ELECTROSTATIC HAZARDS IN THE USE OF FLEXIBLE INTERMEDIATE BULK CONTAINERS

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Flexible intermediate bulk containers (FIBC'S) are gaining in popularity throughout the European chemical and process industries. They are usually made from polypropylene fabrics, but in recent years "antistatic" versions of these bags have been developed. It has long been recognised that conventional big bags, if used in flammable vapour or dust atmospheres, could present an electrostatic ignition source. This paper describes the results of a recent experimental research programme involving full scale trials with polyester pellets in big bags constructed both of polypropylene and polypropylene fabrics containing conductive threads. It has been shown that the use of standard polypropylene bags in sensitive flammable atmosphere can give rise to risk of fire or explosion. Trials have also shown that a particular type of FIBC containing a network of earthed threads did not ignite atmospheres of 0.25 mJ ignition energy, even if some of the threads were electrically isolated.

KEYWORDS

Electrostatics, Safety, Flexible Intermediate Bulk Containers, Sparks.

INTRODUCTION

Polypropylene FIBC's are being used increasingly in industry for the convenient transport of powders. It has been speculated, however, that discharges of static electricity from these bags could be produced with the capability of igniting sensitive flammable atmospheres. For this reason a number of so called antistatic big bags are available, although little work has been done to establish the electrostatic hazards (reference 1).

Electrostatic charges are usually generated whenever two materials rub, slide or separate from each other after contact. Electrostatic charge generation is therefore expected during filling and emptying of FIBC's.

It is very likely that powder is already charged before entering the FIBC by upstream handling operations. When charged powder is collected in an insulating FIBC, the charge will be accumulated in the FIBC, which can lead to electrostatic discharges between the FIBC and any earthed surroundings.

During unloading of an FIBC, large electrostatic charges are generated because of both induction effects and also the sliding and rubbing movement of powder particles with the FIBC fabric.

Such charge storage on the FIBC surface can be partially or completely eliminated by using bags made from earthed antistatic or electrically conducting fabrics.

TEST MATERIALS AND MEASUREMENT PROCEDURES

The experiments presented here were carried out on three types of Mulox FIBC manufactured from Amoco Fabrics material each containing polyester pellets using a humidity controlled full scale FIBC testing rig. The characteristics of the FIBC's and the polyester pellets are described in this section together with details of the experimental arrangments.

Test FIBC's

Three types of FIBC's have been tested viz:-

1. An extrusion coated polypropylene FIBC which was wholly insulating.

2. A polypropylene FIBC with woven conductive yarns which was considered antistatic. The yarns were woven in parallel lines in the bag walls with a 2 cm spacing. The conductive yarns were connected together at the top and bottom edges of the bag by an electrically conducting copper braid. Two copper earthing loops were provided at the top and bottom edges of the bag as shown in figure 1. The conductive yarns had an electrical resistance of about 5000 Ω per meter.

3. A polypropylene FIBC with woven conductive yarns which was considered antistatic. This bag was similar to the antistatic bag except that it had an external low conductivity coating on the outside as illustrated in figure 1.

   The values of electrical resistance and charge decay time measured on these bags are shown in table 1.

TABLE 1 - Results of Electrical Resistance and Charge Decay Time Measurements

Sample	Relative Humidity (%)	Resistance(1) (Ω)	Charge(2) Decay Time (sec)
Polypropylene bag (insulating)	56	$1x10^{13}$	130
Polypropylene bag (insulating)	18	$5x10^{13}$	1100
Antistatic bag	56	$1.7x10^{5}$	<1
Antistatic bag	18	$1.3x10^{5}$	<1
Antistatic bag (insulating coating on the outside)	56	$5x10^{10}$ (outside)	<1 (outside)
	56	$1.6x10^{5}$ (inside)	<1 (inside)
Antistatic bag (insulating coating on the outside)	18	$3.5x10^{11}$ (outside)	<1 (outside)
	18	$6.5x10^{4}$ (inside)	<1 (inside)

(1) Measured according to B55958
(2) Time for charge to decay to $^1/_e$ of initial reference value

Polyester Pellets

Bulk volume resistivity (measured according to B55958 - reference 2) and charge decay time measurements on a sample of the test polyester pellets showed that they were very insulating both at ambient and low relative humidities. The volume resistivity and the charge decay time of the pellets were > 10^{14} Ωm and > 3600 seconds respectively.

Mass Flow Rate Measurements

The sub carriage of the test rig, which was insulated from ground, was used to lift and, hence, also isolate the FIBC from ground. The sub carriage stood on a compressive load cell which permited continuous monitoring of the powder weight. Polyester powder was transferred to the test FIBC from a storage hopper by a spiral conveyor and a flexible hose. The material mass flow rate was calculated by dividing the total mass of conveyed material into the FIBC by the loading time.

Pellet Charging Methods

The polyester pellets were charged by natural tribo charging during transportation from the storage hopper to the test FIBC's. During some experiments the natural charging levels of polyester powder was increased with the aid of a corona charge injector. The aim of this practice was to create extreme conditions and ensure that electrostatic discharges could happen. The corona charge injector, comprised a solid rod with protruding needles mounted along the axis of a short section of pipe. The device was positioned at the end of the flexible hose of the spiral conveyor, upstream of the FIBC.

Streaming Current Measurements

When suspended by their straps, the FIBC's were, electrically isolated from both the test rig and earth. Antistatic FIBC's were earthed by connecting their earthing loop to ground via an electrometer to allow measurements of current (charge per unit time) on the polyester entering the FIBC's.

The streaming currents entering the insulating (extrusion coated polypropylene) FIBC were measured by placing them inside an antistatic FIBC and connecting the latter to earth via an electrometer.

A Keithley model 602 electrometer was used to perform the current measurements.

Surface Potential Measurements

Two rotating vane electric field meters were calibrated to measure the average potential on the outside surfaces of the test FIBC's.

An electrostatic voltmeter was used to measure the voltage on the individual conductive yarns or the earthing loop of the FIBC's when not earthed.

Measurements of the Incendivity of Discharges

A gas shroud probe was used to assess the incendivity of discharges from the surface of the FIBC's. The probe comprised a 19mm diameter metal sphere which was surrounded by a localised environment of propane/air of known ignition energy. The charge transfer of any discharge to the probe was measured on a storage oscilliscope.

The propane/air mixture used in the experiments was adjusted to give a minimum ignition energy of 0.25 mJ. Any electrostatic discharge from the surface of the FIBC's which was capable of igniting this mixture was considered to have an equivalent electrical energy of at least 0.25 mJ [reference 3].

Control of Relative Humidity

The FIBC test rig was enclosed within plastic sheeeting forming an environmentally controlled test area. Dehumidifiers were used to control the relative humidity to a minimum of 15%.

All test samples were conditioned at the particular relative humidities required for each experiment for about 10 hours before the tests were started.

EXPERIMENTAL RESULTS

The experimental results are presented for each of the FIBC's.

Extrusion Coated Polypropylene FIBC (Insulating)

Table 2 shows the results of streaming current and surface potential measurements carried out during the filling of an insulating FIBC at a temperature of 25°C and relative humidity of 20%. The mass flow rate of powder into the bag was 0.79 Kg/s.

Table 2 - Results of Electrostatic Measurements during filling an Insulating FIBC with Polyester Pellets

RH = 20%   Temp = 25°C

Corona Voltage (kV)	Streaming Current (A)	Specific Charge Density (C kg-1)	Surface Potential (KV)
0 (natural charging)	-0.9×10^{-6}	-1.1×10^{-6}	-26
-5	-1.1×10^{-6}	-1.4×10^{-6}	-26
-10	-1.5×10^{-6}	-1.9×10^{-6}	-26
-20	-2.5×10^{-6}	-3.2×10^{-6}	-29

The discharges from the outside surface of the bag to the metal electrode of the gas emitting probe could easily ignite the gas air mixture (MIE = 0.25 mJ) during all the trials. Some 20 ignitions were obtained. The charge transfer to the probe for a single discharge was typically -9nC.

The same experiment was repeated at an ambient relative humidity and temperature of 50% and 20°C, respectively with a streaming current of -1×10^{-6} A (specific charge density = -1.3×10^{-6} C kg^{-1}). The potential on the outside surface of the bag was measured to be -28kV. The gas mixture in the gas emitting probe was again repeatedly ignited by discharges from the bag wall.

Emptying the insulating FIBC, produced surface potentials up to +33kV. It was not however possible to ignite the gas emitting probe from the **positively** charged surface of the FIBC. About 20 ignition attempts were made.

Polypropylene FIBC with Woven Conductive Yarns (Antistatic)

For these experiments the earthing loop of the bag was connected to ground via a current- measuring electrometer. Table 3 shows the average surface potential of the antistatic bag as a function of the streaming current defined as the charge on the pellets entering the bag per unit time. The specific charge was obtained by dividing the streaming current (Q s^{-1}) by the mass flow rate of pellets (kg s^{-1}).

TABLE 3 - Surface Potential as a Function of Streaming Current (Bag Earthed)

RH = 18% Temp = 29°C

Corona Voltage (kV)	Streaming Current (A)	Specific Charge (C kg-1)	Surface Potential (During filling) (kV)	Surface Potential (After emptying) (kV)
0	-1.4×10^{-6}	-1.5×10^{-6}	-5	-1.5
-5	-1.6×10^{-6}	-1.6×10^{-6}	-3	-2.0
-10	-1.7×10^{-6}	-1.7×10^{-6}	-3	-1.5
-15	-1.8×10^{-6}	-2.0×10^{-6}	-3	-3.0
-20	-2.2×10^{-6}	-2.4×10^{-6}	-3	-1.5

The results show that the earthed conductive yarns in the polypropylene bag prevent build up of a potential greater than about 5kV on the outside surface of the bag. This surface potential was not sufficiently high to ignite the gas in the test probe. About 100 ignition attempts were made.

Table 4 shows the potential on the outside surface of the bag and the potential on the earth loop when the latter is isolated from ground during powder filling.

TABLE 4 - Results of Surface potential Measurements on the Antistatic Bag (Bag not Earthed)

RH = 18% Temp = 29°C

Corona Voltage (kV)	Streaming Current (A)	Specific Charge (C kg-1)	Surface Potential Voltage (kV)	Earth Loop (kV)
0	$-1.4x10^{-6}$	$-1.8x10^{-6}$	-14	-9.0
-5	$-1.6x10^{-6}$	$-2.0x10^{-6}$	-12	-6.0
-10	$-1.7x10^{-6}$	$-2.2x10^{-6}$	-9	-6.5
-15	$-1.8x10^{-6}$	$-2.3x10^{-6}$	-11	-6.5
-20	$-2.2x10^{-6}$	$-2.8x10^{-6}$	-11	-6.8

In this case gas emitting probe was readily ignited by discharges from the outside surface of the antistatic bag i.e. when it was not earthed.

Comparison of results of table 3 and 4 clearly indicate the effectiveness of the earthed conductive yarns in preventing surface potentials greater than -5 kV from developing on the bag. The decrease in surface potential with an increase in the streaming current and also the reason for observing a lower voltage on the earth loop than on the surface of the unearthed bag, could be due to the loss of electrostatic charge by corona from the conductive yarns and the earthing braid.

At an ambient relative humidity of 52% the maximum surface potential obtained with the earthing loop connected to ground was -300V. At this humidity the maximum surface potential obtained with the bag isolated from earth was -4.4 kV. The gas emitting probe was ignited by discharges from the outside surface of the unearthed antistatic FIBC.

Polypropylene FIBC with woven conductive yarns (antistatic), with an insulating coating on its outside surface

The results of the experiments on this type of FIBC were very similar to the results of the tests carried out on a polypropylene FIBC with woven conductive yarns and no outside coating.

Polypropylene FIBC with some or all the Woven Conductive Yarns Isolated from each other and Earth

Table 5 shows the results of similar experiments on an antistatic FIBC with isolated conductive yarns on one side and earthed conductive yarns on all three sides. The mass flow rate of polyester into the FIBC was 0.8 kgs^{-1}.

TABLE 5 - Potential Measurements as a Function of Streaming Current

RH = 14% Temp = 25°C

Streaming Current (A)	Potential on one conductive yarn (kV)	Potential on the side of of FIBC with isolated yarns (kV)	Potential on the sides of FIBC with earthed yarns (kV)
-1.0×10^{-6} (natural charging)	-1.5	-2.6	-0.14
-1.8×10^{-6} (corona points at a potential of -20 kV)	-1.5	-2.4	-0.12

The discharges from the side of the FIBC with electrically isolated yarns were not energetic enough to ignite the gas emitting probe. Some 40 trials were made.

With the antistatic FIBC completely isolated from earth it was possible to ignite the gas emitting probe by discharges from the side of the FIBC with isolated conductive yarns. The streaming current and the surface potential on the side of the FIBC with yarns isolated from each other during this experiment were -1×10^{-6} A and -10 kV respectively. The voltage of any individual isolated yarn was about -9.0 kV. The measured capacitance of an isolated yarn was again about 10 pF. Similar results were obtained when an antistatic FIBC with insulating coating on the outside was tested.

In another experiment using polyester pellets, the conductive yarns on all four sides of an antistatic FIBC were isolated from each other and from the earthing loop but the earthing loop of the FIBC was connected to ground. With a streaming current of -1.0×10^{-6} A (specific charge = -1.3×10^{-6} C kg^{-1}) the surface potential on the walls of the FIBC with isolated yarns and the voltage on an isolated yarn were -3.2 kV and -2.1 kV respectively during filling. It was not possible to ignite the gas emitting probe with discharges from the walls of the bag with isolated yarns.

The gas emitting probe was, however, ignited by discharges from the sides and from the earthing loop of the FIBC when the latter was isolated from earth during filling. The surface potential and the voltage on an insulating yarn in this experiment were -10 kV and -7.6 kV respectively.

On emptying the FIBC the surface potential on the walls and on an isolated yarn were about +4.5 kV and +2.4 kV respectively. Gas probe ignition was not achieved during emptying operations.

DISCUSSIONS

Extrusion Coated Polypropylene FIBC (Insulating)

Potentials of the order of -26 kV could be produced on the outside surface of an extrusion coated polypropylene FIBC being filled with polyester pellets. Electrostatic discharges from the FIBC to the gas emitting probe ignited a propane/air mixture with a minimum ignition energy of 0.25 mJ. Potentials as high as +33 kV were measured on the FIBC during emptying. The gas emitting probe could not be ignited by discharges from the surface of a positively charged insulating FIBC. It has previously been suggested that the incendivity of discharges from positively charged surfaces are much less than from negative surfaces. In reference (4) Tolson found that propane could not be ignited by discharges from a positive surface. It was also found that a positive surface charge density about 4.5 times greater than that of a negative surface charge density was required to ignite hydrogen. Lovstrand in reference (5) explained this by the different character of the positive brush discharges which do not form luminous channels but only weak luminous cones at the electrode surface.

It is, however, very possible to achieve negative surface potentials on the insulating FIBC by using materials other than polyester pellets as both the magnitude and polarity of the charge transfer depend very much on the nature and the surface condition of the contacting materials.

Polypropylene FIBC with Woven Conductive Yarns (Antistatic)

With the earthing loop of such a bag **connected to ground** the average maximum surface potentials measured during filling and emptying of the bag were -5 kV and -3 kV respectively. Despite many trials at low (less than 20%) and ambient (~50%) relative humidities the surface potentials on an earthed antistatic FIBC were not sufficiently high to ignite a propane/air mixture with a minimum ignition energy of 0.25 mJ.

Potentials on the outside surface of an electrically isolated antistatic FIBC reached a maximum value of -14 kV (specific charge = -1.8×10^{-6} C kg^{-1}) the gas emitting probe was easily ignited by discharges from the outside surface of the **electrically isolated** antistatic bag. In fact a potential of about -5 kV on the isolated earthing loop of the antistatic bag could readily ignite the gas emitting probe. It is therefore very important to ensure that antistatic FIBC's are earthed during filling and emptying.

Polypropylene FIBC containing Woven Conductive and Coated on the outside with an Insulating Material

Experiments on this type of antistatic FIBC yielded similar results to those for an antistatic FIBC with no insulating coating. This was probably because the electrostatic charges on the powder and also on the inside wall of the FIBC were screened by the earthed conductive yarns. Since the insulating coating is on the outside of the FIBC, electrostatic charges on the powder were still in contact with the earthed conductive yarns and could therefore relax to earthed over a period of time which depended on the resistivity of the bag contents.

Polypropylene FIBC with some or all of the Conductive Yarns Isolated from each other and Earth

Electrostatic discharges from the surface of one side of an antistatic FIBC with electrically isolated conductive yarns did not ignite the gas emitting probe. The conductive yarns on the other three sides of the FIBC as well as those on top and bottom were connected to the copper braiding earth loop and to earth for these tests.

With the conductive yarns on all four sides of an antistatic FIBC isolated from each other and from earth the gas emitting probe could not be ignited by discharges from the sides of the FIBC containing isolated yarns. It was, however, possible to ignite the gas emitting probe by discharges from the isolated copper braid.

The reason why discharges from a surface of an earthed antistatic FIBC containing isolated conductive yarns failed to ignite a propane/air mixture with an minimum ignition energy (MIE) of 0.25 mJ may be related to stored energy on the yarns.-

The maximum surface potential measured on the side of a FIBC containing isolated yarns was -3.4 kV and the potential on individual isolated yarns was less than -2.1 kV when the copper braiding earthing loop was earthed.

The stored energy on an isolated yarn is given by

$E = {}^{1}/_{2}\ CV^2$

where C is the capacitance of a single yarn (10^{-11}F) and V is the voltage. Assuming the isolated yarn voltage is similar to the surface potential then:

$E = {}^{1}/_{2} x 1 x 10 x^{-11} x 3400^2$

E = 0.06 mJ

This is much smaller than the minimum ignition energy of the gas mixture.

If the measured voltage on each isolated yarn is used in the above equation the stored energy will be 0.02 mJ, which is even smaller.

If, however, all the conductive yarns are connected to the copper braiding earth loop but disconnected from earth, then the total capacitance of the FIBC was measured to be $120 x 10^{-12}$ F. Assuming a very modest voltage of 5000 V on the yarns, the stored energy will be 1.5 mJ, which is greater than the MIE and could, therefore, cause ignition.

If interconnected parts of the bag become isolated from the main earth braiding, spark energies in the range 0.06 to 1.5 mJ would be expected. Bag design and robust earthing is clearly important to prevent this situation arising.

CONCLUSIONS

Extrusion Coated Polypropylene FIBC,s (Insulating)

The surface potentials produced on these FIBC's both on filling and emptying can provide incendive discharges.

Such FIBC's should not be used in the presence of a flammable vapour. A theoretical risk of ignition also exists if a dust cloud of low ignition energy is present at filling or emptying.

Polypropylene FIBC's with Interconnected Woven Conductive Yarns (Antistatic)

It was not possible in the trials to ignite a propane/air mixture with a minimum ignition energy of 0.25 mJ by discharges from such FIBC's **provided they were earthed** during filling and emptying. An unearthed bag produced incendive discharges.

The presence of some unearthed and isolated conductive yarns in such FIBC's did not lead to ignition of a flammable atmosphere with a minimum ignition energy of 0.25 mJ provided the copper braiding earth loop was grounded. The maximum energy which was stored on an isolated conductive yarn was calculated to be 0.06 mJ.

Bag design is important in preventing larger sections of the bag becoming isolated from the main bag earth braid.

Polypropylene FIBC containing Woven Conductive Yarns and Coated on the outside with an Insulating Material (Antistatic)

The presence of an outer coating did not affect the electrostatic properties of the antistatic bags tested.

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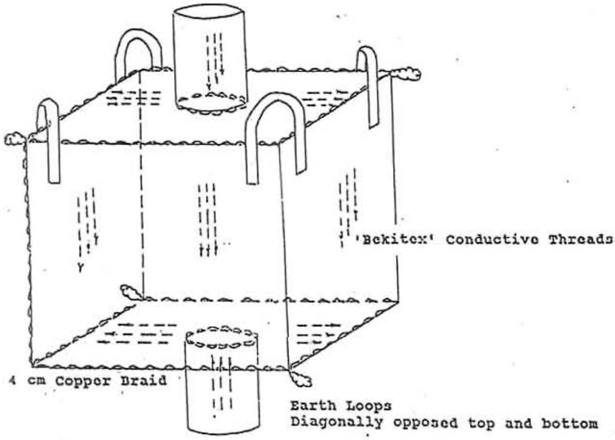

Figure 1 : Antistatic FIBC