The company

1 General Foods Ltd is the British subsidiary of General Foods Corporation of America. In 1947 the company acquired the Birmingham factory of Alfred Bird and Sons which produced custard powder and other packaged dry foods. In 1965 this factory moved to new premises on a modern trading estate in Banbury.

2 Approximately 2000 people are employed in the production, packaging and sale of foods such as instant coffee, custard powder and other dessert products.

The site

3 The factory is on a 42 acre site surrounded by public roads on three sides, with other industrial developments nearby (see fold-out at back of book). Next to the southern perimeter of the site there are residential premises. All the factory buildings are enclosed within a landscaped area and none is directly adjacent to any public right of way.

4 Desserts processing is carried out in a two storey building of reinforced concrete frame construction with brick cavity wall and window in-filling. The explosion occurred in the south east corner of the first floor where the basic ingredient, corn starch, was conveyed to four custard powder manufacturing lines.

Corn starch

5 Corn starch (corn flour) in fine powder form, particle size approximately 15 microns (μ) is the basic ingredient for custard powder production. It is produced by a milling process from maize, the grains of which contain starch granules in the endosperm.

6 In common with other finely divided organic materials corn starch, when dispersed in air to form a dust cloud having a composition within the explodible range, can readily be ignited to burn with explosive violence. This hazard is well documented in relation to corn starch.

7 Flammable dust explosions typically occur in the following way:

(a) a primary explosion within process plant, or external to it following loss of contaminant, causing pressure waves to spread outwards;
(b) the resulting pressure waves dislodge accumulated material on plant and building ledges which in turn ignite to form a secondary explosion which usually has a more devastating and widespread effect than the primary explosion.

In this incident only a primary explosion occurred and this was outside the plant.

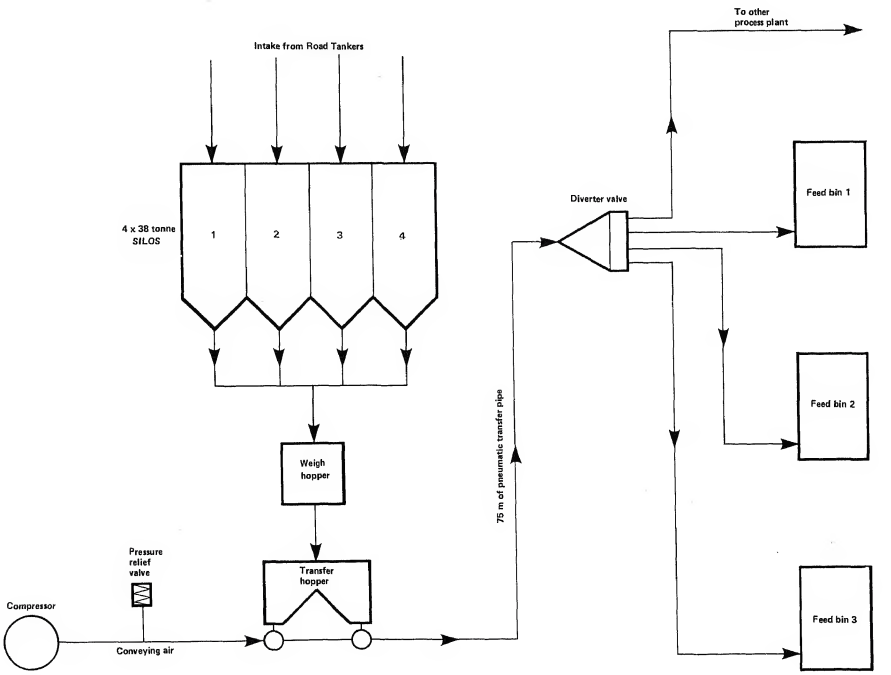


Fig 1 Process flow diagram

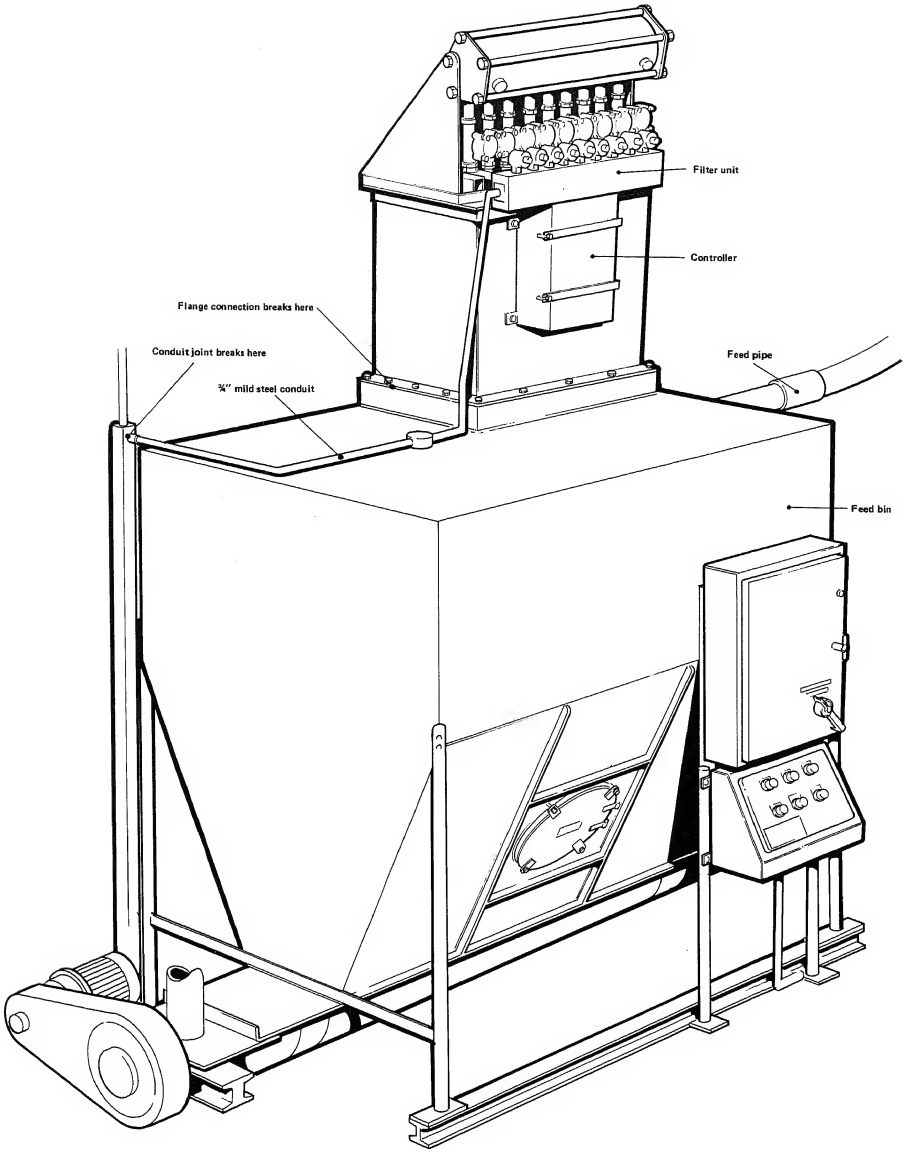


Fig 2 Feed bin and filter unit

The plant

8 Corn starch was delivered to the factory daily by road tankers. These were discharged pneumatically into bulk storage silos from which it was drawn off as required through a weigh hopper into a transfer hopper. The base of this hopper was in the form of two inverted cones fitted with rotary feeder valves. Corn starch was transferred from the hopper bottom through these valves and conveyed pneumatically by a system operating at 48–69 KN/m^2 (7–10 lbf/in^2) through a transfer pipe to the processing area. The transfer pipe ran some 75 m at high level through the factory. The conveying air was supplied by an air compressor. To prevent over-pressurisation of the compressor it was protected by a pressure relief valve (see Fig 1).

9 The transfer pipe entered the processing area at a point under the roof adjacent to the control room and terminated at an electrically controlled diverter valve which directed the flow to any one of four feed bins, three of these directly supplying custard powder manufacturing lines. The bins were of 3 t (tonnes) capacity and overall measured 2.3 m long by 1.36 m wide by 2.2 m high. There were no devices on the bins to prevent over-filling.

10 On top of each feed bin there was a filter unit which was connected to the bin by a rectangular bolted flange (see Fig 2). The purpose of the filter unit was to remove corn starch from the conveying air stream which was vented into the workroom through the filter discharge. The individual fabric filter socks in each unit were provided with automatic reverse air flow cleaning and for this there was a separate compressed air supply to each unit. Each filter sock in a unit was cleaned in sequence when the compressed air supply was operated by solenoid operated valves in the filter control unit. There was a 220V AC electrical supply to each unit which was routed via a vertical trunking at the side of each feed bin and then by conduit across the bin top.

11 The conveying system was controlled by an operator working in the control room. The diverter valve in the conveying system enabled the operator to deliver a known quantity of starch to any one of the three feed bins for the custard processing lines, as requested by a process operator on the process floor. The siting of the control room did not give the control room operator a clear view of the process floor.

Diverter valve and flow control system

12 The valve (see Fig 3) consisted of one inlet port and eight outlets. The starch flow entered the valve through the inlet port and of the eight outlets three were connected to the three custard powder manufacturing lines, four were blanked off and a further port was available to supply other plant. Material flow through the valve, from the inlet to a given outlet, was through an internal connecting pipe, one end of which was linked to the inlet and the other attached to a circular plate. This plate, and hence the connecting pipe, was rotated by a small electric motor. External to the inner valve chamber there was an electrical switch at each outlet port position. The operating stems of the switches were spring loaded and each switch was actuated by a connecting plunger which passed to the inner chamber of the valve. A cam on the rotating plate depressed the plungers, and hence the stems of the switches, and, depending on which outlet port had been selected, actuated an electromagnetic brake to stop the rotation of the plate so that the connecting pipe was in line with the selected port.

13 When the operator in the process area required more corn starch in a particular feed bin he pressed a demand button on the process line which illuminated a signal light for the appropriate feed bin on a display panel in the control room. The filling operation then involved two separate phases of the control system namely valve outlet port selection and material transfer.

14 Initially the control room operator turned a selector switch to the bin indicated and a light showing the bin selected would then be illuminated on the display panel. On selecting a change of valve position a control sequence released the brake and energised the motor to drive the plate of the valve and hence the connecting pipe to the selected port. As the plate rotated, the cam left the plunger depressing the switch of the port it was moving from and the switch spring returned the stem of that switch and the plunger to the non-operated state. On reaching the selected port the cam would depress the plunger at that port and hence operate the switch interrupting the supply to the motor and applying the brake to lock the plate and connecting pipe in line with that port.

15 The control room operator then initiated the transfer and filling operation which was automatic until complete when a 'bin full' light came on at the display panel.

16 Although each of the feed bins had a nominal storage capacity of 3 t they normally contained only 2 t. It took approximately 13 minutes to transfer a batch of 2 t of material in two consecutive 1 t loads from the weigh hopper to a feed bin. Once the transfer operation commenced it could be stopped by the control room operator in one of two ways:

(a) after the transfer of the first 1 t batch the second 1 t batch could be held in the weigh hopper; or
(b) at any time by pressing an emergency stop button which would stop the compressor and hence the conveying air supply.

17 The transfer process would normally cease on receipt of a signal that the second tonne of corn starch had passed through the transfer hopper and then through the system to a feed bin when a 'bin full' light would show on the display panel. This light did not, in fact, indicate a full bin, only the transfer of the 2 t of material.

Explosion

18 Some 20 men were working in the dessert processing area on Wednesday 18 November 1981. At about 21.15 the feed bin of No 1 line was empty and that of No 2 line nearly empty. The custard plant operator alerted the control room

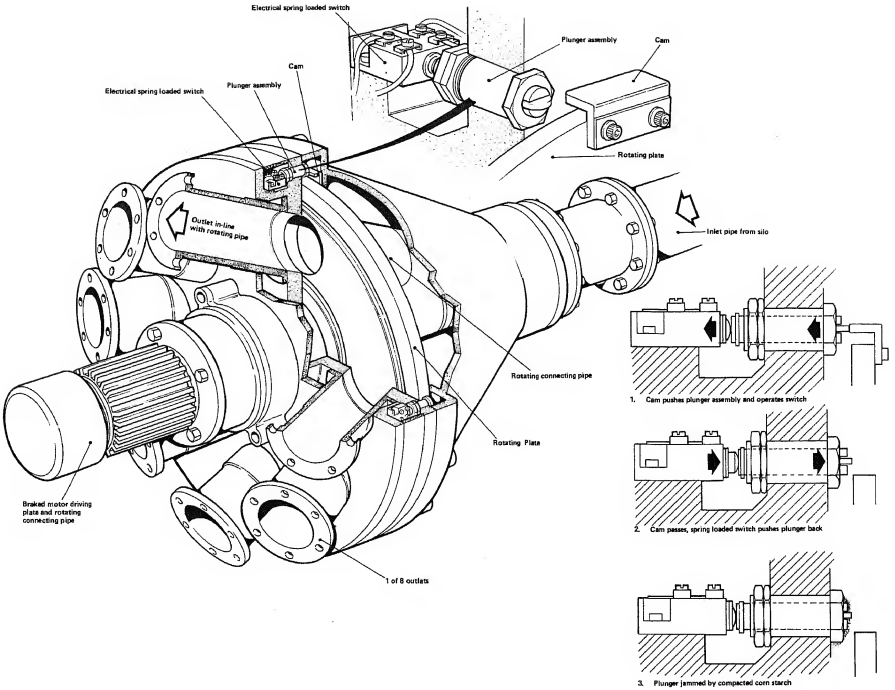


Fig 3 Diverter valve

operator that these two bins required filling. By 21.30 a 2 t batch had been conveyed to No 1 bin, the filling process stopped and the plant operator left the processing floor. About 21.45 the control room operator set the selector to No 2 bin and initiated the weighing and transfer operation to convey a 2 t batch to this bin. He then went into the rest room adjacent to the control room.

19 At about 21.50 the section manager and another man saw corn starch escaping out of No 1 bin as they walked across the processing floor and at about the same time the leakage was noticed by men in the rest room which prompted the control room operator to return to the control room. He and the section manager confirmed that the selector was set for filling No 2 bin. By this time large quantities of corn starch were escaping out of No 1 bin, apparently from the dust filter at the top and an inspection panel on the side, creating a dense fog of suspended powder in the vicinity. At this point several witnesses saw a flash near the top of the bin and a wall of flame spreading outwards and downwards from the bin top. Descriptions were of a gale force wind with a flame front behind, which flashed through the area including the control room and the rest room.

20 Nine men who were in these two rooms, or between them and No 1 feed bin suffered burn injuries. They managed to escape unaided from the area and were given emergency first aid treatment at the factory before transfer to the local hospital. Eight, with varying degrees of burns to hands and face, were subsequently transferred to the special burns unit at Stoke Mandeville Hospital.

Damage due to explosion

21 Damage to the fabric of the building was substantial, but fortunately due to its position and the time when the incident occurred, there were no people about outside and no injuries were caused from falling masonry, or flying debris (see Fig 4).

22 Windows and brickwork were blown out on all four sides of the building with the south side receiving the most damage. Here brick and glass from heights between 6 m and 12 m were projected for horizontal distances of up to 8 m and 14 m, respectively. Small fragments of glass were thrown 20 to 30 m near the east end corridor.

23 On the west side of the building brick and glass were projected up to 10 m and 14 m respectively. Pieces of glass were buried 25 to 100 mm deep in a soft grass bank. Material from the north wall had fallen out, and on the east side glass from the windows of the control and rest rooms had

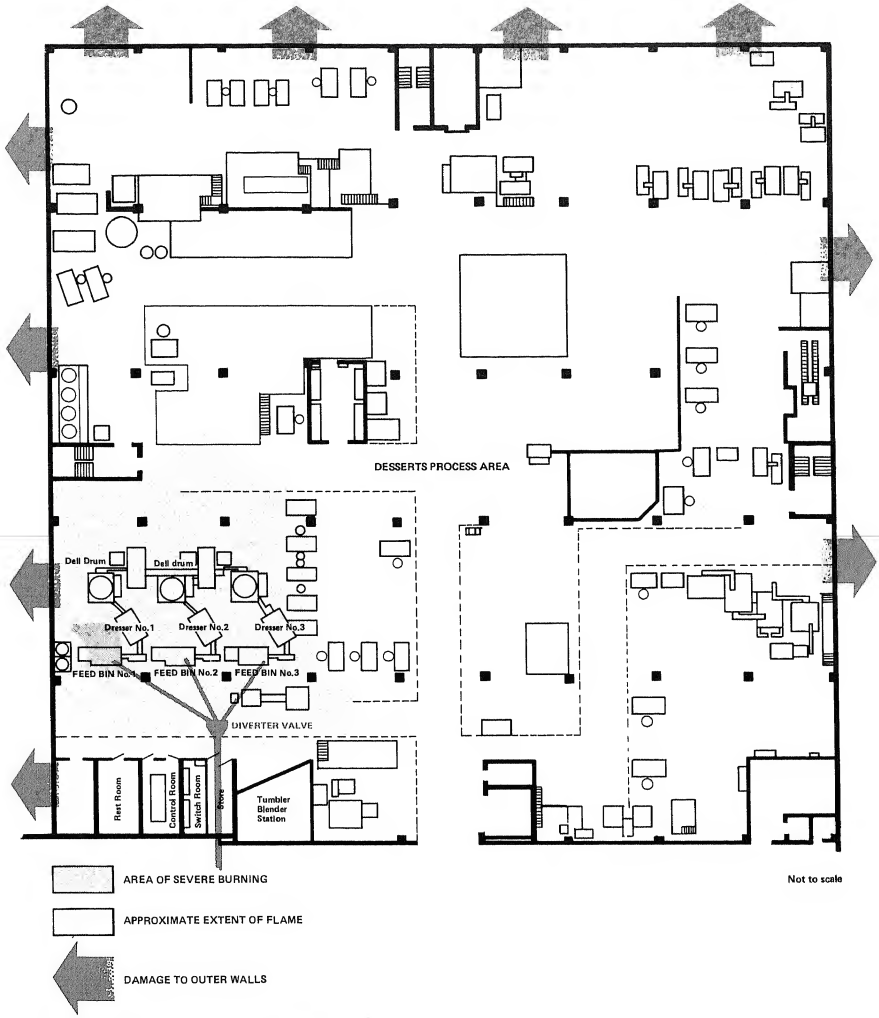


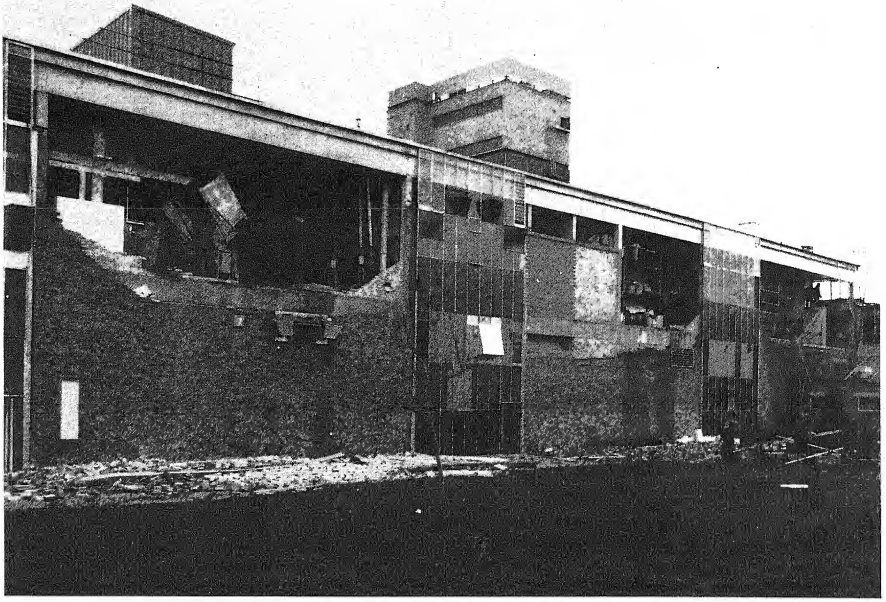
Fig 4 Plan showing damage to desserts processing area

been thrown some 9 to 12 m across the roof of the east end corridor.

24 There was very little pressure damage inside the building. The area most affected was around the control room and rest room doors and a nearby office. The wired glass of the control room doors had been shattered and the chipboard wall, above the rest room door, had been displaced. There were other pockets of minor structural damage in rooms outside the production area where pressure waves had passed through openings linking with the area. It was estimated that a pressure rise in the building within the range of 7–16 KN/m^2 (1–2.3 lbf/in^2) would account for the observed effects.

25 On the process floor there was flame damage over an approximate area of 34 m by 22 m corresponding to about one fifth of the total floor area (see Fig 4). The limit of propagation was clearly indicated by scorched paper, plastic and wood. Further serious fire damage had been prevented by the operation of the automatic sprinkler system. The most severe burning occurred at high level (over 3 m) centred on No 1 feed bin.

26 There was additional evidence of local fires occurring with extensive damage at a time clocking point, close to the control room door, where the sprinkler system had not operated.



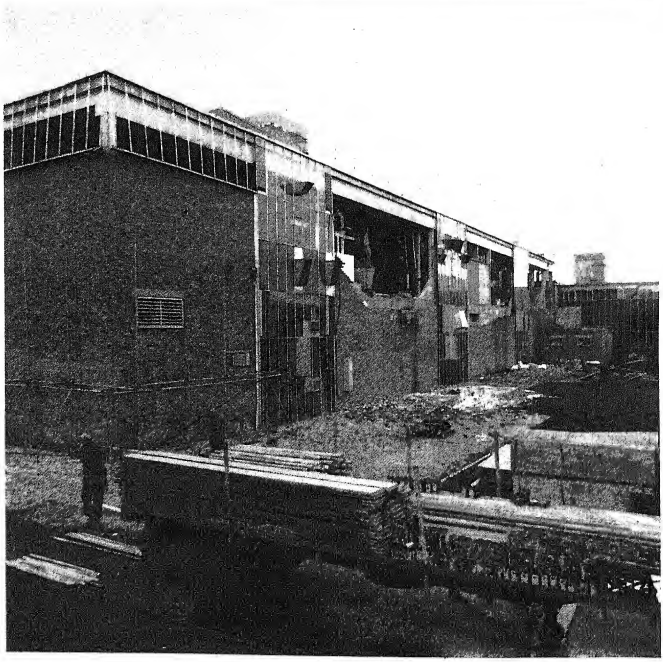


Fig 5 General views of damage to building

27 Although damage to the plant initially appeared substantial, closer examination showed it was mainly superficial and was largely the effect of fire and the water from the sprinkler system. The most significant damage to plant was that caused by the over-pressurisation and consequent bursting of the plant rather than the explosion.

Investigation

28 Immediate investigation of the incident was made by the Principal Inspector of Factories who was on the scene within two hours following notification from the company via the police. He was able to identify, from information given to him by fire brigade officers, that the explosion was due to ignition of process material and not an explosive device. Investigation continued for several days with the assistance of company personnel, electrical and chemical inspectors of factories and scientific staff from the Health and Safety Executive's Research and Laboratory Services Division.

29 An assessment of building and plant damage indicated that the cause of the explosion and subsequent fire was related to the feed system of No 1 line.

30 The investigation revealed the following significant points:

(a) the sides and top of No 1 feed bin were bowed outwards by internal over-pressure;
(b) the top filter unit had been torn off its mounting and was lying on the floor by the bin;
(c) the filter unit retaining bolts were either stripped, or snapped and the connecting flange was distorted;
(d) both the hopper and the filter unit were completely full of corn starch;
(e) there was no corn starch in the conveying system. It had all been delivered to the bin;
(f) the compressed air supply to the filter unit was ruptured;
(g) the electrical supply to the filter unit was severed. The steel conduit and wiring to the filter unit control were broken away from the supply trunking and lying on the floor under the unit. The two conductors inside were still connected to the filter control unit but had ruptured where the conduit had broken away from the metal supply trunking. The condition of the broken ends of the wire conductors, remaining both in the conduit and the supply trunking, indicated that electrical arcing had taken place;
(h) the controls on the control console in the control room indicated that flow was to No 2 bin and that batch transfer was complete;
(k) on opening the diverter valve the connecting pipe was found to be in line with No 1 port;
(l) at No 2 port the switch was in the depressed position being held by the operating plunger. This plunger was found to be permanently held in the depressed position due to an accumulation of compacted corn starch inside the valve;
(m) when removed from the valve No 2 switch stem operated freely under the action of the switch spring;
(n) the compressed air conveying system was not fitted with any form of pressure relief device designed to protect it; the only pressure relief valve fitted was that to protect the air compressor. This valve was nominally set to open at 179 KN/m^2 (26 lbf/in^2). When removed and tested it actually opened at 269 KN/m^2 (39 lbf/in^2).

31 The company safety policy referred to the danger of explosion from sugar and starch dust. This policy was supplemented by specified safe working procedures for operations on plant handling these materials and an operator instruction programme which included demonstrations of dust explosions.

Conclusions

32 A clear sequence of events leading to the explosion was established.

33 Number 1 feed bin was charged normally but when the control operator selected No 2 the internal connecting pipe in the diverter valve did not move and flow continued to be directed into No 1. This bin filled until the corn starch clogged the outlet filter preventing the escape of the conveying air. Corn starch began to escape from parts of the plant creating a dust cloud. Pressure caused the sides of the bin to bulge outwards and continued to build up until the bolts securing the filter unit to the bin progressively failed and the unit was displaced. Increased ejection of material produced a substantial dust cloud which was possibly further dispersed when the compressed air supply to the filter unit was broken away. The dust cloud was ignited by electrical arcing of the supply conductor to the unit which had been ruptured when the unit was displaced.

34 The conclusion is, therefore, that the events took place due to the inability of the control system to recognise that the connecting pipe in the diverter valve had not been moved from No 1 to No 2 outlet port.

35 When the control room operator changed the selector from No 1 to No 2 the connecting pipe in the diverter valve did not move as the control system was already cancelled by No 2 actuating switch already being held in the depressed position by the accumulation of corn starch on its operating plunger. The electrical supply to the drive motor and brake release was already disconnected by No 2 switch and the connecting pipe stayed at No 1 port.

36 Although the diverter valve was a vital part of the system, there was no direct indication of the position of the internal connecting pipe and the display panel indicator was actuated by the position of the selector switch only. There was no effective interlocking with the supply system to ensure that the valve was in the position selected before conveying of corn starch could commence.

37 As the valve was at high level adjacent to the ceiling, access for maintenance purposes was difficult. There was evidence that the valve required frequent attention and that corn starch leakage tended to accumulate in the valve chamber. Significantly, No 2 position was at the bottom of the valve and could therefore be expected to be more prone to contamination with corn starch.

38 There was no indication of corn starch levels in the hoppers. 'Bin full' lights on the display panel merely showed

the completion of a transfer process. There were no control devices to indicate, or ensure, that a bin selected to receive a batch had sufficient space to accept it.

39 The control arrangements of this plant were such that there was always possibility of overfilling a feed bin. It could happen, as in this case, because of plant failure, but could also happen due to human error.

40 The feed bins and conveying system were not designed to withstand any substantial pressure, nor were they provided with any form of pressure relief other than the relief valve fitted to protect the compressor.

41 Failure occurred at the rectangular flange connection between the filter unit and the hopper top. There was clear evidence of a variety of damage to the retaining bolts.

42 Once the dust cloud was produced there were three possible sources of ignition:

(a) frictional spark produced by the displacement of the filter unit;
(b) incendive spark arcing from the electrostatic charge generated by the flow of material through the system;
(c) incendive spark from arcing due to rupture of the electrical supply to the unit.

Detailed scientific analysis, plus a consensus of observations of eye witnesses, indicate beyond reasonable doubt that the source of ignition was electrical arcing caused when the conduit for the electrical supply to the filter unit broke away from the supply trunking, causing rupture of the electrical conductors.

43 The evidence indicated that approximately 1 t of corn starch was emitted, most of this being deposited on the floor around No 1 feed bin. It is not possible to estimate how much was involved in the explosion but from a knowledge of the minimum explodible concentration for this material (about 0.04 kg/m^3 (0.0025 lbs/ft^3)) it is estimated that a dust cloud containing as little as 30 kg of corn starch could have been sufficient to account for all the observed effects. It is fortunate that the dust cloud occupied only a small part of the total volume of the first floor. This aided dissipation of the pressure generated by the explosion, otherwise the consequences could have been much more severe.

44 The company was well aware of the risk of dust explosion and the need for precautions both against primary explosion within process plant and secondary explosion in working areas. Throughout the factory there were arrangements to deal with the primary risk and an instruction programme to all operatives highlighted the need for general cleanliness to reduce the secondary risk. There was, however, a lack of appreciation throughout the organisation of the hazards which could arise from an uncontrolled dust cloud emission arising from the plant.

45 This incident highlights the fact that safety of plant handling potentially dangerous material depends on a combination of good engineering design and installation, effective care and maintenance, operator training, awareness and understanding of the hazards involved and good managerial control.

46 Furthermore, it underlines the need for analysis of potential problems in process systems. Such analysis would, in this case, have determined the deficiencies of the electrical control system and plant design which could then have been remedied.

Legal considerations

47 The premises are a factory subject to the Factories Act 1961, the Health and Safety at Work etc Act 1974 and subordinate legislation under these Acts.

48 The injuries to employees and the explosion were reportable and were reported as accidents and a dangerous occurrence under the Notification of Accidents and Dangerous Occurrences Regulations 1980.*

49 Section 2(1) of the Health and Safety at Work etc Act 1974 requires every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees. The duty extends to the provision and maintenance of plant and systems of work that are, so far as is reasonably practicable, safe and without risks to health [Section 2(2) (a)] and the provision of such information, instruction, training and supervision as is necessary to ensure, so far as is reasonably practicable, the health and safety at work of employees [Section 2(2) (c)]. Action in respect of these general obligations is referred to in paras 52 to 58.

50 Section 31 of the Factories Act 1961 deals with precautions with respect to explosive or inflammable dust, gas, vapour or substance. Briefly, there are requirements to enclose all plant and remove or prevent accumulations of dust that may escape, and to exclude possible sources of ignition. In addition, unless a plant is constructed to withstand pressure likely to be produced by an internal explosion all practicable steps shall be taken to restrict the spread and effects of such an explosion by the provision of chokes, baffles and vents, or other equally affective appliances. In this case, the plant was totally enclosed and the explosion did not occur within the plant itself; it is doubtful if there was a contravention of this Section.

51 The electrical installation was subject to the Electricity (Factories Act) Special Regulations 1908 and 1944. Although the source of ignition was electric arcing these regulations were not directly relevant as the arcing was caused by severe mechanical damage to a particular part of the electrical system which was otherwise adequately installed.

Action taken by company after incident

52 In consultation with the Factory Inspectorate, the company carried out a full review of its operations involving the handling of flammable dust and, in particular, the custard plant supply system was redesigned.

53 The more important elements are as follows:

(a) a new control system has been installed which includes

*SI 1980/804

interlocking arrangements to prevent a repetition of the plant failure which led to this explosion. The new system is based on programmable electronic controllers, the integrity of which has been systematically assessed;

(b) high and low level detectors have been installed in the feed bins with a sequence control system to prevent overfilling;

(c) the feed bins have been enlarged and strengthened to withstand the maximum pressure which can be developed in the conveying system. They have been fitted with over-pressure relief valves vented to discharge safely outside the building;

(d) the feed bins have also been fitted with explosion relief panels, again venting safely outside the building;

(e) improved dust filter units, incorporating explosion relief panels, have been fitted to the feed bins;

(f) the multi-port diverter valve has been replaced by a series of two-way valves. The setting of these is displayed on the control room panel: in addition the control room operator can visually check by direct observation;

(g) there is a new control room sited where the operator can see the process plant;

(h) a number of emergency stop buttons have been installed at appropriate points around the plant which when operated will stop the air compressor;

54 The company safety policy has been reviewed and new instruction and operating procedures instituted. All appropriate personnel have been retrained on the dangers from corn starch dust and this has been extended to include the precautions necessary to prevent an explosion external to plant.

55 Maintenance procedures have been improved and their priority emphasised. Arrangements to implement a new planned maintenance scheme have been expedited.

56 The company is incorporating explosion relief during the reconstruction and repair of the building walls.

Recommendations

57 The purpose of this report is to bring to the notice of those concerned with the design, construction, installation and use of plant in which flammable materials are processed or handled the need to take all practicable steps to prevent and to mitigate the effects of explosions.

58 The incident graphically illustrates the need for:

(a) those who design such plants or use existing plants to carry out analysis to identify possible modes of failure and to ensure that the necessary precautions to reduce the risk of failures and mitigate their effects form an integral part of the plant;

(b) users to have an adequate safety policy with effective organisation and arrangements to carry it out to ensure that the dangers are fully appreciated and that safe systems of work are established and implemented;

(c) staff employed to be properly informed of the process hazards and adequately trained to ensure safe operation of the plant and properly instructed as to the action to be taken in the event of plant failure developing;

(d) proper arrangements to be made for plant maintenance to ensure that plant failure cannot initiate conditions in which an explosion might occur; and

(e) the provision of suitable buildings with adequate explosion relief to house plant of this type in the event of it not being practicable to install the plant external to buildings.

Action taken by the Health and Safety Executive

59 The Health and Safety Executive is in the course of:

(a) drawing to the attention of trade associations, representing manufacturers of flammable dust handling plant, the need to carry out assessments of possible failure modes so as to enable precautions to be built in to the plant at the design stage;

(b) seeking the cooperation of the Royal Institute of British Architects in drawing to the attention of their members the particular considerations to be taken into account when designing buildings to house plant of this type; and

(c) reviewing its own published guidance, and that of others, on flammable dusts to ensure that comprehensive information is available.

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