EXPLODING CORN

P J Caine, G P Ackroyd
Syngenta Process Hazards Section, Huddersfield Manufacturing Centre, Leeds Road, Huddersfield, West Yorkshire HD2 1YZ, UK

Seed processing is an ever expanding area of Syngenta's agribusiness. It currently represents approximately 20% of the company's business by sales ($m). The plethora of individual sites range wildly in size, and they are located in many different countries around the world.

A typical seed process is quite basic, often only involving cleaning, sizing, drying and product packing operations. Although in some cases a more complex seed treatment step will also be incorporated. In general, the raw materials handled are much less ignition sensitive than those used for active ingredient (AI) manufacture. However, the majority of operations still present a significant process safety risk.

This paper provides an overview of a typical corn processing facility and the associated fire and explosion hazards it presents. It also details the necessary safety measures required to facilitate safe operation and compliance with local legislation.

The basic technology and simpler business model in seeds processing means the approach to process safety has to be different compared with typical, more cost effective AI manufacture – this will be discussed too.

INTRODUCTION

In recent years seed processing has become a major part of Syngenta's agribusiness. It currently represents approximately 20% of the company's business by sales ($m). This area of the business is likely to grow further still as the company has an active policy for acquiring compatible enterprises within this sector.

There are a large number of individual seed sites currently within the organisation and they occupy literally all areas of the globe, e.g. USA, Brazil, France, Spain, Hungary, China, and many more countries.

Syngenta often retains the original brand name of seed businesses it acquires as they are always very well established and respected companies. Also, considerable value is normally attached to existing brand names – Hilleshog for example (as shown in Figure 1).

All of the major crop varieties are represented within the current business portfolio, e.g. barley, corn, oilseed rape, soybean, sugar beet, sunflower and wheat, as well as fruit, vegetables and flowers.

In the following paragraphs a typical corn processing facility will be examined. The associated fire and explosion hazards it presents are discussed along with the necessary safety measures required to operate such a facility safely. In addition, emphasis is given to the basic technology and simpler business model adopted in seeds processing, and how this results in a more pragmatic approach to process safety compared with typical, more cost effective AI manufacture.

CORN PROCESSING

A typical corn processing facility consists of the following unit operations:

- Raw material offloading
- Husking
- Drying – sometimes optional
- Shelling
- Cleaning
- Conditioning/sizing
- Treatment – sometimes optional
- Packaging and storage

RAW MATERIAL OFFLOADING

Deliveries to site are made by trucks at the beginning of the processing campaign, typically at the end of August within Europe. Discharging is achieved by the trucks tipping up the rear container sideways, with the raw corn simply flowing by gravity into a large silo. The corn is mechanically manoeuvred on to a belt conveyor which transports material to the husking area.

HUSKING

Husking is carried out in a dedicated building which is divided into two parts. The husk is conveyed to the building via a belt conveyer that is open to atmosphere. The operation is characterised by a two stage process in which the leaves and stalks are removed from the corn cob. In the first stage a mechanical device strips the unwanted part of the corn cob with all of the material falling by gravity to individual sorting tables below. During the second stage the corn cob is selected by hand and placed on a belt conveyer for transport to the drying facility. The waste material is conveyed, again by belt conveyer, to a waste husk cutting machine and then discharged to truck to be used as animal feed. Any material that has not been properly husked is conveyed back to the husking machine.

DRYING

It is often necessary to dry the corn following the husking operation due to its relatively high moisture content. The

Figure 1. Syngenta seed processing site in Nerac, France

Figure 2. Drying chambers for husked corn hoppers

husked corn is conveyed to the drying unit by means of a belt conveyer that is again open to atmosphere. It is then fed into large hoppers where it will sit for approximately 3 days, during which time warm air is constantly circulated through it inside a dedicated chamber.

The warm, drying air is generated by heating it directly using natural gas burners. The heated air is fed into the dryer arrangement via the top of the first hopper (they are grouped in pairs). It passes down through the first hopper then across and up through the adjacent hopper, finally being exhausted through the top of the second hopper. The temperature of the drying air is typically 40°C. In a standard facility there may be as many as 20 hoppers within the dryer assembly, see Figure 2.

SHELLING

The dried corn is conveyed to the shelling hopper via a bucket elevator. It is then gravity fed to the shelling machine. This piece of equipment consists of a number of rotating metal parts which strip the corn kernels from the cob. The waste from the shelling machine is belt conveyed into a dedicated waste bin. Extract is provided to the shelling machine by means of a dedicated cyclone and fan.

CLEANING

The cleaning operation is essentially a crude sizing exercise where corn kernels are selected by means of mild attrition. Corn is gravity fed to the cleaning machine via an intermediate hopper. A dedicated filter and cyclone is provided for the cleaning machine. The selected corn is bucket elevated to the next stage of the process. The waste material is screw conveyed to an elevator and then to a dedicated waste bin.

CONDITIONING/SIZING

The selected corn is bucket elevated to a levelling auger to begin the conditioning process. The corn passes through a number of classifying units (sizers and gravity tables) which sort the kernels by size and density, see Figure 3. The corn is then gravity fed to large hoppers and either discharged to big bags or elevated to the next stage of the process if a treatment is required. Extraction to each of the gravity tables is provided by its own dedicated cyclofan, these in turn are served by a dedicated filter. The waste material from each of the different items is screw conveyed to a dedicated waste bin.

TREATMENT

The final stage of processing involves applying a liquid additive to the corn. The liquid is sprayed onto the corn kernels. A dedicated filter is provided for the treatment machine.

PACKAGING AND STORAGE

Packaging is applied using a hopper and automated conveyer belt arrangement, and storage is provided in a large warehouse on site.

Figure 3. Conditioning/sizing machine

HAZARD ASSESSMENT

The main focus of the hazard assessment is to identify which parts of the process are likely to present problems with regard to dust cloud flammability and bulk thermal stability. It is then necessary to characterise material from these areas with respect to its ignition sensitivity. Once this data has been collated, a detailed assessment can be performed considering each unit operation in turn. Often when the detailed assessment is complete, a significant number of general themes/considerations will emerge regarding the nature of the flammable atmospheres and types of ignition source that may be present. These general considerations are documented as an introduction to the stage by stage assessment. The final step is to outline recommendations for safe operation. This takes the form of a basis of safety statement with associated precautions.

The assessment process for the typical corn processing facility outlined previously is detailed in the following pages, beginning with the flammability characteristics of corn dust which are presented in Table 1.

The data highlights that dust arising from corn processing is generally less ignition sensitive compared with typical AIs. However, if it is ignited the consequences will be similar.

Corn samples tend to be thermally stable in small scale tests up to temperatures of about 200°C. Typically this will equate to temperatures in excess of 140°C on process scale. The thermal stability profile of treated corn samples may be different to untreated material, particularly as most of the treatments will be thermally less stable than corn. This type of material should be tested on a case by case basis.

FLAMMABLE ATMOSPHERES – GENERAL CONSIDERATIONS

The material characteristics for corn show the dust generated during processing is capable of forming flammable dust clouds in air. Therefore, precautions will be required to ensure safe operation of the processes operated with regard to fire and explosion hazards, and to ensure compliance with local legislation (e.g. ATEX). However, the precise precautions required also depend upon the frequency with which a flammable atmosphere is anticipated.

In a typical facility such as the one described, the nature of the operations carried out and the often extensive provision of ventilation, means the probability of such flammable atmospheres occurring is rather low, i.e. predicted Zone 22 (IEC 60079-10-2 details the classification of areas for explosive dusts). This usually forms an integral part of the safety precautions in the general plant area, since none, or very little of the electrical or mechanical equipment is likely to be specifically certified as being suitable for use in a flammable atmosphere. This is a legacy condition due to the previous lack of process safety awareness within the general seed processing fraternity.

Where a non-flammable atmosphere is achieved by ventilation, it is generally recommended that the dust concentration is in fact kept to $<25\%$ of the lower flammable limit (LFL) to provide a safety margin. This typically equates to a concentration of 10 g/m^3.

Avoiding flammable atmospheres by the use of ventilation will be employed as the basis of safety not only in the general plant environment, but also in the ducting to cyclones, filters and other items of dust collection equipment. This is to avoid the possibility of a minor event in one location propagating into other units and causing a much more serious incident. To achieve this, in addition to maintaining the dust loading at $<10\ g/m^3$ in the air stream, it is also necessary to avoid dust deposits in the ducting. This can generally be achieved by employing an air velocity of $>18\ m/s$, though other approaches can also have the desired effect.

Within filters, the nature of their operation is such that flammable dust clouds are likely to be formed due to the accumulation of material. In addition, although it can be difficult to identify specific potential ignition sources within them, there is a history of dust cloud explosions in such equipment. Bradley and Baxter (2002) state one third of the 47 incidents involving combustible powders that were reported to the HSE during the 2 year period ending 2000 occurred in dust extraction equipment. These are often attributed to overheated material being drawn into the ventilation system, progressing through the non flammable atmosphere in the ducting, until a flammable atmosphere is finally encountered in the filter. Also, a number of items within the filter can give rise to an electrostatic discharge. As a result, it is relatively common for such items to be fitted with explosion relief panels. Dust cloud explosions within cyclones are not as common. Flammable atmospheres will be generated during operation but they tend

Table 1. Fire and explosion hazard data for corn dust

Material Characteristic	Test	Result
Classification	Vertical Tube	Group A (flammable)
Maximum Explosion Pressure	20l Sphere	6–8 bar g
Dust explosion Constant	20l Sphere	~100 bar m/s (ST1)
Dust Cloud Minimum Ignition Temperature (MIT)	Godbert Greenwald Oven	>400°C
Dust Cloud Minimum Ignition Energy (MIE)	Kuhner MIKE 3	>30 mJ
Temperature Class	T5 mm Hotplate	T2 – T4
Burning Class at ~100°C	Train Fire	>4

not to be as extensive within the equipment and the only identifiable ignition source is hot material conveyed in. As a consequence the fitting of explosion relief panels is not common practice on such units however, it may be necessary in certain cases. It needs to be recognised that although the provision of explosion relief panels will protect the items themselves, an ignition in a vented unit has to be prevented from propagating into connected equipment, and this can be achieved by ensuring that the connecting pipe work does not contain a flammable atmosphere.

In general, where a filter is dedicated to a single piece of equipment, in particular one that is unlikely to generate a potential ignition source, it may be possible to base safety on the elimination of potential ignition sources. However, this is increasingly difficult if the filter is connected to more pieces of equipment, and if the equipment has a high probability of giving rise to an ignition source. This may also be the case for cyclones performing a similar duty.

IGNITION SOURCES – GENERAL CONSIDERATIONS

Potential ignition sources generally fall into one of the following categories; static electricity, electrical equipment, impact and friction sparks, mechanical friction and burning/smouldering material (refer to BS EN 1127-1:2011 for a comprehensive overview of potential ignition sources). In much of a typical facility safety will be based on controlling these potential ignition sources. In addition, it is still considered good practice to eliminate potential ignition sources in locations where this is not the basis of safety in order to minimise the demands on the protective systems and to avoid confusion over which precautions apply in different areas.

Electrostatic discharges from electrically conducting items such as personnel and metallic items and plant could be sufficiently energetic to ignite any of the flammable materials handled in the process. Therefore, the risk of such discharges occurring will need to be avoided by reliable earthing. Discharges from insulating materials such as common plastics (e.g. plastic bucket in elevator) are not sufficiently energetic to ignite the flammable corn dust handled provided that the plastics are not present with an earthed metal backing (e.g. plastic lined pipe work).

Ignition sources arising from electrical equipment (e.g. arcing, sparking and hot surfaces) can be prevented by selecting equipment that is appropriate for the materials in use and the methods of handling them. In existing facilities (such as the one described here), since none or very little of the current electrical equipment is rated for use in a hazardous area, this risk will have to be controlled by restricting the spread of flammable atmospheres. In new facilities serious consideration must be given to sourcing and installing correctly rated equipment.

Under certain circumstances sparks generated by friction or impacts can introduce an ignition risk. Corn dust does not appear sensitive to steel on steel impact sparks, which are of relatively low energy. However, it could be ignited by a thermite spark as a result of impacting rusty metal on aluminium, titanium, magnesium or their alloys. This risk is usually avoided by restricting the use of these metals and their alloys in areas where a flammable atmosphere may occur.

Heating due to mechanical friction, which can give rise to a source of ignition, is generally avoided by the selection of appropriate equipment coupled with suitable maintenance. It is considered that this ignition risk can be controlled by implementing relatively standard precautions (e.g. maximise clearances between moving parts, prevent the ingress of tramp material that could become trapped between moving parts, and, where the rating of the atmosphere is appropriate, consider providing monitoring to warn of impending failure or overload cut-outs on motors to prevent overheating if binding does occur).

Ignition sources arising from hot smouldering material are credible and not easily avoided. They may contain enough energy to ignite a flammable corn dust cloud (e.g. inside a dust filter) as well as being capable of initiating a full propagating combustion or thermal decomposition within the bulk material itself (e.g. in process vessels or in storage). In an attempt to prevent 'localised' hot material forming, and material self heating processes in general, it is important to control elevated temperature operations (e.g. drying) by selecting a safe operating temperature which incorporates a suitable safety margin. This approach will be effective in elevated temperature environments. However, it is extremely difficult to achieve the same outcome in high energy mechanical equipment, where hotspot formation (small 'nests' of hot material) is almost inevitable. Therefore, downstream process units likely to contain a flammable atmosphere (e.g. a dust filter) will often require some form of additional protection as avoiding this particular ignition source cannot be guaranteed.

Stage by stage basis of safety for unit operations during corn processing.

RAW MATERIAL OFFLOADING

The relative humidity of the corn is $\sim$40% when it arrives on site. This inherent dampness will significantly limit the propensity for dust cloud formation. Also, as the offloading area is not enclosed, any dust cloud that is formed will persist for only a very short period of time. The most appropriate basis of safety will be the absence of a flammable atmosphere.

HUSKING, SHELLING, CLEANING, CONDITIONING

Within the equipment, the relatively low dust loading coupled with the extraction is likely to mean that the atmosphere is generally non-flammable. The possible exception is the mechanical husking machine within which a reasonable amount of dust can be generated. The most appropriate basis of safety will be the elimination of all potential sources of ignition allied with the fact that adequate extract will ensure a flammable atmosphere is unlikely to be present most of the time (i.e. zone 22).

DRYING
In a large chamber drying system, although unlikely it is possible for a flammable dust cloud to form as fine material may drop through the hopper into the vacant chamber below, or immediately before and after the drying has taken place when material is conveyed in and out of the hopper. The most appropriate basis of safety will be the elimination of all potential ignition sources. Self heating is unlikely to be an issue due to the relatively low drying temperature used, i.e. 40°C.

TREATMENT
In similar vein to the other process equipment, within the machine itself (see Figure 4), the relatively low dust loading coupled with the extraction is likely to mean that the atmosphere is generally non-flammable. The most appropriate basis of safety will be the elimination of all potential sources of ignition allied with the fact that adequate extract will ensure a flammable atmosphere is unlikely to be present most of the time.

The thermal stability profile of treated corn may be different to that of untreated material, although the extent to which will obviously depend on the nature of the treatment. A sample would be tested to confirm this. Treatments are applied at the end of the process. Therefore, it is unlikely that any major issues will be encountered as product is simply gravity fed into a hopper and discharged to big bags. However, this may not be the case if treated material is stored for prolonged periods of time (particularly at elevated temperature) in large volumes, or if it is dried or further processed in any way. Consideration should be given to such potential scenarios as they may introduce a thermal stability hazard.

PACKAGING AND STORAGE
The packaging line generates very little dust within the equipment itself. This, coupled with the fact that there is no dust extraction (and hence accumulation), is likely to mean that the atmosphere within the equipment is generally non flammable.

Figure 4. Corn treatment machine

DUST COLLECTION SYSTEMS
Within filters and cyclones that are dedicated to one specific item of equipment, the probability of an ignition source arising is extremely low, providing the equipment does not have any high speed rotating parts. The most appropriate basis of safety may be the elimination of all potential ignition sources.

Within filters and cyclones that serve a number of process machines and general buildings, the probability of an ignition source arising is increased compared with a dedicated system, particularly if material is mechanically conveyed between equipment – which is nearly always the case. The most appropriate basis of safety will be explosion protection.

CONVEYING SYSTEMS
A flammable atmosphere will not be present in most of the conveying systems as they are typically open belt conveyers. The screw conveyer is an enclosed unit but it is highly unlikely a flammable atmosphere will be formed within it as it merely conveys waste from the conditioning and cleaning operations. However, it should be cleaned periodically to prevent the build up of any fine particles. Extract is provided to the bucket elevators and this will prevent dust cloud formation. This is important as it is difficult to eliminate ignition sources within such units. The most appropriate basis of safety will be the absence of a flammable atmosphere, allied with avoiding ignition sources in mechanical conveying equipment which is enclosed.

LEGISLATION
As previously mentioned, the hazard assessment process has to take local legislation into account. Such legislation is well established within the European Union (EU) and the North America Free Trade Area (NAFTA), but less so in the rest of the world.

EU
In 2003 the ATEX directives (Directive 94/9/EC) came into force in Europe, detailing the requirements and responsibilities for equipment used in hazardous areas. The general approach is similar to that used for many years with electrical equipment in gas/vapour atmospheres, but the ATEX regulations also cover non-electrical ignition sources (e.g. mechanical friction and static electricity) and flammable dust clouds. As a result, all European seeds sites now have to comply with these directives. The general requirements for electrical and non-electrical equipment for use in potentially explosive atmospheres are detailed within BS EN 60079:2009 and BS EN 13463:2009 respectively.

NAFTA

In NAFTA, the fire and explosion hazards of combustible dusts have recently been highlighted by a series of major dust explosion incidents, across a range of industries. The most notable of these was that at the Imperial Sugar manufacturing facility at Port Wentworth, Georgia which suffered a massive dust explosion in February 2008, initiated by a hotspot ignition source, resulting in 14 fatalities. This incident (and several others) was investigated by the US Chemical Safety Board (CSB), who issued a detailed report and a series of recommendations. Key among them was that Occupational Safety and health Association (OSHA) implement a more rigorous regulatory program with regard to combustible dusts. To pre-empt any changes in enforcement, the Combustible Dusts Steering and Planning Team (CDSPT), was set up in order to carry out a systematic assessment of the dust explosion hazards across all the NAFTA seeds sites. This team has identified a program of corrective actions to be implemented over the next few years in order to make sure all sites meet an acceptable standard.

The general requirements for preventing fire and dust explosions when processing combustible dusts, and the correct specification for selecting electrical equipment are detailed within NFPA 654 and NFPA 70 respectively.

A MORE PRAGMATIC APPROACH

The basic technology and simpler business model in seeds processing means the approach to process safety has to be different compared with typical, more cost effective AI manufacture. This is best illustrated with an example that has already been touched upon within this paper:

> *"In general, where a filter is dedicated to a single piece of equipment, in particular one that is unlikely to generate a potential ignition source, it may be possible to base safety on the elimination of potential ignition sources. However, this is increasingly difficult if the filter is connected to more pieces of equipment, and if the equipment has a high probability of giving rise to an ignition source. This may also be the case for cyclones performing a similar duty."*

The above paragraph clearly outlines the more pragmatic/risk based approach that is adopted for seed processing safety. In a typical AI plant, a dust filter would be fitted with an explosion vent as a matter of course irrespective of its duty, even though this may be considered an 'over the top' approach. Another example of this conservative approach within AI manufacture is the use of nitrogen inerting as a generic basis of safety for entire processing plant, when in reality many individual operations could be safely operated using a different, and often more cost effective basis of safety.

A further example of the more pragmatic approach within seeds is the manner in which the 'elimination of potential ignition source' basis of safety is implemented on a corn site. The rotational speed of a mechanical part exceeding a recommended specification criterion will be tolerated, providing adequate maintenance and robust monitoring of such equipment is in place. However, on an AI plant, a more suitable piece of equipment would most likely be sourced for the operation, one which met or could be adapted to meet the specification value.

CONCLUSIONS

Corn processing presents a fire and explosion hazard. The dust generated during processing is less ignition sensitive than typical AI material. However, the ramifications for plant equipment, personnel and the environment will be similar should ignition occur.

A more pragmatic/risk based approach to hazard assessment is adopted for corn processing. This is necessary as most of the facilities have pre existing equipment and layouts that do not necessarily conform to current legislation. In addition, the business model for the more simplistic operations performed on a corn site does not facilitate the standard 'belt and braces' philosophy that exists for the more complicated and larger scale AI manufacture.

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