Executive Summary
Dust explosions and fires has become a major issue in the pellets industry as well as in other woodworking industries with devastating consequences in many cases. The industry is struggling with ever increasing insurance premiums and has been looking for cost effective means of mitigating the risks. Part of the problem is the limited understanding of the complex behavior of dust explosions among plant operating personnel as well as corporate management. This document is intended to increase the understanding from a practical standpoint and to provide references to the important regulatory system for control of dust explosions and fires. A dust management scheme is outlined which if implemented would eliminate much of the risk at a minimal cost. The scheme is built upon a sharing of responsibility between management, operations and maintenance personnel and at the same time providing a robust safety record as the basis for safety inspections and audits. The allowable dust level is determined by a model and inexpensive instrumentation which can be used by plant operating personnel and based on characterization of the dust by scientific means.

1. Introduction
Housekeeping in wood manufacturing facilities such as pellet manufacturing plants traditionally has not had the priority it deserves for a number or reasons. The issue of cleaning has a connotation of lesser significance than keeping a plant operating and producing revenue generating products. Cleaning of floors is a nuisance since the generation of dust never stops but it is as important as regular maintenance of machinery. This document describes a methodology for evaluating how much dust on floors, girders and beams is acceptable in order to stay within reasonable margins of safety. Several guidelines are published on this subject but are not necessarily accessible without substantial effort. Also, these guidelines are not always adapted to the characteristics of the type of dust encountered in pellet plants. Based on lab testing of a couple of fundamental parametric values related to the specific characteristics of the
dust the method described will allow the operator of a pellet plant to evaluate the necessary safety precautions which needs to be taken as it relates to housekeeping.

2. Anatomy of dust explosions

Dust explosions typically have two phases, a primary explosion cased by ignition from a mechanical spark or electrostatic discharge, overheated rotating device (ball bearing, idler, guide roller etc.) or bead from hot work or similar, followed by a secondary explosion. The secondary explosion is a result of dust lodged on the floor, beams, girders, railings etc becoming airborne as result of the pressure wave from the primary explosion and begin to deflagrate (propagation of burning material at high speed). In a dusty environment there is usually also very fine dust suspended in the air for a long period of time\(^1\) which also contributes to propagation of a deflagration throughout a building. The conversion of dust from a layer to a dust cloud changes the dynamics radically since the dust becomes oxygenated and fluid. If there is a secondary explosion it is often far more damaging since it extends the explosion to much larger spaces where people may be working. Precautions to take for limiting primary explosions are well documented and consist of a combination of prudent design of facilities and machinery and proper maintenance, including cleaning of specific equipment. Precautions to take for limitation of secondary explosions are recommended by NFPA\(^2\) and OSHA\(^3\) in North America and consists primarily of maximum thickness of dust layers. Table 4.0 (see footnote 1) summarizes the explosibility characteristics of dust from pellets produced in British Columbia (white dust) and pellets produced in Nova Scotia (bark dust).

<table>
<thead>
<tr>
<th>Test Parameter (dust &lt;63 μm)</th>
<th>Measure</th>
<th>White Dust</th>
<th>Bark Dust</th>
<th>Coal Dust</th>
<th>Lycopodium Spores</th>
<th>Testing Standards</th>
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<tr>
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<td>8.4</td>
<td>7.3</td>
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<td>12.5</td>
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3. Occupational Safety and Health Administration.
3. **Calculation of Maximum Recommended Dust Layer Thickness**

NFPA\(^4\) 664 focuses on dust in the wood working industry, Chapter 11 and Annex A, paragraph 6.4.2.2 or NFPA 499\(^5\), Chapter 5 are stipulating a dust layer thickness of more than 1/8” (3.2 mm) is considered unsafe if the dust is covering a certain percentage of floor or other flat surfaces in a facility. The bulk density of wood dust is around 250 - 550 kg/m\(^3\). A procedure for estimation of dust concentration in a space volume as a result of a secondary explosion is illustrated below. The result is evaluated in view of the Minimum Explosible Concentration (MEC) in Table 4.0 above based on some assumptions regarding the space volume in a building.

**Example**

Area selected = 15 m * 25 m = 375 m\(^2\)
Dust layer thickness = 1/8” = 3.2 mm
Bulk density = 500 kg/m\(^3\) @ moisture content 5%
Floor area covered with dust = 5%
Total amount of dust in the selected area = 375 * 0.0032 * 500 * 5/100 = 30 kg
Height of the selected area = 4 m
Total space volume in the selected area = 375 * 4 = 1500 m\(^3\)
Concentration of dust in the space volume = 30/1500 = 0.020 kg/m\(^3\) = 20 gram/m\(^3\)

The 20 gram/m\(^3\) compared to 70 gram/m\(^3\) (as per Table 4.0) provides a good safety margin of 71%. If the area covered with dust is 30% the calculation looks as follows;

Dust in the layer = 375 * 0.0032 * 500 * 30/100 = 180 kg
Concentration = 180/1500 = 0.120 kg/m\(^3\) = 120 gram/m\(^3\)

The 120 gram/m\(^3\) is unsafe and would easily sustain a deflagration if a primary explosion were to happen.

Due to the violent turbulation of the dust when dislodged by a pressure wave the concentration of the dust in most cases can be assumed to be spread evenly within a space volume. The larger the area is covered by a layer of dust the more critical the condition becomes. A spreadsheet model\(^6\) has been developed which can be used for evaluating safety margin for explosions based on the following parameters;

- Estimated average thickness of a dust layer within selected floor area
- Bulk density of the dust (from lab test)
- Minimum Explosible Concentration (MEC) of the dust (from lab test)
- Floor area
- Ceiling height

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- Horizontal surface area within the space volume of beams, girders, railings etc.
- Estimated percentage of selected floor area covered by dust
- Estimated amount of lofted dust in space volume
- Average dust concentration suspended in the air in space volume
- Selected safety margin in relation to measured MEC

The model is iterative and lends itself for estimation of the risk level in selected areas. The model allows for sectionalizing the footprint area during inspection to simplify determination of the estimated average thickness of the dust layer for the total floor space area.

Example of the output from this model is illustrated in Graphs 1. This particular graph is valid for dust with MEC 70 gram/m\(^3\) and a bulk density of 500 kg/m\(^3\).

![Graph 1. Calculated Concentration of dust in gram/m\(^3\)](image)

The concentration of dust \(C_d\) is inversely proportional to the space volume \(V\). This means that a space volume twice as large would produce the same dust concentration

\[
C_d = \frac{(d_{th} \times 1000 \times A \times (A_d/100) \times d_b)}{V}
\]

where
- \(C_d\) = concentration of dust in space volume gram/m\(^3\)
- \(d_{th}\) = dust layer thickness mm
- \(A\) = total floor area m\(^2\)
\[
\begin{align*}
\text{d}_b &= \text{dust bulk density} \quad \text{kg/m}^3 \\
\text{A}_d &= \text{floor area covered by dust} \quad \% \\
V &= \text{Space volume} \quad \text{m}^3
\end{align*}
\]

From Graph 1 it can be concluded that a dust layer with thickness of 3.2 mm (1/8th inch) covering 20% of the selected floor area the concentration of dust is estimated to 75 gram/m$^3$. With an MEC of 70 gram/m$^3$ for dust generated in BC pellet plants deflagration could be propagated throughout a building as a result of a primary explosion. A safety margin of 50% to the MEC (50% of 70 gram/m$^3$ = 35 gram/m$^3$ from Table 4.0) as established by lab test is recommended. If 10% of the floor area is covered by a 3.2 mm layer of dust the estimated dust concentration is 40 gram/m$^3$ which is less than the MEC for the dust on Table 4.0 and provides a safety margin of 43%. This safety margin may be sufficient although 50% safety margin should be the target. A housekeeping guideline stipulating a maximum thickness of a dust layer of 1.6 mm would provide a safety margin of 50% or better even if the dust layer is covering approximately 20% of the floor area. Alternatively, a thickness of the dust layer of 3.2 mm covering less than 5% of the floor would also be within the 50% safety margin. This illustrates the importance of keeping as large areas as possible clean.

The MEC is a measure related to the characteristics of the dust such as chemical composition of the material, moisture content, Limiting Oxygen Concentration (LOC), particle size distribution and shape of the dust particles (see foot note 1 for more details). The NFPA 499 and NFPA 664 are not necessarily accounting for the explosibility characteristics as measured by lab test for a particular dust in question.

4. **Considerations for Determination of Safety Margin**

With MEC established at 70 gram/m$^3$ for the material as per Table 4.0 and a safety margin of 50% the maximum allowed dust concentration should be less than 35 gram/m$^3$ keeping in mind that the MEC is tested as per Standard starting at room temperature and the reactivity of most materials increase with temperature. The shop floor temperature in an operating pellets plant may in certain areas be considerably higher causing a more reactive initial state which would justify the 50% safety margin to be on the safe side. The MEC as well as the bulk density of the dust are essential parameters when determining guidelines for housekeeping to keep a manufacturing plant safe. Without those values the guidelines becomes a gamble and the housekeeping may not achieve what it is supposed to achieve – as safe working environment as possible.

The speed of a deflagration is subsonic which means the burning dust is propagating at up to 343 m/sec at a temperature of +20°C and even higher at higher temperatures. The burnout time for many particles would be several seconds. This means that particles in a deflagration wave penetrating objects in its way in a contained building will continue to burn at temperatures above +250°C for several seconds which is sufficient to initiate fires in combustible materials and cause severe burn injuries if a person is exposed to
the ignited dust storm. Spaces inside buildings may have constrictions such as hall ways which may magnify the propagation of the deflagration speed. The average distribution of dust as calculated in a model does not tell the entire story since the dust is unevenly spread due to eddies behind walls etc. With a high speed deflagration wave sweeping through a building a deflagration may propagate between clusters of high concentrations of dust. In an environment where dust layers are forming on floor and flat surfaces there is always dust aloft in the air. The airborne concentration is very much depending on the distance to the source of the dust, air movement and the particle size of the dust. The following diagram illustrates the sedimentation time as a function of particle size (for more details foot note 1) for particles in still air.

**PARTICLE SEDIMENTATION TIME IN STILL AIR**

[Diagram showing sedimentation time for different particle sizes]

A substantial portion of the airborne dust in a pellet plant is smaller than 10 micron which means that those particles add to the airborne concentration caused by a secondary explosion. Normal condition in an industrial environment is that the air is in constant turbulence which means that particle sizes less than 100 micron remain lofted.

Dust particles settling further away from the source are smaller and tend to have a flatter surface area and are therefore more sensitive to ignition. Location of dust sampling is therefore an important consideration since it will affect the explosibility characteristics.

For establishing an average dust explosibility characterization the dust collected in a baghouse is a good source since the dust collected usually comes from a space with high turbulence which means a mix of larger and smaller particles. For establishing the
Extreme dust explosibility characterization the dust should be collected in an area with dust as far as possible from the source.

5. Research Regarding Dust Layers
Since the MEC is dependent upon particle shape and the sedimentation speed as well as spatial distribution in an area it is important to know where to take samples for testing. Research is needed to develop guidelines for sampling of explosible dust. This issue is under review by ISO Technical Committee 238 for Solid Biofuels and will require extensive research for a variety of dust, impact of air turbidity on settling characteristics of dust and other operating conditions. Unfortunately there is no guideline or standard for how to sample dust. Research\(^7\) is under way to determine the best procedure for sampling dust. The generally accepted technical testing standards explosibility do not prescribe any method for sampling and do not even acknowledge the importance of sampling and how it may affect the explosibility characteristics. The ASTM Standards for example stipulate that the moisture content of the sample shall be below 5% but allows “manufacturing” of the dust using a hammer mill which does not produce a representative dust. The CEN Standard on the other hand stipulates a test sample as received with no restriction on the moisture content which has a major impact on the explosibility characteristics. These differences allow only a limited direct comparison of results from the two standards. ISO/TC238 is currently working on resolving this issue by harmonizing\(^8\) the sample preparation requirement.

Determination of thickness of dust layers is currently done by visual observation and therefore becomes an arbitrary process. A simple methodology needs to be developed for quick measurement in the working environment in support of inspectors and auditors. Small tripod mounted meters using a laser beam with a resolution of ±0.15 mm are available for reasonable price (CAD 350) and can be calibrated to a clean floor could be one approach. The picture illustrates a prototype measurement setup on a tripod with the laser spot clearly visible.

A spot measurement procedure takes only a few seconds and the data can be transferred to a computer for further statistical processing and reporting. Research\(^7\) is under way to determine the efficiency, precision and safety of such method. Since dust tend to accumulate in uneven layers, for this method to be useful there has to be spots selected in an industrial plant which are representative of dust generation and where fairly even dust layers are formed.

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\(^8\) ISO/TC238 Working Group #4
6. **Recommendations and Guidelines**

The guidelines documented by NFPA are considered the industry standard. Most spaces in a pellet plant should be classified as Class II Division 1 (see NFPA 499, Chapter 4.1). The wood dust itself is classified as Group G (see NFPA 70, Chapter 500.6). Each area of a manufacturing plant shall be classified in accordance with the Hazardous Zone definitions in NFPA 70, Chapter 506. Most of the production areas of a pellet plant would fall into Zone 20.

The discussion in this document focuses on the dust issue in pellets manufacturing plants. Much of the issues as well as potential solutions are probably applicable also to other wood working operations such as sawmills, planer mills and board plants.

**Preventive Measures**

Buildings were explosions can be expected due to release of dust and difficulty with proper housekeeping shall be designed for explosion protection by deflagration venting as recommended in NFPA 68 and 69. Equipment in such areas requires equipment compatible with Temperature Class (T code) in accordance with NFPA 70, Chapter 500.8 depending on the Hot Surface Ignition Temp (19 mm) as established by ASTM E2021.

NFPA 664, Annex A paragraph 6.4.2.2 provide some general guidance regarding dust layer thickness, floor size and bulk density of dust but is not necessarily applicable to the environment in a pellets mill with dust of different bulk density.

It is recommended that a site evaluation is done for any specific area to make sure the guideline for robust maximum dust layer thickness is established. Such evaluation should be done in areas where dust is systematically accumulating and where housekeeping is difficult to maintain.

**Dust Characterization**

Each pellet mill should have the MEC established by a certified lab in accordance with testing standards given in Table 4.0. Equally important is to establish the bulk density of the dust generated in the plant to make sure the fundamentals are met for establishing a safe limit for dust layer thickness as well as housekeeping guidelines to keep the floor areas sufficiently clean and the dust level below the allowable limit. Both of these parameters are unique for each pellet plant since it relates to the feedstock used as well as the comminuting technology used for processing the feedstock.

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Without knowing the MEC and dust bulk density the safety rules for a production plant and safety management becomes a guessing game. A safety margin policy of 50% or better should be established for any pellet manufacturing plant.

Proposed Dust Management
A successful scheme to control dust explosions must include, besides actual characterization of the dust, a split responsibility between management, operations and maintenance and has to be based on robust and measurable data. Whoever is assigned the responsible of controlling the dust level in a manufacturing plant should be equipped with methodology to record thickness of dust accumulation in layers and spaces where dust is continuously suspended in the air. Inspections and recordings needs to be done at preset intervals. This should be done every time just before vacuuming takes place. The record should be made available to all levels of personnel by posting to cultivate awareness of the importance to control the dust level;

- Frequent accumulation of explosive dust is an indication that a preventive measure likely needs to be taken in terms of redesign of a piece of machinery or change of operating procedures. The responsibility falls on plant or corporate management to act upon in this respect.
- Awareness of recorded data of dust layers promotes more frequent and diligent housekeeping routine. This responsibility falls on the housekeeping or maintenance crew to act upon in this respect.
- The record shall be available to inspection and safety audit bodies for determination if the safety certification for the plant can be upheld. The dust certification becomes part of the safety approval process which affects WorkSafe as well as insurance rates.

One approach might be to use a thickness measurement instrument since it is an “independent” factor providing neutrality for verification of safety compliance. A well calibrated thickness meter and well kept record of measurements could eliminate much uncertainty and disputes regarding safe operating procedures and eliminate poorly designed operating equipment and procedures. It should be noted however that locations with dust layers for determination of dust layer thickness needs to be selected with care in order to be truly representative. A flat surface where dust regularly is accumulating in a well defined layer is the best. The meter data record promotes collaboration between management, plant operations and maintenance. A well kept record would also serve as a valuable forensic tool if the accident is still there.

The ISO/TC 238 will come out with sampling and sample preparation recommendations as a result of the on-going research. The target date for release of recommendations is sometime during 2013.

The generation of dust never gives up and can only be fought with diligence.