EXPLOSION HAZARDS AND PROTECTION IN THE USE OF INTERMEDIATE BULK CONTAINERS

P Holbrow
Health and Safety Laboratory, Harpur Hill, Buxton, SK17 9JN

INTRODUCTION

Intermediate bulk containers (IBC) in the form of rigid intermediate bulk containers (RIBC) and flexible intermediate bulk containers (FIBC) are increasingly being used for the storage and transport of powders, flakes and granular materials.

Many flammable dusts are stored and handled using IBC, but they are weak containers and if an explosion occurs without adequate explosion protection, they may rupture due to the high explosion pressure. The consequence may be external fires and injury to personnel.

Some explosions that have occurred during the filling/emptying of FIBC have been attributed to static electricity and so called "anti-static" FIBC have been developed. However, they do not provide protection against other sources of ignition e.g. burning powder from upstream units. IBC are normally closely linked to other process equipment e.g. mills, blenders, dryers, in which combustion of bulk powder may be initiated. This may increase the possibility of burning material initiating a dust explosion in the IBC.

Explosions have also been attributed to ignitions outside the dust containment system. In a recent incident, an ignition started outside an FIBC, at a filter associated with a pneumatic conveying system. An adjacent aluminium hopper was fed from above by the FIBC. The fire at the filter spread to the aluminium hopper, which failed, and then spread to the FIBC, melted the fabric and caused the contents to spill into the fire. A dust cloud formed in the hopper which then resulted in an explosion.

The increase in container volume can markedly change the characteristics of the dust cloud in the container. Where relatively small drums are used, filling times are relatively short, the powder concentration within the filling stream is normally above the Upper Explosion Limit, and little, if any, separation of "fines" occurs in the ullage space. All these factors mitigate against the initiation of a propagating explosion. However, in IBC, the filling stream forms a smaller part of the volume and a dispersed cloud can be formed around it. The dust cloud characteristics will depend on the physical form of the powder and the filling procedure but in many cases there will be an increased tendency for a dust cloud within the explosion limits to be formed. Furthermore, if the filling procedure is such that the "fines" can separate from the coarser material, then a dust cloud requiring a lower energy for ignition may be formed.

This paper considers the use of IBC and the explosion prevention and protection techniques that are currently used. This paper does not consider the storage or handling of liquids, however any potentially explosive vapour or gas external to the IBC does require consideration.

STANDARDS

There are a number of standards that are relevant to intermediate bulk containers including:

1. BS EN 1898:2001 Specification for flexible intermediate bulk containers (FIBC) for non-dangerous goods. This standard superseded the British Standard BS6382: 1983 Part 1 Recommendations for FIBC for non-dangerous goods in January 2001.
2. The UN Recommendations on the transport of dangerous goods has replaced British Standard 6939 (7 parts). There is also a draft European standard, ISO/DRAFT 16467:2000, Transport packages for dangerous goods — test methods for IBC, which has similar requirements to the UN Recommendations.
3. Electrostatic safety of flexible intermediate bulk containers is assessed in accordance with BS 5958 Part 1 & 2 1991, *Control of undesirable static electricity*. The CENELEC report PD R044-001, based on BS 5958 and other documents, has been updated and issued as PD CLC/TR 50404:2003. Reference is made to powder storage in containers including type A, B, C and D FIBC; these are discussed later.
4. Draft European Standard IEC 61340-4-4 Electrostatic safety of flexible intermediate bulk containers (FIBC) — Test method and requirements. The draft standard gives the test requirements for electrostatically safe FIBC that are intended for use in the presence of flammable material or in a hazardous atmosphere. A new draft standard IEC 61340-4-6 is also applicable.

DESIGN AND OPERATION

RIGID INTERMEDIATE BULK CONTAINERS

Construction

Rigid intermediate bulk containers are often referred to as IBC. Because of the robust construction of rigid IBC, when compared with FIBC, they are classed as multi-trip containers. Manufacturers offer a wide range of rigid intermediate bulk containers each having different design features to suit a given application.

With capacities in the order of 300 to 3000 litres they are generally four sided with a coned shaped bottom to aid discharge. Other shapes include cylindrical containers, which use less material in their construction, are easier to clean and can better withstand internal pressure.

Most commonly, the materials of construction are carbon steel, stainless steel and aluminium. Grounding is relatively easy and earthing straps are often fitted as a matter of course. Rigid plastic IBC are manufactured with a rigid plastic body which is designed to be in contact with the contents (either directly or through an inner liner or lining). Polyethylene containers are normally mounted in a mild steel or stainless steel frame. However, some polyethylene containers are moulded such that a steel frame is not required. Carbon impregnated black polyethylene containers to dissipate charge build-up are manufactured as a conductive IBC and are classed as anti-static.

Other less common materials of construction are fibreboard, wood and composite. Some rigid IBC are UN certified for the transportation of certain hazardous goods. For the transport of dangerous goods by sea, rail and road throughout Europe, IBC are generally only used when they are permitted for specific contents and when the IBC design has been officially tested and bears the appropriate marking.

Rigid IBC filling

Filling of metal or rigid plastic IBC is generally via a central access hatch. Automated filling can be achieved using a containment transfer system (CTS). The operator does not have to remove or replace the lid nor operate a valve. The CTS typically consists of a flanged containment unit that connects to the feed silo, a lift table to locate and lift the IBC and a control panel. With the IBC placed under the CTS unit and the controls initiated, the IBC is lifted and docks with the CTS, the CTS opens the IBC lid and filling takes place. When filling is completed, the lid is automatically replaced and the IBC is separated from the CTS.

Rigid IBC discharging

Conventional valves such as butterfly, slide, gate, and so on, create an opening at the silo outlet, bin or IBC but the discharge of some products may be difficult. Many powders may not flow consistently and may bridge over even very large outlets. It may be impossible to close the valve in some cases. One method of overcoming this problem is to install a specialized IBC cone discharge system. The product within the IBC is sealed by the cone to ensure a dust-tight seal. To discharge the product, the IBC is placed on a purpose designed IBC discharge station. Once located on the station, the IBC outlet engages a lip seal at the discharge station to create a dust-tight seal. When the open signal is received, a probe rises within the discharge station and locates into the cone valve. The probe expands to seal and lock tightly inside the cone and then lifts the cone valve into the IBC. The probe/cone then pulses and/or vibrates to discharge the product.

FLEXIBLE INTERMEDIATE BULK CONTAINERS

FIBC offer many advantages. They are lightweight, weighing a small percentage of the weight of the contents and are much less expensive than rigid IBC. It is easier to discharge difficult products and the containers are hygienic since plastic liners protect the product. They are low maintenance since replaceable liners eliminate cleaning costs.

The main disadvantage when compared to a rigid IBC is that they are susceptible to damage, for example from the fork of a forklift truck and they therefore have a more limited life span.

Construction
The capacites of FIBC are generally no greater than 3 m^3 and are designed to be lifted from above by integral or detachable devices. An FIBC, designed and intended for one filling and one discharge only, is designated as a "single-trip FIBC". An FIBC intended to be used for more than one filling and more than one discharge is designated as a "multi-trip FIBC".

FIBC are manufactured largely from UV stabilized woven polypropylene with most commonly one, two or four lifting points. Sufficient suspension points should be attached to the top corners or the rim to give stability. Traditionally, the more usual shape is approximately cubic, fitted with a filling chute and an emptying cone. The containers are usually stacked on pallets or lifted by four loop straps at each corner.

The FIBC is stitched with man-made fibre or twine and some heavy duty FIBC have welded seams. The fabric can also be woven as a circular tube. FIBC can be coated with thin film to keep the product from leaking out of the weave, whilst some FIBC have disposable polythene or polyethylene liners that are used to prevent product seepage through the fabric and to improve watertightness. Electrically conductive liners are also available for use in antistatic bags. Where liners are used in multi-trip FIBC, the need for cleaning is avoided and the life of the FIBC is extended.

Performance
The National Engineering Laboratory (NEL) provides an independent testing and evaluation of FIBC. However, many of the major FIBC manufactures carry out their own testing.

In common with rigid IBC, some FIBC are UN certified for the transport of certain hazardous goods. For FIBC that are intended to contain non-dangerous solid materials in powder, granular or paste form, and designed to be lifted from above by integral or detachable devices, BS EN 1898:2001 specifies the materials, construction and design requirements, type test, certification and marking requirements.

Electrostatic safety of flexible intermediate bulk containers is assessed in accordance with BS 5958 Part 1 & 2 1991, Control of undesirable static electricity. The CENELEC report PD CLC/TR 50404:2003 is also used and this is based on BS 5958 and other documents. A new document is currently in draft form, IEC document 61340-4-4 IEC:2001, and deals exclusively with the electrostatic safety of FIBC. This draft document describes procedures for evaluating the electrostatic safety of all types of FIBC that are intended for use in flammable or explosive environments with ignition energies of more than 0.15 mJ. The procedure uses a re-circulating FIBC filling rig, an ignition probe, a gas control system, mixing apparatus and calibration apparatus. The FIBC is suspended in the recirculation rig initially with the top filling spout open and the emptying spout closed. Polypropylene pellets (nominally 3 mm) are loaded into the recirculation system and begin to fill the FIBC until it is approximately half full, at which point the bottom spout is partially opened to maintain the fill level so that the out-flow matches the in-flow. The pellets become charged by triboelectric action but if necessary, additional charge may be injected by the incorporation of high voltage corona points inside the filling chute. A series of ignition tests is carried out by bringing the ignition probe up to the side of the charged FIBC with a calibrated flammable propane gas mixture flowing through the probe having gas mixture volume concentrations of approximately 4% propane, 33.6% oxygen and 62.4% nitrogen. The mixture has an ignition energy of 0.15 mJ. The sequence of ignition attempts is made at various points on each of the four sides of the FIBC, making a total of 200 ignition attempts. No ignition should occur in any attempt.

Heavy duty FIBC

These are expensive and constitute a small portion of the market. They are made from PVC coated polyester cloth and usually have complex metal lifting devices fixed to, or detached from, the top of the bag. They have the most demanding test specification which includes an 8:1 safety factor. They are intended for multiple use and are repairable.

Standard duty FIBC

Standard duty or multi trip FIBC are usually made from woven polypropylene cloth and may contain a polyethylene liner, to protect the contents and prevent leakage. They have a safety factor of 6:1 and the most usual load is 1000 kg. A discharge spout at the base has ties to seal the bag and can be used to close a partially discharged bag or to regulate the rate of discharge and they are retied before the bag is refilled. The life of this bag is between 15 and 20 trips and is dependent on the nature of the contents and on the handling and transport methods used.

Single trip FIBC

The single trip FIBC is intended for only one filling operation. They usually have a flat bottom and discharge takes place by cutting open either the bottom to allow full discharge or by cutting a T-shaped slit at the side and controlling the discharge by inserting a board vertically downwards. They have a safety factor of 5:1.

FIBC bag filling and discharging methods

General

Filling and discharging is generally done through spouted top and bottom openings, where the bottom spout requires only unfolding/untying to begin gravity unloading. Some FIBC require a cut to be made in the fabric. However, industries such as the pharmaceutical industry require sophisticated filling and discharge systems where hygiene and containment are of paramount importance.

FIBC filling

The main objective during filling is to ensure that the entire product enters the bag and does not spill. In the most basic filling system, the FIBC is located on a pallet or platform beneath the filling spout with a support frame supporting the lifting straps. The filling spout is connected to a filling point and the product is fed into the bag. This could be via a wide range of devices including: gravity feed, a rotary valve or screw feeder.

However, filling methods can be more sophisticated with features designed to enable filling to take place more safely, cleanly and efficiently.

Minimizing dust leakage is an important feature. Inflatable seals are often used to connect the filling spout of the FIBC to the filling head to ensure a dust tight connection. The seal is generally a rubber tube which encircles the spout and is lightly inflated sufficiently to seal the bag or liner.

For bags with liners, inflation of the bag is necessary before filling. Inflating the FIBC using air is commonly used to help square the bag and eliminate any creases. In some cases, inflating the collapsed bag with nitrogen is done for mitigation of the explosion risk by inerting, and for product quality reasons.

FIBC discharging

FIBC are generally loaded onto a discharge station by hoist or forklift truck. Typically, a discharger will comprise an open topped, four sided hopper. One side of the hopper incorporates an access door that allows the operator access to the discharge spout to untie the tying-off strings.

When the tying-off strings of the discharge spout are released without proper control, and depending upon the product characteristics, the product could either discharge rapidly or could fail to discharge at all. A correctly designed discharger should be able to cope with the extremes. This is achieved by use of design elements such as product flow control systems, clamps and seals to prevent dust leakage.

A flow choke can be used to hold back the product whilst the ties are released. This seals the liner above the ties using sliding clamp plates, or wire rope, which can be released in a controlled manner after the strings have been released. Flow can be stopped and the bag retied when only part of a bag needs to be discharged. When a bag is discharged, the inner liner can become an operational problem. A liner tensioner is used to wind-up the liner which otherwise would slacken and elongate as it empties. Bag tensioners are used to gradually raise and tension the bag as its weight decreases during discharge.

Flat-bottomed single trip FIBC are emptied by cutting the bag. A simple and efficient method is to use a discharge hopper incorporating knife-edge. As the bag is lowered onto the hopper the bag is split and also makes contact with a rubber membrane, creating a seal to prevent dust leakage.

FIBC can be vacuum unloaded. The hose is inserted into the product via the top of the FIBC and a vacuum pump extracts the material. The hose is antistatic or conductive with grounding of metal connectors.

IGNITION SOURCES

ELECTROSTATIC IGNITION SOURCES

General charging (rigid and flexible FIBC)

Electrostatic charging is a normal occurrence in most powder handling processes and this is of prime importance during filling and emptying operations. Charge accumulations could occur on equipment, including drums and containers, and on bulk materials that are insulating. Filling represents the most hazardous operation since the material undergoes dispersion and can therefore acquire charge during the separation processes occurring in transport. The bulk material and its associated charge are then packed into a small space. Here, the charge is not able to flow to the ground quickly enough, even with a conductive and grounded receiver. This generates a high space charge density and electric field. In addition to charge accumulation there can be problems due to heat accumulation and the possibility of entrainment of smouldering lumps.

Charging processes in FIBC

Any powdered insulating material filled into an FIBC is likely to acquire electric charge. Any insulating material will acquire an electrical charge when contacted and separated from another material; the process is called contact electrification. Relative movement of the two surfaces during contact generally enhances the charging effect; this is called triboelectrification. During FIBC filling, the product will typically pass through ducts and the particles will constantly collide with the surfaces of the ducts and with each other. There is plenty of opportunity for the filling product to become charged. As the charged product enters the FIBC, the surface of the container will become charged in a number of ways. Triboelectrification of the container surfaces will occur as the product collides with the surfaces, charge may migrate to the container surface from the charged filling product and corona charging may occur. The latter charging is as a result of the bulking together of the charged product in the container to form a cone. At the tip of the cone the field from the charge on the product is concentrated and may reach the breakdown value for air. Charge released in the air is repelled from the cone and may build up on the surface of the container.

If powder is charged when it enters the FIBC then the insulating properties of the standard polypropylene FIBC will cause charge to accumulate in the bag as more powder is added. Under conditions of exceptionally high charging, for example following pneumatic transfer of powder, the charge levels on the powder can be so high that the compacted powder produces electric field strengths both inside and outside the bag which can exceed the dielectric strength of air. The rate at which charge dissipates depends on the electrical resistance between the stored charge and ground. An electrostatic spark occurs when an isolated charged object is suddenly grounded. For air, the breakdown strength is approximately 3000 kV/m.

Assessment of the electrostatic ignition risk in powder handling plants requires a decision as to whether a dust cloud can be ignited by brush or propagating brush discharge, spark, cone or corona.

Brush discharges can occur from the bulk product or from the highly insulating surface of the FIBC or the liner and have an energy content of up to 3 or 4 mJ.

Propagating brush discharges may occur across the FIBC fabric or liner if the FIBC is filled with a highly charged product and the breakdown voltage of the FIBC wall including the coating and liner exceeds 4 kV. They have much higher energies than ordinary brush discharges and occur if a double layer of charges of opposite polarity is generated across a thin sheet of a non-conducting material for example, across an insulating FIBC wall. This type of discharge is capable of igniting dusts. Propagating brush discharges may only occur during the filling and emptying of FIBC with highly charged, highly insulating product.

Propagating brush discharges may be excluded if the volume of resistivity of the fabric is lower than about 10^8 Ohm or if the breakdown voltage across the FIBC fabric is less than 4 kV.

Spark discharges from a conductive FIBC or a conductive part that is not earthed are able to ignite dusts. An electrically insulating bag (standard polypropylene) which has become contaminated with a conducting substance, such as water, may also be capable of producing spark discharges from the contaminated area to any nearby earth. If the conductive bag is earthed then spark discharges from the bag are not possible. Spark discharges from a charged conductive product are possible but can be excluded by using earthed conductive FIBC or by introducing an earthed metal rod down to the bottom of an insulating FIBC prior to filling. Spark discharges from a person or other external conductive object can be excluded by earthing the person or object.

Cone discharges can occur across the surface of the powder heap in the FIBC. Cone discharges can be a little more energetic than brush discharges, but their limiting energy is dependent on the diameter of the bag being filled as well as the particle size of the powder.

Corona discharges are associated with conductors with sharp points or edges. They can occur when such an earthed electrode moves towards a highly charged object or when the conductor is raised to a high potential. The very weak gas discharge or corona from the sharp point of the conductor occurs with a constant discharge over a long time with an extremely low energy and is only capable of igniting extremely sensitive flammable gas air mixtures.

A summary of the main types of discharge that may occur when filling or emptying FIBC is shown in Table 1.

If the bag receiving the powder is made from a conducting material that is connected to earth, then brush and propagating brush discharges from the bag fabric are no longer possible. External bag contamination and external object charging by induction are also

Table 1. Types of discharge

Type of discharge	Description	Energy
Spark	From isolated conductive product From isolated conductive FIBC	Depends on capacitance and voltage
Brush	From insulating bulked product From FIBC made from insulating material	<4 mJ
Propagating brush	From FIBC made from insulating material of high dielectric strength	Several joules
Cone	From coarse insulating bulked product	<10 mJ

no longer relevant. If the bag is not earthed or becomes disconnected from earth then energetic spark discharges can occur under certain conditions. During emptying, which could take as little as 15 seconds, electrostatic charging mechanisms will again be present.

Classification of FIBC

Three common terms used in the FIBC industry are 100% plastic FIBC, antistatic FIBC and fully conductive FIBC.

i) *100% plastic FIBC* are collapsible, rectilinear plastic containers. 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. While they may be nitrogen purged prior to filling, they cannot be grounded.

ii) *Antistatic FIBC* 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 the weft direction, or both. Antistatic FIBC have also been produced with antistatic coatings or with ungrounded systems of isolated conductive threads, which limit charge accumulation by corona discharge and have an intrinsically low capacitance.

iii) *Fully conductive FIBC* contain sufficiently high loadings of conductive material (typically carbon black) to render all the plastic conductive.

Classification of FIBC according to their ability to avoid electrostatic hazards have been made by divided them into four types: A, B, C and D.

Type A FIBC have a woven structure with no electrical-property specification. This type is intended for use in situations where there are no risks from electrostatic discharges. They are suitable only with non-flammable products in non-flammable environments.

Type B FIBC are non-conductive, but have the added requirement that the fabric wall has a breakdown voltage of less than 4 kV to prevent the occurrence of a propagating brush discharge. Use of a standard non-conducting plastic liner may raise the wall breakdown voltage to above 4 kV, raising the possibility that a propagating brush discharge could occur at high filling rates or emptying.

Type C FIBC are designed to be electrically conductive and have a resistance to earth from any location on the FIBC, including the slings, of less than 10^8 Ohm. Typically, Type C contain a matrix of conductive fibres within the synthetic-fibre weave terminating in a conductive strip that is earthed during filling or emptying. Some bags carry the conductive strip into the lifting loops so that the bag will be grounded when hung on a grounded loading/unloading station. Using a Type C bag requires permanent grounding of the bag during the whole period while the bag is filled or discharged. The discharge from an ungrounded bag aligns to a single discharge point and such a discharge may be strong enough to ignite dust clouds.

Type D FIBC have conductive threads that are not interconnected and may also have a partially conductive coating. They are electrostatically-dissipative bags and it is claimed that no grounding is required since special static-dissipative fibres and antistatic coatings are present to safely dissipate electrostatic charges by a combination of corona discharge and enhanced surface conductivity. There is no specification for the electrical properties for the fabric of a static dissipative bag. Instead, each design is qualified by special test procedures in which the propensity of "worst-case" bag discharges to ignite flammable gases with known ignition energies are investigated. Typically the system of conductive fibres has a capacitance too small to give incendive sparks at the maximum voltage attained; the latter is limited by corona discharge above 1–2 kV plus the action of a anti-static agent applied to the fabric. There is some controversy surrounding the Type D bag, the Hazardous Cargo Bulletin[1] reported concerns over reports that using the unearthed Type D bag can cause ignitions in atmospheres with minimum ignition energies of less than 0.25 mJ.

NON-ELECTROSTATIC IGNITION SOURCES

Potential sources of ignition classified as non-electrostatic and likely to be relevant to IBC include open flames, hot surfaces, mechanical sparks, arcs from electrical equipment and self-heating of solids. The HSE gives practical advice and application of the law relating to the control and prevention of these ignition sources[2].

Many incidents have been caused by careless use of welding or flame cutting equipment, or other hot work. Sparks can travel long distances, particularly if work is carried out at a high level. It is therefore important that hot work is effectively isolated from bag filling operations.

The requirements for protected electrical equipment for use in atmospheres of flammable dusts are given in BS 6467: Parts 1 and 2 (1985 and 1988). Advice is given on the design, selection, installation and maintenance of equipment. The main factors to control are the maximum surface temperature and restriction of dust ingress to the enclosure.

It is preferable to site electrical equipment away from dusty areas, but if installation is close to dusty areas, a dust tight enclosure is recommended to prevent the risk of dust ignition inside the apparatus. BS EN 60529 classifies types of enclosures and gives them an index of protection.

It is necessary to ensure that the maximum surface temperature produced by an item of electrical equipment exposed to dust is below that required to ignite the dust either as a layer or as a cloud.

Many materials are prone to spontaneous heating, which may be caused by air oxidation, biological reaction or exothermic decomposition. Where materials may be handled hot, for example in a drying process prior to discharge into an IBC, maximum temperatures need to be controlled.

Ignitions have occurred as a result of burning or smouldering material from an upstream process. Potential risks from smouldering material can be reduced by isolation methods, i.e. slam-shut valves or by methods of interlocking, i.e. power isolation from rotary valves.

EXPLOSION PROTECTION AND PREVENTION

RIGID IBC

Venting

In some applications, IBC may be designed to withstand the maximum explosion pressure generated by a dust explosion. These vessels would be designated as pressure resistant vessels or pressure shock resistant vessels, but the cost is high and IBC of this strength are not common. Most rigid IBC are classed as weak vessels with, typically, a metal wall thickness of 2–3 mm with a maximum strength in the order of 0.3–0.4 bar. Where the vessel is relatively weak, explosion relief venting is an option but does not appear to be used very often in this type of vessel.

Where explosion venting is used, the preferred method is to install the explosion vent to the ducting immediately upstream of the IBC. Since personnel are likely to be working in the vicinity of an IBC filling point, the vent is either ducted to a safe area or a flameless venting device is fitted.

Suppression

Explosion suppression is important in cases where explosions could cause the emission of gases, vapours or dusts which are toxic or otherwise harmful to the surroundings. These systems are designed to prevent the creation of unacceptably high pressure by gas or dust explosions within enclosures that are not designed to withstand the maximum explosion pressure. The explosibility data of the dust must lie within the range of applicability of suppression systems.

The design of the suppression equipment will depend on a range of factors including the volume of the plant and the severity of the dust explosion hazard. Suppression is likely to be most suited to a permanent installation, it is not applicable to plant that is moved from site to site. Typically, detection is by threshold membrane detectors that provide an electrical contact when the pressure load exceeds a preset value. A range of suppression hardware is available including hemispherical explosion suppressors, mounted inside the plant, which are suited to small volume plant components. Other types include single exit and dual exit suppressors which use a high speed valve to release suppressant. For the more violent dust explosion hazards, high rate discharge suppressors (HRDs) are more appropriate.

Inerting

Inerting is often done as part of the product quality control procedures where oxidation of the product is to be avoided. This fortunately has the advantage of acting as an explosion prevention measure. Where there is an explosion risk it is common practice to ground IBC, the filling stations and discharge valves, and use nitrogen blanketing to inert the atmosphere within the IBC.

Inerting a flammable dust/air mixture can be achieved by replacing the oxygen in the air by an inert gas such as nitrogen. Dust/air mixtures can explode only if the oxygen required for combustion is available in the immediate vicinity of each dust particle. The maximum oxygen concentration at which dust explosions are just not possible cannot be predicted; it depends on the nature of the combustible material and has to be determined experimentally in each case and will vary with the type of inert gas.

Where inerting is used, effective monitoring of the atmosphere should be provided, with automatic action such as shutdown, if the oxygen concentration exceeds a predetermined level.

Earthing

The metal frame and body of the IBC is, in many cases, grounded as the IBC is loaded onto the metal support frame. However, to ensure that earthing is achieved, a system is used where earthing is provided by automatically engaging a spring plate as the IBC is mounted on the support frame. Apart from the benefit of automation, this also eliminates any doubt associated with a manual system of earth clamps.

FIBC

There are no known examples of explosion venting or explosion suppression applied to FIBC installations.

Inerting

Inerting is used in FIBC filling operations and many of the basic principles applicable to rigid IBC, is also applicable to FIBC. Typically during FIBC filling operations the FIBC is filled with the product via a spouted filling opening. Inside the FIBC is a separate carbon impregnated conducting liner. Before filling, the liner is grounded to earth and the bag and liner are sealed at the filling neck using an inflatable seal and finally clamped with an outer steel clamp ring. The seal is dust tight. The inner conducting liner is inflated with nitrogen via an annular inlet at the neck for a timed period before the purge lines are closed using inlet and outlet valves. The purged nitrogen can be recycled to the plant. It is not necessary to monitor the oxygen level as the degree of inerting is determined by timing the inert purge flow rate through the known volume of the system. Following the introduction of nitrogen, the bag retains a slight positive pressure which removes creasing in the bag and promotes the complete filling of the bag with no empty voids. Inerting can also be carried out during discharge.

Earthing

Type C FIBC are electrically conductive and require permanent grounding of the bag during the whole period while the bag is filled or discharged. Typically, earthing clamps are attached to earthing tags on the FIBC, enabling charge to dissipate before it builds up to an excessive level. Earthing relies on a) the operator correctly fitting the earthing clamp, b) in the case of a multi-trip bag, that the bag has not degraded and lost some of its anti-static properties, and c) that the correct type of bag has been used. It is considered that there is a need to earth conductive objects in the vicinity of Type D FIBC in order to avoid corona charging.

EXPLOSION INCIDENTS

Plant operators are generally in close proximity to the FIBC when opening the outlet spout at the base of the FIBC and later the operator may shake the bag to release residual powder. In the event of ignition of the powder, the operator is likely to be caught in the flames. If the flames propagate into the FIBC, a deflagration may occur inside the FIBC causing the bag to rupture due to the pressure development from the ensuing explosion. The following examples illustrate how incidents involving different types of intermediate bulk containers can occur. Whilst it is well known that the electrostatic hazard posed by FIBC can ignite flammable vapours, these examples illustrate the hazard posed by flammable dust clouds.

1. Dust explosion events almost always start inside the process where powder is being moved or processed. However, a recent incident in the UK illustrated that ignitions can be initiated outside the dust containment system. In this incident, at a factory producing plastic packaging, an ignition started with a fire in an air filter associated with a pneumatic conveyor system. An adjacent small aluminium hopper was fed from above by the FIBC. It was located on the top of the hopper with its outlet spout untied. The powdered product was a fine free flowing polymer additive. The fire at the filter spread to the aluminium hopper, which failed, probably when some of the metal melted. This allowed powder to escape into the fire already present, and more powder to flow into the top of the hopper from the FIBC above. The fire then spread to the FIBC, melted the fabric and caused the contents to spill into the fire. A dust cloud formed in the hopper which then resulted in an explosion.
2. In an incident in 1989, described by Britton[(3)], a fine organic herbicide comprising 6–8 micron particles was being discharged from a 100% plastic FIBC. There were no flammable liquids involved. The material was being discharged from the FIBC into a steel chute, approximately 0.45 m diameter × 5 m long, and then into a weigh bin with an attached dust collector. The FIBC needed to be beaten with a rod to loosen the contents. An operator was emptying the FIBC and when he observed that the FIBC was emptying very fast. As it completed emptying, he saw a mushroom cloud of smoke around the FIBC and then a wall of flame travelling towards him. A second employee, approximately 6 m away, heard a rumble and saw a fireball engulfing the FIBC emptying area. The two employees were injured, one with second degree burns. Flash fire damaged equipment, there was structural damage to the building walls and ventilation ductwork was damaged due to overpressure. According to Britton a possible scenario was that the FIBC may have been wet due to rain entering the suppliers truck. The water may have created a conductive patch on the FIBC capable of yielding sparks.
3. A company was transferring the contents of a batch of 100% plastic FIBC into a row of drums[(3)] on a concrete floor. While one operator worked the hoist, a second held two vacuum hoses near the top of each drum to minimize dust leakage into the room and a third operator regulated flow from the FIBC. At the time of the incident, the drum was being filled and the FIBC was being “puffed” to shake out residual powder. The three operators observed the material on fire, in the drum. Flame

propagated into the FIBC and all three operators received first degree burns. It was clear that "puffing" the FIBC, when almost empty, created a dust cloud. The operators and drums were not grounded and a spark may have occurred between the operator holding the vacuum hoses and the ungrounded top of the drum.

4. An incident[4] occurred in which product was being transferred from a hopper to an IBC via a butterfly valve and a flexible hose. The IBC was a rigid metal container which was sitting on a metal floor and was adequately grounded. The dedusting system attached to the IBC had a 75 mm flexible low conductivity rubber hose between the metal cover and metal pneumatic duct leading to a bag filter. The hose was not earthed. The 200 mm diameter transfer hose was made of a flexible low conductivity rubber with a spiral metal wire but this was not earthed. Having observed that the rate of flow was decreasing, the operator fully opened the butterfly valve. The material then began to flow rapidly into the IBC, such that the metal cover resting on top of the IBC lifted and "danced about". An explosion then occurred and a fireball expanded into the workplace inflicting some first and secondary degree burns on the operator. The subsequent incident investigation found that the explosion was not as violent as predicted by the dust explosibility data. The dust concentration was thought to have been below the optimum concentration which resulted in a weak explosion. There was little damage to the equipment; the fireball did not propagate from the IBC to the bag filter, and there was no secondary fireball in the workplace. The investigation revealed that even though the butterfly valve had been fully opened, bridging caused material flow to cease and there existed simultaneous electrostatic charging and dissipation. The charges were caused by movement of material into the loading hopper, above the IBC. At the same time, charges were being dissipated to the walls of the loading hopper. New material was added to the top of the pile in the hopper. When the bridge collapsed, a conglomerate of electrostatically charged material fell into the IBC. The displacement of air in the IBC caused the cover to "dance about". At this point, the cover was ungrounded and was in the presence of an electric field from the falling charged conglomerate. This caused an electrostatic charge to be induced into the metal cover which then discharged an incendive spark to the grounded IBC.
5. A Type B FIBC, with a breakdown voltage <4 kV to prevent propagating brush discharges, and was considered suitable for this duty, was being filled with a plastic product[5]. A short time before the explosion, there was a greater throughput of product and possibly a greater proportion of fines in the bulk material. The product was described as a low-conductivity product, the resistivity of the bulk material was $>10^{12}$ ohm.m and the MIE was 3–10 mJ. The material was conveyed pneumatically from a mill through a dust separator into the FIBC. The system was made from a conductive material and was grounded. The potential sources of ignition such as the mill overheating or ingress of foreign objects could be excluded. Past experience had shown that the product could produce strong electric fields emanating from the FIBC. This fact did not, however, cause concern since propagating brush discharges were not expected. Analysis of the explosion incident suggested that while the highly charged

bulk material was being filled into the FIBC, a cone discharge originated in the product. As the plastic product had a broad particle size distribution, with particles about 1 mm diameter down to a fine powder, cone discharges with an energy up to multiples of 10 mJ could occur. Following the incident the FIBC was replaced with a conductive and grounded Type C FIBC. The report stated that cone discharges may not be completely prevented in this type of FIBC. It is believed that the changed direction of the electric field (the wall of the FIBC now at zero potential) means that the energy of the cone discharges are considerably reduced. There was no detail relating to the extent of the fireball or the damage sustained although the report did indicate that there was "little damage to the plant".

CONCLUSIONS

The trend towards IBC in preference to smaller containers can markedly change the characteristics of the dust cloud. Filling times in small drums are relatively short, the powder concentration within the filling stream is normally above the Upper Explosive Limit, and little, if any, separation of "fines" occurs in the ullage space. All these factors mitigate against the initiation of a propagating explosion. However, in IBC, the filling stream forms a smaller part of the volume and a dispersed cloud can be formed around it. The dust cloud characteristics will depend on the physical form of the powder and the filling procedure but in many cases there will be an increased tendency for a dust cloud within the flammable limits to be formed. Furthermore, if the filling procedure is such that the "fines" can separate from the coarser material, then a dust cloud requiring a lower energy for ignition may be formed.

The major hazard in any dust explosion arises when the dust enclosure ruptures, the dust is dispersed in the general plant area and a secondary explosion is initiated. The use of IBC will increase the possibility and extent of secondary dust explosions in that (a) they are mechanically weaker than drums and will rupture more readily with possibly a large split and (b) a greater quantity of powder is available for dispersion.

Many of the explosion incidents involving FIBC are attributed to spark or electrostatic ignition sources and so called "anti-static" fabrics have been developed. However, these are solely intended to prevent electrostatic discharges from the FIBC fabric itself, that is, make the FIBC electrostatically equivalent to metal IBC. This does not preclude the possibility of incendive discharges from the bulk powder. Nor does it provide protection against other sources of ignition e.g. burning powder from upstream units. Many process plant designs integrate closely the powder processing stages. The packaging of materials into an IBC can result in a more direct link between units (e.g. mill, blenders, dryers), in which combustion of bulk powder may be initiated. This may increase the possibility of burning material initiating a dust explosion in the IBC.

Explosions may be prevented by inerting the atmosphere to control the oxygen content to a safe level. However, it appears that monitoring of the oxygen content is rarely done in preference to blanket inerting or relying on known volumes and gas flow rates. Explosion suppression is not normally used to protect FIBC but it is often used for the protection of rigid IBC. However, inerting is often preferred where it is an economic option.

Explosion venting of rigid IBC is used but is not common, mainly due to the inconvenience of fitting explosion vents to the body of an IBC. A practical alternative is to install the explosion vent to the ducting immediately upstream of the IBC; this will only be effective during the filling operation. During product discharge, venting is more difficult, but an explosion vent fitted to a rigid IBC can be achieved by using removable top section. A telescopic duct over the top section of the IBC would relieve the explosion.

REFERENCES

1. Hazardous Cargo Bulletin. Cs and Ds fight it out, P59–60. July 1998.
2. HSE, Health and Safety series booklet HS(G)103, Safe handling of combustible dusts, precautions against explosions, ISBN 0 7176 2726 8, 2003.
3. Britton L. G. Static hazards using flexible intermediate bulk containers for powder handling. Process Safety Progress (Vol. 12, No. 4), October 1993.
4. Pratt T. H. Static electricity in pneumatic transport systems: three case histories. Process Safety Progress (Vol.13, No. 3) July 1994.
5. Glor M. Overview of the occurrence and incendivity of cone discharges with case studies from industrial practice. Journal of Loss Prevention in the Process Industries Vol. 14 No. 2, March 2001 123–128.