prevent charge accumulation or control discharge incendivity. Efforts to prevent charge accumulation have focused primarily on the use of grounded conductive threads and laminates, while efforts to control discharge incendivity have attempted to exploit the corona discharge phenomenon to reduce surface potential.

A newly-developed FIBC offers protection against incendive electrostatic discharges without the need for grounding. The new design incorporates antistatic threads that dissipate charge through limited corona discharge and an antistatic coating that modifies the discharge mechanism.

Despite the evolution of control technologies, relatively little full-scale experimental work has been performed to quantify the electrostatic hazard associated with FIBCs and prove the effectiveness of control technologies. In response, Chilworth Technology, Inc., has developed extensive facilities for the comprehensive testing and evaluation of FIBCs. As a part of the development of the new FIBC design described above, three types of FIBCs were evaluated to determine their suitability for use in flammable atmospheres having a minimum ignition energy (MIE) of 0.25 millijoules (mJ) or greater. This value is typical of many common industrial organic solvent vapors. The principal test methods and a sample of the test results are discussed in the following sections.

2. DISCHARGE INCENDIVITY TESTING

2.1 Method

Testing involved suspending a full-size FIBC by its four corner straps from a steel frame positioned above steel hopper. The FIBCs were suspended in a way that ensured that they were completely isolated from electrical ground. The test powder -- polypropylene pellets -- was transferred from the steel hopper to the FIBC at a rate of approximately one kilogram per second (kg/s) by means of a screw conveyor. Polypropylene pellets are highly insulating -- having a volume resistivity exceeding 1 x 1014 ohm.meters -- and provide the basis for a reasonable worst-case electrostatic charging scenario.

The discharge chute from the screw conveyor was positioned so that each FIBC was filled from above. A corona charge injector system positioned within the discharge chute made it possible to apply additional electrostatic charge to the test powder. As a result, the charge density on the test powder could be controlled within a range of -5.5 x 10-7 to -3.0 x 10-6 coulombs per kilogram (C/kg). A negative charge was applied to the test powder because discharges originating from negatively charged surfaces are known to be more incendive than those arising from positively charged surfaces [Reference 4].

As the test powder is transferred to the FIBC, static charge accumulates as the bag fills and the electric field at the surface of the bulking solid intensifies -- a phenomenon known as charge compaction [Reference 5]. When the field strength is sufficient, the air immediately above the powder is ionized and negative ions are accelerated away from the negatively charged test powder and towards the FIBC walls. Consequently, the maximum electrostatic field intensity on an FIBC surface generally corresponds to the powder fill level.

The incendivity of electrostatic discharges was determined using a gas-emitting probe [Reference 6]. The probe consists of a stainless steel tube with an acrylic shroud at the head and a blowgun-type lever valve at the base. A flammable gas having an MIE of 0.25 mJ was delivered through the tube creating a localized flammable atmosphere within the shroud. A grounded spherical electrode located within the shroud was used to induce electrostatic discharges from the charged FIBC surfaces.

Attempts were made to produce discharges from the FIBCs during both bag filling and emptying by steadily approaching the charged surfaces with the gas probe. Discharges having energies exceeding 0.25 mJ ignited the flammable atmosphere within the probe shroud. The potential on charged FIBC surfaces was measured using an electrostatic fieldmeter.

The humidity within the test area was controlled using a dehumidifier which was capable of maintaining the environment at less than 20 percent relative humidity. For low humidity testing, the test area and FIBCs were conditioned at less than 20 percent relative humidity prior to testing.

2.2 Results

Three types of FIBCs were tested; (1) a standard FIBC; (2) a groundable FIBC employing conductive threads; and (3) a new FIBC design employing ungrounded antistatic threads and an antistatic coating.

The standard FIBC was constructed from a polypropylene fabric and had a standard polycoating on the inside surfaces. FIBCs are frequently coated on the inside and/or outside surfaces to prevent product migration and to protect product from moisture. The groundable FIBC was similar in construction to the standard FIBC, but incorporated conductive threads woven in a warp orientation at a one-inch spacing. The conductive threads were electrically-joined at the FIBC seams and connected to a common grounding table. The groundable FIBC was tested while grounded as well as when left ungrounded. The new FIBC tested incorporated proprietary antistatic threads woven in a warp orientation at a one-inch spacing into a polypropylene base fabric with a proprietary antistatic coating on the inside surfaces.

2.2.1 Standard FIBC

Under the test conditions, the standard FIBC readily produced electrostatic discharges that ignited the flammable atmosphere in the gas probe. In 200 trials performed under various humidity conditions, 200 ignitions were observed. Electrostatic field intensity measurements indicated potentials on the surfaces of the standard FIBC of up to -40 kilovolts (kV).

The discharges produced from the charged surfaces of the standard FIBC are of the type known as brush discharges. Brush discharges are produced when an electrode having a sufficiently large radius of curvature, i.e., a spherical or rounded electrode, approaches a charged insulating surface. As the electrode approaches the charged surface, the field strength between them intensifies. If the field strength exceeds the dielectric strength of the atmosphere above the charged surface, a brush discharge occurs. Because charge on the insulating surface has limited mobility, not all of the charge participates in the discharge. The resulting discharge channels resemble the bristles of a brush. Brush discharges are known to exhibit effective energies of 3-5 mJ and thus pose an ignition threat to many common flammable vapours.

2.2.2 Groundable FIBC

The groundable FIBC was first tested while grounded. The FIBC was grounded through an electrometer for purposes of measuring the charge density created by the bulking of the test powder. Only the groundable FIBC could be tested in this way, due to its construction and grounding tab. The charge density ranged from -1.5 x 10-6 to -2.4 x 10-6 C/kg. Despite the high levels of charge on the test powder, electrostatic field intensity measurements indicated potentials on the surfaces of the grounded FIBC of only -3 to -5 kV. During 100 trials under these charging conditions, no discharges capable of igniting the gas probe were observed from the groundable FIBC when suitably grounded. These results clearly illustrated the effectiveness of this type of FIBC in limiting surface potential and thus controlling electrostatic discharges when grounded.

When conductive threads are woven in warp, weft, or both directions, they form a lattice or grid that surrounds the entire FIBC. The conductive threads are typically interconnected at the seams and attached to a common grounding table, as in the groundable FIBC tested. When the FIBC is grounded during materials handling operations, the charge accumulating on the insulating polypropylene fabric induces an opposite charge on the conductive thread. This has the effect of reducing the net charge on the FIBC surface to a level below which incendive discharges would not be expected.

In contrast, when the groundable FIBC was left ungrounded, 10 gas probe ignitions were observed in 10 trials. The charge density during these trials ranged from -1.8 x 10-6 to -2.8 x 10-6 C/kg. These charging levels for the test powder resulted in potentials ranging from -9 to -14 kV on the FIBC surfaces. When groundable FIBCs are not grounded, their conductive elements represent isolated conductors. Electrostatic discharges from charged isolated conductors are known as spark discharges. While their effective energy is dependent upon the level of static charging and the capacity of the conductor to store charge, spark discharges are frequently energetic enough to ignite flammable vapours [Reference 7].

2.2.3 New FIBC with Antistatic Threads and Coating

When the new FIBC design was subjected to the prevailing electrostatic charging conditions described above, no gas probe ignitions were observed in 500 trials performed under various humidity conditions. Electrostatic field intensity measurements indicated potentials on the surfaces of the new FIBC of up to -32 kV. Notably, the surface potential for the new FIBC was typically 8 kV less than that observed for the standard FIBC despite identical electrostatic charging conditions.

It was postulated that the new FIBC design controlled the incendivity of electrostatic discharges utilising two mechanisms. First, the antistatic threads reduced the surface potential by means of limited corona discharge. Then, the antistatic coating modified the discharge mechanism by controlling the flow of charge to the discharge site. It was necessary to develop an additional test, however, to better understand the differences between discharges from the FIBCs tested and thus better assess their suitability for use in flammable atmospheres.

3. CHARGE TRANSFER TESTING

3.1 Method

To better characterise the electrostatic discharges from charged FIBC surfaces, it was decided that the most useful data would be that pertaining to charge transfer. The predominant factor influencing the incendivity of electrostatic discharges is the amount of energy or charge transferred between the charged surface and the grounded object approaching it. When charge flows, an electrical current is created. Thus, each electrostatic discharge can be characterised by the current created when charge is transferred from the charged surface to ground.

Because of the relationship between current and charge transfer, the total amount of charge transferred in an electrostatic discharge can be determined by plotting current versus time and integrating the resulting waveform. This type of measurement and analysis was well suited for the programmable digitizers used during this testing. Testing involved electrostatically charging FIBC fabric samples and inducing discharges from the FIBC surface using a grounded spherical electrode. The waveform was captured by grounding the electrode through the input of the digitizer. Samples were charged using either a corona charging probe driven by a high voltage powder supply or manually using a wool cloth.

3.2 Results

Typical current versus time waveforms for electrostatic discharges from sample of standard FIBC fabric and a sample of the new FIBC fabric are shown in Figure 1. When the standard FIBC fabric was charged to a surface potential of -45 kV, it produced electrostatic discharges characterised by charge transfer on the order of 120 nomocoulombs (nC). In contrast, when the new FIBC fabric was charged to a surface potential of -49 kV, it produced electrostatic discharges characterised by charge transfer of about 4 nC. Figure 2 shows the results of testing performed with the gas probe grounded through the digitizer which indicated that a charge transfer of at least 50 nC is required for a discharge to ignite a flammable atmosphere having an MIE of 0.25 mJ.

The above results suggested that the amount of charge transferred during discharges from the standard FIBC fabric is on the order of 30 times that transferred during discharges from the new FIBC fabric. Since the FIBC fabric samples were charged to nearly the same surface potential, it is postulated that the difference in charge transfer can be attributed -- at least conceptually -- to differences in what may be referred to as surface capacitance (Cs).

Capacitance is a measure of the ability of an object or material to store charge. However, capacitance is a concept normally reserved for conductors or systems or conductors and is generally not considered to be applicable to insulating materials such as fabrics. The energy of electrostatic discharges from conductive objects is given by the equation:

$$E = 1/2\ CV2 \qquad \text{[Equation 1]}$$

where, E = discharge energy (joules)
C = capacitance (farads)
V = potential (volts)

Our intention is to use this relationship and our notion of surface capacitance as an approximation to better understand the charge transfer mechanism.

This notional surface capacitance is a factor of the area of the material from which a discharge is drawn, multiplied by a correction factor to account for the fact that the entire charge from that area is not transferred. In fact, if it is assumed that the same discharge mechanism occurs regardless of the surface conductivity of the material, then one might expect the surface capacitance to be directly related to the surface area from which the discharges are drawn.

For uniformly charged insulating surface -- such as the standard FIBC fabric -- charge within a radial distance of approximately 50 millimetres (mm) from the central point of discharge might reasonably be expected to be discharged when approached by a grounded spherical electrode. To achieve the 30-fold decrease in charge transfer observed during testing, the new FIBC fabric must limit the effective discharge area -- and thus our notional surface capacitance -- accordingly. The allowable radius of the discharge area would be reduced to 9 mm. The new FIBC fabric accomplishes this reduction in the discharge area through the use of a proprietary antistatic coating which changes the surface conductivity.

Notably, rather than the single discharges suggested by Figure 1, brush discharges from charged FIBC surfaces are actually comprised of a series of discrete discharges. Subsequent testing using a digitizer capable of higher frequency data sampling confirmed this phenomenon. A typical discharge event waveform captured during testing of the new FIBC fabric is shown in Figure 3.

A discharge event for the new FIBC fabric is typically comprised of 3-5 individual discharges over a wide range of surface potentials. Figure 3 shows that when the new fabric was charged to a surface potential of -30 kV, it produced a series of four discharges. The primary discharge in the series was characterised by a charge transfer of only 1.3 nC, with subsequent discharges less than 0.5 nC. Similar results were observed during numerous trials. These charge transfers are consistent with the negative results for the new FIBc observed during discharge incendivity testing. Again, Figure 2 shows that at least 50 nC is required for a discharge to ignite a flammable atmosphere having an MIE of 0.25 mJ.

In contrast, a discharge event for a standard FIBC can be comprised of 1-10 or more individual discharges. Under comparable electrostatic charging conditions, the primary discharge in a discharge event for a standard fabric was characterised by a charge transfer on the order of 100 nC. This charge transfer is consistent with the positive results for the standard FIbC observed during discharge incendivity testing. The remaining discharges in the series are generally characterised by charge transfer of 10 nC or less.

These results suggest that the charge on an FIBC surface is transferred as a series of discharges of typically decreasing energy. In this regard, a comparatively much lower level of charge is transferred in discharges from the new FIBC fabric because the effective discharge area is limited by the antistatic coating employed.

4. CONCLUSIONS

4.1 Standard FIBC

Under the test conditions, a standard polypropylene FIBC was observed to readily produce electrostatic discharges capable of igniting a flammable test atmosphere having an MIE of 0.25 mJ. Consequently, the use of standard FIBCs in or around flammable atmospheres is not recommended.

4.2 Groundable FIBC

Under the test conditions, it was not possible to produce electrostatic discharges capable of igniting the flammable test atmosphere from a groundable FIBC provided the FIBC was suitably grounded. Conversely, when this FIBC was left ungrounded, it was observed to readily produce incendive discharges. Thus, this style of FIBC may be used in or around flammable atmospheres provided it is suitably and securely grounded during all materials handling operations.

4.3 New FIBC with Antistatic Threads and Coating

Under the test conditions, it was not possible to produce electrostatic discharges capable of igniting the flammable test atmosphere from a new type of FIbC for which there is no grounding requirement. Charge transfer measurements indicate that electrostatic discharges are produced from the surface of the new FIBC fabric when charged, but that these discharges are significantly less energetic than those produced from a standard FIBC fabric exhibiting similar surface potential.

The test results suggest that the design controls the incendivity of electrostatic discharges from its surfaces by means of antistatic threads which reduce surface potential by limited corona discharge and an antistatic coating which modifies the discharge mechanism. It is believed that the coating reduces the effective discharge area by reducing the surface conductivity of the fabric.

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