PREVENTION OF FIRE AND EXPLOSION IN SPRAY DRYING PLANT

A CODE OF PRACTICE FOR DESIGNERS, MANUFACTURERS, SUPPLIERS AND USERS

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PREFACE

For many years it has been recognised that the dust of many commonplace materials such as dried milk products, flour, starch, sugar and wood, can form explosible dust clouds. Some of the most spectacular industrial accidents have been caused by the accidental ignition of such dusts. In spray drying processes materials which start as a liquid, and, while in that form, present no risk are converted into a powder which is often explosible. Despite precautions taken in the past by industry, explosions have contiued to occur in spray drying plants. The fact that the consequences of recent explosions have not been so severe is due largely to the co-operation of the industry in taking the precautions which research into the causes of dust explosions has indicated are necessary.

This booklet provides a useful compilation of the measures which the Association of British Preserved Milk Manufacturers agrees are necessary to prevent and control the hazards and has been prepared by the industry with the active collaboration of the Health and Safety Executive. I commend it to all concerned with the spray drying of foods.

A McLean
Area Director
Health and Safety Executive
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Stanley Precinct
Bootle
Merseyside

FOREWORD

There have historically been legal, technical and practical uncertainties surrounding explosion prevention and protection in spray drying installations in the UK dairy industry. In publishing this Code of Practice, the Association of British Preserved Milk Manufacturers is attempting to overcome uncertainty and initiate a move towards positive management of the problems, for new and existing drying systems, by users and suppliers throughout the food industry.

The "authors" of the Code represent a broad spectrum of the dairy industry and food industry in general. Senior specialists from the Health and Safety Executive made a major contribution. There was also consultation with all major suppliers of spray drying equipment and appropriate trades unions.

The Code is the product of eight meetings over a fourteen month period from February 1986. The high quality and usefulness of the end result is attributable to the hard work and commitment of all concerned. Thanks must go to them.

JAK Thomas
Health and Safety Adviser
Dairy Crest Foods
Chairman of the Working Party

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TERMS OF REFERENCE

To produce practical guidance for the dairy industry on the design, operation and maintenance of spray drying plant for the prevention of fire and explosion, and the minimising of their effects.

These recommendations are applicable to other food products having similar dust explosion characteristics.

The plant to be considered includes:

- all spray drying plant
- fluidised bed dryers and other powder handling equipment
- dust collection equipment
- bulk storage facilities

SECTION 1: INTRODUCTION

1.1 BACKGROUND TO THE PROBLEM

1.1.1 In the ten year period up to 1982, three explosions in spray drying plant were reported to the Health and Safety Executive's Factory Inspectorate. Information on four other "non-reportable" explosions was also obtained. In recent years, due largely to changes in Regulations relating to the reporting of dangerous occurrences and closer contact with the industries concerned, it has become evident that there has been a considerably larger number of incidents involving spray drying plant. One group of companies, using twenty five dryers, has experienced ten incidents over a five year period, and during 1986 four explosions were repoted to the Health and Safety Executive. There have also been a number of occasions where suppression systems have operated within plants, thus avoiding the calamitous results of powder ignition. Fortunately, none of these explosions resulted in injury to personnel.

1.1.2 A number of explosions have also been reported, usually informally, from the Continent and from Ireland. Pineau stated in his report **(1)** that until 1980 there was an average of four major incidents reported annually in France.

1.1.3 The number of spray drying plants operating in Europe is not known, but in Great Britain there are about 85 producing milk and other food powders. The incidence rate is therefore high, as also is the potential for devastation of plant and buildings. Details of some of the known explosions are given in Appendix I.

1.1.4 As a result of these incidents, attention has been focused on existing standards of explosion protection. The relative merits of venting, inerting and suppression have been considered together with methods of preventing the ignition of the powder in the first instance.

1.1.5 Many of the principles which follow can also be applied to other potentially explosive powders which are produced in spray dryers where heated air and powder streams pass co-currently through the plant.

1.2 APPLICATION OF STANDARDS

1.2.1 These guidelines are primarily intended for new installations but their adoption for existing plant should be fully considered.

1.2.2 Various circumstances can arise where these standards cannot be applied to existing plant. In this situation, discussions will need to take place between plant management, employee representatives and the Health and Safety Executive to arrive at a safety standard that adequately safeguards the health and safety of employees and members of the public, as far as it is reasonably practicable.

1.3 SUMMARY OF UK LEGAL POSITION

1.3.1 Section 31 of the Factories Act 1961 **(2)** indicates precautions which must be taken in relation to the use of any explosible or flammable dust or other substance. Many food powders being produced in spray drying plants come within this category and in order to meet the requirements of this section it is necessary that any plant used for this purpose must be so constructed as to withstand the pressure likely to be produced by such an explosion. Alternatively, all practicable steps must be taken to restrict the spread and effects of such an explosion by the provision of chokes, baffles, vents or other equally effective appliances such as explosion suppression systems. "Practicable" in the legal context is interpreted as meaning possible in the light of current knowledge and invention. Responsibility for complying with this legal requirement rests firmly upon the occupier of the premises.

1.3.2 The Health and Safety at Work etc. Act 1974 **(3)** places a more general duty upon employers in that they must ensure, so far as is reasonably practicable, the health, safety and welfare at work of all employees. This is specifically extended to include the provision and maintenance of plant, systems of work and training of employees. A further duty is placed on employers and self-employed persons to ensure, so far as is reasonably practicable, that persons not in their employment are not exposed to risks to their health or safety. This extends to visitors and even to members of the public. The term "reasonably practicable" used in this Act has been interpreted in the Courts to evaluate the degree of risk against the cost involved in averting the risk. Thus an employer may be able to prove that certain action required by the enforcing authorities is not "reasonably practicable" for him to carry out if he can show that the risk in his process or undertaking is insignificant in relation to the sacrifice in money, time or trouble involved in the measures necessary to avert the risk.

1.3.3 Designers, manufacturers, importers and suppliers of plant also have a duty imposed by the Health and Safety at Work etc. Act 1974, Section 6. They have to ensure that the plant has, so far as is reasonably practicable, been designed and constructed such that it will be safe and without risk to health when properly used. They must also arrange for the carrying out of such testing and examination as may be necessary for the performance of this duty. They must take the necessary steps to ensure that adequate information about the use for which the plant has been designed and tested and any conditions necessary to ensure its safety are provided to the user.

1.3.4 Although the Factories 1961 appears to require a higher standard than the Health and Safety at Work etc. Act 1974, in practice both statutes would probably be interpreted by a Court of Law to require the standards outlined in this Code since the incidence of explosions in spray drying plant and the catastrophic results are well documented and the potential is there for serious, indeed fatal, injury.

1.3.5 In general terms, the plant should be of sufficient strength and so constructed as to comply with the requirements of Section 2 of the Health and Safety at Work etc. Act 1974 and Section 31 of the Factories Act 1961. The plant should have guards secured in place or interlocked to ensure that there can be no contact with dangerous moving parts in order to meet the requirements of Sections 12-14 of the Factories Act 1961. It is essential that the design should allow for easy cleaning, disinfection and sterilisation to comply with the requirements of the Milk and Dairies (General) Regulations 1959 **(4)** and the Milk (Special Designations) (Scotland) Order 1980 **(5)**.

1.3.6 The Food Hygiene (General) Regulations 1970 **(6)** and the Food Hygiene (Scotland) Regulations 1959 **(7)** also require that equipment with which food is liable to come into contact shall be so constructed that it can be kept clean.

1.3.7 Legislation relating to the health and safety of persons operating or directly affected by the plant is enforced by HM Inspectors of Factories who are part of the Health and Safety Executive. The enforcement of food hygiene legislation is undertaken by Environmental Health Officers employed by Local Authorities.

1.3.8 In applying this Code, employers should inform and consult with the appropriate employee representatives to comply with Section 2(6) of the Health and Safety at Work etc. Act 1974, and the Safety Representatives and Safety Committees Regulations 1977 **(8)**, where they apply.

1.4 OTHER CONSIDERATIONS

This is intended to be a technical document, which does not include detailed advice on other important issues such as:-

(i) staff training;
(ii) the application of proper maintenance procedures, including permits to work;
(iii) the application of formal safe systems of work.

These must be taken into account by users of the Code for specific applications.

SECTION 2: SCOPE

2.1 LIMITS OF THE CODE

2.1.1 This Code is directed to designers, manufacturers, suppliers and users of food spray drying plant. It applies to all spray drying plant, including the new generation of two-stage dryers with integrated fluidised beds and filtermat drying systems.

2.1.2 The Code is primarily concerned with the spray drying of milk and its derivatives. It will also be useful for those involved in processing other food products which fall into the same dust explosion class.

2.1.3 In considering the explosive characteristics of dusts, products can be classified by their Kst value. This is covered by the German standard VDI 3673(1979) **(9)** and by the American standard NFPA No. 68 (1978) **(10).**

2.1.4 Dusts can be grouped into four classes based on their Kst value (rate of pressure rise).

TABLE 1

Dust Explosion Classes

Dust Explosion Class	Kst bar.m/sec.	Characteristics
st 0	0	No Explosion
st 1	0-200	Increasing
st 2	201-300	severity of
st 3	301 +	explosion

While this Code may be applied to both Class st 1 and st 2 products, its main application will be to Class st 1 products, since most food products fall into this Class, e.g. dried milk powder, sugar fines and coffee. A few food products exhibit the more severe characteristics of group st 2, the most common being starches.

A small number of industrial dusts, notably aluminium, fall into Class st 3 and are particularly difficult to handle.

2.1.5 Particular care must be taken when manufacturing a new product in an existing plant.

The characteristics of the new material must be assessed to ensure that they do not represent a greater risk than those for which the dryer was originally designed.

2.2 GENERAL CHARACTERISTICS OF THE PROCESS

2.2.1 Milk Powders and Related Food Products

Data on the explosion characteristics of food materials can be found in published literature. Care must be taken in using published data because the explosion characteristics are influenced by:

- particle size
- moisture content
- composition
- test method

2.2.2 It will often be necessary to commission specific test work to establish the behaviour of the material in question. The sample used for the test work must represent the worst case conditions, particularly in terms of dryness and particle size. Interpretation of the data should only be undertaken by those experienced in the field of explosion protection. The values given in Table 2 are only typical values.

TABLE 2
Explosibility of Milk Powder

Dust	Minimum ignition temperature ^0C	Minimum explosible concentration kg/m^3	Minimum ignition energy J	Maximum explosion pressure bar	Maximum rate of pressure rise bar/sec
Skimmed milk powder*	490	0.05	0.05	6.6-6.8	110-159
Milk powder+	440	0.06	-	5.8	28
Skimmed milk powder+	500	0.06	-	9.0	99

*Data obtained from small scale tests. +Data obtained from large scale tests.

2.2.3 <u>Types of Plant</u>

Food industry spray dryers can be considered to be co-current units with air inlet temperatures up to 250^{0}C. Feed concentrations would be typically in the range of 38-70% total solids producing a product with less than 4% moisture.

2.2.4 Hygienic design is a key parameter and this characterises units developed for the food industry.

2.3 DESCRIPTION OF TYPICAL PROCESS

2.3.1 Figure 1 illustrates a co-current dryer with secondary cooling (see overleaf).

2.3.2 The feed material enters the dryer through an atomiser or nozzles. The layout assumes that the feed material would be heated and provided to the dryer under pressure from a pump.

2.3.3 The heater battery provides the hot air to the dryer. Heat recovered from the dryer exhaust minimises the energy consumption.

2.3.4 The air and product separate at the bottom of the dryer. The exhaust air is cleaned in a recovery cyclone and has a filter unit before heat recovery and discharge to exhaust.

2.3.5 Post drying treatment is illustrated as a fluid bed unit. The fluid bed exhaust air is cleaned before discharge and the recovered material either recycled to the dryer or returned to the dried product.

2.3.6 Pneumatic conveying systems are often used to transfer product to bulk storage.

2.3.7 Primary control is achieved by maintaining the target air temperature at the outlet of the dryer by adjusting the air flow or feed flow. Automatic adjustment of the outlet temperature gives more accurate control of the final moisture content of the product.

2.3.8 Target inlet air temperature is kept constant.

2.3.9 The air flows are normally balanced to ensure that the dryer operates under a slight negative pressure.

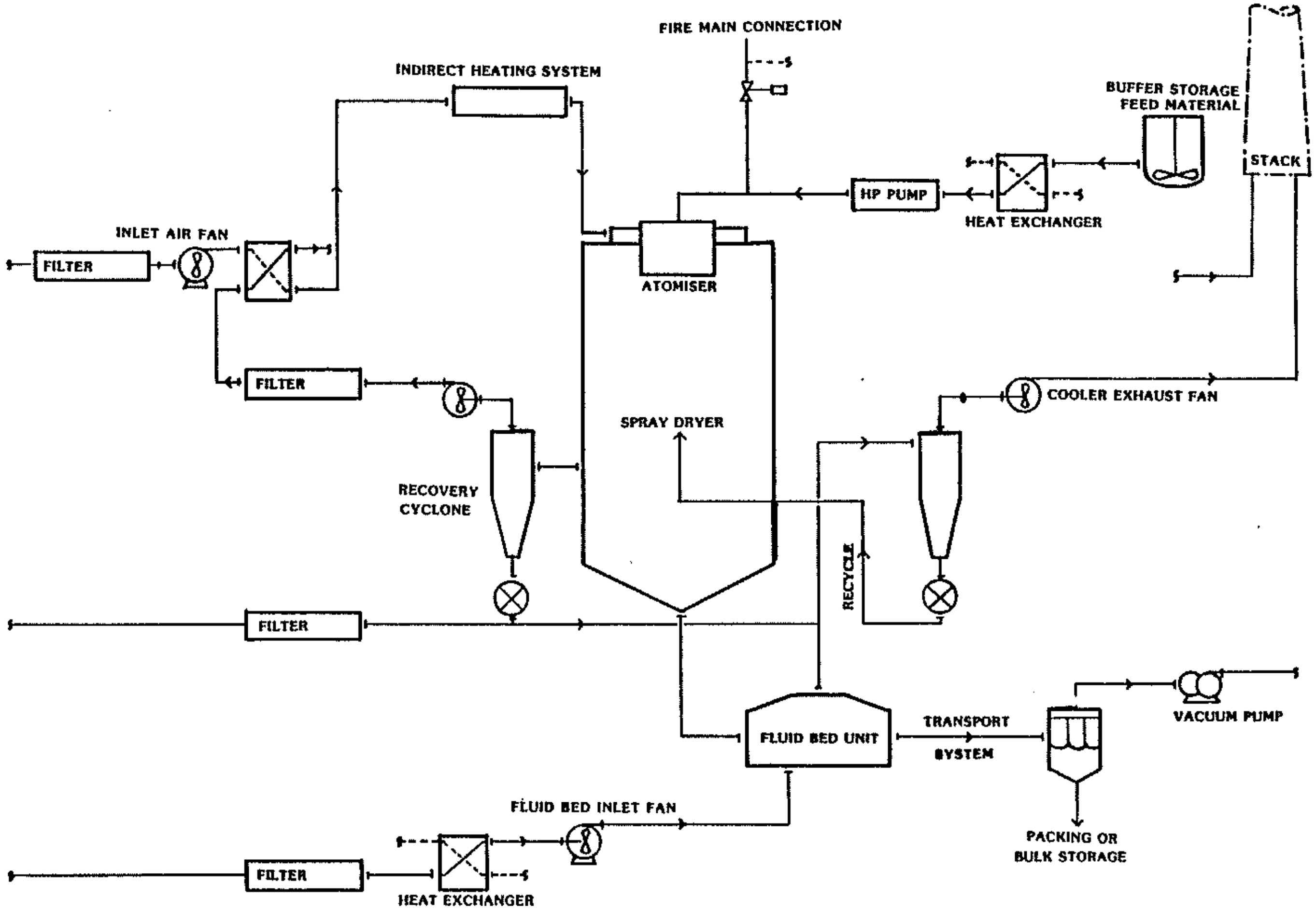

Figure 1: Schematic line drawing of typical spray drying plant.

SECTION 3: HAZARDS AND PREVENTION

3.1 FIRE AND EXPLOSION - GENERAL

Food powders are flammable and, in suspension as a cloud dust, explosible. Milk powder is used as a typical example for the purposes of this Code.

3.2 FIRES

3.2.1 Milk powder may burn without causing an explosion. Accumulations of powder may be subject to overheating if they adhere to surfaces in the hot zone of the dryer. In these circumstances self-heating may occur and the powder accumulations become incandescent.

3.2.2 It is important to note that self-ignition of a powder layer does not occur at any one particular temperature. It will depend mainly on the thickness of the layer that builds up, i.e. the thicker the layer, the lower is the temperature at which self-ignition can occur. An increase in the moisture content and the time the layer is allowed to remain also determine the self-ignition temperature.

3.2.3 The effect of milk composition is less well understood. This has been studied by a number of workers; some have shown that fat-filled milks have lower ignition temperatures than skim milk, others have shown the opposite, although certainly fat-filled milks are more likely to form deposits in dryers. This has been summarised by Beever **(11)** (see Table 3 overleaf) in terms of the critical thickness of layer for two ambient temperatures; 200^{0}C representing a typical temperature likely to be met in the spray dryer, and 100^{0}C, which approximates to the surface temperature found lower in the dryer. It can be seen that there is typically a factor of 10 difference between the critical thicknesses at 100^{0}C and 200^{0}C.

3.2.4 In summary, it should be assumed that, at the temperature at which conventional spray dryers operate (i.e. between 250^{0}C at the inlet and 80^{0}C at the outlet), if powder deposits form, then self-ignition is probable. The critical points in the dryer are the top, where the hottest temperatures occur, and at the base and any ledges, where the thickest deposits may build up.

Surfaces such as the dryer cone and walls, cyclone walls and transfer ductwork must be designed such that the angle of any surface is insufficient to support a build-up of powder. Precautions such as air scouring, mechanical sweeping or knocking devices should be employed wherever a build-up is likely.

3.2.5 Small powder fires may not always be apparent except in the form of product spoilage, as indicated by the presence of charred particles in the powder. Nevertheless, any burning powder passing through the system represents a potential source of ignition for an explosion.

3.2.6 Uncooled material held in bulk storage may be subject to spontaneous heating if left undisturbed for a period of time.

TABLE 3

Critical Thicknesses for Self-Ignition of Milk Powders

Products	Minimum thickness for self-ignition of layer at 200°C cm	Minimum thickness for self-ignition of layer at 100°C cm
Skimmed milk Skimmed milk Skimmed milk	1.7 1.1 0.9	17 15 12
Coconut-oil filled milk Coconut-oil filled milk	1.3 1.4	13 14
Tallow filled milk - 30% Tallow filled milk	1.1 1.5	20 15
Whole milk Whole milk	1.0 1.7	17 10
Buttermilk Buttermilk	0.9 0.8	13 10
Filled milk (formulation unknown)	1.4	14
Whey	1.3	32

Source: Beever P.F. Fire and explosion hazards in the spray drying of milk (11).

3.3 EXPLOSIONS

3.3.1 A dust explosion may occur when milk powder is dispersed in air and exposed to a source of ignition. However, certain overriding conditions must prevail before an explosion can occur:-

(i) the dust must be airborne in a concentration within its explosible range, typically 100g/m^3 minimum;

(ii) the ignition source must be strong enough to initiate combustion, typically 50 mJ minimum;

(iii) there must be sufficient oxygen in the air to support combustion.

3.3.2 Primary Explosions

A primary explosion is one which takes place within the confines of a component of the drying system. It is important to recognise that an explosion in one component may set off an explosion in other inter-connected components. A primary explosion will cause a rapid rise in pressure within the component, typically up to 8 or 10 bar. The component may react in different ways as follows:-

(i) if of sufficient strength, it will retain the pressure and confine the explosion;

(ii) it may fail and rupture to allow the release of pressure;

(iii) it may allow the release of pressure through purpose built vents which open at low pressure, typically 0.1 bar.

3.3.3 In a spray drying plant the most vulnerable areas for primary explosions are:-

(i) in the lower part of the main chamber;
(ii) in the cyclones;
(iii) above the fluid beds;
(iv) in an empty silo;
(v) in pipework and ducting which carries product and air.

At these points both powder and air are present; provided that an explosible concentration is present, all that is missing for an explosion to occur is a source of ignition. If a source of ignition is introduced, the propogation of the flame front through the dust suspension causes a rapid increase in temperature and pressure which gives rise to explosive effects. The presence of finer particles and higher ambient temperatures, both of which are a feature of more modern drying systems, is more likely to lead to explosions.

From this it can be seen that the elimination of all possible sources of ignition is essential in explosion prevention.

3.3.4 Secondary Explosions

If, during an explosion, a component ruptures or a vent opens, a pressure wave will emerge followed by a cloud of yet unburnt powder. This will be followed by the flame front, which will continue to ignite the powder emitted and ignite other powder which might be present in the environment and raised into suspension by the pressure wave. Thus a fireball is formed which will continue to travel and burn, driven by the increasing pressure from the primary explosion, until the supply of suspended oxygen is exhausted. Good housekeeping is crucial to limiting this fireball effect, which is termed a secondary explosion.

A secondary explosion may be retained within the confines of the building. Alternatively, if the magnitude of the explosion relative to the size and strength of the building is sufficiently high, the pressure may rise to the point where wall panels, ceiling/roof panels and windows are blown out or, in extreme cases, where more serious structural damage may result.

3.4 SOURCES OF IGNITION

3.4.1 Explosions can be instantaneous or develop from initial fires. Fires are a fairly common occurence in food product spray drying plant. The possibility of explosions and fires occuring can be reduced by removing known sources of ignition.

3.4.2 Flames

No naked flames should be allowed in any area of the building coming into direct contact with a powder production unit. The normal "No Smoking" rule should be rigidly enforced.

Air heating units employing a flame should have the combustion units situated in a totally enclosed section with walls and door having a fire resistance approved by the Fire Officer. Doors leading from the room to the powder plant should be equipped with strong self-closing mechanisms and have a sealed lip construction. Air supply to the room should be by powered vent such that there is over-pressure in the room compared with the powder building in order to prevent dust ingress into the room.

Direct fired heating systems should not normally be used to provide hot air for the process. Where such systems are used a separate combustion chamber should be provided to keep flames well away from the flammable dust. It is possible that incandescent particles could enter the dryer through the air supply. This can be prevented by:-

(i) locating the air intake in a clean area;

(ii) the provision of a suitable filter on the air intake;

(iii) keeping the inside of heating systems clean and dust free.

Gibson and Schofield **(12)** have shown that incandescent particles would have to be 3-5mm diameter at temperatures of 600°C to cause ignition. These large particles are usually removed from the hot gases before they pass into the process by means of a mesh filter with a hole size not exceeding 3mm (User guide to fire and explosion hazards in the drying of particulate materials, I. Chem. E., Rugby 1977 **(13)**). Filters should be inspected regularly and cleaned in a safe place. Direct fire burners should be cleaned regularly and operated in such a way as to ensure complete combustion. Erratic burning and flame blow-off should be investigated and remedied immediately. If air is recirculated through the heater, considerable care should be taken that any entrained dust is removed. Detailed advice on required standards for the use of gas or oil burners is available in Codes of Practice (**(14), (15), (16), (17), (18) and (19)**).

Any laboratory requiring a naked flame should preferably be housed in a separate building or, if in the powder building, the room should be supplied with its own source of filtered air.

3.4.3 Hot Surfaces and Self-Ignition

Hot surfaces are inherent in the operation of a spray dryer and occur in the hot air inlet sections, on the surface of air heating units and on mechanical equipment that is malfunctioning. Auto-ignition temperatures of milk powder clouds vary between about 440 and 500^{0}C depending on the characteristics of the product. Such temperatures do not occur under normal operation.

Component parts of the structure of spray dryers, in direct contact with primary drying air, can heat up to temperatures in excess of 200^{0}C. Such temperatures are more than enough to initiate accelerated oxidation and spontaneous heating of powder layers. This may lead to self-ignition of accumulations of product adhering to internal surfaces of components of a dryer. This is of particular concern in cases where inlet temperatures of 250^{0}C are experienced, which are not uncommon on new drying systems. Product accumulating in the hot zone of the dryer can begin to burn and become incandescent. It can become a source of ignition elsewhere in the system where particles of incandescent material become detached and travel on the air stream to high risk areas where the product is dry and in suspension with the air. In addition, where a fines return is incorporated into the system, fines returned to the hot zone could be ignited by incandescent material adhering to the structure.

High temperatures occur on the surface of air heating units. Filter units must be provided prior to each air heating exchanger either by a 'filter room' concept or by individually filtering each heater battery air supply. It is likely that the bacteriological requirements for filtration will exceed those of dust filtration but, in any case, the filter must be capable of removing particles to Class 4 of BS 5295, Part 1, Section 4 **(20)**.

While shut down, the plant should be isolated from the burners to prevent leakage of gas into the plant and at start-up combustion products should not be fed to the process until flame is established (I. Chem. E. 1977 **(13)**).

Each filter unit must be fitted with a device to indicate the fouling level of the filter media. This may be automatic or manual. Automatic versions should give a visual, non-cancellable signal in an appropriate position. If manual devices are employed, a daily log must be kept of the readings.

The main chamber of the spray dryer should be designed to minimise surface temperatures. The most likely area for excess temperatures is at the area surrounding the air inlet point. By the use of insulation and air cooling techniques, this area should be designed to minimise the temperature of the chamber whilst avoiding any temperature drop of the drying air. All cooling measures must be such as to ensure that no condensation takes place during normal operation.

3.4.4 Mechanical Friction

Friction heating will occur whenever one surface is moving relative to another. It is important to recognise that this is not limited to faults arising from two surfaces meeting unintentionally. It can also occur in lubricated items such as gearboxes and bearings. One of the high risk areas, due to its rotational speed and high stress, is the atomiser.

Vibration, oil temperature and oil pressure monitoring equipment should be an essential feature of atomiser protection. The feed line to the atomiser should be provided with a duplex filter equipped with a pressure differential monitoring device to ensure that only material of the correct particle size is fed to the atomiser, thus avoding incorrect spray patterns in the chamber and premature fouling of the atomiser wheel. Fouling of the wheel can lead to the build-up of product behind the wheel and frictional temperature build-up.

A lower risk area is the outlet fan for the dryer. Whilst the bearings for these units are normally mounted externally to the fan casing, failure may cause the impellor of the fan to touch the casing and create a hazard.

Bearings should be provided with vibration monitoring equipment on outlet fans to the dryer and on any other fans handling powder laden air.

3.4.5 Impact Sparks

This is a common source of ignition (see Appendix I for details of known incidents). Impact sparks may arise from fragments of metal from drying system components which have become detached. The most common cause of impact sparks has been due to the atomiser wheel parting from the shaft and hitting the chamber walls.

The design of this detail must ensure that a properly assembled wheel will not come apart from the shaft. The dismantling and assembly of the wheel must be carried out by a person trained in this procedure.

3.4.6 Electrical Sparks

Electrical power either from the mains or batteries is a source of ignition, producing sparks of energy substantially in excess of that required to ignite dusts. Sparks produced during the normal working of switches, contact breakers, fuses, etc., can readily ignite dusts unless precautions are taken.

As a general precaution, the installation of electrical equipment should be avoided where an explosible dust is likely to occur. For example, switchgear may be installed in a room separated from the main working area. Where this precaution cannot be taken and the equipment must be used in the presence of dust, electrical equipment should be totally enclosed and dust tight. British Standard BS 6467 (21) specifies requirements for electrical apparatus for use in the presence of combustible dusts. All plant and electrical equipment should be adequately bonded. Lighting in spray drying areas should be of the covered type to avoid hot debris from an exploding bulb or tube.

All lighting to the drying chamber should be indirect and external.

All motors in the building must be brushless. Particular attention must be paid to single-phase portable devices such as vacuum cleaners and drills to comply with this requirement.

All electrical equipment should be installed in accordance with the latest amended edition of the I.E.E. Wiring Regulations **(31)**.

3.4.7 Electrostatic Discharge Sparks

Sparking from this source is low energy, often below the 50 mJ minimum for ignition of typical milk powders. However, variations in this energy and the flammability of the powder can occur. Electrostatic discharge therefore needs to be taken into account as a potential source of ignition. Electrostatic insect killers should be checked for their suitability.

BS 5958, Parts 1 and 2 **(22)** cover the Code of Practice for the control of undesirable static electricity. The most common source of danger is the retention of charge on a conductor. The accepted method of avoiding the hazard is to connect all components to each other and to earth by electrical paths with resistances sufficiently low (usually 10 ohms) to permit the relaxation of charge.

The criterion of 10 ohms is generally suitable for wholly metallic systems but may not be appropriate to systems involving non-metallic components.

Recommendations for earthing based on BS 5958 need to be compatible with the requirements for general earthing and lighting protection (CP 1013 **(23)** and BS 6651 **(24)** should be consulted).

The importance of earthing features for safety should be appreciated by all concerned and a regular monitoring system established, whereby all earthing devices are inspected visually on a regular basis. In addition, measurements of earthing rsistance should be made before the plant is brought into use, at each scheduled maintenance and after any other modification or maintenance, and a log kept in order to indicate any changes.

The building should be protected against lightning strike (see BS 6651 **(24)**) and professional advice should be sought in relation to the installation and the effect of other buildings.

3.4.8 Hot Work

Welding and cutting produce localised heating of plant and sparks, which are known to have caused dust explosions. Similar hazards arise from operations such as soldering, burning and the use of power tools. Work carried out on the outside of equipment can easily heat up any dust left inside the equipment. No flammable material should be left in the vicinity of welding operations (e.g. wooden structures, tarpaulins). Hot work is subject to the statutory requirements of the Factories Act 1961, Section 31 (4) **(2)**.

HSE Booklet HS(g)5 Hot Work: welding and cutting on plant containing flammable materials **(25)** and HSE Guidance Note GS5, Entry into confined spaces **(26)**, give further advice.

3.4.9 Permit to Work

No hot work should be carried out unless the plant has been shut down, emptied and cleared of dust or the dust rendered non-explosible. The introduction of a written permit to work system is useful. Particular care must be taken where outside contractors are involved.

3.5 DETECTION

3.5.1 Detection systems must be employed to determine when operating temperatures are rising above the norm.

Quick acting, thin temperature sensors should be placed in the main exhaust flow, in the chamber bottom (for fixed fluid beds), in the cyclone exhaust manifold, in any exhaust air filters and in any device, such as sound attenuators, where it is possible for powder to accumulate and receive burning particles from up stream. Where a second stage is provided, then this should also be fitted with temperature sensors in its outlet air system. Even so, these are unlikely to detect local burning of deposits in remote regions of the dryer, at least in the early stages.

3.5.2 During the course of self-heating, charred lumps may fall from the dryer walls into the product. It is essential that the product be monitored for the appearance of charred particles.

Provision must be included for the sampling of the finished powder by the operator in order that he may take routine samples (hourly) to check for scorched particles and internal discolouration of oversize spheres.

With spray dryers which discharge into a system of fluid bed dryers a number of oversize spheres appearing on the sieve may be associated with fire or overheating problems in the system. Sometimes these spheres are black or discoloured, clearly indicating problems, but sometimes they are white on the surface and charred inside.

It is recommended that spheres be broken and examined at hourly intervals.

3.5.3 Removable inspection panels may be provided in order to examine whether build-up of powder is taking place under operating conditions. These ca be provided in every closed vessel, such as cyclones and filter casings, and at each otherwise inaccessible location. When the dryer is commissioned, these areas should be frequently examined and design changes initiated to remove any detected problems. Under normal running conditions, inspection should thereafter take place at monthly intervals

However, should any of the operating conditions change, then more frequent inspection should be established.

The panels should be designed such that they maintain the strength of th parent vessel. Panel fastening devices should require the use of tools for their removal.

3.5.4 Other means of detection of combustion include monitoring of carbon monoxide levels and detection of infra-red radiation.

3.6 INERTING

Prevention can be achieved by reducing the oxygen level below that necessary to support combustion. The technique is only rarely applied ir large food manufacturing plants. The principles of inerting are discussed in Appendix II.

3.7 OPERATIONAL REQUIREMENTS

3.7.1 To ensure compliance with the legal requirements outlined in paragraph 1.3.2 and to reduce the possibility of a fire developing, it is necessary for a contribution to be made by everyone concerned with the operation of the dryer.

3.7.2 Management should clearly define levels of authority with regard to operational duties, cleaning and maintenance. It should also establish clearly defined emergency procedures. Preferably, all these matters should be in writing and may form part of an operation manual, or the company safety policy.

3.7.3 Examples of work required to be undertaken at specific intervals are given in Appendix III, which may be usefully copied as a checklist and amended as necessary to account for local conditions. All aspects of operation and maintenance should be in accordance with the plant manufacturers' instructions and this Code of Practice, and personnel involved in these operations <u>must</u> be adequately trained.

3.7.4 It is recommended that a written record is kept of tests carried out on high temperature protective devices, fire protection systems and measures designed to prevent the accumulation of powder. These records should be reviewed by an appropriate level of management on a regular basis.

3.7.5 Control of Deposits

It has been stated previously (para. 3.2.4) that self-ignition of powder deposits is probable and steps must therefore be taken during operation to reduce the chance of this occuring. Powder deposits can be formed in several ways:-

(i) air currents can cause material to build up near the top of the dryer. This is more likely to be a problem in rotary atomisers and it is important that the air flow rate and the atomiser speed are correctly adjusted to minimise this. In multi-purpose dryers air distributor vanes may also have to be adjusted;

(ii) after washing, unless the dryer chamber is sufficiently cleaned, wet patches of product will remain which will dry out on heating up of the dryer, providing a base for further deposit formation;

(iii) incorrect start up procedure. The chamber wall may become wetted through excess water or feed concentrate being fed to the dryer and a similar circumstance to the above can be created as the wall dries out. This can be particularly dangerous as oxidation occurs much faster in wet powder;

(iv) where the feed contains added fat and the mixing of the feed is incomplete, especially in cases of high fat concentrations, separate fractions of concentrated skim milk and fat will be atomised and the uneven atomisation could cause fat to be deposited on the wall;

(v) the production of certain types of powder requires fine powder to be returned to the atomiser, i.e. very near to the hottest part of the dryer chamber. If fines are returned directly below the atomiser disc, care must be taken that the return tube is accurately centred, otherwise powder may be blown onto the hot surfaces at the top of the dryer. Similarly, it should be ensured that the outflow nozzle is clear. This can be monitored by the delivery pressure.

In many cases, continuous air "brushes", powder scrapers, vibrators and knocking hammers are provided to prevent powder accumulations on the chamber walls during operation. It is important to ensure that these are correctly maintained.

The danger area for deposits is the ceiling around the atomiser, where critical thickness may only be in the order of 17mm. If a deposit is formed anywhere, the plant should be stopped whilst it is cleared as explosions have occured due to the broken pieces of incandescent powder being carried by the air flow into the dust cloud within, for example, the fluidised bed.

The inner surfaces of the chamber around the hot air inlet(s) should be looked at (using a battery operated hand torch) after each run and before any cleaning of the chamber. If any powder deposits in this area appear charred, the cooling arrangements should be checked.

3.7.6 Temperature Control

At each start up and shut down the dryer should be established on water before switching to product feed and a return of water should be made before switching off. The method of operation should preclude powder flowing back into the air disperser and heating section.

Abnormally high temperatures can be caused in the dryer if the feed stops due to maloperation, with the danger of powder deposits in the dryer subsequently igniting. It should be arranged that if feed failure should occur, either the air heater is switched off (preferably automatically), or that the switch over to water feed takes place with operation on a two

On reaching the first high level, the alarm should be sounded and the feed switched over to water. If the feed failure is caused by a minor blockage, the water flow may dislodge it and, once normal temperatures have been restored, the feed can be resumed. If the water cannot pass to the atomiser, the temperature will rise to a second level, after which the air heater should switch off.

Control must ensure that once the heater is switched off the main blower continues for sufficient time to prevent heat accumulation inside the dryer (unless there is a fire inside the dryer). In the event of blower failure the heater and feed must switch off automatically.

The fire protection system may also be activated dependent upon the temperature reached in the dryer.

The flow of powder through the dryer should be monitored. If powder begins to accumulate in the base of the chamber then the dryer should be shut down. Unless this is done, the temperature in the dryer will begin to rise and ignition may occur. Stopping the operation will also reduce the amount of material in the dryer that can become involved in any subsequent fire or explosion.

3.7.7 Training and Education of Operators

As well as being adequately trained to operate the plant and appreciate the importance of carrying out the checks detailed in Appendix III, operators should be made aware of the characteristic smell of burnt particles. They should also be instructed to be continually on the watch for burnt particles in the powder, lumps at the silos and powder deposits in the outside yard, and should know the appropriate action to take if these are found.

3.7.8 Figure 2 illustrates areas requiring particular attention in design and during operation and maintenance procedures (see overleaf).

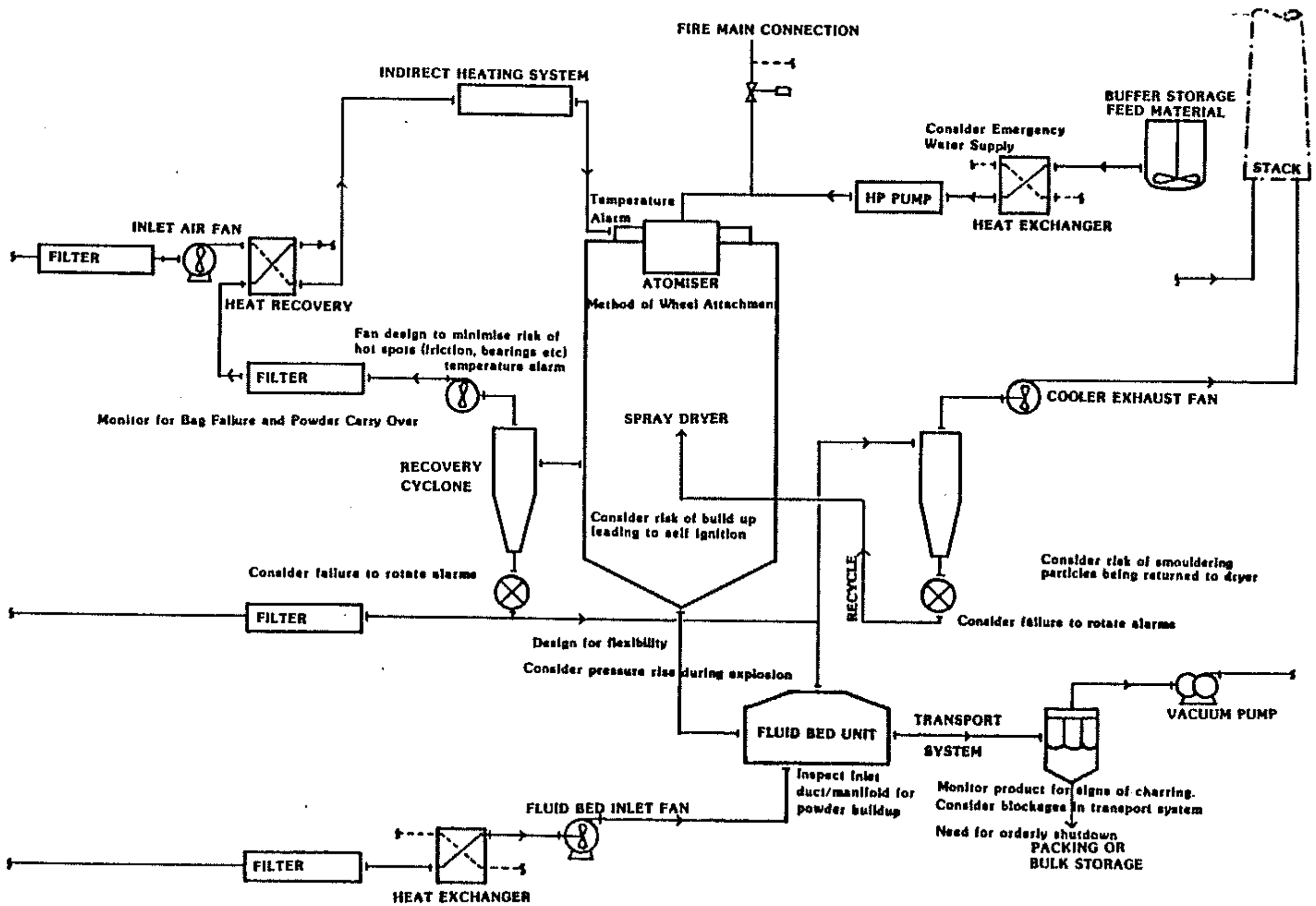

Figure 2: Typical spray drying plant - areas requiring particular attention in design and during operation and maintenance procedures.

SECTION 4 PROTECTION

4.1 GENERAL

The options open to the designer to minimise the impact of dust explosion are:-

(i) Venting

(ii) Suppression

(iii) Use of pressure vessels

(iv) Isolation

The design of these systems requires a knowledge of the explosion pressure characteristics of the product.

The basic techniques are applied to the whole range of equipment found on spray drying plant.

The designer must look at the total plant in assessing the protection requirements to achieve an integrated approach. Several options may be used in any one plant to achieve the most effective protection system.

4.2 EXPLOSION VENTING

4.2.1 Background

The basic principle of venting provides for the rapid opening of a vent of sufficient area so as to allow unburnt dust and explosion products to escape, thus limiting the pressure rise to an acceptable level. The acceptable pressure rise is determined by the requirement that the vessel should not rupture and in some cases it may be required that it should not deform.

This maximum pressure is called the 'reduced explosion pressure'. or Pred.

In a given vessel the 'reduced explosion pressure' will depend upon the size, number and location of the vents, the opening pressure and inertia of the vent cover, the presence of ducts from the vent, the presence of obstructions inside the vessel and the state of the dust cloud.

The general subject of explosion protection is covered in depth in Guide to dust explosion prevention and protection, Part I - Venting, I. Chem. E., Rugby 1984 **(27)**. These notes draw out the key points and their relevance to Class st 1 food materials. With care, the information can also be used to evaluate options for handling Class st 2 materials.

Ths sizing of vents requires information on the explosion pressure characteristics of the dust and the characteristics of the vessel or container.

Explosion vents must discharge to a safe location. This is normally achieved in new plant by ducting vents to the outside of the building or locating plant externally. Venting of the building may be necessary. A frame building with light-weight cladding is preferred for buildings handling explosible dusts in order to prevent severe damage or collapse from secondary explosions.

Where plant is allowed to vent into a building, as occurs on some existing equipment, full consideration must be given to:-

(i) the risk of secondary explosion;

(ii) building design and its ability to withstand pressure rise from the primary explosion and secondary explosions;

(iii) the introduction of "no go" areas during production runs to keep personnel at a safe distance from vents or the provision of adequate blast deflector panels.

Vent duct design can increase the maximum pressure (Pred.) reached in a vessel. The following guidelines for duct design are given in the I. Chem. E. Guide **(27)**:-

(i) vent ducts should be as short as possible and preferably less than 3m in length;

(ii) the cross-sectional area of the duct should be the same as or up to 10% greater that the vent panel size. An increase in cross-sectional area in the direction of flow would be beneficial;

(iii) the duct cross-section can be round, square or rectangular (up to 5:1 aspect ratio). Circular ducts are often preferred because of their greater strength for the same gauge of metal;

(iv) there should be no change of shape of the vent duct along its length that could impede the flow of combustion products or the movement of vent covers;

(v) vent ducts should be straight because of the unpredictable effects of bends. Short bends of long radius may be acceptable to divert the discharge, but expert guidance should be sought;

(vi) vent ducts should be constructed to have the same pressure-shock resistance as the vessel being protected.

The design of the vent and ductwork needs to consider both weatherproofing and hygiene.

4.2.2 Sizing of Vents: Vent Ratio Method

This is the traditional method and for Class st 1 food materials the following vent areas are recommended:-

TABLE 4

Recommended Vent Areas according to Vent Ratio Method.

VESSEL SIZE	VENT AREA
Up to $30m^3$	$1m^2$ for each $6m^3$
$30m^3$ - $300m^3$	Ratio reduces linearly from $1m^2$ for each $6.1m^3$ to $1m^2$ for each $25m^3$
Over $300m^3$	Apply VDI 3673 **(9)**

These figures can be expressed as in Figure 3:

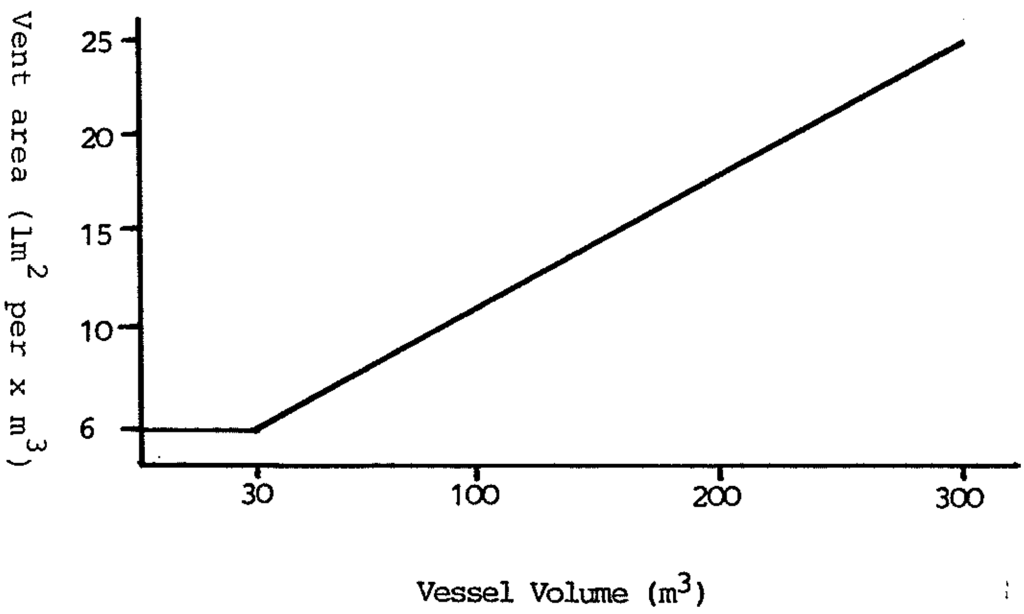

Figure 3: Vent ratio method

The effect of the duct on the pressure in the vessel is illustrated in Fig. 4 and it can be appreciated that this increase is large and could cause the vessel to rupture. For vent duct lengths greater than approximately 3m the maximum reduced pressure is less dependent on the duct length since the velocity in the duct is expected to be close to the speed of sound, so the frictional resistance is of less significance.

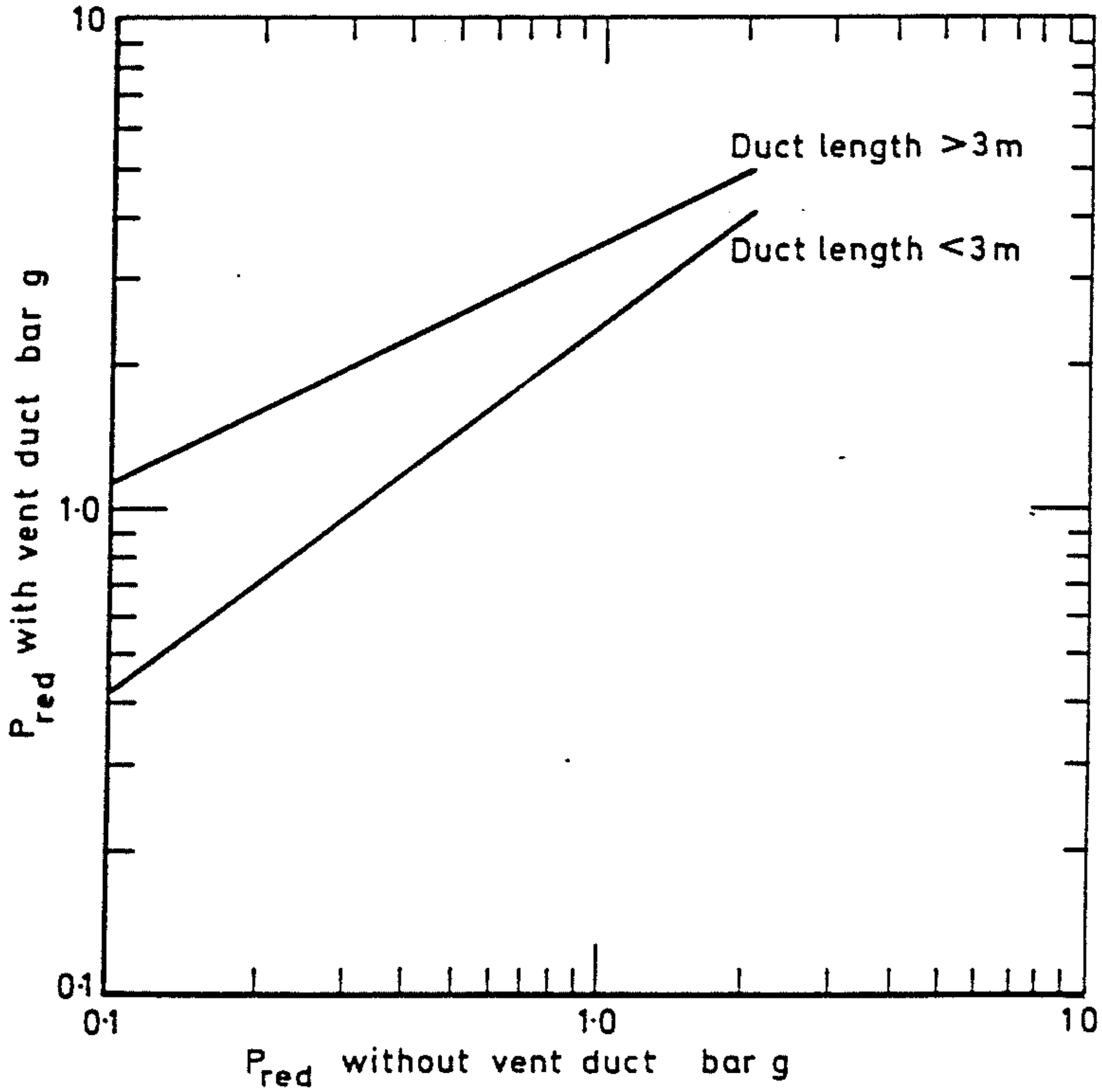

Figure 4: The effect of vent ducts on the pressure in a vented vessel.

Source: VDI 3673 **(9)**

On existing equipment the sizing has often been based on an estimate of the volume containing an explosible concentration of dust. Traditionally, with a food spray dryer it has been considered that only one third of the dryer volume has a dust concentration that would allow an explosion to occur. This might still be acceptable within the terms of Section 1.2 of this document, but on new equipment the calculation should assume the full working volume.

The vent ratio method is based on a maximum reduced explosion pressure of 0.14 bar g and allows for a high degree of turbulence and flame front fragmentation. To apply the vent ratio method the designer must meet the following two criteria:-

(i) the vent opening pressure should not exceed 0.03 bar g and the vent cover should not weigh more than 25 kg/m^2;

(ii) discharge ducts, if incorporated, should be less than 3m long (vent ducts are not recommended for very weak vessels).

4.2.3 Sizing of Vents: Nomograph or Cubic Law Method

Based on more recent research, primarily in Germany, this method is considered to represent a more precise calculation technique and can result in smaller vent areas on larger vessels. VD1 3673 **(9)** details this procedure.

The vent area appropriate to a particular vessel volume is read from a standard nomograph, an example being given in Figure 5. A family of nomographs has been produced covering a range of values of Pstat., the opening pressure of the vent, and Pred., the reduced explosion pressure.

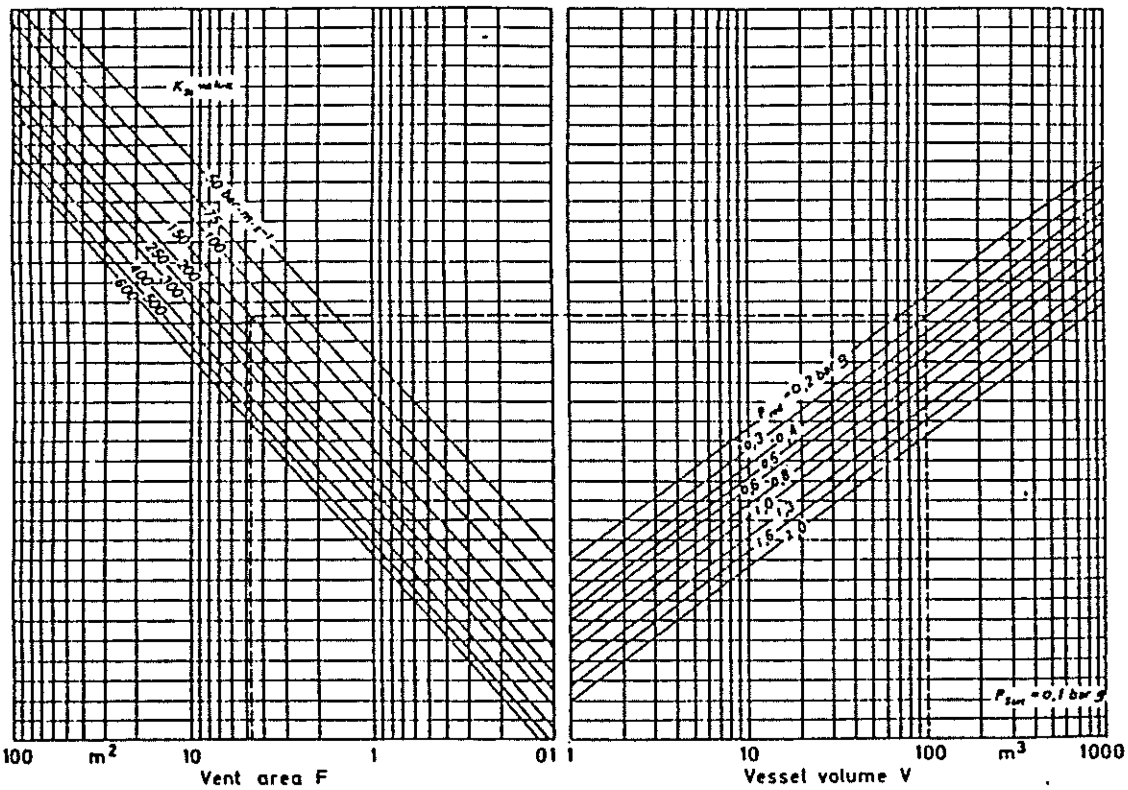

Figure 5: Nomograph Source: VDI 3673 **(9)**

Further families of nomographs are available for different Kst values within 0-200 range covered by Class st 1 materials. On large installations with materials of low Kst values the use of these nomographs can give a significant saving in vent area.

The calculation technique also allows the effect of duct design on Pred. to be estimated.

The specific areas of application of the nomograph method and the necessary conditions are summarised in the I. Chem. E. Guide **(27)** as:-

(i) KST should be measured in the 20 litre sphere. The appropriate test methods are discussed in the I. Chem. E. Guide **(27)**.

(ii) the lowest reduced pressure that can be designed for without extrapolation is 0.2 bar g.

(iii) the vent cover inertia must be low and the weight of the cover must be less than 10 kg/m^2.

(iv) the vessel volume is between 1 and 1000 m^3.

(v) the volume used in the nomograph should be the total free volume of the vessel.

(vi) the turbulence in the vessel is similar to that in the test method.

(vii) the vessel should have a length-to-diameter (aspect ratio) less than 5:1 and preferably 3:1.

(viii) the basic method takes no account of vent ducts. Separate graphs allow the duct effect to be estimated.

4.2.4 Design Considerations

In specifying a protection system based on venting, the following points should be considered:-

(i) the problems of interconnected vessels;

(ii) the need for the venting system and vent closure method to be of hygienic design;

(iii) the constraints on vent opening pressure and mass if a vent door is used;

(iv) accessibility of the venting device for inspection, testing and maintenance (with the stickier food products it is important to regularly check that devices like doors are free to operate);

(v) location of vents. With dryers, cyclones and silos the top of the vessel is often the preferred location. Some dryers do have side vents where it is more convenient for layout. The location of the vent does need to take into account the need to protect equally the whole unit. In some cases the geometry of the unit may require a number of vents distributed across the unit (e.g. long horizontal dryers). Typical locations are shown in Figure 6 (see overleaf).

(vi) where vents discharge internally to areas where people are likely to be present, suitable blast deflectors should be fitted for their protection in the event of an incident (see Appendix I, 7).

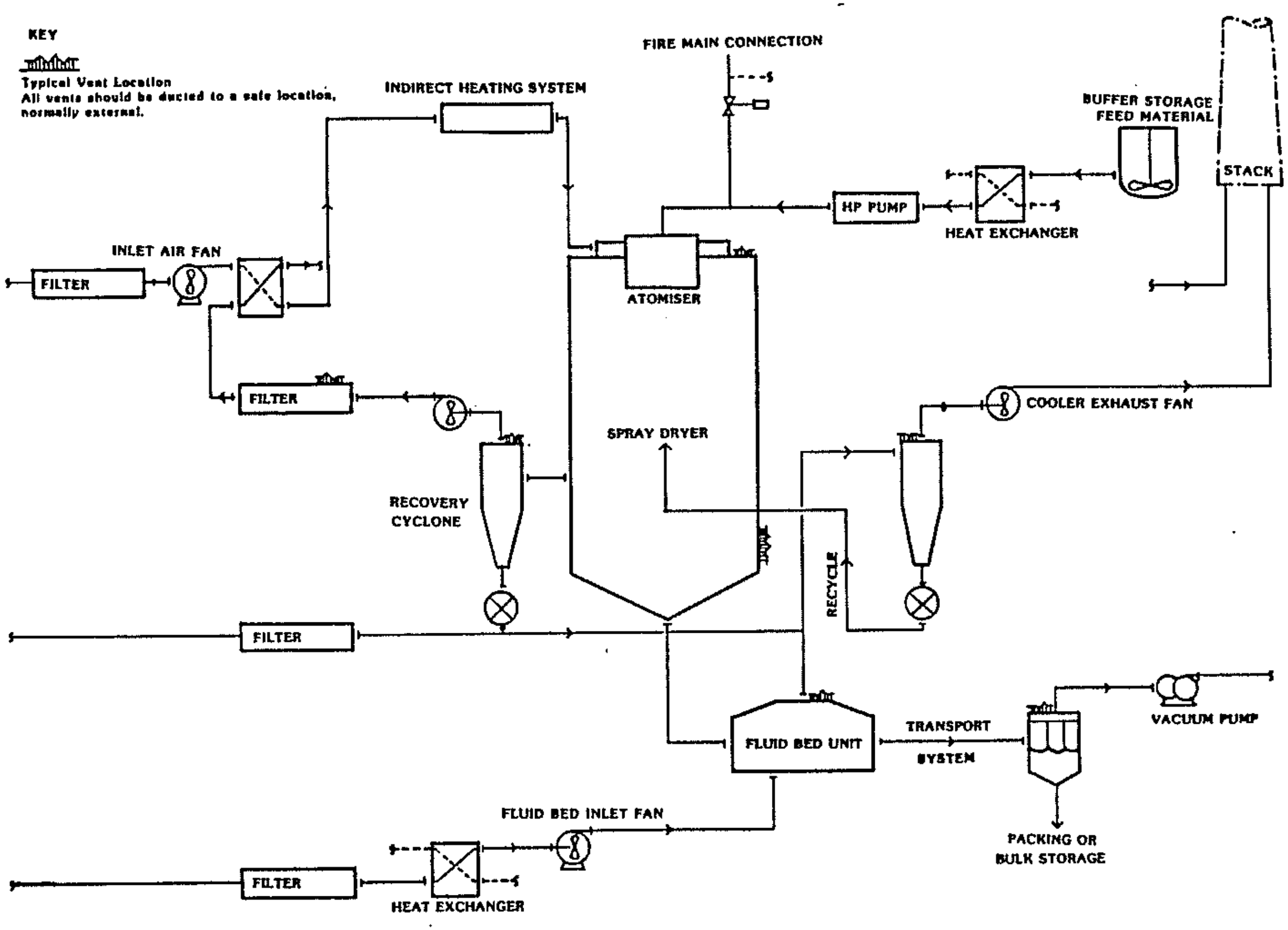

Figure 6: Typical spray drying plant - typical venting locations.

4.2.5 Pressure Rating

For all equipment the design pressure of the plant needs to be specified in conjunction with the design of the protection system, with due regard to capital cost. The design options are pressure resist method and shock resist method, and these are defined in Section 4.4.

4.3 EXPLOSION SUPPRESSION

4.3.1 Background

Explosion suppression systems exploit the typically 30-100 msec that it takes for an explosion to generate a destructive pressure in a containing vessel.

Explosion suppression is a technique by which a developing explosion in a confined volume is detected and arrested during its incipient stage. Sufficient chemical suppressant has to be discharged into the growing fireball in the vessel at a fast enough rate to extinguish all flames before a destructive over-pressure develops, thus preventing or minimising damage.

There is an increasing trend toward the specification of suppression for explosion protection. Explosion suppression is often used where it is not possible to vent the contents of the vessel to a safe place or the hygiene aspects make the design of venting systems difficult, although suppression may introduce its own related hygiene problems.

The sophisticated nature of these systems requires a high level of maintenance.

4.3.2 Principle of Operation

An explosion suppression system comprises explosion detectors, explosion suppressors and a central control unit. For a given explosion hazard in a vessel the reduced explosion pressure for a suppressed explosion depends on:-

(i) the type of detector (pressure or radiation);

(ii) the threshold level of detection at which the explosion is recognised;

(iii) the suppression efficiency of the suppressant;

(iv) the number of suppressors fitted;

(v) the mass of suppressant;

(vi) the throw and dispersion of the suppressant.

The pressure created at an early stage of an explosion within an enclosure spreads itself evenly at the speed of sound in all directions.

The explosion detector is required to recognise the existence of an explosion immediately after ignition. Pressure sensors are well suited for the detection of incipient explosions in explosion suppressant systems.

The control system detects changes in the explosion sensor output, activates the suppressors in a very short period of time and automatically shuts down the plant in a safe manner, e.g. cutting of the supply of fresh product into the protected vessel and the fans supplying air. The control system prevents the plant restarting without the suppression system being rearmed.

The hardware used to store the suppressant comes in various forms depending on the manufacturer, but when discharged must:-

(i) give a high mass discharge rate;

(ii) have a high suppressant discharge velocity to give effective throw;

(iii) give good angular dispersion of the suppressant.

Discharging a spray of liquid or powder into a flame front results in a number of complex effects, the most important for dust explosions being <u>quenching</u> (heat abstraction from the combustion zone by energy transfer) and <u>inhibition</u> (interference with chenical reactions in the flame).

4.3.3 <u>Design Considerations</u>

Unlike venting, the design methods for suppression are based on proprietory information. The systems have to be specified and designed in conjunction with the suppliers.

Specification of the system will require:-

(i) dust explosibility parameters - maximum explosion pressure and the maximum rate of pressure rise;

(ii) plant shape and layout;

(iii) plant component shock resistance - the maximum pressure that the component is designed to withstand;

(iv) processing parameters, such as pressure and temperature;

(v) processing conditions - in particular the level of turbulence.

Particular care must be taken if systems are to be specified for plant with any of the following characteristics:-

(i) vessel aspect ratio greater than 2:1;

(ii) partially vented vessels;

(iii) vessel fitted with fixed or mobile apparatus which could impede the distribution of suppressant;

(iv) operating pressures and temperatures substantially higher or lower than normal atmospheric conditions;

(v) high level of turbulence and/or product throughput;

(vi) vessel volumes substantially greater or smaller than those used in the efficacy test.

4.4 USE OF PRESSURE VESSELS

4.4.1 Background

For a given material and configuration of equipment the maximum explosion pressure can be predicted from small scale test data.

Where the equipment is relatively small or hygiene constraints limit the applicability of other systems, then it may be preferable to design the vessel to withstand the pressure rather than invest in one of the other protection systems.

This technique is often applied to cylindrical components such as ductwork.

4.4.2 Design Considerations

Vessel design can be based on either pressure resistant vessels or pressure-shock resistant vessels.

4.4.3 Pressure Resistant Vessels

These vessels are designed to contain an explosion without rupture or deformation.

4.4.4 Pressure-Shock Resistant Vessels

These vessels are designed to withstand the maximum explosion pressure without rupture but would be liable to permanent deformation.

This approach reduces capital cost but accepts that following an explosion the vessel might need substantial repair or replacement.

4.5 PROCESS ISOLATION

4.5.1 Individual plant items should be protected by one of the methods described and should be isolated from each other in order to:-

(i) control the transfer of burning and smouldering material;

(ii) allow the protection system to be matched to a specific volume of plant;

(iii) avoid an explosion in the first vessel causing pre-compression, increased turbulence, and hence an increase in the rate of pressure rise in the second vessel.

Typically, rotary locks and screw conveyors are recommended. The I. Chem. E. Guide **(27)** discusses, in general terms, the options. In specifying the equipment, full account needs to be taken of the handling problems and hygiene aspects associated with food products.

Where, under normal operation, it is preferable to maintain an uninterrupted process flow, fast acting slide valves or suppressant barriers may be considered.

In specifying these systems the risk of vessel collapse should be considered where isolating sections of the plant exposes a vessel to increased negative pressure.

4.5.2 Flexible connections are particularly vulnerable to rupture where pressure builds up and suitable blast deflectors should be fitted (see Section 4.2.4 (vi)).

SECTION 5: FIRE CONTROL

5.1 GENERAL

Fires may occur:-

(i) within the drying system;
(ii) within the dryer building;
(iii) in plant or buildings adjacent to the dryer/dryer building.

Such fires are potential sources of ignition for:-

(i) explosions within the drying system;
(ii) explosions within the confines of the dryer building where there may be a dust laden atmosphere.

All fires must, therefore, be dealt with promptly and efficiently to prevent the escalation of even small fires into major incidents involving destructive explosions and human injury.

5.2 FIRES IN THE DRYING SYSTEM

5.2.1 General Response

For drying systems, once a fire has been detected the operating procedure must initiate a shut down and control sequence either manually or automatically. Whether automatic or manual the following basic procedure is recommended:-

(i) activate alarm and call fire brigade;
(ii) cut off heat supply;
(iii) cut off air supply;
(iv) change atomiser feed from product to water and maximise flow;
(v) close down powder transport systems and isolate plant components;
(vi) activate extinguishing devices;
(vii) monitor progress.

The basic procedure outlined above needs tailoring to suit the design of the drying system which will govern the sequence and timing of the response period, e.g. main fans may need to be kept on for a short time to cool heat exchangers, preventing damage or further danger from heat accumulating.

5.2.2 Fighting a Fire

In general this should be left to the Fire Brigade. However, if contained within a drying chamber or other vessel, the fire should be tackled using internal injection points if these have been installed for this purpose. Access doors and inspection hatches should not be opened.

The basic rules of first aid fire fighting should be followed.

For drying chambers, the main chamber doors or explosion doors in the vertical walls of the dryer <u>must not be opened</u> until a fire has been extinguished. The reasons for this are:-

(i) there may be falling debris in the form of burning product;
(ii) the possible emission of hot gases under pressure;
(iii) the possible influx of oxygen which may cause a dying fire to burn more vigorously.

5.3 FIRES WITHIN THE DRYER BUILDING OR ADJACENT BUILDINGS

Normal procedures should be followed to control accidental fires of this nature. Apart from limiting damage to the building, the objective is containment to prevent the fire becoming a possible source of ignition for powder in the drying system or the environment.

The emergency procedures followed in such incidents should include an emergency shutdown of the dryer system.

Fire fighting should not be attempted in circumstances where personnel are placed in danger.

5.4 FIRE EXTINGUISHING AGENTS AND EQUIPMENT

5.4.1 Water is the best extinguishing medium, although extensive uncontrolled use of water can result in unnecessary product damage. Where used, water should be in the form of a spray rather than a solid jet to enable it to deal more effectively with the nature of dust fires.

Chlorinated hydrocarbons (B.C.F. Extinguishers) are not suitable because contact with hot surfaces may result in the production of phosgene - a highly toxic gas.

The use of inert gases requires specialised knowledge and is not generally suitable.

5.4.2 Equipment

On site equipment will normally be specified as an integral part of the drying system or by recommendation from the local Fire Prevention Officer. The latter will include minimum standards expressed in specific terms in a Fire Certificate under the Fire Precautions Act 1971 **(28)**.

Experience has shown on occasions that the Fire Brigade, responding to a new dryer location for the first time, are unable to gain access with their equipment because of the nature and scale of the dryer installation.

Similarly, water supplies are sometimes found to be lacking in quantity and pressure to reach affected areas of plant.

There should be full discussion and practical trials with the Fire Brigade. A test of their equipment to reach all parts of the dryer installation with adequate water flows should be made.

Water storage tanks on site will be the best source of water for fire fighting. Where possible and appropriate these should be adapted to feed directly into Fire Brigade equipment.

5.5 EMERGENCY PLANS

These should be formally developed and include:-

(i) the display of written instructions for personnel including evacuation procedures, assembly points etc.;
(ii) provision for fire fighting and evacuation drills;
(iii) provision for staff training in all aspects of fire control and the use of fire fighting appliances;
(iv) the allocation of responsibilities to personnel for specific emergency duties;
(v) the means to be adopted for contacting the emergency services.

Emergency escape routes should be designed to direct people away from blast zones and dusty areas wherever possible.

In addition there should be a regular and documented checking procedure for the maintenance of:-

(i) escape routes free from obstruction;
(ii) escape routes marking;
(iii) escape routes emergency lighting;
(iv) alarms and alarm points functioning;
(v) fire fighting/control appliances and equipment;
(vi) explosion panels/doors operating and free from powder accumulations.

5.6 ADDITIONAL INFORMATION

The above is no more than a summary and cannot claim to be comprehensive in its scope. In planning fire control and emergency procedures the following may prove useful sources of information:-

(i) plant suppliers, installers and manufacturers;
(ii) the Fire Protection Association;
(iii) the local Fire Prevention Officer;
(iv) the Health and Safety Executive;
(v) the insurance companies;
(vi) BS 5908, Code of Practice for fire precautions in chemical plant **(29)**.

APPENDIX I

DETAILS OF KNOWN INCIDENTS

The following information is known about explosions in spray drying plant used in the dairy industry over the period 1972-1986.

	PRODUCT	CAUSE	RESULT
1.	Milk Powder	Spinner drive shaft seized. Spinner came off and fell into chamber causing a spark.	Drying chamber fitted with explosion relief panels suffered no damage. Secondary explosion in recuperator led to substantial damage to plant and building.
2.	Milk Powder	Damaged O rings on injector nozzles allowed seepage and build-up of product, resulting in spontaneous combustion/self-ignition and burning particles falling into air/dust mixtures.	Due to operation of explosion relief doors no structural damage resulted. Fire damage confined to doors and surrounding structure.
3.	Milk Powder	Build-up of solid deposit of powder on roof and inside surfaces of drying chamber leading to spontaneous combustion/ self-ignition.	Explosion relief vents avoided serious plant damage. Plant stopped for over 24 hours due to fire which was extinguished by internal sprinkler system.
4.	Milk Powder	Friction when the air distributor fell to the floor of the dryer.	Unknown
5.	Fat Filled Milk	A plate fastened to the top of the atomiser disc had become detached, risen up the atomiser shaft and rubbed on the top portion of the atomiser assembly. The resultant frictional heat melted the stainless steel plate. Hot globules of falling metal ignited the powder.	The flexible skirt sealing the base of the dryer to the fluid bed dryer was blown off. Flames emitted from explosion relief panels set fire to the roof of the building.
6.	Cheese Powder	An accumulation of powder on the coils of the air heater caused the fire.	The stainless steel bed of the fluidiser was distorted and the feed belt was

			partially burnt out.
7.	Skim Milk Powder	Burning material in the fines recycle line to the fluidised bed. Milk had passed back through a faulty non-return valve onto a direct electric element air heater.	Explosions in the fluidised bed dryer and the spray dryer relieved safely through vents provided. Weak plastic connections between the fluidised bed dryer and connecting ductwork allowed venting to a working area.
8.	Milk Powder	The atomiser flying off and hitting the dryer wall caused a spark.	Unknown.
9.	Skim Milk Powder	Material deposited around the fines return pipe ignited.	Explosion in spray dryer; damage unknown.
10.	Milk Powder	The atomiser was given too much lubricating oil which soaked into powder deposited on the underside of the roof of the dryer. The oil soaled powder ignited spontaneously.	Fire, no explosion.
11.	Milk Powder (High fat content).	Build-up of powder at entry to fluidised beds leading to blockage. Self-ignition occured and when blockage broken up, hot pieces entered bed area causing ignition.	Extensive damage to fluidised beds and pipework. Vents on dryer allowed flames into building causing damage to walls, windows and ceilings.
12.	Coconut Oil Fat-Filled Milk.	An accumulation of dust in the lower third of the dryer. Source of ignition unknown but thought to be self-ignition.	Damage to the dryer, cyclone, and fluidised bed.
13.	Milk Powder	Thought to be the electrical drive motor for the atomiser disk, which was inside the dryer.	The access door in the roof area was blown off and the top of the roof of the dryer became detached and moved off centre. Fire caused extensive damage to production and storage facilities. Cost of the damage was estimated at around £1 million.

14. Milk Powder	Poor system of cleaning the spray dryer possibly leading to self-ignition of powder.	The inspection doors burst open and two of the seven cyclones and the first fluidised bed were badly damaged.
15. Milk Powder	Fine milk powder spilled through the ill-fitting base of the fluidised bed dryer. The incoming hot air caused the powder to ignite. This triggered a local explosion in the duct. This explosion lifted one sheet at the bottom of the fluidiser and set fire to the fluidised bed of powder. Burning particles were sucked in by the exhaust fan and blown into the spray dryer triggering a dust explosion within the tower.	The roof of the dryer was blown upwards into the weatherproof enclosure venting the explosion into the building.

APPENDIX II

DRYING IN AN INERT GAS ENVIRONMENT

Background

The application of inerting on large food industry spray dryers is rare. The technique is applied occasionally on ancillary equipment such as conveying systems, hoppers, filters, silos and mills.

Inerting involves the partial or complete substitution of the air with which the dust is mixed by an inert gas. Typically nitrogen, carbon dioxide or flue gases are used.

For a given dust and assuming ignition with an electric spark, carbon dioxide tends to be more effective than nitrogen due to its greater molar heat capacity. The oxygen level can therefore be maintained at a slightly higher level for carbon dioxide than nitrogen and still prevent ignition.

The design of the system requires data on the lower explosive limit of the product with the specified inert gas. Test methods are discussed in Field, P., Explosibility assessment of industrial powders and dusts **(30).**

As a general guide, the levels of oxygen required to prevent ignition and explosion of most dusts are in the range 8-15% with carbon dioxide and 6-13% with nitrogen.

The plants normally operate at positive pressure to avoid uncontrolled ingress of oxygen defeating the inerting system.

Design Considerations

Inert gas systems are sophisticated and specification and design is normally handled by specialists. The design would consider the following:-

(i) effective and efficient gas supply and control systems to produce and maintain the inert atmosphere;

(ii) oxygen monitoring at key points coupled to automatic shutdown and alarm systems;

(iii) the need to maintain minimum leakage to avoid oxygen entry, to avoid risk to operators from a build-up of the inerting gas in the operating area and to minimise operating costs;

(iv) detailed consideration should be given to start-up and shutdown sequences to ensure that the plant is protected through all phases of operation.

(v) operating at elevated temperatures above 100^0C requires careful interpretation and extrapolation of the test data from which target oxygen levels are established;

(vi) the need for back-up systems in the event of a failure of the inerting systems;

(vii) there must be stringent control over access by operatives when inert gas is used in the plant.

APPENDIX III

CHECKLIST

Daily inspections should be made of the following:-

(i) the inside surfaces of the dryer and associated plant, including the air dispenser, to ensure that there are no deposits of powder;

(ii) hammers, scrapers or other devices intended to prevent accumulation of powder, to ensure that they function correctly;

(iii) air filters, to ensure that they are clean and in good condition;

(iv) the atomiser, to ensure that it is in a good and clean condition and that the oil level is correct;

(v) the control system, with particular reference to operating devices for use in emergency;

(vi) general cleanliness of plant and building - remove accumulations of dust from floors, pipework etc.

Weekly checks should be made on:-

(i) all protection and alarm devices;

(ii) high temperature protection devices;

(iii) powder deposits on the inlet face of air heater batteries.

Monthly, the earth continuity of the chamber, powder ducts, cyclone and silos should be checked. Checking of inspection panels.

See also checks recommended in paragraph 5.5.

This checklist should be modified according to local needs.

APPENDIX IV

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