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Analysis of the Common Ignition Sources in the Milling Industry

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In the summer of 2007, in Fossano, Italy, one of the most catastrophic and famous dust explosions in Italy, caused by flour dust, occurred in Molino Cordero, a historic cereal milling and flour storage plant. The explosion happened during the pneumatic unloading operation of a tank truck, previously accidentally overfilled. Five people lost their lives, and the building was partially destroyed by the powerful explosion. The forensic reconstruction and investigation of this accident were carried out years after the explosion. This paper has presented an assessment of the main potential ignition sources that can be expected in a flour mill, taking into account the typical equipment that is normally installed in this process. The target is to provide the employer and the users of flour mill plants with basic information that can be helpful in carrying out the specific explosion risk assessment, necessary for every single process. Possible improvements, which could be implemented to reduce the risk of explosion to a tolerable level, will be highlighted.

1. Introduction

Dust explosions pose a significant threat to various industries, and among them, the grain and flour processing sectors have been particularly susceptible to catastrophic incidents; according to Combustible Dust Incident Reports (Cloney, 2021), food and wood products accounted for almost 75% of recorded fires and explosions. Historical data reveals the significant impact of agricultural activity and food production, ranging from 33% to 50% since 2017. Grain and flour dust, generated during the handling, storage, and processing of agricultural commodities, possess explosive properties that can lead to destructive explosions and fires. Factors such as static electricity discharges, uncontrolled flames, and high-temperature equipment can ignite these dust explosions. Recognizing the importance of understanding and mitigating the risks, this study aims to enhance the industry's knowledge and promote effective strategies for managing dust explosions in the milling industry. Laboratory tests were conducted on common types of flour, including type 00 flour and semolina flour, to assess their combustibility, explosibility, and other relevant properties. These tests provided insights into particle size distribution, moisture content, burning class, minimum ignition energy, and other key factors. The results of these tests help identify potential hazards and develop appropriate safety measures. The study also emphasizes the importance of considering the intended use and environmental conditions when assessing explosion risks. Based on the test results, a table defining the process intended use is provided, aiding in risk assessment. The paper also discusses potential ignition sources in the milling industry, such as hot surfaces, glowing nests, and mechanical sparks. Safety guidelines based on product behaviour and temperature thresholds are proposed to minimize the risk of ignition. By analyzing the characteristics, causes, and preventive measures associated with dust explosions in the milling industry, this study seeks to contribute to a better understanding of the risks involved and promote effective risk management strategies and accident prevention.

2. Combustible dust in the milling industry

Different types of combustible dust are generally present in the milling industry; the ignition behaviour of some of the most common of these has been experimentally determined through laboratory tests at laboratories under the ISO 17025 accreditation scheme, according to international standards and guidelines.

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Each situation must be assessed individually: it must be verified which types of dust are present in the different sections of the process, including the particle size distribution and the humidity, considering that the dust clouds are normally formed from the finest fraction of the product.
In this context, it is important to underline how, for example, the minimum ignition energy decreases with decreasing particle size or moisture content of the product. To gain a better understanding of the risks associated with milling, handling, and storage of flour, laboratory tests were conducted on different products, a crucial step for an explosion risk assessment. Testing products in the laboratory is a crucial step for risk analysis and determining whether a product is flammable or not. Unfortunately, laboratory tests are often time-consuming and costly. Additionally, it is important to consider that some powders have a high commercial value, making it impossible to conduct laboratory tests on large quantities of samples or volumes. In response to this need, various predictive models have been presented in the literature for the explosive properties of organic powders, for calculating Kst (Copelli et al., 2019; Scotton et al., 2020) or MIE (Copelli et al., 2021). These tests aimed to assess the combustibility, explosibility, and other relevant properties of these flours in order to identify potential hazards and develop appropriate safety measures. By conducting these laboratory tests, a more comprehensive understanding of the risks involved in the milling industry can be achieved, contributing to the development of effective risk management strategies and the prevention of accidents and incidents. The tests conducted included granulometric analysis, residual moisture content, powder bulk resistivity, burning class, Hartmann Tube, Minimum Ignition Energy (MIE), Minimum Ignition Temperature of a dust cloud (MIT cloud) according to Godbert-Greenwald, Minimum Ignition Temperature of a 5 mm dust layer (MIT layer 5 mm), Grewer test, and hot storage test in a 400 ml wire mesh basket. For two products, Wheat flour and Semolina, the tests were performed on both as-received and milled and dried samples. The granulometric analysis provided insights into the particle size distribution, which is crucial for understanding the dust behaviour, the same for the residual moisture content. The powder resistivity test assesses the electrostatic hazards associated with handling and processing the flour. The burning class gives information about the risk of smoldering material or glowing nests along the process. The Hartmann Tube test and, if required, the following MIE test in the MIKE apparatus, are crucial to assess the potential of different ignition sources. The Godbert-Greenwald tests determines the minimum temperature at which ignition can occur in a dust cloud. The Grewer is a screening test to basically understand the exothermic decomposition potential of the product, while the hot storage test, performed at isoperibolic conditions at defined temperatures and volumes, provide more precise information of possible exothermic decomposition, considering also the effect of heat accumulation of bulk product. Process conditions such as temperature, pressure and turbulence also influence the ignition behaviour of dust clouds, which must be considered in the assessment of explosion risk. By testing Wheat flour and Semolina on both as-received and milled and dried samples the study tried to define the influence of particle size distribution and humidity on some safety parameters. This approach provides a more comprehensive understanding of the risks associated with the handling, storage, and processing of the flours, facilitating the development of appropriate safety measures and risk mitigation strategies. The following tables list the results of the laboratory tests carried out. They are used as a reference in evaluating the potential ignition sources of the most common process equipment ordinarily present in the milling industry.

Table 1: Laboratory tests performed on different Grain dust samples

Parameter	Sample 1	Sample 2
Grain size d_{50} (as-received)	200 μm	58 μm
Grain size d_{50} (milled sample, tested)	45 μm	15 μm
Humidity	Dried (vacuum, 1h, 50°C)	Dried (vacuum, 1h, 50°C)
Burning class at 20°C	4	3
Burning class at 100°C	5	5
MIT layer 5 mm	250°C	
MIE with inductance	100 mJ - 300 mJ	30 mJ - 100 mJ
MIE without inductance	300 mJ - 1.000 mJ	100 mJ - 300 mJ
MIT cloud (Godbert-Greenwald)	350°C	
Bulk resistivity	10^8 Ωm	10^8 Ωm

Table 2: Laboratory tests performed on different Wheat flour samples

Parameter	Sample 1	Sample 2
Grain size d_{50} (as-received)	100 μm	84 μm
Grain size d_{50} (milled sample, tested)	36 μm	28 μm
Humidity	Dried (vacuum, 1h, 50°C)	Dried (vacuum, 1h, 50°C)
Burning class at 20°C	3	3
Burning class at 100°C	5	5
MIT layer 5 mm	260°C	>400°C
MIE with inductance	100 mJ - 300 mJ	300 mJ - 1.000 mJ
MIE without inductance	300 mJ - 1.000 mJ	>1.000 mJ
MIT cloud (Godbert-Greenwald)	350°C	370°C
Bulk resistivity	10^7 Ωm	10^8 Ωm

Table 3: Laboratory tests performed on a sample of Wheat flour, as-received and after milling and drying

Parameter	As-received	Milled and dried
Grain size d_{50} (as-received, tested)	78 μm	
Grain size d_{50} (milled sample, tested)		53 μm
Humidity	11,17%	1,93%
Burning class at 20°C		2
Burning class at 100°C		2
MIE with inductance	>1.000 mJ	30 mJ - 100 mJ
MIE without inductance	>1.000 mJ	300 mJ - 1.000 mJ
MIT cloud (Godbert-Greenwald)	450°C	440°C
Bulk resistivity	10^8 Ωm	10^{11} Ωm
Screening self-ignition (Grewer)		120°C (1st exotherm)
Hot storage 400 ml (at 150°C)		peak height 0°C
Hot storage 400 ml (at 160°C)		peak height 1°C (>8h)
Hot storage 400 ml (at 170°C)		peak height 4°C (>6h)
Hot storage 400 ml (at 180°C)		peak height 279°C (>6h)

Table 4: Laboratory tests performed on different Semolina samples

Parameter	Sample 1	Sample 2
Grain size d_{50} (as-received)	300 μm	35 μm
Grain size d_{50} (milled sample, tested)	100 μm	35 μm (not milled)
Humidity	Dried (vacuum, 1h, 50°C)	Dried (vacuum, 1h, 50°C)
Burning class at 20°C	3	3
Burning class at 100°C	5	4
MIT layer 5 mm	260°C	
MIE with inductance	100 mJ - 300 mJ	
MIE without inductance	>1.000 mJ	
MIT cloud (Godbert-Greenwald)	390°C	
Bulk resistivity	10^{10} Ωm	10^9 Ωm
Screening self-ignition (Grewer)	190°C (1st exotherm)	

Table 5: Laboratory tests performed on a sample of Semolina, as-received and after milling and drying

Parameter	As-received	Milled and dried
Grain size d_{50} (as-received, tested)	149 μm	
Grain size d_{50} (milled sample, tested)		84 μm
Humidity	10,55%	3,26%
Burning class at 20°C		3
Burning class at 100°C		3
MIE with inductance	>1.000 mJ	30 mJ - 100 mJ
MIE without inductance	>1.000 mJ	300 mJ - 1.000 mJ
MIT cloud (Godbert-Greenwald)	440°C	440°C
Bulk resistivity	10^8 Ωm	10^{10} Ωm
Screening self-ignition (Grewer)		140°C (1st exotherm)

Table 6: Laboratory tests performed on different Waste dust samples from the first cleaning step

Parameter	Sample 1	Sample 2
Grain size d_{50} (as-received)		205 µm
Grain size d_{50} (milled sample, tested)		24 µm
Humidity		Dried (vacuum, 1h, 50°C)
Burning class at 20°C	4	3
Burning class at 100°C	4	5
MIT layer 5 mm		310°C
MIE with inductance		30 mJ - 100 mJ
MIE without inductance		>1.000 mJ
MIT cloud (Godbert-Greenwald)		360°C
Bulk resistivity		10^8 Ωm
Screening self-ignition (Grewer)	160°C (1st exotherm)	180°C (1st exotherm)

3. Process intended use

To perform any explosion risk assessment, the definition of the intended use is required, including the dust products ignition behaviour. Based on the above Tables from 1 to 6, considering, for example, atmospheric process conditions and adopting a safety margin, the intended use could be defined according to Table 7.

Table 7: Process intended use according to tables from 1 to 6 in the case of atmospheric process conditions

Parameter	Grain dust	Wheat flour (not dried)	Semolina (not dried)
Burning class at 20°C	≤4	≤3	≤3
Burning class at 100°C	≤5	≤5	≤5
MIT layer 5 mm	>210°C	>210°C	>210°C
MIE with inductance	>30 mJ	>100 mJ	>100 mJ
MIE without inductance	>100 mJ	>300 mJ	>1.000 mJ
MIT cloud (Godbert-Greenwald)	>300°C	>300°C	>300°C
Bulk resistivity	<10^{10} Ωm	<10^{10} Ωm	<10^{10} Ωm
Screening self-ignition (Grewer)	>140°C (1st exotherm)	>100°C (1st exotherm)	>120°C (1st exotherm)
Thermal decomposition (400 ml)		>140°C	

4. Main potential ignition sources in the milling industry

Standard EN 1127-1 lists the possible ignition sources; under certain circumstances, some can become potential, i.e., igniting the explosive atmosphere in the milling industry. Considering the products ignition behaviour, based on the intended use according to Table 7, following a basic evaluation of the main process-related ignition sources. Hot surfaces can be a potential ignition source when the temperature reaches dangerous levels, compared with both MIT layer 5 mm and MIT cloud. Considering a safety margin, a hot surface should be regarded as capable of igniting a 5 mm dust layer when the temperature is above 135°C and a dust cloud when the temperature is above 200°C. This information should also be considered when defining the temperature class required for electrical or mechanical equipment. Based on the burning class of the products glowing nests are a potential ignition source. They can be generated after products exothermic reactions, for example, by hotspots, overheating, mechanical friction, unsuitable electrical equipment, or trivial ignition sources due to hot works. Considering self-ignition (Grewer) and thermal decomposition in a 400 ml wire mesh basket, glowing materials can be expected when the products for any reason are heated up above 100°C. Based on MIE with inductance and MIT cloud, mechanical generated sparks like impact sparks are not potential, while friction sparks can ignite a dust cloud when relative speed is sufficiently high to provide the necessary equivalent energy. In the milling industry, in general, with a relative speed ≤1 m/s there is no hazard of ignition of dust clouds, while higher relative speeds must be assessed on a case-by-case basis considering, at least, the equipment concerned, relative speed, applied power, presence of any controls such as thermal switches or circuit breakers to protect the electric motor. Electrical apparatus is always a potential ignition source; so proper safety features are required, based on equipment marking, including Atex category required according to the installation zone and periodic checks and maintenance. Moreover, equipment installed in the milling industry should be at least of group IIIB and temperature class ≤135°C.Some static discharges are not potential, like Corona and Brush discharges, because of the sufficiently high MIE without inductance, or not foreseeable like Cone discharges because of the low enough Bulk resistivity.Propagating brush discharges are a potential ignition source and must be effectively prevented by avoiding thin insulating coatings on metals or other conductive materials when affected by repeated electrostatic charging processes. If coatings are used, they should have a sufficiently low leakage resistance (<10^{11} Ω), or low dielectric strength (breakdown voltage <4 kV), or thicknesses greater than 10 mm. Spark discharges are a potential ignition source and must be effectively prevented by proper grounding and bonding of all the conductive (volume resistivity ≤10^4 Ωm) and dissipative (10^4 Ωm < volume resistivity ≤10^9 Ωm) parts of equipment affected by electrostatic charging processes. Finally, lightning is always a potential ignition source, for this reason, proper lightning protection of the building and the equipment is required, subject to periodic checks and maintenance. Other ignition sources, listed in standard EN 1127-1, are not considered since they are not the most important in the milling industry, but must be in any case evaluated in any explosion risk assessment.

5. Main process equipment in the milling industry

Following information regarding potential ignition sources and possible technical and organisational measures for controlling the risk of explosion for the main process equipment widely adopted in the milling industry.
The type and the extent of the safety measures required to achieve the safety target, must be defined, on a case-by-case basis, according to the specific explosion risk assessment. In general, electrical equipment requires a proper Atex category, according to the installation zone, and at least group IIIB and temperature class ≤135°C. Periodic checks and maintenance are necessary to ensure the equipment maintains its safety features. Bucket elevators, based on recorded explosions, are the equipment most likely to cause an ignition in the milling industry. Even in the case of the application of very efficient aspiration, it is not possible to prevent, inside bucket elevators, explosive dust clouds and dust layers during normal operating conditions. Mechanical ignition sources are likely to occur: friction sparks and local overheating with consequent thermal decomposition of dust layers, followed by glowing phenomena. These mechanical ignition sources are mainly due to: friction between metal buckets and elevator casing, belt slippage and misalignment, and bearings overheating. To control the above mechanical ignition sources, technical measures can be adopted, like belt speed limitation until possible, belt slippage and misalignment monitoring, and bearings overheating monitoring. Possible product clogging into the elevator boot can also cause thermal decomposition, and consequent glowing nests can be expected. Adopting a detection system able to alarm in case of boot clogging is not always easy to apply; in some circumstances, this malfunction can be detected using a level switch in the upstream equipment, able to monitor an abnormal accumulation. Proper grounding and bonding of all the conductive parts of the elevator can prevent ignition by spark discharges. The adoption of a dissipative belt (surface resistances on both sides < 3x108 Ω) can guarantee, at the same time, grounding of metallic buckets and the prevention of propagating brush discharges that could occur in case of isolating belt. Periodic checks and maintenance are required organisational measures to maintain mechanical equipment efficiency and reduce the probability of occurrence of potential ignition sources. Dust collectors, like bag filters, can contain an explosive dust cloud inside the dusty air plenum during normal operating conditions, particularly after the activation of the air jet cleaning system, but even on the clean gas side in case of failure of the filter media. The ignition sources able to cause an ignition are mainly hot surfaces and mechanical generated sparks, in the event of a simultaneous failure of filter media and fan installed in the emission pipe or spark discharges in case of grounding failure. Filter media failure can be controlled by installing a triboelectric detector or a safety filter; while a fan with proper Atex marking, subject to periodic checks and maintenance, can control hot surfaces and mechanical generated sparks. Moving parts can be present inside the filter, like rotary valves, that should not be considered as potential ignition sources until they have a peripheral speed ≤1 m/s and limited applied power. Proper grounding and bonding of all the conductive parts, including filter bag cages, can prevent ignition by spark discharges. Propagating brush discharges should not be expected in case the filter is used for aspiration purpose, since the limited dust concentration in the aspirated air should limit charging processes on insulating inner coatings if present. The probability of occurrence of an explosive dust cloud inside silos and cells depends on the product stored inside: grain or milled dust, and, in the case of grain: after pre-cleaning, cleaning or wetting procedures. Moving parts can be present inside silos and cells, like rotary valves and screw conveyors. In the case of rotary valves, hot surfaces and mechanical generated sparks should not be considered as potential ignition sources until they have a peripheral speed ≤1 m/s and limited applied power. In the case of screw conveyors, hot surfaces could occur, in particular at support pins and bearings, while applied peripheral speed sometimes can be >1 m/s, so every situation must be assessed on a case-by-case basis. In some situations, silos and cells are built in metal, so grounding and bonding are required to prevent ignition by spark discharges, but sometimes they are made in concrete or, if very old, even in wood. Propagating brush discharges should not be expected when insulating inner coatings are not used, and, in any case, limited impact of dust at high speed should limit charging processes. The probability of occurrence of an explosive dust cloud inside chain conveyors, also called redlers, can usually be

limited by adopting a proper aspiration. In these circumstances, the presence of an explosive atmosphere inside must be considered, at least due to abnormal operating conditions.

In these circumstances the risk of ignition from mechanical friction between blades and casing can easily be controlled by periodic checks and maintenance. Grounding and bonding are required to prevent ignition by spark discharges while propagating brush discharges should not be expected when insulating inner coatings are not used. Pneumatic transports contain an explosive dust cloud inside during normal operating conditions; the probability of occurrence can change according to the process setup. Sometimes diverter valves are applied along the pipes but, considering that they are not operated during pneumatic conveying or, in any case, they usually move with a speed ≤1 m/s, they should not be considered as potential ignition sources. Grounding and bonding are required to prevent ignition by spark discharges; the use of flexible pipes made of insulating polymer can compromise the grounding and bonding of some metallic pipe sections. In these circumstances, special electrical connections are required, or alternatively, the adoption of flexible pipes made of dissipative material. Propagating brush discharges should not be expected when insulating inner coatings are not used. According to the explosion risk assessment, constructional explosion protection may be required to reach the safety target (residual risk) to reduce the impact of a possible explosion in case the safety measures are not suitable to reduce the probability of an explosion to a sufficiently low level. Constructional explosion protection can be represented by explosion venting or explosion suppression, combined with explosion decoupling to prevent explosion propagation to the interconnected process equipment. It is important to underline how a secondary explosion must be prevented since it's affected by increased explosion violence caused by high turbulence, pressure piling and broad flame jet ignition.

6. Conclusions

In conclusion, this scientific paper emphasizes the importance of understanding and managing the risks associated with dust explosions in milling facilities. The insights gained from laboratory tests on different dust products provide a basis for identifying hazards and implementing safety measures. This study contributes to advancing our understanding of the risks involved in grain and flour processing, making it a valuable resource for industry professionals and safety experts. The findings highlight the need for proactive measures to mitigate the risks of dust explosions. By implementing recommended safety guidelines and incorporating risk assessments into operational practices, the industry can significantly reduce the occurrence and severity of dust-related incidents. This ensures the well-being of workers, protects assets, and promotes a safer working environment. Hazard analysis and risk assessment are crucial for maintaining safety. By identifying potential hazards and assessing associated risks, organizations can implement control measures and preventive actions to minimize accidents. A thorough evaluation of all potential ignition sources allows targeted mitigation strategies to be put in place, such as avoidance of effective ignition sources and, when necessary, reduction of the explosion effects by means of constructional explosion protection.

Regularly reviewing and updating hazard analysis and risk assessments enables organizations to adapt to changes and ensure ongoing safety and compliance. This comprehensive approach fosters a culture of safety, protects lives and property, and contributes to the long-term success and sustainability of the plant and the organization as a whole.

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