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Dust Explosion Investigation in Turkey

Mercan Z. Burcu

TR MOLSS Labour Inspection Board Adana Group Directorate
Huzurevleri Mah. Turgut Ozal Bulvari Yukseller Plaza No: 214 K:1 01360 Cukurova Adana / Turkey
zburcumercan@gmail.com

CSB (US Chemical Safety Board) identified 281 combustible dust incidents between 1980 and 2005 that killed 119 workers, injured 718 others and damaged several industrial facilities. These incidents occurred in 44 states, many different industries and involved a variety of different materials. Seven of the incidents, which have occurred in the past decade, had catastrophic results with multiple fatalities and significant community economic impact.
Like all fires, a dust fire occurs when fuel is exposed to heat in the presence of oxygen. Removing any one of these elements of the classic fire triangle eliminates the potential for a fire. In addition to the familiar fire triangle of oxygen, heat and fuel, dispersion of dust particles in sufficient quantity and concentration can cause rapid combustion known as a deflagration. If the event is confined by an enclosure such as a building, room, vessel, or process equipment; the resulting rise in pressure may lead to an explosion. These five factors (oxygen, heat, fuel, dispersion, and confinement) are collectively known as the dust explosion pentagon.
Suspended dust burns more rapidly and confinement allows for pressure buildup. Removal of either the suspension or the confinement elements prevents an explosion, although a fire may still occur. Furthermore, the concentration of suspended dust must be within an explosible range for an explosion to occur. This is analogous to the flammability range commonly used for vapors; such as natural gas and propane. Dust explosions can be very energetic creating powerful waves of pressure that can destroy buildings and hurl people across a room. People caught in dust explosions are often either burned by the intense heat within the burning dust cloud, injured by flying objects or falling structures.
On January 29, 2003, a massive dust explosion in Mersin, Turkey resulted in the deaths of two workers, serious injuries of two more and destruction of the facility. The casualty count would have been higher; had the time of the explosion been on a crowded workshift.
The explosion occurred in a building which had nine huge semolina silos inside. The day of the accident there was planned work that included some welding atop of the silos. Also, there was organizational fault when they failed to check about the methane gases which escape from the semolina spoilage. All of the fire triangle were present. The ambient air for oxygen, welding work for heat and methane for fuel. After the primary small explosion and fire started, the dust which accumulated on the equipments dispersed in the ambient air above the silos in the building. At that time, all the conditions for dust explosion were present; with the addition of dispersion and confinement.
The investigation of the accident, accomplished by the Turkish Labour Inspection Board, will be evaluated with conditions that formed the dust explosion, findings about the accident, precautions for prevention and control of the accident.

1. Introduction

Combustible dusts are fine particles that present an explosion hazard when suspended in air under certain conditions. A dust explosion can cause catastrophic loss of life, injuries, and destruction of buildings. The dusts of most solid combustible materials, when dispersed in air and ignited, can burn rapidly, introducing the potential for a dust explosion. Wood, aluminium, coal, flour, milk powder, dyes and pharmaceuticals are examples of materials that have caused explosions. Many chemicals used and produced by the chemical industry are in dust form. The explosive behaviour of these materials should be adequately characterized prior to processing, handling, shipping and use (Crowl, 2003). Also most solid organic materials, as well as many

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metals and some non-metallic inorganic materials, will burn or explode if finely divided and dispersed in sufficient concentrations (Eckhoff, 2003).

Dusts can present both fire and explosion hazards. First, dust layers, which collect on hot equipment surfaces may heat, smoulder and catch on fire. The dust layer provides thermal insulation to the equipment resulting in higher surface temperatures and increased likelihood for ignition. Second, dust particles may entrain with air forming a combustible dust cloud (Crowl, 2003).

Like all fires, a dust fire occurs when fuel (the combustible dust) is exposed to heat (an ignition source) in the presence of oxygen (air). Removing any one of these elements of the classic fire triangle eliminates the possibility of a fire. A dust explosion requires the simultaneous presence of two additional elements—dust suspension and confinement. Suspended dust burns more rapidly, and confinement allows for pressure buildup. Removal of either the suspension or the confinement elements prevents an explosion, although a fire may still occur (Amyotte et al., 2003).

Five elements are necessary to initiate a dust explosion, often referred to as the “Dust Explosion Pentagon”. The first three elements are those needed for a fire, i.e., the familiar “fire triangle”: Combustible dust (fuel), ignition source (heat) and oxygen in air (oxidizer). An additional two elements must be present for a combustible dust explosion: dispersion of dust particles in sufficient quantity and concentration, confinement of the dust cloud. If one of the above five elements is missing, an explosion cannot occur (OSHA, 2009).

An initial (primary) dust explosion in processing equipment may shake loose accumulated dust, or damage a containment system (such as a duct, vessel, or collector). This causes the dust to become airborne and this additional airborne dust, if ignited, may cause one or more secondary explosions. These can be more destructive than a primary explosion due to the increased quantity and concentration of dispersed combustible dust and the larger ignition source (Mannan, 2005)

Dust explosions can cause large-scale loss of life and catastrophic damage to facilities.

1.1 Major dust explosions and statistics

Between 1995 and 2003 several significant dust explosions caused fatalities and/or injuries, destroyed facilities and community economic impact like the explosion in Turkey.

On December 11, 1995, an explosion and fire virtually destroyed the Malden Mills Polartec fleece fabrics facility in Methuen, Massachusetts, injuring 37. According to reports by OSHA, the U.S. Fire Administration (USFA), and the Massachusetts State Fire Marshal’s Office, the originating event was likely a dust explosion involving nylon flock fibres (U.S. Chemical Safety and Hazard Investigation Board, 1996).

One of the seven boilers that supplied power to the Ford Motor Company’s River Rouge manufacturing plant (near Dearborn, Michigan) exploded on February 1, 1999, killing six workers and injuring 36. Although the initial event was a natural gas explosion, witness accounts of dust accumulations before the explosion provided strong evidence of a secondary coal dust explosion. Coal dust accumulated on horizontal surfaces in the powerhouse was lofted and ignited by the initial explosion (U.S. Chemical Safety and Hazard Investigation Board, 1996).

On January 29, 2003, a massive dust explosion at the West Pharmaceutical Services facility in Kinston, North Carolina, killed six workers and destroyed the facility. The explosion involved a part of the building used to compound rubber (U.S. Chemical Safety and Hazard Investigation Board, 2004)

On February 20, 2003, a series of dust explosions at the CTA Acoustics (CTA) facility in Corbin, Kentucky, claimed the lives of seven workers, injured 37, and destroyed the acoustic insolation for automation manufacturing facility. On the day of the explosion, a curing oven that had been left open because of a temperature control problem likely ignited the combustible resin dust stirred up by workers cleaning the area near the oven (U.S. Chemical Safety and Hazard Investigation Board, 1996).

The CSB found that combustible dust explosions are a significant industrial safety problem. From 1980 to 2005, identified 281 combustible dust incidents that killed 119 and injured 718 workers, and caused significant material damage (U.S. Chemical Safety and Hazard Investigation Board, 1996).

Combustible dust explosions can occur in any industry handling combustible dusts, including metal fabrication, plastics, furniture and wood products, and chemical manufacturing however, four industry sectors (food products, lumber and wood products, chemicals, and primary metals) account for over half (U.S. Chemical Safety and Hazard Investigation Board, 1996).

A wide range of materials cause combustible dust incidents. Wood, food-related products, and metals each account for over 20 percent of explosions, and plastics for 14 percent (U.S. Chemical Safety and Hazard Investigation Board, 1996).

2. Investigation

The initiating event for a secondary dust explosion is not be a dust explosion at all. It’s methane explosion because of semolina spoilage. A secondary explosion occurs when dust accumulated on floors or other surfaces is lofted and ignited by a primary explosion. The blast wave from the secondary explosion can cause accumulated dust in other areas to become suspended in air, which may generate additional dust explosions. Depending on the extent of the dust deposits, a weak primary explosion may cause very powerful secondary dust explosions.

2.1 The company and facility

The pasta producing company was incorporated in 2007 in Mersin, at south of Turkey. The annually production is 160.000 ton pasta and 180.000 semolina which export and import. It has 83 workers at the time of the incident occurred.

Pasta producing consist six stages: mixing and kneading, rolling, pasteurization, cutting, drying, packaging. The semolina is stored in huge silos. Pipes move the flour and water to a mixing machine equipped with rotating blades. The mixture is kneaded to a lumpy consistency. Than the mixture moves to a laminator where it is pressed into sheets by large cylinders. A vacuum mixer machine further flattens the dough while pressing air bubbles and excess water. For pasteurization, the roll of dough moves through a steamer for killing any existing bacteria. Depending on the type of noodle to be produced, the dough is either cut or pushed through dies. Than for drying the pasta is placed in a drying tank in which heat, moisture, and drying time are strictly regulated. At last stage, fresh pasta is folded in premeasured amounts into clear plastic containers. While the container is sealed with a hot press, a small tube sucks the air of the container and replaced it with a mixture of carbon dioxide and nitrogen to prolong the product's shelf life (U.S. EPA, 1995).

The facility where incident occurred is before mixing and kneading part of the pasta production which is for feeding the semolina to process. It's four floor building which has nine semolina storage silos which are ten meter height, three meter diameter cylindrical shaped with walls are epoxy coated. At the top of the silos there are concrete covers which are thirty centimeter thinness, 7 ton weight. Also each silos has a venting gap with metal cover which is thirty centimeter square shaped. More than these nine silos, three more smaller semolina storage silos, transportation tubes, stairs and elevators are in same floor of the building too (Figure 1).

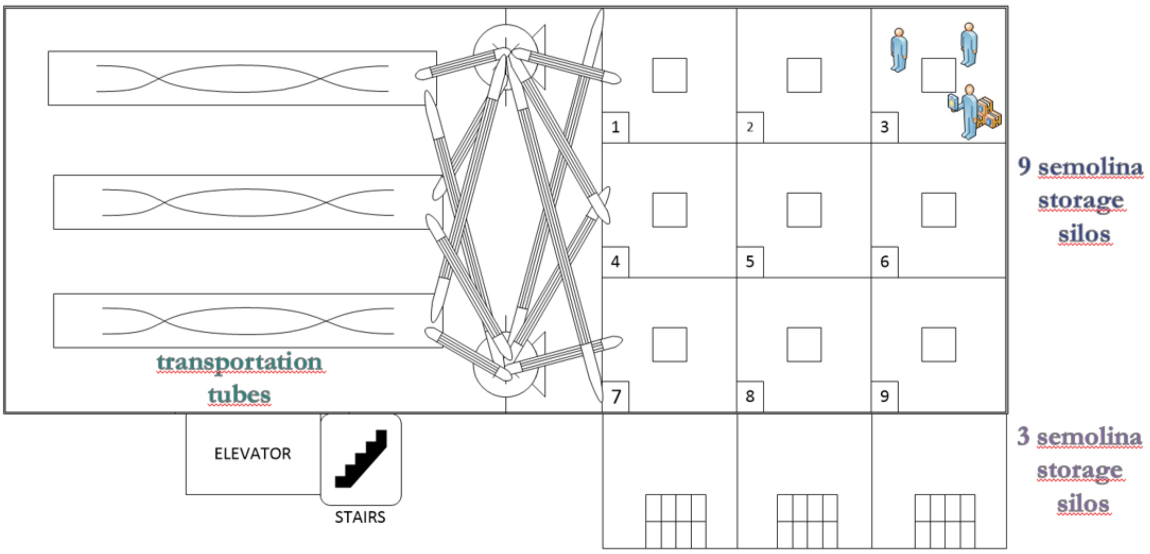

Figure 1: Sketch of the floor which incident occurred.

Semolina dust which is knows as combustible. For semolina dust, at explosion severity test dust deflagration index is 79 bar meters per seconds which gives clue of the speed of the pressure rise. Also maximum pressure of the dust cloud explosion is 7,6 bar gram.

2.2 The incident

At about 02:00 pm on January 1, 2010, small methane explosion occurred atop of the semolina silos at pasta producing company in Mersin, Turkey. It was occurred while a planned work that included welding. For this work there workers was at fourth floor of the building with the equipment which is needed for welding work. But also there was an organizational fault that they did not check about the methane gase which escape from the semolina decomposing inside the silo. When methane (as fuel), air (as oxygen) and welding work (as heat) was combined the explosion occured.

After the primary explosion, fire started and the dust which accumulated on the equipments dispersed in the ambient air above the silos in the building. At that time, all the conditions for dust explosion were present with the addition of dispersion and confinement. And rest of dust explosion occured respectively. Seconds later, massive dust explosions propagated throughout the entire building which has mixing facility. Thirty centimeter thick, seven ton weight concrete covers heaved and buckled from the explosive force of the dust explosion. The plank walls of the mixing facility was shattered and blown into the raw material area.
When local fire department personnel arrived they were confronted with dense smoke, intense heat, ruptured fire water mains, and large amounts of debris strewn around the fully involved burning buildings. Workers at the facility had already started search and rescue efforts and injured workers were being triaged at the main gate.
Two workers died at the scene, including one who were drowned with the semolina inside the silos. Five workers were treated for serious burns and injuries. After a few months, one more died and other four has permanent disability with life altering conditions.

3. Results and Discussion

The investigation of the accident, accomplished by the Turkish Labour Inspection Board, it is evaluated with conditions that formed the dust explosion, recommendations for prevention and control of the accident by standards given.

3.1 Recommendations

In many of these incidents, workers and managers were unaware of the potential for dust explosions, or failed to recognize the serious nature of dust explosion hazards. The CSB reviewed Material Safety Data Sheets (MSDS) of 140 known substances that produce combustible dusts and found poor or inadequate transmittal of information regarding potential dust hazards; 41% of the MSDSs reviewed by the CSB did not warn users about potential explosion hazards. Of the remaining 59% of MSDSs sampled, most of the information was either not stated in a place or manner clearly recognized by workers, or was not specific to hazards related to combustible dusts (U.S. Chemical Safety and Hazard Investigation Board, 1996).
Factors in the incidents about the dust explosion:
• Workers and managers were unaware of dust explosion hazards, or failed to recognize the serious nature of dust explosion hazards.
• Facility management failed to conform to standards that would have prevented or reduced the effects of the explosions.
• The facilities contained unsafe accumulations of combustible dust and housekeeping was inadequate.
• Procedures and training to eliminate or control combustible dust hazards were inadequate.
• Government enforcement officials, insurance underwriters, and health and safety professionals inspecting the facilities failed to identify dust explosion hazards.
An uncontrolled dust explosion in a warehouse, storage bin, or processing unit can eject high-velocity structural debris over a considerable area, propagating the accident and resulting in increased injuries. Deflagration venting reduces the impact of dust and vapour cloud explosions by controlling the release of the explosion energy. The energy of the explosion is directed away from plant personnel and equipment. Deflagration venting in buildings and process vessels is usually achieved by using blowout panels. The blowout panel is designed to have less strength than the walls of the structure. Thus, during an explosion, the blowout panels are preferentially detached and the explosive energy is vented. Damage to the remaining structure and equipment is minimized (Crowl and Louvar, 2002).
Clearly, good housekeeping in processing areas is important to prevent and mitigate dust explosions. Special procedures and equipment are required to transfer combustible dusts into and out of processing equipment and to process these materials safely (Mody, 1988).
The best way to prevent secondary dust explosions is to minimize dust accumulations. Ensuring good housekeeping, designing and maintaining equipment to prevent dust leaks, using dust collectors, eliminating flat surfaces and other areas where dust can accumulate, and sealing hard-to-clean areas (such as the area above a suspended ceiling) can effectively prevent secondary dust explosions (Eckhoff, 2003)
However, proper equipment and techniques to clean combustible dust accumulations must be used. Care must be taken to minimize dust clouds, and only vacuum cleaners approved for combustible dust locations used (Mody 1988)

3.2 Standards

A list of international standards that would have prevented or reduced the effects of the dust explosions is given at Table 1.

Table 1: List of standards about dust explosion

Standard number	Standard description
EN 1127-1:2007	Explosive atmospheres, basic concepts and methodology specifies methods for the identification and assessment of hazardous situations leading to explosion and the design and construction measures appropriate for the required safety
EN 13237-1:2003	Potentially explosive atmospheres – Terms and definitions for equipment and protectve systems
EN 13821:2002	Potentially explosive atmospheres – Explosion prevention and protection – Determination of minımum ignition energy of dust/air mixtures
EN 14034-4:2004	Determination of explosion characteristics of dust clouds
EN 14373:2005	Explosion suppression systems
EN 14491:2006	Dust explosion venting protective systems
EN 14797:2006	Explosion venting devices
EN 15089:2009	Explosion isolation systems
EN 60079	Explosive atmospheres
EN 61241:2005	Electrical apparatus for use in the presence of combustible dust
NFPA 654	Standard for the prevention of fire and dust explosions from the manufacturing, processing and handling of combustible particulate solids
NFPA 33	Standard for spray application using flammable or combustible materials
NFPA 61	Standard for the prevention of fires and dust explosions in agricultural and food processing facilities
NFPA 68	Standard on explosion protection by deflagration venting
NFPA 69	Standard on explosion prevention systems
NFPA 70	The national electric code
NFPA 91	Standard for exhaust systems for air conveying of vapours, gases, mists and noncombustible particulate solids
NFPA 484	Standard for combustible metals
NFPA 499	Recommended practice for the classification of combustible dusts and hazardous (classified) locations for electrical installation in chemical process areas
NFPA 655	Standard for prevention of sulphur fires and explosions
NFPA 664	Standard for the prevention of fires and explosions in wood processing and woodworking facilities
NFPA 850	Performance based standard for fire protection for light water reactor electric generating plants

4. Conclusions

Common factors to most of the incidents are:

- Facility management failed to conform to NFPA standards that would have prevented or reduced the effects of the explosions.
- Company personnel, government enforcement officials, insurance underwriters, and health and safety professionals inspecting the facilities failed to identify dust explosion hazards or recommend protective measures.
- The facilities contained unsafe accumulations of combustible dust and housekeeping was inadequate.
- Workers and managers were often unaware of dust explosion hazards.
- Procedures and training to eliminate or control combustible dust hazards were inadequate.
- Previous fires and other warning events were accepted as normal, and their causes were not identified and resolved.
- Dust collectors were inadequately designed or maintained to minimize explosions.
- Process changes were made without adequately reviewing them for potential hazards.

Dust control recommendations are:

- Implement a hazardous dust inspection
- Testing, housekeeping and control program
- Use proper dust collection systems and filter
- Minimize the escape of dust from process equipment or ventilation systems
- Use surfaces that minimize dust accumulation and facilitate cleaning
- Provide access to all hidden areas to permit inspection

- Inspection for dust residues in open and hidden areas at regular intervals
- Use cleaning methods that do not generate dust clouds if ignition sources are present
- Use only vacuum cleaners approved for dust collection
- Locate relief valves away from dust deposits.

For protection of dust explosion, ignition controls should be:

- Use appropriate electrical equipment and wiring methods
- •Control static electricity, including bonding of equipment to ground, controling smoking, open flames, and sparks
- Control mechanical sparks and friction
- Use separator devices to remove foreign materials capable of igniting combustibles from process materials
- Separate heated surfaces from dusts
- Separate heating systems from dusts
- Select and use industrial trucks properly
- Use cartridge activated tools properly
- Use an equipment preventive maintenance programs.

Injury and damage control methods:

- Separation of the hazard (isolate with distance)
- Segregation of the hazard (isolate with a barrier)
- Deflagration isolation and venting
- Pressure relief venting for equipment
- Direct vents away from work areas
- Specialized fire suppression systems
- Explosion protection systems
- Spark/ember detection for suppression activation
- Develop an emergency action plan
- Maintain emergency exit routes.

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