FPInnovations

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FEBRUARY 26, 2013

SAWMILL WOOD DUST SAMPLING, ANALYSIS and EXPLOSIBILITY

FPINNOVATIONS

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FINAL REPORT: 301007168

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Executive Summary

This study examined fugitive wood dust accumulation, particle size, moisture content[1] (MC) and explosibility by analyzing samples collected from 18 sawmills across BC. This information is intended to assist the sawmilling industry's efforts to mitigate risks from dust accumulation but it does not provide benchmarks or a risk assessment for sawmills. In this study, mills are grouped by the timber they process (SPF-spruce/pine/fir, MPB-mountain pine beetle-killed lodgepole pine and DFC-Douglas-fir and western red cedar) and the regions in which they are located (BC Coast, Central Interior, Northern Interior and Southern Interior). Seven of 12 mills located in the Central and Northern Interiors were processing primarily MPB at the time of sampling. Three of the 4 mills located in the Southern Interior were processing SPF at the time of sampling. The 2 Coastal sawmills were processing Douglas-fir and western red cedar (DFC) but Douglas-fir was also being processed by a mill in the Central Interior and a mill in the Southern Interior. The remaining 4 sawmills were processing SPF.

An average of over 21 samples from each sawmill (380 in total), were collected from the one-day site visits. Actively accumulating fine dust samples (300), smaller than a few millimetres, were targeted but grab samples (80) were also collected when large quantities of fine dust were required. It is important to note that many of the samples collected were intended for specific analyses so not all the samples received the same analyses. Also, many samples did not have sufficient mass for particle size analysis and were only analyzed for MC and accumulation rate. From all the samples available for analysis:

- 42% were greater than 25% MC on a wet basis while 20% were 12% MC or less;
- 45% had accumulation rates estimated to lead to 3.2mm (1/8-inch) depth or more in an 8-hour production shift while 19% had rates that would lead to accumulation of greater than 55mm (over 2-inches) in the same period;
- 25% of the particles, as a percentage of the total mass, passed through the 425μm sieve.

Examining sawmills by the timber processed showed:

- MPB sawmills had dust samples that were drier with 28% at 12% MC or less, and finer with 21% of the samples passing through the 250μm sieve;
- In SPF sawmills, 19% of the dust samples were 12% MC or less, and 9% passed through the 250μm sieve;
- In DFC sawmills, 10% of the dust samples were 12% MC or less, and 4% passed through the 250μm sieve;
- SPF sawmills had the highest average accumulation rates with 23% of the collected samples exceeding 50mm or more in 8 hours compared to 17% for MPB and 15% for DFC mills.

The regional comparison showed similarities with the timber processed by mills in the regions. The Northern and Central Interiors where all the MPB sawmills were located, on average had drier and finer dust. The Southern Interior had mainly SPF sawmills and had the highest average accumulation rates. On average, Coastal sawmills had wetter samples.

[1] Moisture content is calculated on a wet basis, which is conventional in scientific use and fire safety codes. Moisture content in the wood products industry is generally expressed on a dry basis, which is a higher number, e.g., wood particulate at 25% wet basis is 33% dry basis.

Within the sampled sawmills, the highest average accumulation rates were found on the Main floor but Basements were found to have finer and drier samples. Most of the High locations had very low accumulation rates and frequently, insufficient mass for particle sieving or MC analysis. One High sample was found to have one of the largest proportions (96%) of dust 425μm or smaller. The machine centres earlier in the sawmilling process, such as Primary breakdown, tended to generate larger particles than later machines such as the Trim-sort. The accumulation rates followed opposite trends with the highest values at the Trim-sort and in Basements followed by Secondary breakdown, Primary breakdown and Transfer systems. Methods to reduce the generation of dust at the machine centres were noted and include increased guarding and duct suction.

To examine the factors affecting wood dust explosibility, 31 dust samples were sent to Chilworth, an independent laboratory, which conducted Explosion Severity testing (Maximum Pressure - P_{max} and Deflagration Index - K_{st}) and Ignition Sensitivity testing (Minimum Dust Cloud Ignition Energy - MIE, Minimum Dust Cloud Ignition Temperature – MIT cloud and Minimum Explosible Concentration – MEC). Included in these were two western hemlock and amabilis fir grab samples that were included in the DFC group to augment the BC Coastal mill samples. The 31 samples were separated and sub-sampled from the grab samples to examine the effect of source, MC and average particle size. In some cases, samples were dried or hydrated to examine MC. Less than 1% of the collected dust passed through the 75μm sieve so consequently no dust was tested in this typically more explosible size fraction. Maximum Pressure and the Deflagration Index both followed expected trends for similar dust-like materials. Compared to values reported in literature, the Deflagration Indexes for the wood sample tests were fairly low but the trends suggest that finer dust would generate values comparable to other materials. It is clear that explosions can occur for average particle sizes larger than 400μm and 500μm. In the SPF and MPB species groups, explosibility does not depend strongly on MC particularly at the smaller particle sizes. Comparing the low MC data, there is not much difference among the explosibility of MPB, SPF and DFC, which suggests MPB-killed timber does not change the properties of wood to create a more severe explosion hazard. However, the processing of MPB may create more dust or dust that is easier to raise into a cloud or other similar effects. The Ignition Sensitivity tests show moderate to low sensitivity to spark ignition and static discharges from small objects such as people. Larger particle sizes generally lead to increased MIT and MEC values and reduced hazard potential.

To identify sawmill areas for focussed dust mitigation efforts, two criteria were applied to the samples. It is important to understand that explosion hazards can exist under many different conditions and in situations not examined in this project. The criteria applied in this project were intended only to segment the samples collected. The criterion applied to the accumulation rate was 3.2mm (1/8-inch) in 8 hours. A deflagrable dust hazard exists when its depth exceeds 1/8-inch or 3.2mm, according to NFPA 664, on upward-facing surfaces and over 5% or more of the total area (coverage area was not examined in this project). In a sawmill, many areas are not accessible during an 8hr production shift so 3.2mm accumulation should be prevented within this timeframe. A higher particle size hazard was assessed based on the proportion of sieved fine particles in the sample. All 24 samples that had an average particle size of 425μm or less were found to be explosible. These samples had a particle size composition of at least 40% of their particles passing through the 425μm sieve, which is the criterion applied to average particle size.

When the accumulation rate and particle composition criteria were applied to the collected samples, 20 samples or 7% are highlighted, which were assessed to be of higher risk in this report. It is important to note that the vast majority of the collected samples had accumulation rates and particle compositions that did not meet these criteria. The majority of these higher risk samples (14) were from MPB sawmills. A majority of the samples (14) were also collected from under or in the vicinity of conveyors and in Basements. This indicates that MPB sawmills are at a slightly higher risk of having hazardous dust accumulations based on the accumulation rate and particle size criteria applied in this report. In addition, conveyors and Basements in MPB and other sawmills are the most likely areas to find hazardous dust.

The explosibility results showed that wood dust can be an explosion hazard and that a small proportion of the dust samples collected in this project showed a similar explosible composition. It is important to highlight that based on the criteria applied to assess dust hazard, the vast majority (93%) of the collected sawmill dust samples fall outside these criteria. Although the examination of each sawmill was not exhaustive, the combined results suggest that the dust mitigation priority should be focused on the sawmill areas where the higher accumulations of fine dust are occurring. This was in Basements and around conveyors, especially in facilities processing MPB timber. Other areas were also identified, but not as consistently as the Basement and conveyors. Higher elevations were found to have lower accumulations but it is important to note that high accumulations could occur here and in other areas, and one sample with a large proportion of fines was found in this location. It is important that individual mill assessments and regular audits be performed to identify the high accumulation areas within individual sawmills. If these problem areas can be mitigated, it should be possible to perform daily inspections of the higher accumulation areas to identify potential hazards and direct clean-up. These inspections should include an identification of instances where unexpected accumulations are occurring such as where guards or dust collection may be malfunctioning. In lower accumulation areas, weekly inspections should be sufficient to detect the accumulations of finer material that meet the more hazardous material criteria applied in this report and to direct clean-up. Since the conditions in sawmills can change with time, and it is difficult to visually identify hazardous dust, a regular long-term dust sampling, and analysis and audit program should be put in place.

Acknowledgement

The authors would like to acknowledge the funding received from the United Steel Workers (USW) - Northern Interior Forest Industry Safety and Health Research and Education Program (SHARP), the Manufacturer's Advisory Group (MAG) and FPInnovations' western industry members. We would also like to thank the 19 sawmills that participated in the dust sampling and their staff for assistance with sample procurement. In particular, we would like to acknowledge Ken Higginbotham (MAG Dust Management Initiative Project Manager) and Kerry Douglas (West Fraser Timber Co. Ltd.) for their assistance in setting-up and coordinating industry support and participation in this project. We would also like to extend our thanks to the excellent technical assistance of Ashleigh Ward, James Drummond and Paul Symons and the helpful advice of Derek Williams (all of FPInnovations). We would also like to acknowledge the explosibility laboratory work and technical expertise provided by Kenneth Lee and Paul Janusauska at FM Global Group and by Brian Kingsley, Don Churchwell and Jason Cargill at Chilworth Technologies, Inc.

Table of Contents

List of Figures

List of Tables

1 Introduction

In response to a request from the Manufacturing Advisory Group (MAG), most of which are FPInnovations' members, an investigation of the dust being generated in B.C. sawmills was undertaken. The objectives of this work were to:

1. Collect data on wood dust particle size, moisture content and its accumulation to support efforts to determine the potential risk of combustibility;
2. Test the explosibility of wood dust samples and the effects of particle size, moisture content and the source/species of particles;
3. Collect data across a range of sawmill processing areas in different regions to support efforts to identify and support the classification of potential areas of risk;
4. Determine dust proportions and accumulation rates to support efforts to design appropriate housekeeping and mitigation protocols and procedures; and
5. Suggest a process to assess the hazard of accumulating wood dust that could be applied in a sawmill audit.

To fulfill these objectives, sawmills included in the MAG, located throughout British Columbia, participated in a sawmill dust investigation as shown in Figure 1. Sampling was not possible at one of the mills due to its closure, so 18 mills were part of the study. Table 1 presents a list of the participating companies, the region of each mill, the date they were sampled and the tree species (mountain pine beetle killed lodgepole pine = MPB, spruce/pine/fir = SPF and Douglas fir & western red cedar = DFC) that were being processed at the mill. The methods used and a summary of the data collected, including particle size and accumulation rates, determined at FPInnovations' laboratory, as well as explosion tests and analyses that were performed by an accredited dust explosion testing facility in Princeton, New Jersey, Chilworth Technologies, Inc., are presented in this report.

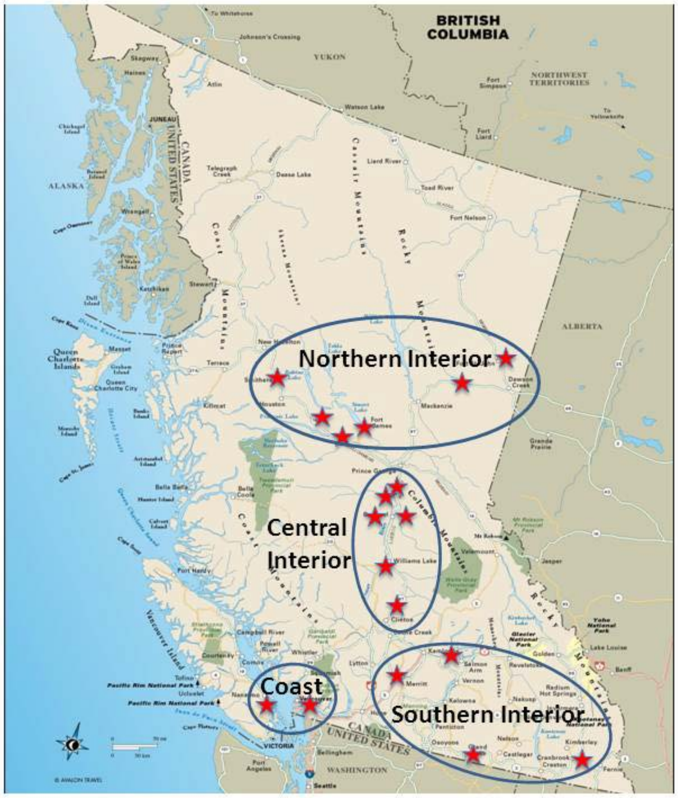


Figure 1 ***Sawmills selected from each BC forest region, including seven that primarily process mountain pine-beetle killed lodgepole pine***

Table 1 ***Participating sawmills, locations and sampling dates and species processed at time of dust sampling***

Region	Date	Wood Processed
Northern Interior	17-Jul-12	MPB - 70%
Southern Interior	02-Aug-12	SPF
Northern Interior	19-Jul-12	MPB - 70%
Central Interior	05-Jul-12	SPF
Northern Interior	04-Jul-12	MPB - 70%
Central Interior	28-Jun-12	SPF
Northern Interior	12-Jul-12	SPF
Northern Interior	Not Sampled	MPB
Southern Interior	20-Jun-12	Douglas fir
Southern Interior	31-Jul-12	SPF
Coast	30-May-12	Cedar
Central Interior	06-Jun-12	Douglas fir
Southern Interior	18-Jun-12	SPF

Region	Date	Wood Processed
Central Interior	25-Jun-12	MPB
Northern Interior	09-Jul-12	MPB - 70%
Northern Interior	11-Jul-12	Fresh MPB
Central Interior	22-Jun-12	MPB
Central Interior	27-Jun-12	SPF
Coast	15-Jun-12	Douglas fir

2 Use of Information

The sawmill dust sampling and analysis described in this report and the explosibility tests were designed to provide information to assist the BC sawmill industry in its efforts to mitigate dust accumulation and to develop an audit system. This information is intended to be used as a reference for comparison purposes only, to focus and assess these efforts. This report does not provide benchmarks and it does not assess risk as this is unique to each situation and sawmill.

The 18 sawmills sampled in the study were selected from mills within the Manufacturing Advisory Group (MAG). Other BC sawmills were excluded, including most of the small- and medium-sized operations. The report notes areas that might be higher priorities for dust mitigation, however this is not conclusive as the sampling conducted in this project was not exhaustive and as noted, many BC sawmills were not considered for inclusion. Target areas for sampling were those of active fine dust accumulation, however all at risk areas may not have been adequately evaluated in this high level overview of sawdust generation and the corresponding explosibility tests. The MAG is leading an extensive program to develop protocols to assess risk and audit mill conditions.

3 Methodology

3.1 Experimental Design

The sampling in this project focussed only on sawmills operating in British Columbia. In addition to the five objectives listed in the Introduction, one of the key purposes of the work was to determine differences between the actively accumulating sawdust produced in sawmills processing mountain pine beetle killed lodgepole pine (MPB), spruce/pine/fir (SPF) and other species including coastal and interior Doulas-fir and coastal western red cedar (DFC). Of the nineteen sawmills selected to participate in this survey, thirteen were located in the Northern and Central Interior regions, at the time of this study the mills in these areas received the greatest concentrations of MPB-killed timber. One mill was closed during the course of the work and was therefore not evaluated.

Within a sawmill, the goal was to collect approximately 10 to 15 samples, but this number varied depending on sawdust accumulations specific to the mill. In most mills, approximately 20 samples were collected. Similar sampling locations were selected in each sawmill to allow for cross-comparison but the specific location where sample traps were deployed was dictated by safety, the mill's layout and construction, and to some extent, the design of the equipment. For instance, very high ceilings were difficult to access and did not permit collection at the greatest heights, which eliminated many planned collection locations.

3.2 Mill Dust Collection Survey

3.2.1 Sample Collection

From the end of May through August, FPInnovations conducted dust sample collection at 18 sawmills located throughout British Columbia. With the exception of two mills, each mill was toured the day before the sampling was performed to determine dust sources, understand how dust moved through the mill, and to spot potential sample receptacle locations. Sampling for each mill was completed in one day.

In each mill, dust samples were collected in receptacles located at various breakdown machines and areas where wood particulate was observed to have accumulated. The times that each receptacle was positioned and removed were recorded. At the first two mills that were sampled, four types of collection receptacles were tested: a bucket lined with a plastic bag (diameter = 25.4 cm); a tray lined with an oven-dried, pre-weighed piece of parchment paper (38.1 x 38.1 cm); a tray lined with an oven-dried, pre-weighed microfiber cloth (38.1 x 38.1 cm); and an unlined tray (23 x 32 cm) (Figure 2A, B, C, and D, respectively). Once the sampling protocol was established, only two of the receptacles were used in the subsequent mills: a bucket lined with a plastic bag (diameter = 25.4 cm) and a tray lined with an oven-dried, pre-weighed piece of parchment paper (38.1 x 38.1 cm) (Figure 2A and B). Sample buckets were placed in areas where dust smaller than a few millimeters was observed to be actively accumulating and the tray receptacles were placed where accumulation appeared to be lighter. Where deemed appropriate, a representative “grab” sample of dust was gathered. Grab samples do not have accumulation rate data (ND).

When sampling was complete, the plastic bags were removed from the buckets, carefully closed to retain the wood dust, and knotted. The sample bag was then placed in a Ziploc bag and sealed to minimize the moisture change. The parchment paper was carefully folded in on itself to keep all the dust on the paper and transferred to a Ziploc bag and sealed. Grab samples were also sealed in Ziploc bags. Samples were returned to the FPInnovations laboratory in Vancouver and frozen until analysis.

At the time the samples were acquired, photographs were taken of each sampling area and moisture content was determined (Exotek hand-held sawdust moisture meter [MC-600SD-A] having a detection range of 8 to 50% moisture) from material that had freshly accumulated. A comparison of the on-site moisture samples and the in-lab measurements, which are more accurate, showed that there was very little change in the samples during shipping. In addition, the ambient temperature and relative humidity were recorded at the beginning of each mill sampling and at several other times throughout the day. There was no noticeable precipitation in the mill regions on any of the collection days. The relative humidity was generally found to vary more during the day than between collection days. An analysis of the sample moisture contents found no apparent correlation with the ambient environment conditions.

3.2.2 Sample Analysis

3.2.2.1 Moisture Content

In the laboratory, the total mass of each sample was recorded. For samples collected in the buckets, sub-samples of well mixed, room temperature sawdust were tested for moisture content (oven-dry method, 105°C). For samples collected on parchment paper, the parchment paper with wood sample was weighed then oven-dried (105°C) for particulate moisture determinations, unless the wet mass was greater than 25g, in this case, a subsample was tested for moisture. The oven-dry mass of the original sample was calculated. Samples having an oven-dry mass of less than half a gram had insufficient material for moisture determination.

Figure 2 Four types of receptacles were deployed to sample sawmill dust as it was generated: A) bucket lined with a plastic bag, B) tray covered with parchment paper, C) tray covered with microfibre cloth and D) an unlined tray (C and D were less effective and used only in the first two mills)

3.2.2.2 Particle Size

For samples having a total as-received mass of greater than 15g, "as-received" (not dried) particle size distributions were determined, using the following ASTM US Standard series of sieves (T.S. Tyler): 1mm, 425µm, 250µm, and 75µm and following the protocols suggested by Pope and Ward (1998). For samples having less than 15g of material, no data (ND) are given for particle size. Sieving was performed with a RoTap™ sieve shaker set for a 15 minute interval. The optimal shaking interval of 15 minutes was determined in a previous, unreported experiment conducted at FPInnovations with fine particulate biomass. Large samples (greater than 80g) were partitioned into representative subsamples for sieving on 30.5 cm diameter sieves. Smaller samples (15 to 80g) were sieved with 20.3 inch diameter sieves. For both sieve sizes, samples were not layered to a depth greater than ½ inch to avoid sieve blinding. The tare value (base mass) of each sieve was recorded prior to sample testing and the mass of material retained on each sieve recorded at the end of the shaking cycle. Percentages of the total amount sieved were calculated for each particle size fraction. Particle size distributions are presented as the percentage of the total mass of the material passing through each sieve.

3.2.2.3 Microscopy

Wood particles are typically not spherical and are more cylindrical in shape. This increases the surface area to volume ratio, which affects sieving and also likely the explosion testing. At a minimum the non-uniformity of the particles will create variability in the results. To better understand the shape of wood particles, macro and scanning electron microscopy (SEM) imaging were conducted on a few samples.

In macro imaging, a portion of each sample was deposited on the glass of a flatbed scanner and scanned along with a scale with the smallest division equal to 0.5mm. In SEM imaging, a portion of each sample was deposited on the surface of carbon tape affixed to a large SEM stub. Excess material was shaken from the stub to retain only particles firmly attached to the stub and to prevent obscuring the smallest particles on the tape. Samples were imaged, uncoated, in a Quanta 400F field emission environmental electron microscope in low vacuum mode. Images were collected and measured in Scandium image analysis software. The images were calibrated with a Geller MRS-3 reference grid.

3.2.2.4 Accumulation Rate

As noted earlier, the time period of accumulation was recorded for all dust samples that were collected from active accumulations. Utilizing the area of collection receptacles, time, and total mass (grams) of oven-dry material collected, the grams of sawdust over one square metre in an eight hour period were calculated for each mill dust sample where data was available.

3.2.2.5 Accumulated Dust Thickness

Deflagration hazard is determined by the thickness of accumulated fugitive, deflagrable dust. According to the NFPA 664 Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities (2012), a deflagrable dust hazard exists when its depth exceeds 1/8-inch or 3.2mm, on upward-facing surfaces over 5% or more of the total area. The 1/8-inch or 3.2mm definition of a deflagrable hazard is applied in this project but it is worthwhile to consider the applicability of the 3.2mm threshold with respect to wood dust. This will also facilitate determining a hazard threshold for the accumulation rate.

Equation for Allowable thickness (NFPA 664 - 2012 - page 664 to 668):

$$\text{Allowable thickness, } T_p \text{ (mm)} = \frac{(3.2mm)(321\frac{kg}{m^3})}{Settled\ Bulk\ Density, \frac{kg}{m^3}}$$

The applicability of the 3.2 mm Allowable Thickness of wood dust is dependent on the Settled Bulk Density as shown in the above equation. A value exceeding 321 kg/m^3 would suggest a lower threshold while a smaller value would suggest a higher Allowable Thickness. FPInnovations examined three particle size fractions (retained by the 425µm, 250µm and 75µm sieves) from two sawmill dust samples from each of 12 mills (24 samples in total). The Settled Bulk Density was replicated in the laboratory by sieving the dust samples over a container having a depth of 3.2mm and diameter of 3cm and recording the mass of sieved dust in the container adjusted to oven dry moisture. The wood dust had an average Bulk Density of 149kg/m^3 and ranged from 93kg/m^3 to 249kg/m^3. This suggests that the assumed 3.2mm wood dust threshold for a deflagrable hazard applied in this study is conservative. It is important to note that it was not the objective of this study to examine the Settled Bulk Density. Other factors such as vibration in sawmills, which may create compaction and increase bulk density were not considered.

The same 24 tests used to examine the Allowable Thickness can also be applied to examine accumulation. Scaled to a square meter area, 100% of the samples had a mass per unit area of 320g/m^2 or more when settled to a depth of 3.2mm. In this study, it is proposed that an accumulation of 3.2mm that occurs in 8 hours or less is an important threshold as it would indicate that inspection and possibly clean-up might be required during a typical production shift. Since some areas are not easily accessed during a shift, equipment and/or process design modifications to reduce this accumulation might be warranted. Therefore, 320g/m^2/8hrs, is a conservative threshold for the accumulation rate.

Following the above approach, a threshold of 160g/m^2/8hrs would suggest the requirement for inspection and possibly clean-up at the end of a two-shift production day and 32g/m^2/8hrs would delay the threshold to the end of a two-shift five-production day week.

3.3 Selection of In-mill Sampling Locations

To achieve the goal of characterizing the accumulating finer dust, the following guidelines were used for selecting in-mill dust sampling locations:

1. Target actively accumulating dust that appears fine (less than a few millimeters in size) excluding larger particulate material as judged by the collection team
2. Give priority to high areas due to the natural filtering of dust and the likelihood of this dust being finer
3. Target as many machines as possible and consistently in all sawmills to allow comparisons of particle size, moisture content, and to a limited extent, the spread of the dust from the machine
4. Target sources of dust where finer dust was naturally separating from the larger material setting two receptacles: one close to the source and one to sample the drifting dust
5. Ignore sawdust or chips going directly into a waste conveyor, which includes material that accumulates on the edge of the chuting that would be pushed into the conveyor as part of regular clean-up

6. Do not sample in locations where traps could be disturbed such as landing decks where traps could be hit by boards. However, place traps above, below or beside these areas if material is accumulating on the floor or cat-walks. Collect grab samples for determining particle composition in cases where it is not possible to calculate an accumulation rate
7. Safety: in cases where sampling was targeted in a locked-out area, place receptacles during breaks and remove them at the shift, or saw change. Access areas above working machines where possible from cat-walks.

For each mill, about ten parchment traps and ten bucket traps were put out, and extra traps were deployed, if required. The target was to collect sufficient quantities of dust to allow for a full analysis to be undertaken. Grab samples were also collected to determine the particle size distribution and/or the moisture content of material that could not be collected with a trap, such as sawdust on a landing deck. Some of these samples were also intended for explosibility tests which require large volumes of material. In these cases, the goal was to collect visibly finer dust.

Table 2 shows a summary of the dust collected at the 18 sawmills denoted A through R. Unfortunately, there were differences in the dust collection locations at each mill due to the different mill configurations, where the dust was accumulating and the availability of safe collection locations. To facilitate comparison among sawmills the areas have been grouped as the log In-feed, Primary breakdown, Secondary breakdown, Trim-sort, Transfer systems, Basement and Planer. Included in these are locations at higher elevations. It is important to note that the Basement samples were collected typically under machinery, transfer systems or dust collection systems. These samples are listed in the Basement category to indicate where the dust was found accumulating.

Table 2 shows that the common collection areas where dust was most often actively accumulating were Primary breakdown, Secondary breakdown and the Basement.

Table 2 Sample number for various machine centres in each mill surveyed, includes grab samples

Mill	In-feed	Primary Breakdown	Secondary Breakdown	Trim-sort	Transfer systems	Basements	Planers	Total
A	1	2	5	0	2	9	0	**19**
B	2	4	3	1	3	7	0	**20**
C	2	5	2	1	5	11	1	**27**
D	1	3	4	0	1	12	0	**21**
E	2	1	5	2	1	12	0	**23**
F	0	5	4	1	1	4	1	**16**
G	0	4	5	1	2	5	0	**17**
H	0	4	6	1	0	8	0	**19**
I	1	4	1	0	1	10	0	**17**
J	0	1	6	1	4	7	0	**19**
K	1	4	5	2	1	8	0	**21**
L	0	7	2	3	0	5	0	**17**

Mill	In-feed	Primary Breakdown	Secondary Breakdown	Trim-sort	Transfer systems	Basements	Planers	Total
M	1	9	6	1	1	21	0	**39**
N	0	2	2	0	3	13	1	**21**
O	0	2	5	0	2	14	0	**23**
P	0	6	1	1	1	12	1	**22**
Q	0	4	2	2	0	10	0	**18**
R	1	2	5	3	4	5	1	**21**
Total	**12**	**69**	**69**	**20**	**32**	**173**	**5**	**380**

3.4 Limitations of the Sampling Method

While the sawdust that collected in the traps provided material for moisture content, particle size analysis and a measure of accumulation rate, the use of traps limits the data interpretation:

1. The traps collected dust from a limited area and were positioned at points in the sawmill with the highest accumulation rates. The distribution of accumulation in an area was not measured. For example, traps were located below a leak in a transfer system; as a result, the measured accumulation rates may represent the maximum for the area.
2. The data includes only information on the dust sample:
    - This project did not collect information on other explosibility risk factors such as ignition sources or the area covered by the dust. Consequently, the information in this report is not intended to provide assessments of risk at the individual sawmills
    - The samples do not provide a measure of the total amount of dust produced by a source, or by the mill as a whole since only dust from a fixed area is collected in each trap

Statistical analysis of the sawdust was planned but ultimately rigorous statistical analysis was not possible due to differences in the collection locations and an inability to include low accumulation rate data. There are a number of factors that led to this unexpected problem:

1) Sampling duration - many sampling locations produced too little dust to allow analysis in the one-day sampling time: less than15 grams does not permit particle size determination and less than 0.5g does not permit moisture determination. Accumulations of less than 0.5 grams were assumed to be negligible, but have been included in the data analyses. An accumulation of 0.7g/m^2/8hrs or less suggests that a year or longer would be required to accumulate 3.2mm of dust.

2) Differences in sampling locations - some machines that generated measureable amounts of sawdust at one mill did not yield any measureable sawdust at another mill. This did not permit a consistent analysis of machine centres in each mill.

3) Sample number - the number of dust samples collected in each mill varied depending on sawdust accumulations specific to the site. Also, as noted above, not every trap yielded sufficient dust for a complete evaluation. In a number of instances, there was no measureable sample.

It is important to note the accumulation rate data are based on measured values from specific locations and may not reflect overall dust accumulations that are occurring in the mill. Areas of active accumulation were targeted and the area for each sample was limited to the dimensions of the sample container, as such, the accumulation rate calculations are specific to the time and location of sampling. This data is meant to provide guidelines for sawdust generation and help identify machine centres that pose the greatest potential for deflagrable dust generation and/or accumulations. It is also important to note that as previously discussed, the sampling regime was not exhaustive and there may be sources of high-risk sawdust that were not evaluated in this project.

3.5 Dust Explosion Testing

To improve the design of the explosion testing in this project, seven wood dust samples were sent to the FM Global Group laboratory in West Glocester, RI for preliminary Explosion Severity testing. These results were applied to help guide the selection the explosibility test samples for this project.

Twenty-five (25) samples were targeted for explosibility tests in this project but ultimately, 31 samples were sent. It was difficult to collect sufficient quantities of fine dust in Coastal BC sawmills. Consequently, western hemlock and amabilis fir (Hem-fir) grab samples were also acquired from nearby sawmills. This number of samples allowed the dust source (MPB - mountain pine beetle-killed lodgepole pine; SPF - spruce/pine/fir; and DFC – Douglas-fir/ western red cedar/Hem-fir), moisture content and particle size to be examined in the explosion testing with a number of approximate replicates to provide an indication of variability. This assumes that other factors, such as the sawmill and the machine from which the dust was generated, are not primary factors affecting explosibility. If these are inaccurate assumptions there should be significant variation in the results and trends among the SPF group, which had the most samples and the most mill and machine sources. Other factors may be important, or even primary factors, but they may not lead to obvious variations in the results since they could cancel each other out, or may just happen too close together, especially with the relatively small number of samples tested.

The focus of the explosion tests was to compare MPB versus SPF and the low and high moisture content samples in this group. Almost half, 12, of the tests examined the particles sizes and their explosibility readings. The remainder of the tests examined higher moisture contents in this group and the third DFC source group.

3.5.1 Sample Collection

For dust explosion testing, fine sawmill dust samples of approximately 10kg were collected in areas of high accumulation at several mills. Ten kg of dust was targeted since Chilworth indicated that 1.2kg of dust was required for a full series of explosion tests and the mixed particle size samples from the sawmill would typically yield 10 to 20% of one particle size class.

3.5.2 Sample Analysis

3.5.2.1 Moisture Content

The moisture content of samples received by FPInnovations was measured from the upper, middle and lower portions of each 10kg sample bag, using the protocol described in Section 3.1.2.1. Chilworth repeated the moisture measurement for samples they received.

For explosibility testing purposes, the moisture content of many of the samples were modified. Many of the dust samples were dried to approximately 5% moisture content (MC) on wet basis. Approximately half of the samples with a MC of 24% were hydrated by FPInnovations in its conditioning chambers to increase the MC for testing. The other portion was tested as received. The samples with MC greater than 5% and less than 24% were tested as received. The MC noted in the Chilworth explosibility tests is measured MC of the test samples.

3.5.2.2 **Particle Size**

The samples selected for explosion testing were processed and sieved differently than the samples destined for particle size, moisture content and accumulation rate analysis as described in Section 3.2.2.2. The purpose of the sieving with the explosion tests samples was to create particles with an average size of approximately 425µm, 250µm, 140µm and then particles smaller than 75µm to examine the effect of these size classes. To accomplish this, each large grab sample batch was sieved sequentially with four sizes of Tyler Standard sieve cloths: 500µm, 355µm, 212µm and 75µm. To perform the suite of explosion tests, approximately 1200g of sawdust was required. None of the samples collected for these tests, even after repeated visits to several sawmills, yielded enough dust that passed the 75µm sieve to perform any of the explosion tests.

Chilworth conducted independent particle sieving on a sub-sample of the particles they received. For particle classes of 500 µm or less: 75µm, 90µm, 106µm, 150µm, 300µm, 425µm and 500µm sieves were used. For particle classes larger than 500µm: 600µm, 710µm, 1000µm and 2000µm were also employed. The average particle sizes note in the Chilworth explosibility tests were calculated based on the results of this sieving.

3.5.2.3 **Combustible Dust Hazard Testing**

Chilworth was contracted to conduct explosibility analysis on the dust samples examining six properties: three as part of Explosion Severity and three as part of Ignition Sensitivity. The Explosion Severity properties include the Maximum Pressure (P_{max}) and Deflagration Index (K_{st}). The maximum rate of pressure rise $(DP/dt)_{max}$ was measured but is not discussed in the report as the results typically mirror the Deflagration index. The Ignition Sensitivity properties included Minimum Dust Cloud Ignition Energy (MIE), Minimum Dust Cloud Ignition Temperature (MIT-cloud) and the Minimum Explosible Concentration (MEC).

4 Results of Dust Sampling and Analysis

In total, 380 samples were collected from 18 sawmills with 168 on-site moisture measurements (data not shown), which included 300 active accumulations and 80 grab samples. Sampling focussed on areas where fine sawdust appeared to be accumulating. In most mills, the Basement was the site of the most actively accumulating sawdust; consequently more than 40% of the samples obtained were from the Basement. Sampling was centred on acquiring fine sawdust that was actively accumulating; therefore almost 80% of the samples were acquired from sawdust as it was being generated.

Of the 380 samples, 21 samples were not analysed for various reasons including keeping some samples in reserve and 15 were processed only for explosibility testing by Chilworth and FMGlobal. Of the remaining 344 samples, 295 samples had accumulation rates calculated, 276 were analyzed for moisture content and 159 were analyzed for particle size. The remaining samples for each characteristic were not analyzed mainly due to insufficient collected material. It should be noted that this is a positive outcome as it indicates that the dust accumulation was lower than expected in many instances. Table 3 gives a summary of sampling distributions with respect to machine centres, elevation, sampling method and the distance from the machine.

One of the challenges with this dust survey was the evaluation of data. Complete analysis of all the sampling traps that were deployed was not possible, as explained above, which limited the types of data analysis that could be performed. For the samples analyzed, unequal sample numbers between sample categories, as shown in Table 12 between species types and regional groupings, and incomplete data for many samples meant that thorough statistical and multivariate analyses were not possible. In the results that follow, the data were explored as thoroughly as possible, by looking at all the data for every variable measured first, then segmenting the data into categories for species and region, and finally, focussing on specific attributes within the mills: machine centres, elevation and distance from machines to explore possible trends and patterns in the data.

Table 3 Number of samples analyzed for accumulation, MC and/or particle size by collection location

By Machine Centre							
	In-feed	**Primary Breakdown**	**Secondary Breakdown**	**Trim-sort**	**Transfer System**	**Basement**	**Planer**
Sample Count	12	67	67	19	29	145	5
By Elevation							
	High	**Main**	**Basement**				
Sample Count	60	139	145				
By Distance from Machine							
	<1m	**1-3m**	**>3m and basement**				
Sample Count	84	36	224				
Sample Method							
	Grab	**Active Accumulation**					
	44	300					

4.1 Data Overview

FPInnovations laboratory performed moisture content, accumulation rate and particle size analyses on all samples with sufficient quantities of dust. Moisture content was determined for 276 samples but for most of the other samples the particle mass was too low (less than 0.5g) to allow moisture content determination. For the purposes of comparison, the moisture contents were segmented into four categories on a wet basis: wet (>25%), medium (21 to 25%), dry (12 to 21%) and very dry (12% or less). The largest proportion of samples had moisture values greater than 25% (wet basis) as shown in Figure 3 while 20% were considered to be very dry.

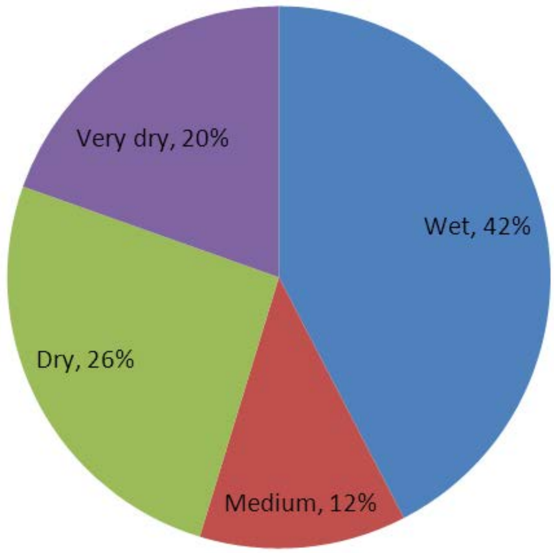


Figure 3 Sawdust samples categorized by moisture content (% wet basis): wet = >25%, medium = 21 to 25%, dry = 12 to 21% and very dry = <12%

The calculated accumulation rates from the 295 available samples showed that the majority, 55%, had less than 320g/m^2/8hrs accumulation, as shown in Figure 4. This accumulation rate is an estimated threshold that would result in 3.2mm of dust accumulation in 8 hours. Nineteen percent of the samples had calculated accumulation rates greater than 5000g/m^2/8hrs, which could result in an estimated 50mm of dust accumulation or more, in 8 hours. It is important to note that this project targeted the highest fine dust accumulation rate areas so these rates would generally represent the highest in the mills sampled. It is also important to consider the accumulation rates at the same time as the particle size of the dust since a high accumulation of fine dust might indicate a more significant hazard. This is discussed in Section 7.

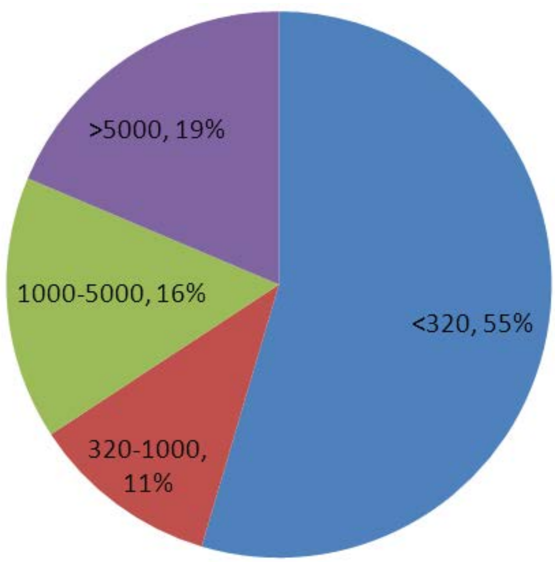


Figure 4 Accumulation rates categorized by grams of material accumulating over a square metre in eight hours

The 159 samples available for particle size analysis were sieved through the 1000µm, 425µm, 250µm and 75µm sieves as noted in Section 3.2.2.2. The total amount of material collected at many sawdust collection traps did not yield enough material to perform particle size distributions with the sieving equipment available. Small amounts of finer particles may have been present on the traps but this material could not be evaluated. This was not considered significant since these samples made significantly less than 1% of the collected dust by mass. Therefore, values for average particle sizes and the percent of material passing through the 425µm sieve for a given region or mill did not account for material that accumulates at a very slow rate. It is estimated that the one day sampling process applied in this project would not detect accumulations requiring more than 3 months to reach a depth of 3.2mm.

Figure 5 shows a summary of the particle size distribution for the samples that were analyzed. On average, 45% of the particles sieved were larger than 1000µm (based on the proportion of the mass of the particles that did not pass through the sieve), while 75% of all particles sieved were larger than 425µm. Note that only 1% of all particles tested were smaller than 75µm based on the mass proportion.

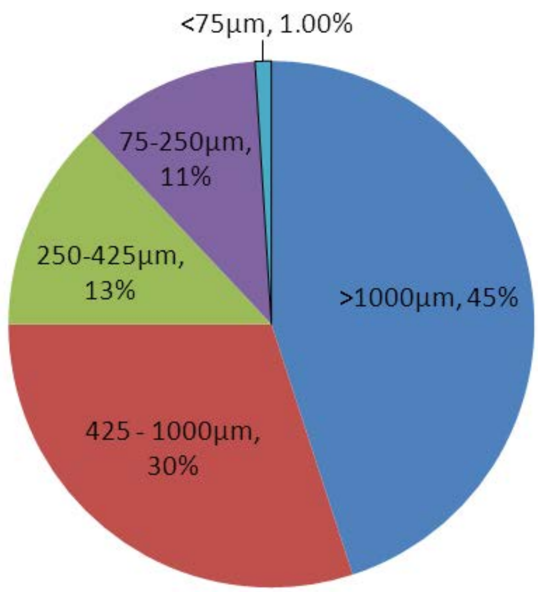


Figure 5 Total percentage of particle mass retained by the 1000µm, 425µm, 250µm, 75µm and pan (<75µm) sieve cloths

4.1.1 Factors Affecting the Precision of Particle Size Classification

The particle size distributions should not be viewed as absolute. There is a number of sawdust and analytical attributes that influence whether a particle will pass through the sieve. These factors would not have a significant impact on the results but it is important to consider them as they will generate some variability in the results. Every sample was submitted to Rotap™ sieving for an equivalent amount of time. The time used to sieve the samples was optimized for a selection of dust samples. In most instances, the time used to agitate the sample would provide adequate separation by size, but limit damage to particles so they were not reduced to smaller sizes by the sieving process. However, a small percentage of fine particulate may be retained on a larger sieve and a fraction may also be broken down passing through to a finer sieve. Cylindrically shaped particulate may also be retained on a sieve that has openings greater than its smallest dimension because it was not oriented such that it could pass through (i.e. the longest dimension of the cylinder was presented to the sieve opening, not the narrowest dimension).

Figure 6, Figure 7 and Figure 8 show a selection of typical particles. Figure 6 shows two samples that passed through the 1000µm sieve but were retained on the 425µm. Sample A appears to be comprised of granular or cylindrical particles that are discrete from each other, while sample B seems to be very fine, fluffy particulate that has agglomerated into clumps. Extended Rotap™ sieving caused sample B to form clumps of the fine material without notably increasing the amount that passed to the finer sieve.

Figure 7 shows material retained on the 1000µm sieve. There appears to be fine sawdust that adheres to the larger material. This may be caused by static electricity or some other factors, but the result is that these fine particles are not separated from the larger sized ones during sieving. During microscopic analysis of the sieved sample fractions, droplets of material that may be pitch were observed, however this was not confirmed experimentally. Pitch would further facilitate the agglomeration of fine particles.

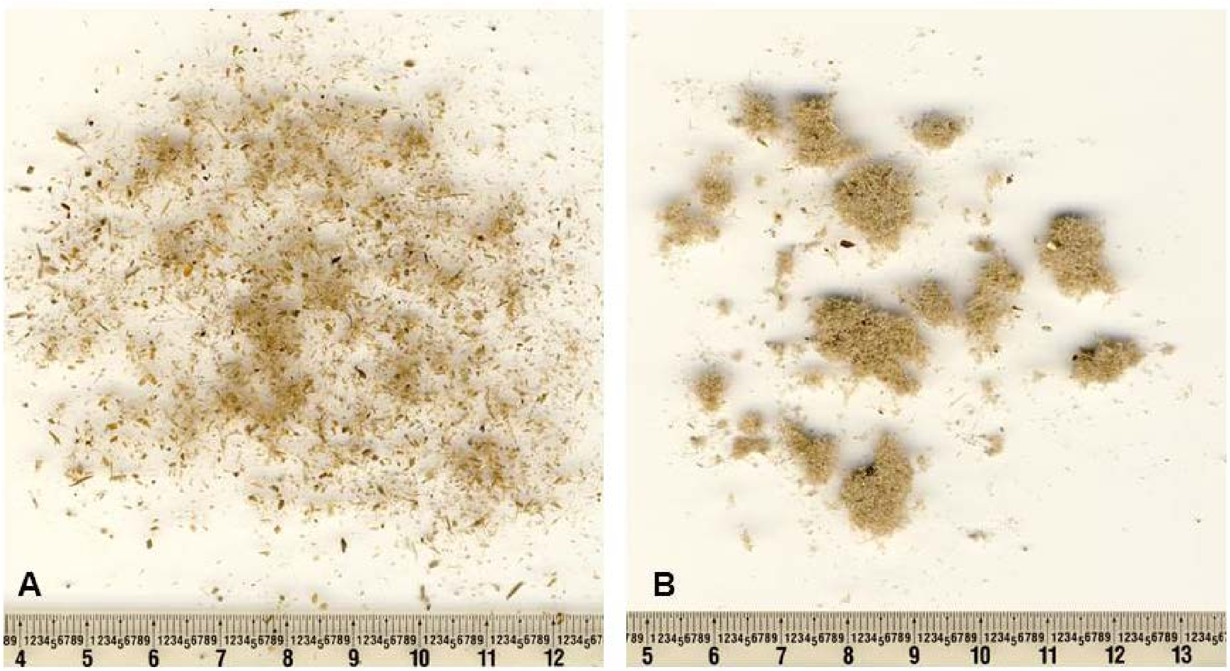


Figure 6 Macro images of two types of sawdust. Both samples passed through a 1000µm sieve and were retained by a 425µm sieve

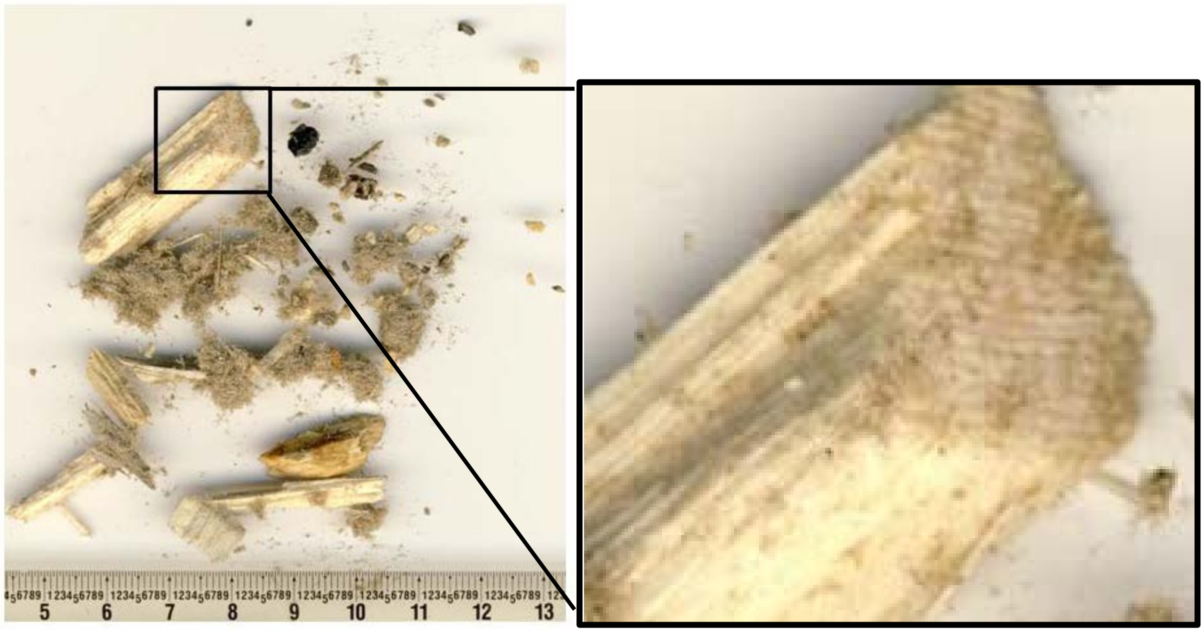
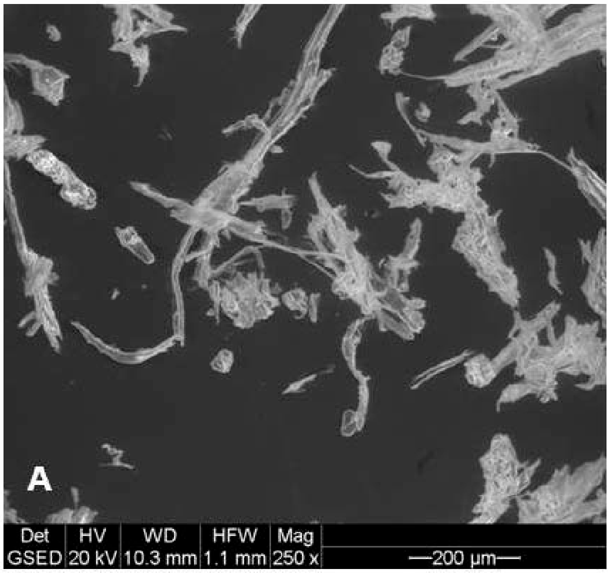


Figure 7 Particles retained by the 1000µm sieve with clumps of fine material adhering to the larger particles

Images of sawdust samples shown in Figure 6 (A and B) that were acquired with a scanning electron microscope (SEM) are presented in Figure 8. SEM images were taken of the material retained on the 1000µm and 425µm sieves for both samples A and B and a selection of the smaller particles were measured for each of these samples (note that the larger particles shown in Figure 7 would not adhere to carbon tape on the SEM sampling stump and consequently, do not appear on the SEM image). The average particle size for small material retained on the 1000µm sieve for sample A was 129µm and was 29µm for the 425µm sieve. For sample B, the average size of the small material measured from both the 1000µm and 425µm sieves was approximately 50µm. These examples demonstrate the limitations of Rotap™ sieving for particle size analysis of sawdust, particularly for material that is comprised of very fine, cylindrically shaped material that will become entangled and form clumps when manufactured in the sawmill or during sieving.



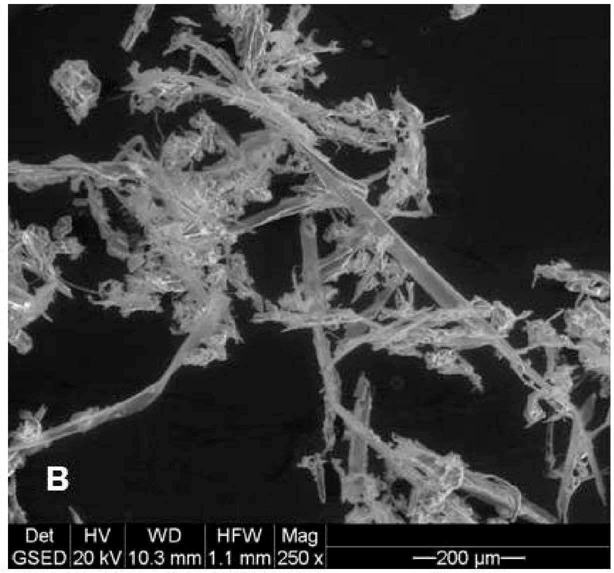


Figure 8 Image A and B are SEMs of the particles from Figure 6, image A and B, respectively

4.2 Comparison of Species

The timber processed by all the mills was segmented into three species/source categories to allow for comparisons among predominantly mountain pine beetle-killed lodgepole pine (MPB), a mixture of spruce, pine and fir (SPF) and a DFC group that includes: coastal western red cedar, coastal Douglas-fir and interior Douglas-fir.

4.2.1 Moisture Content

Atmospheric conditions were collected in each mill and sampled multiple times during the collection period (data is not included in this report). Unfortunately, its effect on the MC of wood dust and especially its change with time was inconclusive likely due to the short sample time. The MC generally showed little change over the 6 to 8 hours of the collection period but this may have been due to the active accumulation, which will be discussed in Section 5.9. Sawdust that accumulates over a longer period of time would generally be expected to equalize to the ambient moisture conditions. Consequently, the moisture analysis in this report focuses on samples analyzed in the laboratory and assumes that the atmospheric conditions have no impact on wood dust that is actively accumulating.

More than 60% of MPB samples were categorized as either dry or very dry, while 25% of MPB samples were wet as shown in Figure 9. This may reflect the processing of drier MPB-killed lodgepole pine. The SPF mills have a somewhat different overall moisture profile; there are many wet, dry and very dry samples, but very few samples with medium moisture values (21 to 25% wet basis). The high portion of wet SPF samples may be explained in part by the processing of green timber. Mills processing species that fall into the DFC group have predominantly wet sawdust (>25% wet basis moisture) and 10% of the samples classified as very dry (<12% wet basis moisture). This moisture distribution suggests the processing of fresh timber.

The effects of sawmill misting systems were also examined but like the ambient moisture conditions, the impact of these systems was unclear and requires further examination. Again, this is likely due to the project's focus on active accumulating saw dust and the 6 to 8 hour duration of the collection period. It would be expected that if the misting systems increase the ambient moisture content that this would have an impact on the moisture content of the sawdust accumulating over a longer time.

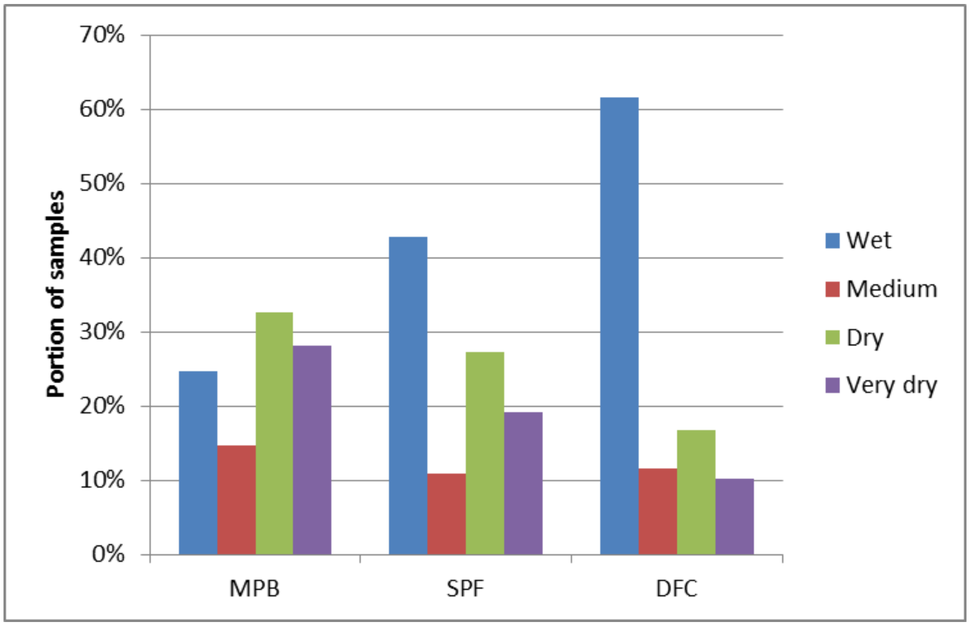


Figure 9 Sawdust samples categorized by moisture content (% wet basis): wet = >25%, medium = 21 to 25%, dry = 12 to 21% and very dry = <12%

4.2.2 Accumulation Rate

The accumulation rate profiles obtained for the three species/source categories are presented in Figure 10. Generally, the rates of sawdust accumulation are comparable in the three categories. The majority of sawdust accumulates at a rate that is less than 320g/m^2/8hrs or less than 3.2mm in 8 hours. The SPF mills appear to have more samples that accumulated in the >5000g/m^2/8hrs class than those processing DFC or MPB: 23% for SPF versus 15% and 17%, respectively. This rate is estimated to result in more than 50mm of dust accumulation in 8 hours. As noted earlier, it is important to reserve judgement on these values as the content of potentially hazardous particles must also be considered.

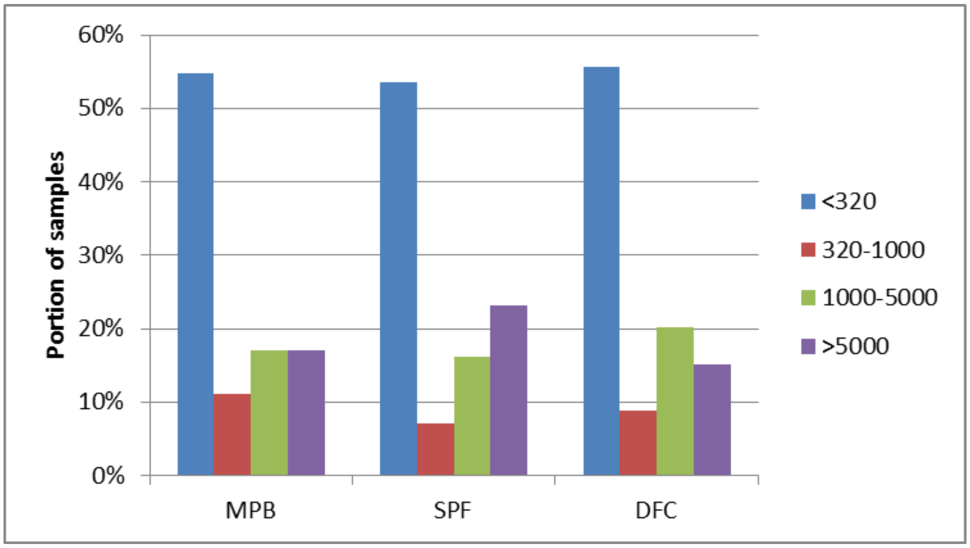


Figure 10 Accumulation rates categorized by grams of material accumulating over a square metre in eight hours

4.2.3 Particle Size

An overview of particle size distribution by species/source is provided in Figure 11. The MPB samples had a significantly larger proportion by mass of finer wood dust 425µm and smaller. Particularly notable is the higher proportion of 250µm and smaller wood dust. Approximately 37% of the MPB sawdust passed through the 425µm sieve and more than 20% of the MPB samples passed the 250µm sieve. For SPF this was 24% and 11%, respectively, and for DFC this was 16% and 6%, respectively. This data suggest that mills processing MPB-killed lodgepole pine have approximately twice the fine sawdust by mass (passes a 425µm sieve). It is interesting to note that the proportion of dust 1000µm and smaller by mass is similar for all three species/source categories.

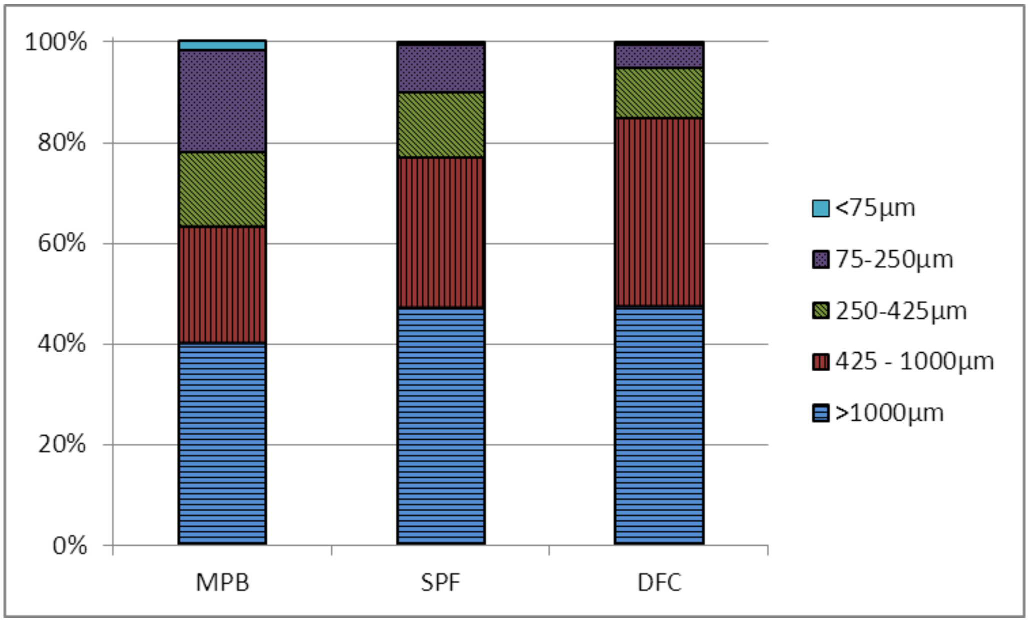


Figure 11 Percentage of particles by mass analyzed that were retained by a given dimension of sieve cloth: 1000µm, 425µm, 250µm, 75µm and pan (<75µm)

4.3 Regional Comparisons

4.3.1 Moisture

The combined data from all participating sawmills was evaluated for regional trends. The mills were divided into four regional categories: BC Coastal, Northern Interior, Central Interior and Southern Interior as shown in Table 1. The moisture content of samples collected in these regions is presented in Figure 12. As expected from the transport and storage of logs in water, the samples from the Coastal region have the highest portion of wet (>25% wet basis moisture) samples and the least amount of dry and very dry samples. The region with the second highest proportion of wet samples at more than 40% was the Southern Interior with only slightly more very dry (<12% wet basis) samples. The Central and Northern Interiors had drier samples with over half being dry and very dry.

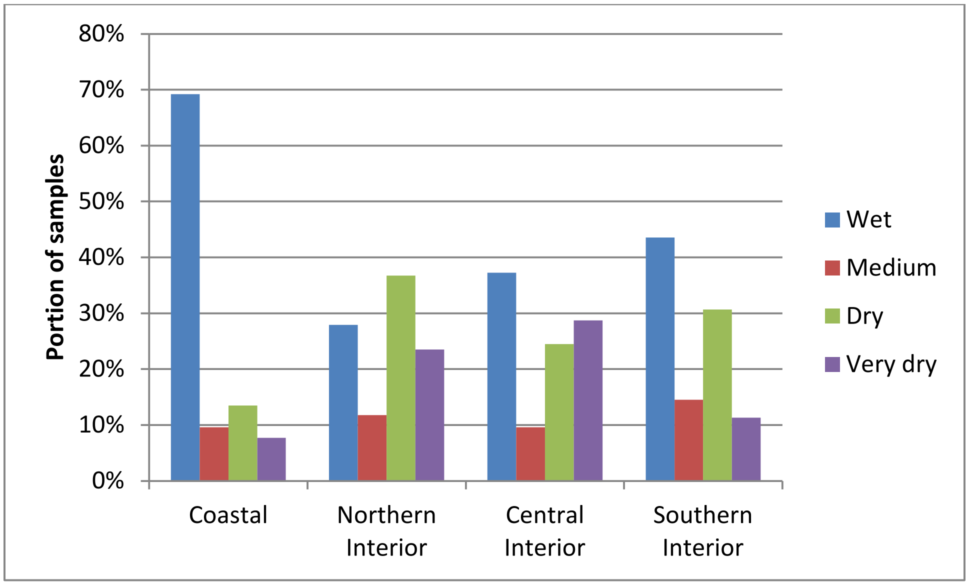


Figure 12 All sawdust samples are categorized by region and moisture content (% wet basis): wet = >25%, medium = 21 to 25%, dry = 12 to 21% and very dry = <12%

The average moisture values for each sawmill are presented in Table 4. The values for the two Coastal mills are the highest but each region has mills with wet average moisture. The Central, Southern and Northern Interior regions each have mills with less than 25% wet basis moisture but the Northern and Central Interior have mills with notably lower average moisture values (<20% wet basis). These mills influenced the overall percentage of very dry samples that are shown in Figure 12 for the two regions.

Table 4 Average moisture (% wet basis) determined for 18 sawmills grouped by region

Region	*Mill*	*Moisture (% wet basis)*	*Region*	*Mill*	*Moisture (% wet basis)*
Southern Interior			*Northern Interior*		
	N	21.0		D	17.8
	G	26.5		E	18.0
	J	26.5		I	21.1
	A	29.4		H	22.8
				O	24.0
				L	25.6
Central Interior			*Coast*		
	C	16.3		K	33.2
	M	21.7		P	43.6
	R	22.6			
	Q	23.1			
	B	26.6			
	F	29.2			

When the regional mill average MCs are considered with the species/source, it is notable that all the MPB sawmills participating in this study were located in the Central and Northern Interiors. The slightly lower average MC of these sawmills reduced the average for the region.

4.3.2 Accumulation Rate

A comparison of accumulation rates by region is presented in Figure 13. The regional trends show some differences in accumulation rates with a significant proportion exceeding 320g/m^2/8hrs (3.2mm in 8 hours). As noted previously, it is important to consider other factors such as the particle size of the dust before assessing the hazard. The Central Interior shows samples with the lowest accumulation rates, with more than 60% below 320g/m^2/8hrs of accumulation. The Coastal and Northern Interior regions followed closely with more than 50% below 320g/m^2/8hrs. The Southern Interior had significantly higher accumulation rates than the other regions with more than 50% exceeding 320g/m^2/8hrs. This region also had the highest proportion of samples in the 320g/m^2/8hrs to 1000g/m^2/8hrs range and the highest proportion exceeding 5000g/m^2/8hrs.

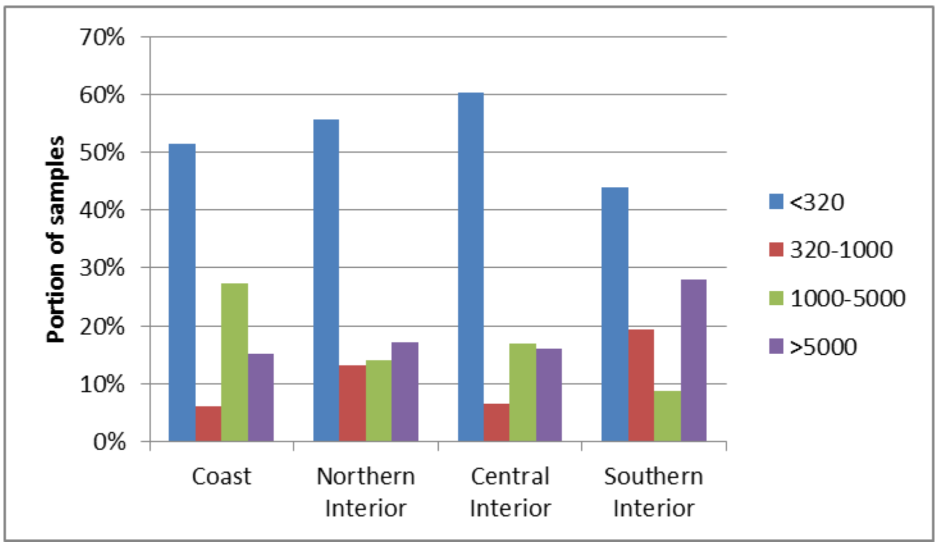


Figure 13 Accumulation rates by region categorized by grams of material accumulating over a square metre in eight hours

When the regional average accumulation rates are considered with the species/source, it is notable that the highest proportion of SPF sawmills participating in this study were located in the Southern Interior. The slightly higher average accumulation rate of SPF sawmills increased the average for the region.

4.3.3 Particle Size

Table 5 shows by region the percentage, based on mass, of particles passing the 1000μm, 425μm, 250μm and 75μm sieve cloths. It is important to reiterate that the dust collection focused on sources of dust with fine particles below several millimetres in size. Table 5 shows that near equivalent portions (approximately 50%) of particles passed through the 1000μm sieve in the four regions, but the Central Interior had a somewhat higher portion (57%) of smaller particles. This indicates that on average, half of the particles in all regions were greater than 1000μm or 1mm in size. The Central and Northern Interior regions had the highest mean proportions of dust in 425µm or smaller category and in particular, 250µm or smaller. Another interesting point is that in every region, there was very little particulate that was fine enough to pass through the 75µm sieve cloth. A comparison of the maximum and minimum percentages for each particle size class and region showed that the material collected in the Northern and Southern Interior have a similar range of values, while the Central Interior exhibits a higher maximum percentage of material that will pass through the 250µm sieve. They also showed that in each region there were mills that had lower percentages of one particle size while others had much higher percentages.

Table 5 Summary statistics by region of average percentage of particles passing through a given sieve opening (µm)

	Coast				**Northern Interior**			
Sieve opening (µm)	***1000***	***425***	***250***	***75***	***1000***	***425***	***250***	***75***
Mean (%)	51	14	5	0	52	28	14	1
Std. Error (%)	6	4	2	0	5	5	3	0
Median (%)	53	6	0	0	48	12	3	0
Std. Deviation (%)	28	20	9	1	34	30	21	2
Range (%)	83	64	31	4	97	96	75	7
Minimum (%)	11	0	0	0	3	0	0	0
Maximum (%)	95	64	31	4	100	96	75	7
Count	20	20	20	20	43	43	43	43
95.0% CI	13	9	4	1	10	9	6	1

	Central Interior				**Southern Interior**			
Sieve opening (µm)	***1000***	***425***	***250***	***75***	***1000***	***425***	***250***	***75***
Mean (%)	57	25	13	1	49	17	7	0
Std. Error (%)	5	4	4	0	4	3	2	0
Median (%)	53	12	2	0	42	9	1	0
Std. Deviation (%)	30	29	23	2	25	21	14	2
Range (%)	90	94	91	8	94	91	73	11
Minimum (%)	10	1	0	0	3	0	0	0
Maximum (%)	100	95	91	8	97	91	73	11
Count	42	42	42	42	39	39	39	39
95.0% CI	9	9	7	1	8	7	4	1

When the particle size proportions are considered both regionally and by species/source, it is notable that the trends in the region tend to follow the species/source processed by the majority of the mills. All of the MPB sawmills examined in this study were in the Central and Northern Interiors and the particle size proportions follow trends similar to these wood species/source.

4.4 Dust Variation Within Mills

When the sawmill dust sampling was designed, it was thought that a number of key factors might affect the dust particle size, moisture content and accumulation rates and therefore might be areas of increased risk. These factors included elevation, above and below the dust generating sources, and the machine centre. Elevation was considered since experience from other industries has shown that dust at higher elevations is typically finer. Machine centres were included since some machines are designed to make larger cuts while others are designed for more refined cuts and consequently, the maximum dust particle size might vary accordingly.

Horizontal distance from the dust source was also considered, but the analysis showed mixed results. Many locations, especially at longer distances from the dust sources, collect dust from multiple sources making it difficult to isolate this factor.

It is important to note that a guiding principle of the sampling process was that samples were collected only where dust was observed to be accumulating. In some instances, there was no obvious dust accumulation or the accumulated dust quantity was too limited for analysis. This sampling principle impacted the results presented in this section and should be considered when drawing conclusions.

4.4.1 Moisture Variation Within Sawmills

The moisture variation by elevation and machine centre are shown in Figure 14, Figure 15 and Figure 16. The average moisture values are calculated for three sawmill elevations: Basement – below the main lumber production floor, Main – the floor of lumber production and High – heights significantly above the main floor such as on cat-walks, on ducting and on top of control booths.

Figure 14 shows the average moisture content for the dust samples collected at each of the 18 sawmills denoted A to R. The Main elevation had the highest average moisture content in 11 of the 18 sawmills. The High elevation had the lowest average moisture content samples in half of the mills where high elevation samples were collected and analyzed for moisture content, but there were also many with the lowest average moisture content in the Basement. It is important to note that many of the sample traps placed at higher elevations did not yield sufficient material for moisture determination and as a consequence were not included in the analysis. If the sampling duration was longer and more material was collected, the findings may have been affected.

When the average moisture content was analyzed by elevation and average distance from the dust generation source as shown in Figure 15, a number of clear differences arose. Within 2 metres of the dust generation source, the samples were drier at High elevations and wetter on the Main floor. Again, at longer distances from the machine the moisture content was more variable likely due to mixing of dust from multiple sources.

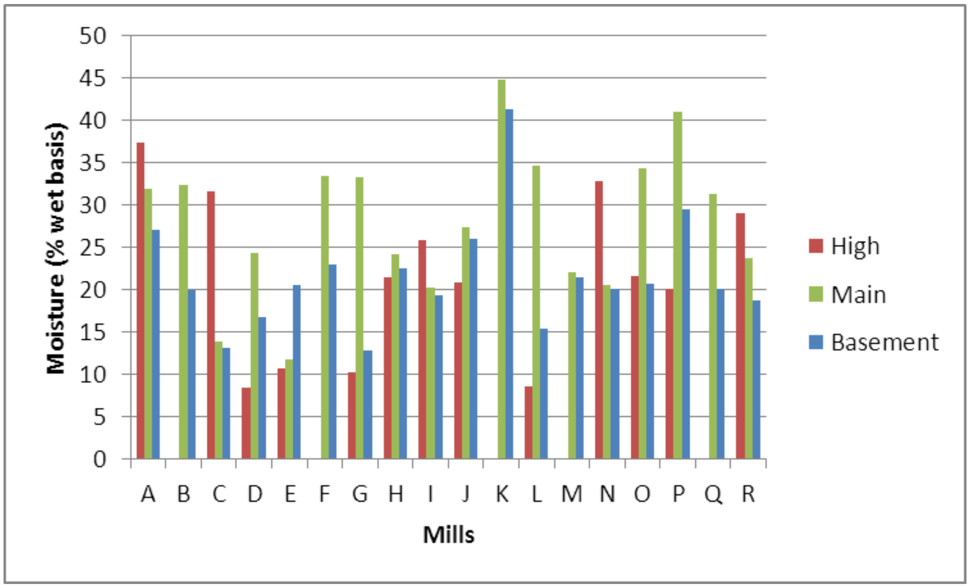


Figure 14 Average mill sample moisture contents for High, Main and Basement elevations (only 14 mills had samples collected from High locations)

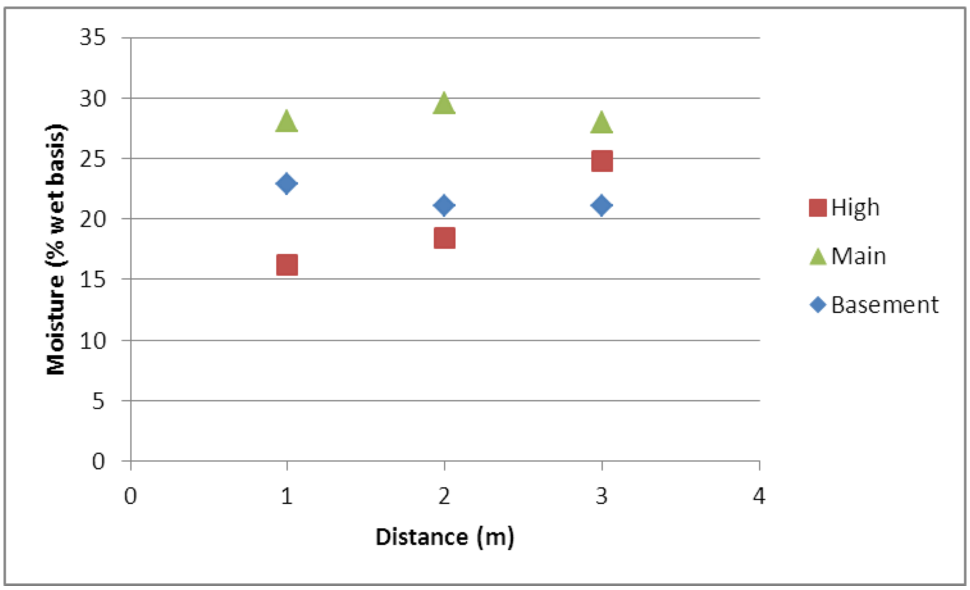


Figure 15 Average sample moisture content by High, Main and Basement elevations segmented by distance from source

The average moisture values (% wet basis) determined from sorting the data by machine centre source are presented in Figure 16. The graph shows that the moisture content is generally higher early in the breakdown process. It is not clear why the moisture content is highest at the Secondary breakdown machines but these included gang-edgers where the saw guide water appeared to increase the moisture content of sawdust. Once the dust is transferred away from the breakdown processes in the Transfer systems, Basements and at the Trim-sort, the moisture content is generally lower. It is important to note that while there are many samples for most of the machine centres, there are only five samples for the In-feed category and four for the Planer as shown in the summary statistics in Table 6. This likely affected the results in these areas as the Planer would generally be expected to have lower moisture contents than the Primary breakdown areas. Furthermore, the range of data within each category is broad and a reflection of differences in the overall moisture for a given site. It is difficult to determine if, for example, the Trim-sort always had lower moisture content samples than Primary and Secondary breakdown. Trim-sort samples were not collected from a mill if active accumulations were not found or the accumulation was too limited for analysis.

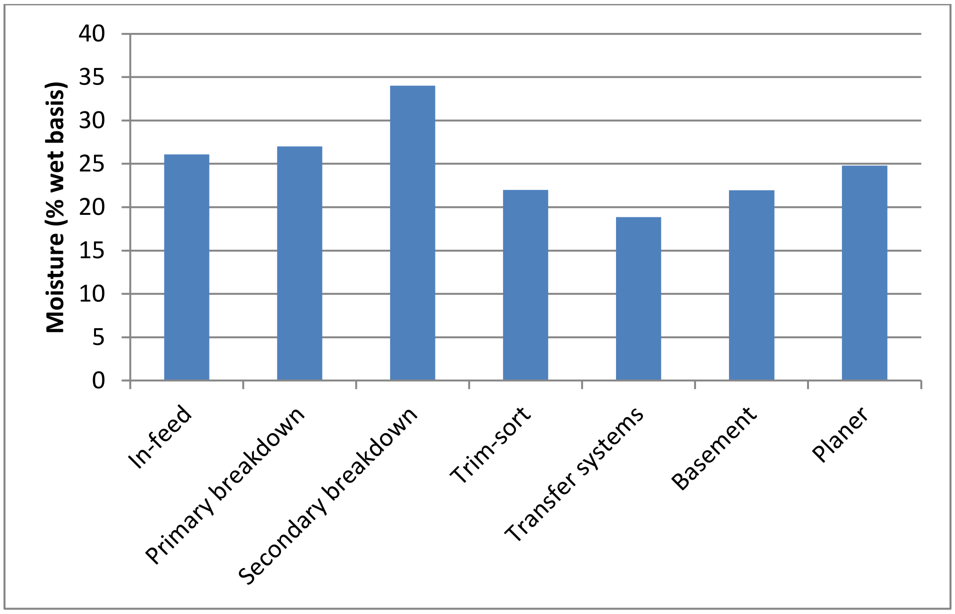


Figure 16 Average moisture content (% wet basis) by machine type

Table 6 Moisture content (% wet basis) summary statistics for machine types

	In-feed	Primary breakdown	Secondary breakdown	Trim-sort	Transfer systems	Basement	Planer
Mean	26	27	34	22	19	22	25
Standard Error	9	2	2	3	3	1	8
Median	23	25	34	23	15	19	25
Standard Deviation	20	16	15	12	13	12	16
Range	45	69	54	39	49	60	33
Minimum	7	0	6	6	6	3	8
Maximum	52	69	60	46	56	63	41
Count	5	46	49	14	21	137	4
95.0% CI	25	5	4	7	6	2	26

4.4.2 Accumulation Rate Variation Within Sawmills

The average accumulation rates ($g/m^2/8hrs$) for the three mill levels (Basement, Main and High) are shown with summary statistics in Table 7. The average accumulations in the Basement and the Main elevations are similar, however the range of values are greater for the Basement. There was one sample obtained in the Basement of a Northern Interior mill that strongly influenced the average accumulation rate. If the sample having a value of greater than 290,000$g/m^2/8hrs$ is removed, the average value for samples that accumulated in the Basements is reduced to less than 5,000$g/m^2/8hrs$. Accumulations at the High level are the lowest, 23$g/m^2/8hrs$ on average. Only two samples from higher levels were greater than 320$g/m^2/8hrs$. One sample at 606$g/m^2/8hrs$ was significantly higher than the others collected. If this sample were removed, all but one would be below the mean shown in Table 7.

Table 7 Summary statistics of accumulation rates ($g/m^2/8hrs$) for samples at three elevations

	Basement	***Main***	***High***
Mean	7190	5487	23
Standard Error	2667	1210	12
Median	427	483	3
Standard Deviation	28604	13362	89
Range	294900	74423	606
Minimum	0	0	0
Maximum	294900	74423	606
Count	115	122	58

Similarly, accumulation rates were evaluated by association with a given machine centre and a summary of the statistics is provided in Table 8. The Trim-sort area appears to generate the greatest amount of sawdust but this is based on a few large accumulations as indicated by the median. The In-feed and Planer had the lowest accumulation rates, however both had only a few samples. This lack of material suggests that the In-feed is not a significant source of sawdust or that the dust is being well contained. Again, if the large accumulation in the Basement were excluded the average accumulation would drop below that of the Trim-sort.

Table 8 Accumulation rate ($g/m^2/8hrs$) summary statistics for machine types

	In-feed	Primary breakdown	Secondary breakdown	Trim-sort	Transfer systems	Basement	Planer
Mean	3	4099	4420	6931	892	7190	89
Standard Error	1	1583	1393	4254	290	2667	71
Median	1	10	433	54	44	427	6
Standard Deviation	4	12665	10883	17540	1393	28604	159
Range	12	74423	73086	64815	4374	294900	368
Minimum	0	0	0	0	0	0	2
Maximum	12	74423	73086	64815	4374	294900	370
Count	10	64	61	17	23	115	5

4.4.3 Particle Size by Elevation

Table 9 presents the percentage of particles that will pass through a given dimension of sieve cloth (µm) for three elevations (Basement, Main and High). Particle size was determined for 75 and 82 samples in Main and Basement levels, respectively. Due to low sample masses (<15g), only two samples that were acquired from High locations could be evaluated for particle size. Again, this is a positive outcome as it indicates that the accumulation at High elevations is low. The Basement samples had much more particulate that would pass through 425µm sieve openings compared to material tested from the Main level. For both of these levels, there was a negligible amount that would be considered very fine particulate (passing a 75µm sieve opening). The two samples tested from higher levels were completely dissimilar in their particle size distributions. For one sample, approximately 97% was comprised of material that was large as it would not pass the 1000µm sieve opening; while the other sample had 96% that passed the 425µm sieve and 75% that was fine enough to pass the 250µm sieve.

The results for the particle size of the two samples collected from High locations suggested that there are two types of material that will be found on these upper levels: large pieces that are flung by certain types of lumber processing equipment and very fine sawdust that becomes airborne and settles at these higher locations. Sampling traps left for extended periods of time are required to adequately evaluate sawdust that accumulates in High locations in the mills. Sampling occurred while the mills were in full production so safety reasons prevented sampling traps from being located at higher levels in many mills.

Table 9 Summary statistics of percentage of particles passing sieve cloth openings (μm) at three elevations

	Basement				Main			
	1000	**425**	**250**	**75**	**1000**	**425**	**250**	**75**
Mean	63	31	15	1	45	17	8	1
Standard Error	3	3	2	0	3	3	2	0
Median	69	19	4	0	39	6	1	0
Standard Deviation	28	30	21	2	29	24	19	2
Range	89	95	91	11	97	98	89	16
Minimum	11	0	0	0	3	0	0	0
Maximum	100	95	91	11	99	98	89	16
Count	82	82	82	82	75	75	75	75
95.0% CI	63	31	15	1	45	17	8	1

	High			
	1000	**425**	**250**	**75**
Minimum	4	3	1	0
Maximum	100	96	75	7
Count	2	2	2	2

A comparison of the particle size segmented by machine centre is shown in Table 10. This data suggests that the Trim-sort, Transfer systems and Basements have the greatest proportion of dust passing through the 425µm sieve. As a consequence, these machines may be greater contributors to either producing or filtering the sawdust to produce finer particulate. As previously mentioned, the mass of In-feed samples was too low for adequate particle size determination in many samples.

When these particle size results in Table 10 are considered along with the accumulation rate data in Table 8, it shows that the Trim-sort and Basements are of a particular concern. These areas have both higher average accumulation rates and a higher proportion of finer dust.

Table 10 Particle size statistics by machine area (% particles by mass passing through the specified sieve opening in µm)

	In-feed				Primary Breakdown				Secondary Breakdown			
	1000	425	250	75	1000	425	250	75	1000	425	250	75
Mean	ND	ND	ND	ND	33	9	3	0	37	9	3	0
Standard Error	ND	ND	ND	ND	6	3	1	0	4	2	1	0
Median	ND	ND	ND	ND	27	4	1	0	35	5	0	0
Standard Deviation	ND	ND	ND	ND	24	12	5	0	25	14	6	1
Range	ND	ND	ND	ND	84	40	17	1	93	64	30	4
Minimum	58	8	0	0	3	0	0	0	3	0	0	0
Maximum	98	95	89	7	87	40	17	1	96	64	30	4
Count	2	2	2	2	18	18	18	18	38	38	38	38
95.0% CI	ND	ND	ND	ND	12	6	3	0	8	5	2	0

	Trim-sort				Transfer Systems				Basements			
	1000	425	250	75	1000	425	250	75	1000	425	250	75
Mean	67	31	16	1	72	45	29	3	63	31	15	1
Standard Error	9	11	9	1	8	11	10	2	3	3	2	0
Median	71	22	6	0	78	44	17	0	69	19	4	0
Standard Deviation	25	32	25	2	28	37	32	5	28	30	21	2
Range	75	94	75	7	85	94	85	16	89	95	91	11
Minimum	24	2	0	0	14	3	0	0	11	0	0	0
Maximum	100	96	75	7	99	98	85	16	100	95	91	11
Count	8	8	8	8	11	11	11	11	82	82	82	82
95.0% CI	21	27	21	2	19	25	22	4	6	7	5	0

5 Mill Observations of Dust Accumulation

This section presents observations made during the dust sampling visits to the 18 participating sawmills. They highlight common areas in sawmills to consider for dust mitigation but were not evaluated scientifically or quantitatively and do not necessarily apply to all sawmills in the study.

Observations are presented by specific sawmill area and fit into three categories:

1. Dust generation: where it comes from
2. Dust flow: how it moves and disperses
3. Dust containment: observations of what works and potential improvements.

5.1 Bandmills

Bandmills were observed to be a major source of dust, likely because of the high surface speed of the saws, the large footprint of the machine, and the wheels that act as fans to increase airflow. While the sawdust is directed downward into the conveyor underneath, the air flow around the wheels catches some of the dust and brings it up on the back side of the bandmill, as shown in Figure 17. Because a gap is needed between the mill floor and the bandmill for changing and setting the saws, the upward flow of dust has an opening out of the machine onto the mill floor and beyond. It should be possible to fit sliding panels or trap doors to close these gaps as shown in Figure 18.

One enclosure around the vertical bandmill was observed during this study, while all of the horizontal bandmills were enclosed, usually in a room-size structure. In the cases of enclosed bandmills, the only significant amount of dust was from the openings for the wood flow, or from leaks around the doors. Generally, the enclosures in BC sawmills have been designed for safety and not dust containment. However, in one recently constructed mill, the entire chipping section and bandmills were enclosed in a separate room, which appeared to reduce the dust accumulation and improved suction. In existing mills, it should be possible to improve enclosures around the bandmills.

Another issue with bandmills is that the bottom wheels are deep in the conveyor area and the air flow they generate interacts with the chuting. If the conveyor is shallow, then the air flow from the wheels can pick up sawdust from the bottom of the conveyor. In small band resaws, which sit on the floor with no conveyor underneath, suction is needed at the bottom wheel enclosure to remove dust. If suction is introduced in the conveyor and floor, it is important to consider the ramifications of sealing this area. It is undesirable to restrict the sawdust and debris flow as there will be a build-up and blockage.

Some conveyors have deep baffles in the conveyor to help contain dust in the basement. The result of the increased sealing, or even the high air flow in the conveyor, is that the conveyor becomes slightly pressurized, and small holes and cracks can extrude significant dust as shown in Figure 19. While improved sealing may be appropriate, the air still needs a place to exhaust. This is when suction in the conveyors is beneficial. Besides removing the sawdust close to its source, suction also reduces the amount of dust being expelled from cracks in the containment shell.

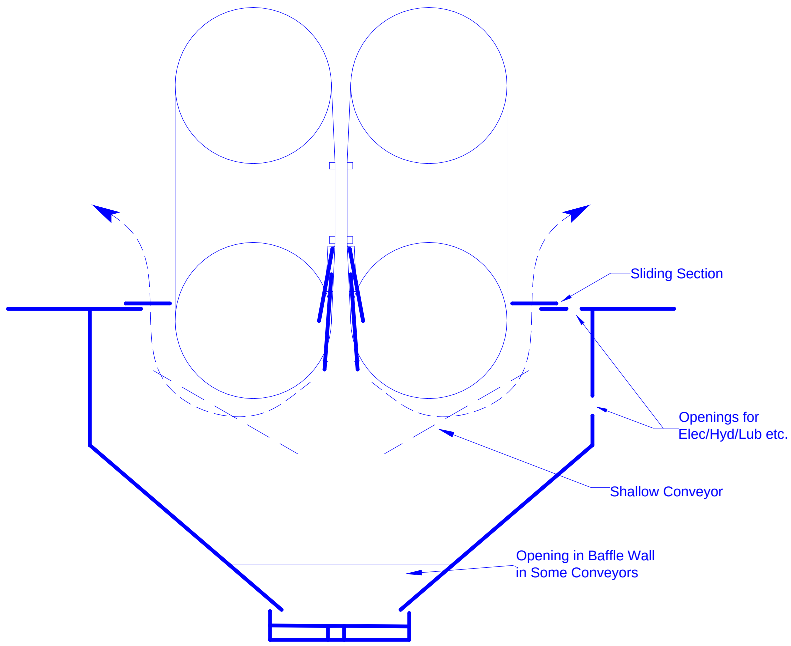


Figure 17 Effect of air flow from the bandmill's bottom wheel on dust circulation

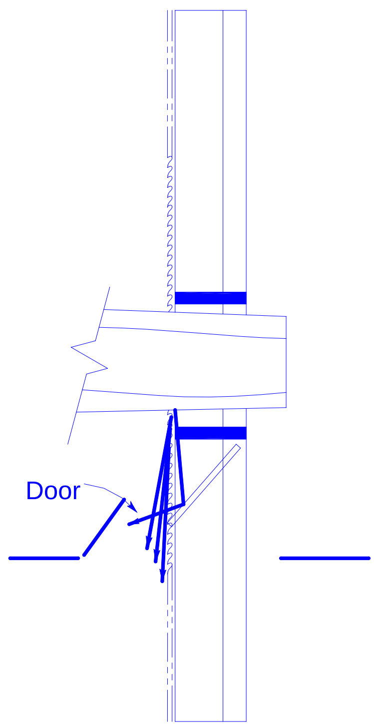


Figure 18 Production of sawdust from a bandsaw

Figure 19 Sawdust on basement floor due to unsealed opening in the conveyor chute

5.2 Chipping Heads

The bottom drum head of the canter presents another situation where air flow can interact between the machine and the enclosure. In this case, the enclosure is a box open at the bottom with the chipping head at the top (Figure 20). The protruding chipping knives act as fan blades that push the chips down, but also tend to pull some air back up, bringing some dust with it. Ideally, the two air flows should be separated, but that would likely result in chips packing up in the chute. Consequently, this is an area where water misting just under the chipping head can help to keep the finer dust in the waste system and not be drawn back up to the mill floor.

The degree that this flow recirculation problem applies to side and top heads depends on the size and path of the chip chutes. If the area is small or the path is long there is more resistance to air flow, so it would be anticipated that more dust will be caught in the air circulation around the chipping head.

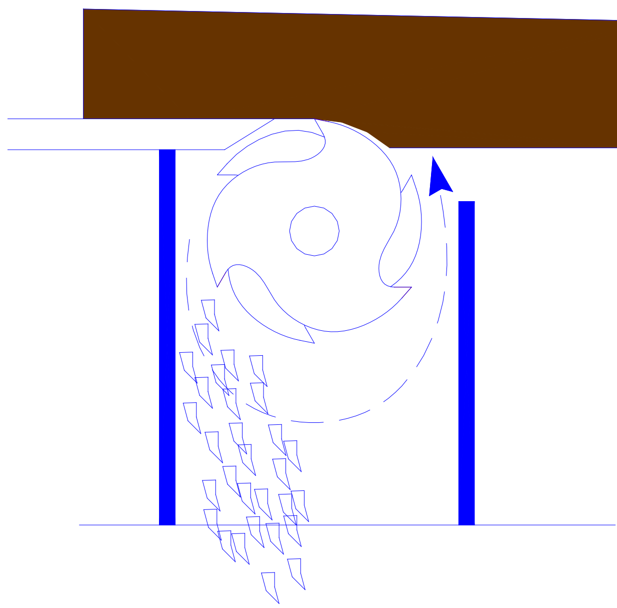


Figure 20 Air flow under drum chipping head

5.3 Circular Saw Gangs

Circular gang saws are well enclosed generally because of safety requirements. Vertical arbour machines are more open because the vertical rolls are exposed. On the other hand, vertical arbour machines have a bed plate under the boards, which retains more sawdust than the bed rolls of a horizontal arbour machine. Since most, if not all, sawmill circular saws are climb cutting, if not all, significant sawdust ends up between or on top of sawn boards and is carried to the out-feed deck or belt. In extreme cases, this dust can be carried throughout the sawmill by the manufacturing process. For either power or conventional lumber cutting, the sawdust from the bottom saw would go directly to the conveyor, at least for horizontal arbour machines.

The relatively small amount of sawdust that gets out of the saw box is usually wet due to the misting from guide lubrication/cooling water. The air flow is very turbulent inside a saw box so there is a good chance that the dust will come into contact with water. Most of the dust that comes out of the machine is generated at the beginning or end of the cut when the cant is not in the way of the sawdust stream from the saws.

5.4 Vibrating Conveyors

The gap between the chuting and the conveyor tray acts to pump fine dust out of the vibrating conveyor. Dust usually drifts inside the vibrating arms and onto the floor as shown Figure 21. Unfortunately, cleaning dust from between the arms and the I-beams would be challenging and safe access must be a prime consideration.

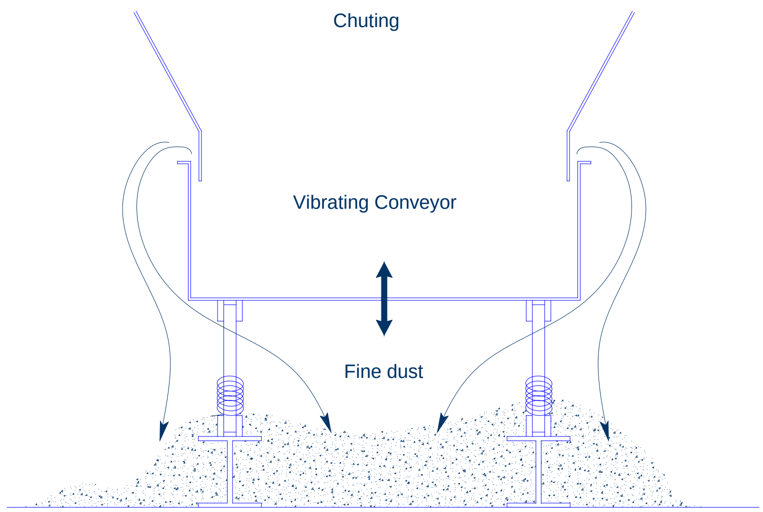


Figure 21 Typical fine dust accumulation under vibrating conveyors

5.5 Transfer and Waste Belts

Belts are used to carry lumber and waste material, but will also carry whatever sawdust comes with the boards, thereby transporting dust beyond its planned destination. Furthermore, fine dust can adhere to the top of the belt or get caught in small cracks in the surface of the belt to the point where the dust will not fall off at the end of the conveyor as shown in Figure 22. Some of this dust, which can be significant, is released on the belt return and can cover a large section of the floor under the belt.

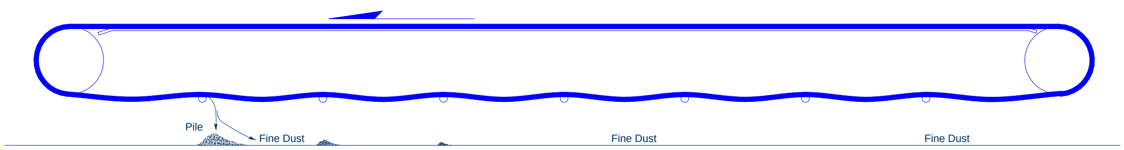


Figure 22 Fine dust deposited under conveyor belt

Fast belts will also behave as a fan due to surface roughness. This in combination with the high speed will raise and disperse dust in the air above the belt or bounce dust down the belt. Fast belts tend to put more dust into the air because more energy is available.

5.6 Trim Saw Waste Belts

Most of the saw dust from trim-saws goes to the waste belts under the trimmer. Assuming that the chuting contains and catches most of the sawdust, fine dust can often end up falling to the floor below. For most belt conveyors, dust adheres to the belt and falls off on the return path as shown in Figure 22.

Even if the returning section has a tray to contain dust, it was commonly observed that the dust falls out at the end of the tray at the tail drum, as shown in Figure 23. A possible solution is to enclose the area under the trail drum and clean it out with suction, which is usually an extension of the suction from the trim-saws.

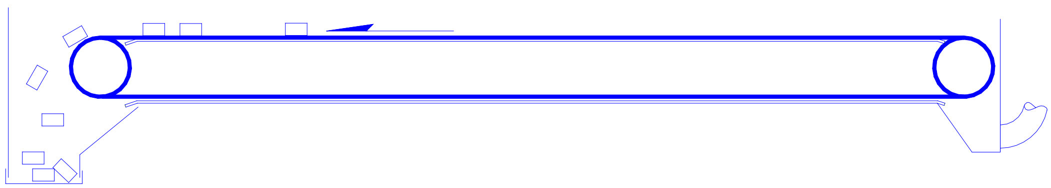


Figure 23 Waste belt under trim saws with good containment of dust

5.7 Landing Decks and Deck Chains

Sawdust can quickly accumulate on landing decks, especially after double-arbour circular saws where much sawdust remains in the board stack. Sometimes dust is put into the air when the boards bounce on the deck, but the main issue is the dust that gets under the deck and into the Basement. This fugitive dust is generally relatively fine.

Most landing decks have an opening to a waste conveyor that runs under the machine line; however, in some cases the opening is too narrow so the sawdust stays on the deck. Sawdust on the deck has generally three possible destinations (Figure 24):

1. Sawdust is pushed by the boards to the end of the deck, where it is dropped on a belt to travel to some other part of the mill
2. Sawdust drops through openings in the deck or at a transition to another transverse deck. This leaked sawdust either falls on the floor under the deck, which needs to be manually cleaned, or falls further into the basement if there is no floor or there are openings in the floor.
3. Sawdust gets in the chain troughs and is dragged to the head sprockets, where it drops off (Figure 24).

Most transverse chains do not have waste conveyors underneath, so if the mill floor is not sealed the Basement has to be swept. Sweep chains are being installed in new mills.

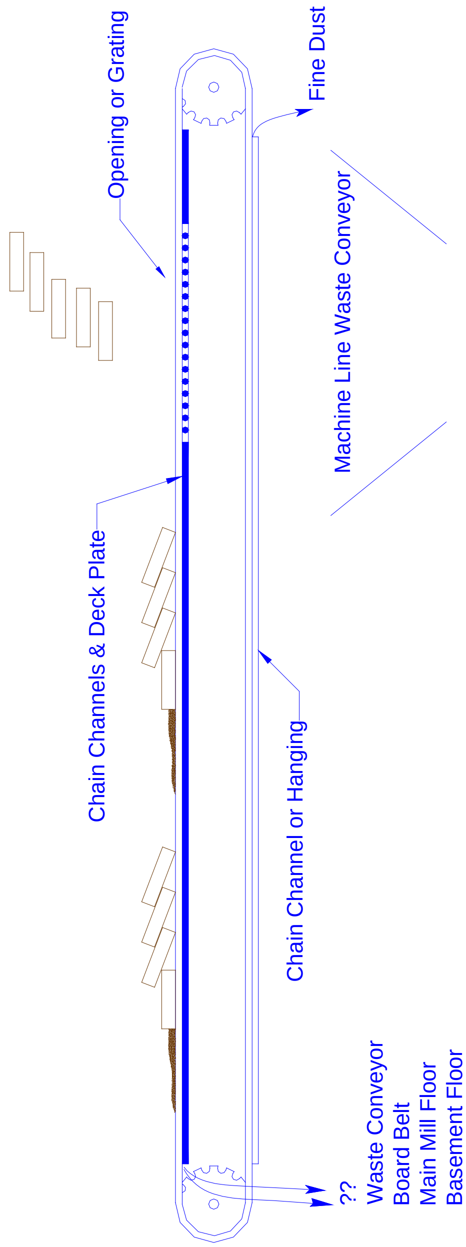


Figure 24 Movement of sawdust on landing deck

5.8 Grinding of Dust

Waste belts and chains often run in trays or troughs in both the main section and for the return. If dust gets under the belt or chain, which was often observed, the dust is ground finer by pulleys/followers and slides through trays and troughs. As noted above, this finer dust is then often distributed to other areas of the sawmill where the belt and chain travels. In the case of dust under belts, the dust can have a grey color, compared to fresh sawdust.

5.9 Dust Drying Rate

During sampling, the rate of dust drying was investigated. The moisture content of a pile of fresh sawdust and of fine dust that drifted away from the pile was examined. A specific example is shown in Figure 25 where the coarse dust in a pile under a conveyor belt was >50% (as measured by the portable moisture measurement instrument) and <5% for the dust about 8 feet from the main pile. Figure 25 illustrates a key point that rapidly accumulating piled dust may reduce the rate of drying since newly accumulated material insulates the pile. Unfortunately, the effect of ambient moisture content on dust samples when examined by distance from the machine did not support a strong relationship likely because accumulations at a greater distance can come from multiple sources. On the main floor and at higher elevations there is generally limited space between the machines. Consequently, the effects of drift, time in the air and ambient moisture content require further examination and analysis.

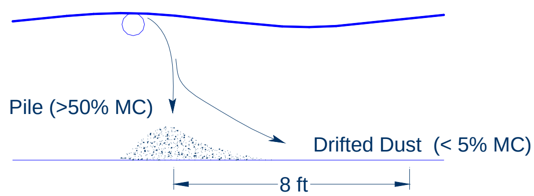


Figure 25 Example of how dust dries as it drifts

5.10 Trim Saw Suction

Most trim saws are fully enclosed with skirting where the boards enter and exit. Inside the trimmer, each saw has a local suction inlet and the overall suction is from both ends of the machine. However, even with the enclosure and skirting, sawdust can escape, either carried out by the boards or feed chains or from leaks in access doors. In a mill, not part of the dust collection survey, the dust collection at the trimmer was very effective: no dust escaped the machine even though there was not skirting. Each saw had a suction adaptor that partially wrapped around the saw (Figure 26).

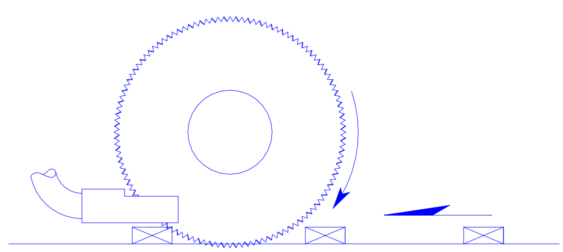


Figure 26 Suction hood for trim saw

5.11 Conveyor Dumps

When one waste conveyor dumps into another there can be a drop of up to meter. When this occurs, the finer dust can separate from the large material and drift. The height of the drop did not seem to be a determining factor. However, the greater the fine dust content in the material, the more drift that could occur but there is fine dust even a wood flow of predominately chips. The drift distance was unpredictable as in some instances it was significant but in others there was none.

A breeze from an opening in the wall or from a fast moving belt was observed to contribute to drifting dust. This breeze adds energy to the dust increasing the amount in the air and its movement out of the main waste stream. A breeze was observed to significantly increase dust drift and in a few cases distribute the dust through a significant portion of the sawmill and at different elevations.

Many dumps have partial or no chuting around them, so some of the dust on the floor could be from over/under chuting. If there is a need to access a dump area to clear out a pile-up, plastic curtains were observed to be effective at reducing dust drift.

5.12 Dust Carried by Boards

In most mills the sawdust drops off the boards soon after leaving a machine, but in unusual cases it can also stick to the boards all the way through to the stackers as noted in Section 5.3. This was observed to occur in unusual cases even if there were several board drops on to decks or conveyor belts. The result is that dust spreads throughout the mill, much of it eventually getting to the Basement floor.

5.13 Mill Air Flow

Dust will also travel because of the flow of air in the mill as noted in Section 5.11. This air flow can be caused by fans, open doors or openings in the walls for conveyors or decks as shown in Figure 27. Wind coming though openings near board landing decks or conveyor dumps can blow dust significant distances through the mill. An issue of concern is one involving the case of a strong wind, which can draw fine dust into the air even separating it from coarser sawdust going into waste systems. While fans were not observed to draw dust into the air, fans can move dust already in the air long distances into areas that are difficult to clean. Basements were observed to be areas where there were significant air flows in a number of sawmills visited in this study.

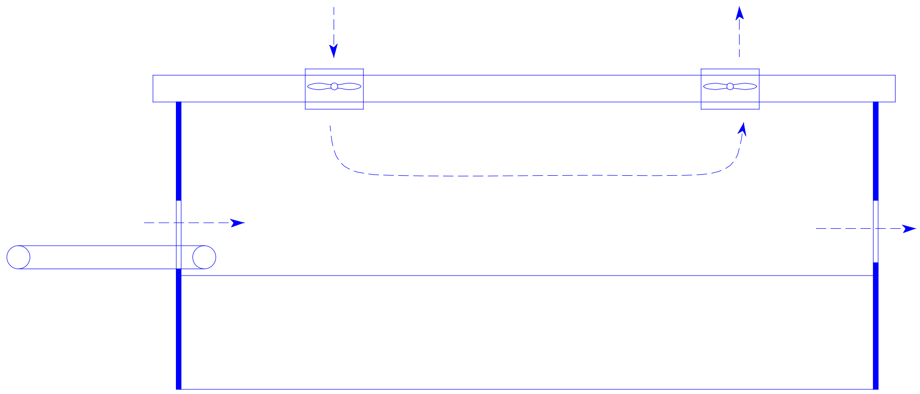


Figure 27 Air flow in a mill from openings and fans

6 Sawdust Explosibility and Tests Results

The contents of this section have been reviewed and largely provided by Chilworth Technologies, Inc. under contract with FPInnovations. Chilworth was engaged to test sawdust samples provided by FPInnovations and to review of the overall explosion test results.

Background information on the five explosion properties is provided first in this section and is followed by a description of some of the factors affecting explosibility. The maximum rate of pressure rise $(DP/dt)_{max}$ was measured but is not discussed in the report as the results generally mirrored the Deflagration index. Finally, a review of the test results for each of the five explosion tests is provided.

6.1 Explosion Severity

The Explosion Severity consists of two parameters: the maximum explosion pressure and the speed of the explosion. To describe the speed of the explosion, the rate of pressure increase is used in the form of the Deflagration Index. Both maximum explosion pressure and the Deflagration Index are determined at the same time. The Explosion Severity describes the possible consequences of the ignition of a dust cloud, but do not provide an indication of the likelihood of ignition.

6.1.1 Maximum Pressure, P_{max}

This is the maximum un-vented system pressure caused by a confined dust/air explosion. It is determined by testing in a standard test vessel (usually a 20-litre test chamber in accordance with ASTM E-1226). Samples are dispersed in the test vessel with resulting concentrations typically ranging from 60 to 2000g/m^3. Attempts are then made to ignite the dispersed dust using a high energy ignition source. The resulting explosion pressure is measured as a function of time, and the highest explosion pressure and rate of pressure rise can then be determined for each test. The highest explosion pressure found over a range of concentrations is the maximum explosion pressure (P_{max}).

Typical dust/air deflagration explosions will produce closed system pressures of about 8 to 10 bar g (116 to 145psig). This property can be used to specify containment design criteria for new equipment as a Basis of Safety or to evaluate equipment failure consequences and risk.

6.1.2 Deflagration Index, K_{st}

Maximum Rate of Pressure Rise, $(dP/dt)_{max}$, is an indicator of the level of violence of the dust explosion in a confined space and the efficiency of the combustion process. The maximum rate of pressure rise is determined using the same tests as for P_{max} and is the maximum slope of the pressure curve, with the highest value found over a range of concentrations used as $(dP/dt)_{max}$. Materials with high values present a more efficient combustion process with faster flame propagation. The rate of pressure rise is dependent on the test vessel volume and therefore this property is used to calculate the (volume-independent) Deflagration Index, K_{st}.

The K_{st} constant is calculated from the maximum rate of pressure rise and the size of the test sphere. This number represents the predicted rate of pressure rise in a one cubic metre container and is a scaling factor used to predict confined explosion behavior in different size enclosures. The Deflagration Index is determined from the maximum rate of pressure rise using the following relationship, known as the Cube Root Law:

$$K_{st} = (dP/dt)_{max} \cdot V^{1/3}$$

where:

K_{st}	=	Deflagration Index (bar•m/s)
$(dP/dt)_{max}$	=	Maximum rate of pressure rise (bar/s)
V	=	Test vessel volume (m^3)

This scaling factor has applications in the design of explosion protection systems such as relief vents or suppression systems and is an indicator of the level of explosion severity presented by the material. Dusts are classified based on the value of the Deflagration Index, as described in Section 6.5.2. Typical values for organic dusts are 50 to 200 bar•m/s.

6.2 Ignition Sensitivity

The Ignition Sensitivity is a measure of the likelihood that a dust cloud will be ignited, but does not provide any information on the consequences (severity) of such an ignition.

There are several properties that describe various aspects of the Ignition Sensitivity. Since the sensitivity to sparks (Minimum Ignition Energy) is not the same as the sensitivity to hot surfaces (Minimum Ignition Temperature), these properties must both be included. In fact, there are two Minimum Ignition Temperatures: for direct ignition of a dust cloud and for ignition of a dust layer. Only the cloud ignition was included in the current investigation.

The explosion limits, in particular the lower limit (Minimum Explosible Concentration) can help decide where explosive concentrations may be found and therefore is also a factor in the likelihood of ignition. Sometimes it is included in the Ignition Sensitivity grouping, although it should really be considered on its own.

6.2.1 Minimum Dust Cloud Ignition Energy, MIE

This value is a measure of the ease of ignition of a suspended dust cloud by low energy ignition sources, such as electrostatic sparks. Materials that have low MIE values are more likely to ignite from low energy electrostatic ignition sources. Such ignition sources include electrostatic charges created when electrically resistant powders are transferred through equipment and the charges built up on personnel. MIEs less than 50mJ are considered to represent a hazard of ignition from weak electrostatic sources. The energy generated on personnel is of the order of 15 to 30mJ.

6.2.2 Minimum Dust Cloud Ignition Temperature, MIT-cloud

This temperature is the point at which a suspended dust cloud will ignite if exposed to a hot surface without any other ignition source. Typical values for organic dusts are 500 to 600°C. This property (or MIT-layer whichever is lowest) is used when specifying the maximum surface temperature for devices and equipment surfaces such as heated dryers and ovens that could be exposed to an ignitable dust/air suspension and in the specification of electrical device surface temperatures in the classification of hazardous areas, the “T Rating”.

6.2.3 Minimum Explosible Concentration, MEC

The minimum explosible concentration (MEC) is the minimum concentration of dispersed dust capable of being ignited and supporting flame propagation. MEC data can be used to specify ventilation and extraction as a means of dust explosion prevention. NFPA 69, Standard on Explosion Prevention Systems, recommends that when control of the flammable atmosphere is used as a Basis of Safety, ventilation should be sufficient to maintain the average fuel concentration to less than 25% of the lower flammable limit (LFL). Thus, ventilation should be designed to be sufficient to limit the average concentration of dispersed dust to less than 25% of the MEC, since the MEC can be thought of as the LFL for an explosible dust. However, the use of ventilation is generally not recommended as a sole Basis of Safety for an operation, since the evolution of localized dust concentrations exceeding the MEC may be inevitable, even when adequate ventilation is provided.

6.3 Factors Influencing Explosibility

6.3.1 Moisture Content

The amount of moisture absorbed within a particle or adhering to the particle surface can greatly affect the relative dust explosibility hazards in several ways. Materials with moisture contents below 5% are considered "dry" and will exhibit the most extreme ignition sensitivity and explosion severity. In addition, the degree of wetness of a particle's surface can increase the particle's electrical conductivity and reduce its propensity to create and retain an electrostatic charge. Surface moisture can also facilitate agglomeration of fine particles and thereby increase the dust suspension's apparent average particle size.

The more moisture a particle contains, the more slowly the explosion will happen and the harder it will be to ignite the particles. However, explosions can happen at quite high (material dependent) moisture contents, as shown for the Explosion Severity of two materials in Figure 28 below[2] [3]:

[2] From BIA-Report 13/97 "Combustion and explosion characteristics of dusts", published in November 1997 by HVGB, Alte Heerstrasse 111, D-53757 Sankt Augustin, Germany; ISBN 3-88383-4696

[3] Note that the lower graph uses "Max rate of pressure rise" instead of K_{st}. This is because the tests were conducted in a 1-m^3 vessel so that the rate of pressure rise and K_{st} are the same.

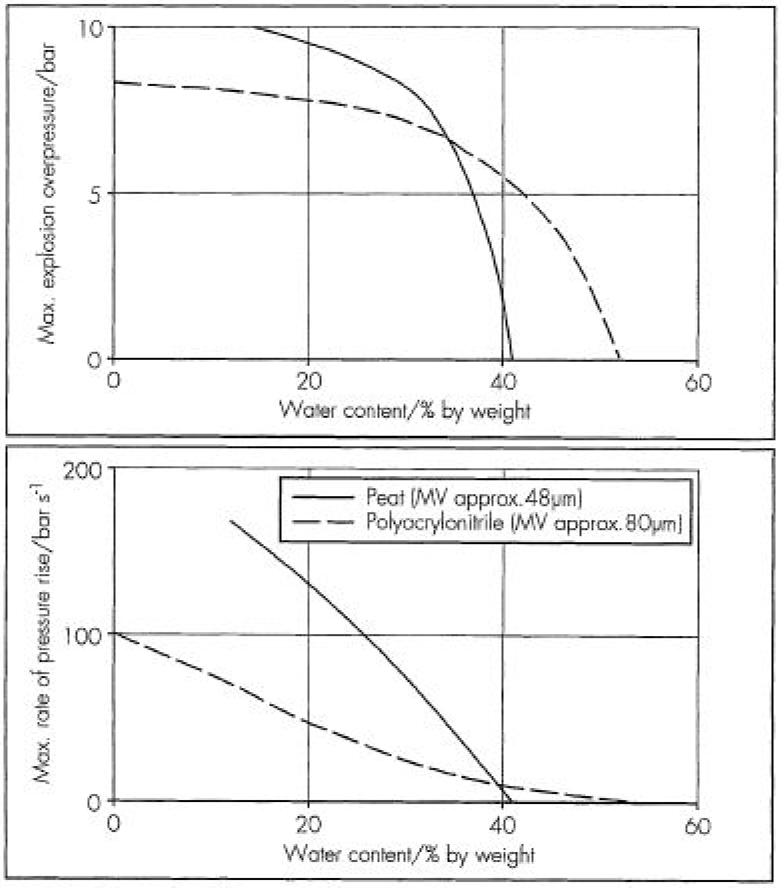


Figure 28 Explosion severity of two materials

The latest edition (2012) of NFPA 664, the Standard aimed at the wood industry, includes in the definition of deflagrable wood dust a limit of 25% moisture content. Figure 28 shows that this moisture content does not, on its own, prevent a dust cloud explosion of any dust.

6.3.2 Particle Size

In general, the smaller the dust particle size the greater the dust explosion hazard. Both ignition sensitivity and explosion severity are adversely affected by reduced particle size. However, the changes are less for particle sizes below about 200 Mesh (particle size less than 75µm). As a result, ASTM Standard dust hazard testing is conducted on the "worst" dust sample, screened at 200 Mesh.

It must be noted that there is not a single particle size that forms the upper limit of combustible dusts. It is often stated that dusts must typically be less than about 500µm in size, but this must be understood as an indicator rather than a limit value. Factors such as the type of dust, the dust particle surface structure and particle shape all play a role. Figure 29 shows the effect of median particle size on the Explosion Severity for several dusts.

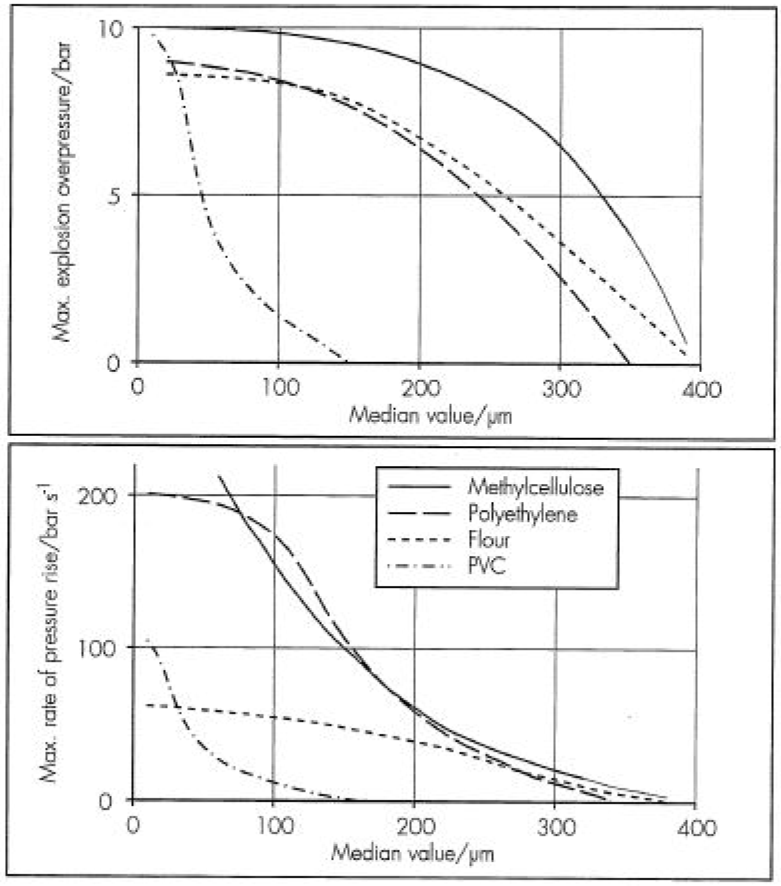


Figure 29 Effect of median particle size on the Explosion Severity for several dusts

The NFPA used to define combustible dusts as dusts passing through a 420µm (U.S. Number 40) sieve. In the latest (2013) edition of NFPA 654 (the general dust explosion standard) this limit has been dropped, and only the explanatory material in Annex A mentions 500µm as a suitable criterion, but warns about cases where even material that does not pass through a 500µm sieve could still explode. NFPA 664 (2012) on the other hand, includes the value of 500µm in the actual definition.

6.3.3 Process Conditions

All flammability data are determined using accepted test methods such as ASTM under standard conditions, so that materials can be compared. However, the process conditions, such as temperature and pressure, can have a profound effect on the behavior of a material. Many processes run at elevated temperatures and this will affect the hazards in the plant. For example, the MIE is especially strongly influenced by the temperature, and a dust that is only moderately sensitive at room temperature may be extremely sensitive at an operating temperature of, say, 100°C.

In order to maintain a cloud of flammable dust mixed with air, turbulence must be present to prevent the dust from settling out. This is taken into account during the standard testing of powders. However, there are situations where the turbulence level is exceptionally high, leading to a more severe explosion than would be predicted based on the standard test results for explosion severity.

One common situation where turbulence may be the cause is when an explosion propagates through connecting pipework from one vessel to another. This will lead to a more violent explosion in the pipe and in the downstream vessel (due to “flame jet ignition”). In addition, connected vessels may experience “pressure piling”, where the pressure in the downstream vessel increases because of the flow from the explosion in the upstream vessel. The second explosion will be more severe (proportional to the absolute pressure at the start of the explosion) than one starting at atmospheric pressure. Protection measures designed using standard design rules are unlikely to be adequate to protect against explosions caused by flame jet ignition and/or exhibiting pressure piling.

The presence of flammable vapors or gases in a flammable dust cloud leads to what is called a “hybrid mixture”. Generally speaking, any fuel air mixture with more than one type of fuel is a hybrid mixture, but the special case of a flammable vapor/gas at a concentration below the LFL with a flammable dust warrants special attention: the MIE of a hybrid mixture can be as low as that of the vapor/gas while the vapor/gas concentration remains below the LFL. Similarly, the explosion severity (Deflagration Index) will generally increase above that of the dust alone because of the influence of the turbulence that is a characteristic of flammable dust clouds.

6.4 Explosibility Test Results

Sawdust samples were sent to Chilworth’s laboratory in Princeton, New Jersey for explosibility testing. Explosion severity tests were conducted first and if the maximum pressure P_{max} was 2.5 bar or higher and/or the Deflagration Index K_{st} exceeded 20 bar* m/sec then the Ignition Sensitivity tests were also conducted.

In all but one sample, Chilworth also conducted moisture content tests and particle size sieving for each dust sample received. A summary of the explosibility test results is shown in Table 11 Twenty-five dust samples were planned but six were added to provide a broader comparison of the three species/source groups, 31 samples were ultimately tested. These extras include two western hemlock and amabilis fir (Hem-fir) grab samples that were acquired from a sawmill nearby the facility where the coastal Douglas-fir was collected. These were added to increase the number of BC Coastal samples in the explosibility testing.

In the table, “NI” indicates a sample that was not tested as there was no ignition in the Explosion Severity Test. In the analyses that follows this section (6.5 onwars), the Douglas, Fir, western red cedar, western hemlock and amabilis fir (Hem-fir) data are averaged in the DFC group.

Table 11 Summary of sawmill dust explosibility test results

Dust Source	Sawmill Sample Location	Moisture Content (% wet basis)	Average Particle Size (µm)	P_{max} (bar)	$(dP/dt)_{max}$ (bar/s)	K_{st} (bar * m /s)	MIE (mJ)	MIT-Cloud (°C)	MEC (g/m³)
MPB	Under belt return	5	207	8	150	41	1000-10,000	470-480	140-160
MPB	Under belt return	5	210	7.7	151	41	1000-10,000	460-470	140-160
MPB	Under belt return	5	271	7.3	62	17	1000-10,000	550-560	350-400
MPB	Under belt return	5	277	7.7	67	18	1000-10,000	510-520	450-500
MPB	Under belt return	25	298	7	56	15	1000-10,000	480-490	2000-3000
MPB	Under belt return	24	369	5	20	5	1000-10,000	50-530	>5000
MPB	Under belt return	5	414	6.8	59	16	1000-10,000	550-560	>5000
MPB	Under belt return	30	420[4]	0	0	0	NI	NI	NI
MPB	Under belt return	5	490	6.7	42	11	1000-10,000	550-560	3000-4000
MPB	Under belt return	5	726	6.9	36	10	1000-10,000	590-600	>5000
SPF	Vibrating conveyor	5	196	8.1	227	62	1000-10,000	460-470	140-160
SPF	Under trimmer/sorter	5	198	6.4	148	40	1000-10,000	470-480	180-200
SPF	Dust conveyor dump flow	19	221	7.5	166	45	1000-10,000	470-480	180-200
SPF	Trimmer/sorter waste chain	5	267	6	76	21	1000-10,000	480-490	300-350
SPF	Dust conveyor dump flow	19	294	7.1	64	17	1000-10,000	470-480	250-300
SPF	Vibrating conveyor	17	313	7	85	23	1000-10,000	470-480	2000-3000
SPF	Under main chip belt	5	334	6.9	50	14	1000-10,000	520-530	160-180
SPF	Dust conveyor dump flow	5	410	6.9	64	17	1000-10,000	430-440	300-350
SPF	Under trimmer/sorter	5	415	4.8	52	14	1000-10,000	400-410	1000-2000
SPF	Dust conveyor	19	434	6.5	39	11	1000-	470-	>5000

[4] Particle size was estimated by averaging other sub-samples from the same grab sample.

Dust Source	Sawmill Sample Location	Moisture Content (% wet basis)	Average Particle Size (μm)	P_{max} (bar)	$(dP/dt)_{max}$ (bar/s)	K_{st} (bar * m /s)	MIE (mJ)	MIT-Cloud (^oC)	MEC (g/m^3)
	dump flow						10,000	480	
SPF	Under main chip belt	29	481	4.7	19	5	1000-10,000	510-530	160-180
SPF	Vibrating conveyor	28	513	5.5	25	7	1000-10,000	530-540	>5000
SPF	Dust conveyor dump flow	20	993	0	0	0	NI	NI	NI
SPF	Trimmer/sorter waste chain	5	1227	4	18	5	1000-10,000	560-570	>5000
SPF	Vibrating conveyor	29	1276	0	0	0	NI	NI	NI
Douglas-fir	Under trim saws	5	183	6.9	73	20	1000-10,000	450-460	180-200
WRC	In-feed of end dogger	5	189	7.9	216	59	1000-10,000	440-450	100-120
Hem-fir	Under waste conveyor	5	244	8.1	158	43	1000-10,000	460-470	160-180
WRC	In-feed end dogger	5	380	7.5	111	30	1000-10,000	480-490	160-180
Hem-fir	Under waste conveyor belts	5	356	6.8	45	12	1000-10,000	510-520	1200-1300
Douglas-fir	Under trim saws	5	393	7.3	54	15	1000-10,000	470-480	1300-1400

6.5 Analysis of Explosibility Test Results

6.5.1 Maximum Explosion Pressure

Figure 30 shows the Maximum Explosion Pressure as a function of the average particle size for different groups of materials. Note that this graph, as well as Figure 31, uses the average particle size (mass weighted average of the particles in each sieved size group) while Figure 28 and Figure 29 use the median particle size (the 50% point by weight of the distribution), as is more common in dust explosion research. Because of the sample preparation, leading to fairly narrow particle size distributions, it proved difficult to determine the median particle size with any confidence. However, where the median particle size could be estimated, it appeared to be close to the average particle size, so any shifts in the graphs should be limited. About half of the data points in Figure 30 represent individual samples, while the others are the average of the results for two or three samples.

The Maximum Explosion Pressure is determined by the amount of material that burns and by the flame temperature, both of which do not vary greatly from dust to dust, and certainly not within a group of similar materials as used in this study. Consequently, most data points are in the same range, except for very high moisture contents and very large particle sizes. Except for the larger particle sizes, the maximum pressures are also in the range that would be expected for similar materials.

For practical purposes, the differences in the values found are not very important, since the pressure resistance of normal dust handling equipment and of buildings is far below the maximum pressures measured. The Deflagration Index, explosion speed, is more important because it determines the necessary explosion protection measures and it is usually a more sensitive parameter.

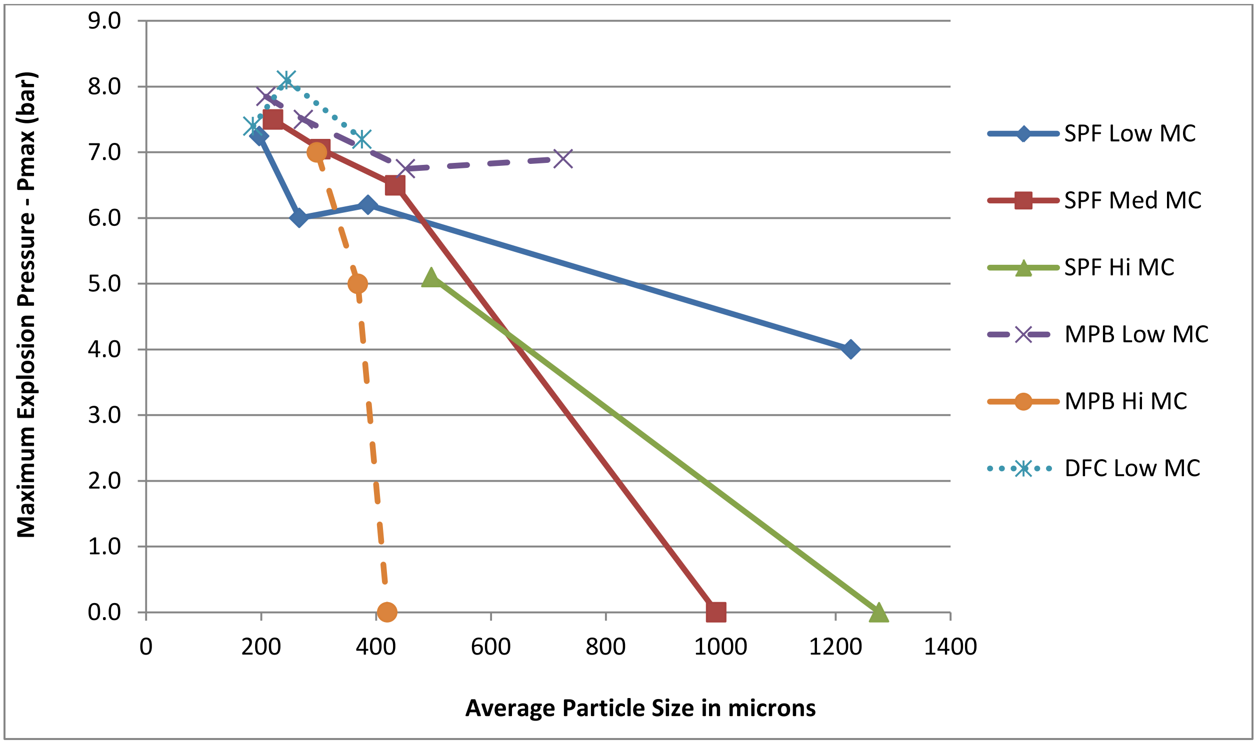


Figure 30 Maximum explosion pressure as a function of the average particle size

6.5.2 Deflagration Index

Dust explosion testing usually concentrates on determining the worst case, and therefore, typically dusts that are fine (smaller than 75µm) and dry (less than 10% moisture content) are tested. In this study, such fine particles sizes were not represented, and therefore, compared with Figure 28 and Figure 29, the data points for the smallest particle sizes are missing. However, the general trend as a function of particle size does compare well with that in Figure 29.

Compared to the values reported in the literature, the K_{st}-values reported here are fairly low: not more than about 60bar*m/s compared to literature values up to and sometimes above 200bar*m/s for various types of wood dust. The trend in Figure 31 clearly suggests that such K_{st} values would be expected if finer dusts were tested.

In terms of practical interpretation, about 60% of the dusts that have ever been tested, and the vast majority of natural products, fall in Dust Explosion Class St1, which comprises K_{st} values up to 200ba*m/s. A very large proportion of those St1 dusts have K_{st} values below 100bar*m/s.

At first glance it would appear that all data simply fall in a fairly narrow band, but some interesting conclusions can be drawn from a more detailed review of the data in Figure 31 and Table 11.
:

- As the particle size increases, the K_{st} values drop in line with the trend in Figure 29. However, it is clear that even at average particle sizes of more than 400 or 500µm explosions still occur. This is usually attributed to the contribution of the (possibly significant) fine fraction which can burn in between the larger particles, but these test samples contained few fines.
- Within the species groups, both for SPF and MPB, the results do not depend strongly on the moisture content for average particle sizes up to about 250µm. For larger particle sizes, the effect of moisture content becomes more pronounced, especially for MPB.
- Comparing the species, in particular the SPF, MPB and DFC low MC data, it can be seen that there is not much difference between them (especially considering that DFC itself contains multiple species).
- The latter finding is significant since it suggests that timber killed by MPB infestation does not change the dust properties to create a more severe dust explosion hazard. It may be that the MPB-killed timber leads to more dust creation, or dust that is easier to raise into a cloud, or similar effects. But based on the results of this research the resulting dust cloud, at least with dry dust in the particle size range investigated, will explode with a severity comparable to non-MPB sawdust.
- Note that the SPF high and medium MC lines could be read to suggest that medium MC dust will ignite at larger particle sizes than high MC dust, which is counter intuitive. However, this interpretation would be wrong, as there is no “high MC” data point around 1,000µm average particle size.

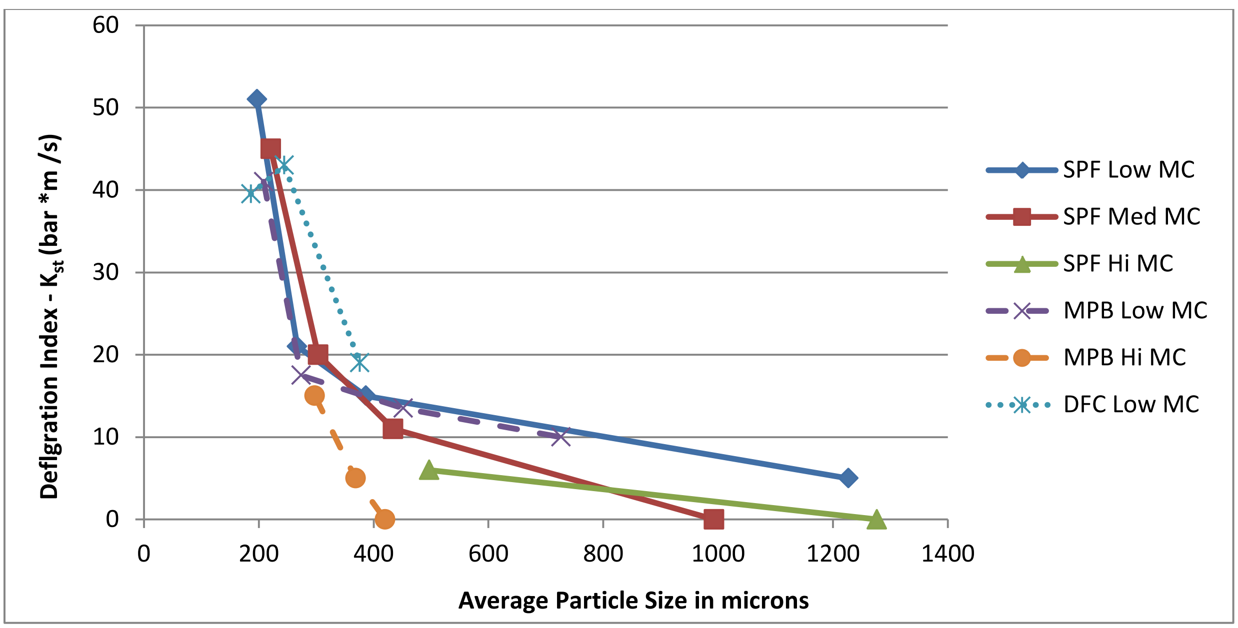


Figure 31   Deflagration index – K_{st} as a function of the average particle size

6.5.3 Minimum Ignition Energy (MIE)

During spark ignition, the igniter effect and the reaction are initially confined to a very small area around the ignition source. As a consequence, the Minimum Ignition Energy is very sensitive to small differences in the conditions. Typically, this is seen as a strong or very strong dependence of the MIE on any variable, such as temperature.

MIE test results are always expressed as “between x and y mJ”, meaning that the sample ignited, for example at 10,000mJ spark energy, but did not ignite at 1,000mJ. This format allows for the fact that the energy levels used in tests are not fixed, so the band width between “no go” and “go” can be variable.

Unfortunately, as Table 12 shows, the results in this project yielded MIE values between 1,000 and 10,000mJ for all samples tested that did ignite in the Explosion Severity tests. This means that no trends can be detected in the spark sensitivity for the range of particle sizes and moisture content tested. “NI” indicates a sample that was not tested as there was no ignition in the explosion severity test.

In terms of interpretation, a MIE of more than 1,000mJ indicates a moderate to low sensitivity to spark ignition, and static discharges from smaller objects, including people, would not be able to ignite such a dust cloud.

Table 12 Summary of Minimum Ignition Energy - MIE

Dust Source	Moisture Content Group	Ave Particle Size (μm)	MIE (Cloud mJ)
MPB	**Low**	**209**	1000-10000
MPB	Low	274	1000-10000
MPB	Low	452	1000-10000
MPB	Low	726	1000-10000
MPB	High	298	1000-10000
MPB	High	369	1000-10000
MPB	High	420	NI
SPF	Low	197	1000-10000
SPF	Low	267	1000-10000
SPF	Low	386	1000-10000
SPF	Low	1227	1000-10000
SPF	Med	221	1000-10000
SPF	Med	303	1000-10000
SPF	Med	434	1000-10000
SPF	Med	993	NI
SPF	High	497	1000-10000
SPF	High	1276	NI
DFC	Low	186	1000-10000
DFC	Low	244	1000-10000
DFC	Low	376	1000-10000

6.5.4 Minimum Ignition Temperature (MIT)

The ignition of a dust cloud by a hot surface creates a larger volume in the cloud that is involved in the ignition process, and the “ignition source” is effective for a longer period. This tends to reduce the effect of small differences in the cloud conditions, and the MIT is less sensitive to variations in the conditions.

The MIT is expressed like a range, similar to that discussed for the Minimum Ignition Energy. Because in this project the “go” and “no go” values were fixed and close together, it is arbitrary whether one bases the analysis on the “go”, the “no go” or the mean of those values. For consistency with the Minimum Explosible Concentration (Section 6.5.5) and because it would err on the side of safety, the data in Table 13 are based on the “no go” (lower end of the range) data. In Table 13 the data for samples with the same average particle size in the same moisture content group have been combined as the average of the individual values.

Some of the data in Table 13 are marked with “(*)”, which indicates that the underlying data show a great range in the results. They may therefore be artificially low or high, depending on whether uncharacteristically low or high data are included in the averaging. “NI” indicates a sample that was not tested as there was no ignition in the explosion severity test.
If one considers the data for all species and all moisture contents, but only the finest sample tested, the MIT data are very similar and range between 445 and 480°C. Considering the particle size effect (fixed species and moisture content) then it is obvious that larger particle sizes generally lead to increased MIT values, as would be expected. Note that a “drop” from 480°C to 470°C is actually within the error margin of the tests so it does not have any significance.

Within the SPF species data there seems to be limited variation among the different samples, except for the largest samples tested. It appears that for MPB the “step up” in the Minimum Ignition Temperature data occurs at smaller particle sizes. There is no obvious explanation for this finding.

Table 13 Summary of Minimum Ignition Temperature - MIT

Dust Source	Moisture Content Group	Avg Particle Size (μm)	MIT (^{o}C)
MPB	Low	209	465
MPB	Low	274	530
MPB	Low	452	550
MPB	Low	726	590
MPB	High	298	480
MPB	High	369	520
MPB	High	420	NI
SPF	Low	197	465
SPF	Low	267	480
SPF	Low	386	450 (*)
SPF	Low	1227	560
SPF	Med	221	480
SPF	Med	303	470
SPF	Med	434	470
SPF	Med	993	NI
SPF	High	497	520
SPF	High	1276	NI
DFC	Low	186	445
DFC	Low	244	460
DFC	Low	376	485 (*)

6.5.5 Minimum Explosible Concentration (MEC)

The Minimum Explosible Concentration is determined in the same equipment as the Explosion Severity. Based on the limited concentrations that can be tested, the results are once again expressed as a range between the highest "no go" (no ignition) and the lowest "go" (ignition). Within this program the concentrations tested were kept constant, so that once again the analysis can be based on the "go", "no go" or the mean of those two. To be conservative, the lowest ("no go") value was used. In this case, this has the added benefit of making it easier to process results where "no go" was found (result >5,000 g/m^3).

Reviewing the data in Table 14 (containing average MEC values for similar samples), it would appear that all fine and dry samples (SPF, MPB and DFC) have similar MEC around 150 g/m^3. Increasing the particle size of dry SPF and MPB seemed to have the same effect on the MEC, if the "(*)" data is disregarded. There are not enough data points for the high moisture content samples to be certain, but it would appear that at least qualitatively they show the same trend. "NI" indicates a sample that was not tested as there was no ignition in the explosion severity test.

Table 14 Summary of Minimum Explosible Concentration - MEC

Dust Source	Moisture Content Group	Avg Particle Size (μm)	MEC (gm/m^3)
MPB	Low	209	140
MPB	Low	274	400
MPB	Low	452	4,000
MPB	Low	726	>5,000
MPB	High	298	2,000
MPB	High	369	>5,000
MPB	High	420	NI
SPF	Low	197	160
SPF	Low	267	300
SPF	Low	386	485 (*)
SPF	Low	1227	>5,000
SPF	Med	221	300
SPF	Med	303	1,125 (*)
SPF	Med	434	>5,000
SPF	Med	993	NI
SPF	High	497	>2,580 (*)
SPF	High	1276	NI
DFC	Low	186	140
DFC	Low	244	160
DFC	Low	376	885 (*)

7 Recommendations for Risk Assessment and Assessing Higher Risk Areas

One of the objectives of this study was to provide suggestions for wood dust risk assessment and to identify high priority areas in sawmills where dust mitigation efforts should be focussed. The moisture content, particle size and accumulation rate information was analyzed along with in-mill observations and explosibility results to identify higher risk factor and areas. It is important to note that this review is not intended to assess risk since there are many other factors that affect explosibility that were not examined in this project and moreover, explosive conditions can occur even in the lowest priority areas. This review is also not intended to suggest that the lower priority areas are less important nor should they be excluded from the focus of dust mitigation efforts.

The assessment of risk and mitigation priorities can be highly subjective especially if it is based only on visual information. Members of the sawmill dust collection team regularly commented on the challenge of judging particle size content as most samples were found to have less fine particle content than was visually estimated. Also, some samples that had high accumulation rates had very little fine dust content. To allow for more quantitative comparisons, two assessment criteria are proposed.

The Chilworth explosibility tests suggest that dust with an average size as large as 400 to 500μm can be explosive. Although, 500μm would be a more conservative threshold, a slightly smaller 425μm was used since in this study the laboratory sieving included only the 75μm, 225μm 425μm and 1000μm sieves. Of the 31 dust samples sent to Chilworth for analysis, 24 samples had an average particle size of 425μm or less and in all cases, these samples had more than 40% of the particles of 425μm or smaller. Therefore, the first assessment criterion was to segment collected dust samples with 40% of the dust particles by mass that were 425μm or smaller.

A second assessment criterion was the 320g/m^2/8hrs accumulation rate described in Section 3.4 since this is the estimated equivalent of 3.2mm of wood dust build-up in 8 hours, based on the oven dry mass. This threshold suggests an area that potentially needs inspection for hazards and possible clean-up during a production shift, especially if the dust covers 5% or more of upward-facing surfaces. Since clean-up is not always possible during a production shift, samples exceeding this threshold suggest areas where process and/or design changes may be required to reduce the accumulation rate and/or fine dust content. The sensitivity of this 320g/m^2/8hrs threshold will be examined in Section 7.2.

The Chilworth explosibility tests suggested that the particle moisture content has little impact on explosibility especially for particle sizes of 250μm or less. Consequently, particle moisture content was not used in the risk assessment criteria.

7.1 Highest Priority Areas

When the collected dust samples were filtered by the 320g/m^2/8hrs accumulation rate and 40% of the dust particles by mass that were 425μm or smaller, the 295 analyzed samples were reduced to 20 or 7%. This is a small proportion of the samples especially since higher accumulations and fine dust were targeted in the sampling. It should be noted again that this prioritization is not intended to suggest that the other samples that did not meet the criteria should not be a concern, especially if they accumulated over a longer period of time and are not removed in a timely fashion.

Figure 32 shows the samples for the three species categories and machine centres filtered by the two criteria noted above. Not every mill sampled produced samples that met these criteria, so only 14 mills are indicated with a letter.

Figure 32 also shows that all of the MPB sawmills had collected dust samples that met the criteria of more than 40% of the particles of a 425µm size or smaller and accumulation rates that would lead to more than 3.2mm in 8 hours, greater than 320g/m^2/8hrs. This was the largest of the three species/sources and suggests a slightly higher potential to find these higher risk samples in MPB sawmills. One of the 4 DFC sawmills had one sample that met this criteria and 4 of the 7 SPF sawmills had at least one sample that met this criteria. Although this appears to be a substantial difference, when these values are expressed as a percentage of the samples collected at each of these mill groups, 10%, 1.3% and 3.6%, respectively, it can be seen that the difference is reduced.

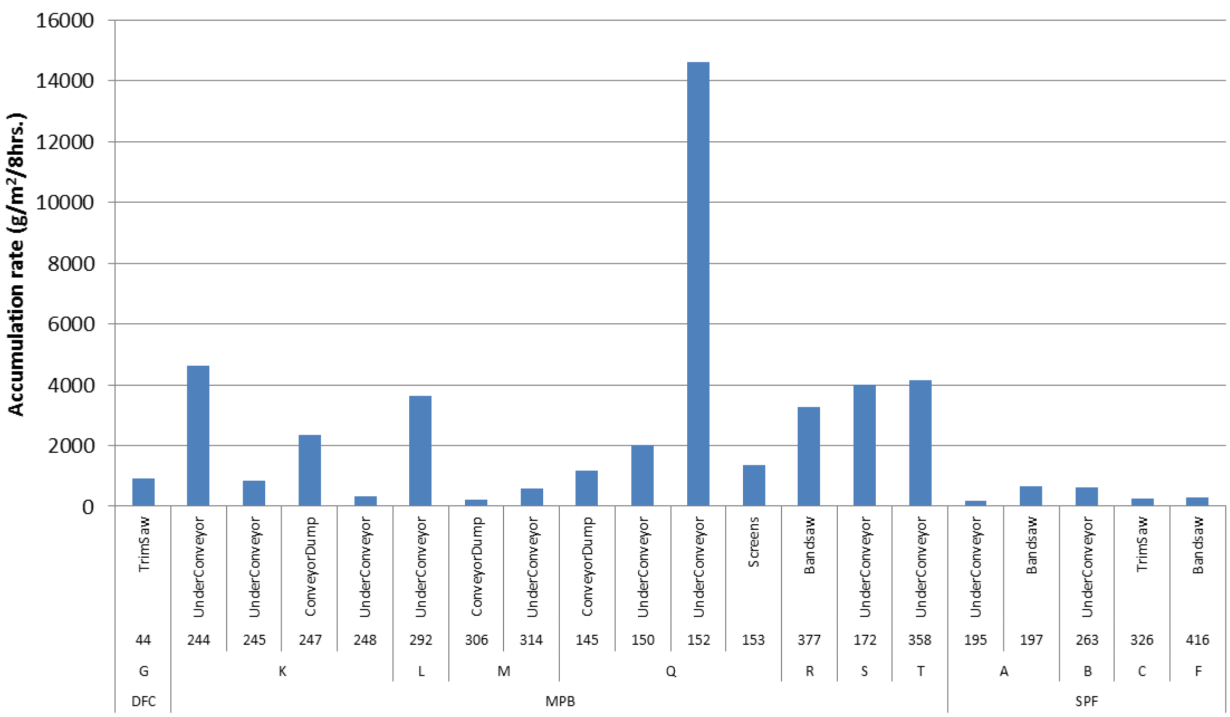


Figure 32 Sawdust samples with accumulations greater than 320g/m^2/8hrs and particle compositions passing through the 425µm sieve of greater than 40%

Figure 32 also shows that the majority of potentially higher risk samples (14), applying the risk assessment criteria proposed in this report, were collected from the vicinity of conveyors and in Basements under conveyors. The top five accumulation rates were from these areas and would generate an estimated 40mm or more in 8-hours. Although the higher risk samples were mainly found in MPB sawmills, these areas tended to be areas of high accumulation in most of the sawmills surveyed. This suggests that the conveyors and the machines in the vicinity of conveyors should be examined for dust mitigation and also considered for design changes. It is important to note that this information cannot be used as an assessment of risk since the upward-facing surface area coverage was not measured.

Figure 32 shows that potentially hazardous dust samples were also collected from around Bandsaws, Screens and Trimmers although not as consistently. Bandsaws (Primary breakdown) are an interesting area as this was the region of the second most collected samples (64). Most of these samples were excluded from the classification of being a potential hazard because most of the particles were much larger (Table 10). Secondary breakdown was an area with the third largest number of collected samples (61). The reason that none of these samples appeared in the potential higher risk classification was again due to low proportion of fine particles (Table 10). Trimmers, which in the report are grouped together as Trim-sort, was an area that was noted previously (Section 4.4.2 & 4.4.3) to be a potential problem due to the number of samples collected, accumulation rates and proportion of finer particles in the samples. Most of these samples were excluded from the higher potential risk category because either the proportion of fine particles was below 40% by mass proportion or the accumulation rates were too low. This illustrates the challenge in assessing risk without a full analysis of the situation.

7.2 Mitigating Other Priority Areas

Other samples and areas with 40% of the particle mass of a 425µm size or smaller, but with accumulation rates smaller than 320g/m^2/8hrs are also very important to consider as design and process changes may also be required and at a minimum, regular inspection and clean-up should be considered. As noted in Section 3.2.2.5, thresholds of 32g/m^2/8hrs would suggest inspection and possible clean-up would be required weekly.

Examining the 32g/m^2/8hrs threshold, two additional samples were included from DFC sawmills. The first sample came from Screens with an accumulation rate of 147g/m^2/8hrs and the second came from the Bandsaws at an accumulation rate of 126g/m^2/8hrs. This reinforces the need to include non-MPB processing sawmills and the Bandsaw and Screen areas in the priority assessment.

It is interesting to note that there were no other samples closer to the 32g/m^2/8hrs threshold with 40% or more of their particle mass composed of a 425µm size or smaller. This is likely a limitation of the sampling process that required the collection to be completed in one day. It does suggest that generally accumulations of finer dust either occur very rapidly within a shift or in a few days or if not, they would require months to accumulate to a depth of 3.2mm. Further and longer term sampling would be required to verify these lower accumulation rates.

It is also important to consider High elevations in the sawmill as this region was suggested as a higher risk area but where none of samples (58) were classified as potentially higher risk, based on the criteria applied in this project. Dust was observed at High locations but the accumulation rates were generally significantly below 320g/m^2/8hrs, except in one instance. In this exception, the machine guard was damaged and larger wood particles were being ejected. Although the accumulation rate was low, one sample that was analysed for particle size showed one of the highest proportions (96%) of dust of 425µm and smaller. This indicates that High elevations should be a region that continues to be closely examined and should be considered in a future study where accumulation is measured over a longer period.

8 Summary

The objective of the study was to compare fugitive wood dust accumulations, particle size and moisture content of dust across regions of BC, species/sources of timber being processed and locations within the sawmill. In addition, samples from select sawmills were also collected for explosibility testing. The purpose of the mill dust sampling and the explosibility testing was to provide information to support the dust mitigation efforts of the BC sawmill industry. This information provides snap shots from the mills sampled and consequently, is intended to be used as a reference for designing and targeting dust mitigation and developing an audit protocol. It is not intended to be a benchmark or to be representative of the sawmills sampled.

Wood dust sampling was targeted for 19 sawmills across British Columbia; 18 were sampled due to one closure. A total of 380 wood dust samples were collected averaging over 20 samples from each sawmill. Actively accumulating fugitive fine dust, smaller than a few millimetres in size, was targeted using a plastic lined bucket for larger accumulations and a parchment covered tray for smaller accumulations. Grab samples were collected and 31 samples were subjected to explosibility testing by an independent laboratory (Chilworth Technologies, Inc.) to examine the relationship of wood dust source/species, particle size and moisture content. Sawdust that was being collected and removed by dust mitigation systems was ignored.

The dust sampling targeted common areas in each sawmill including the log In-feed, Primary breakdown, Secondary breakdown, Trimming & Sorting, Planing, lumber conveying systems, waste conveying systems, Basements and locations at higher elevations above machinery. Although these systems and areas were consistently targeted, samples were collected only where sawdust was observed to have accumulated or to be actively accumulating. Consequently, the most samples (173) were collected in Basements, followed by 69 in both the Primary and Secondary breakdown areas, 32 near Transfer systems and 20 by the Trim-sort. The fewest (12) were collected at the log In-feed and five by Planers. This variability created differences in the data collected in each mill making statistical analysis and comparison challenging. Alternatively, the data was segmented by common elements such as source and elevation but it is important to note that not every sawmill is necessarily represented in these groups.

A selection of particle moisture content measurements were made on-site (data not shown) during sampling and 344 of the collected samples were analyzed by the FPInnovations' Laboratory in Vancouver. This analysis included: moisture content measurements, accumulation rate and/or particle size classification through sieving 1mm, 425µm, 250µm, and 75µm cloths. Samples that were smaller than 15g could not be analyzed for particle size and samples smaller than 0.5g could not be analyzed for moisture content. The samples smaller than 0.5g were also assumed to be negligible but were included in the accumulation rate analysis.

Two hundred and seventy-six samples were of a sufficient mass for moisture content analysis on a wet basis. The moisture contents were grouped into four categories: Wet>25%, Medium<=25% & >21%, Dry<=21% & >12% and Very Dry<=12%. Of the collected and analyzed samples 42% were Wet, 12% were Medium, 26% were Dry and 20% were Very Dry.

The accumulation rate was analysed for 295 samples excluding grab samples as there was insufficient information for rate calculation. To provide some context for the accumulation rate, a test of typical

425µm, 250µm, and 75µm size fraction particles was conducted to estimate a conversion constant that would allow the mass of accumulated dust to be converted to a depth. An important threshold was proposed to be 1/8-inch or 3.2mm of dust accumulation in 8 hours. A conservative conversion constant value was identified as $320 g/m^2/8hrs$, which would be approximately, 3.2mm accumulation in 8 hours for sawdust. Fifty-five percent of the tested samples had accumulation rates of less than $320 g/m^2/8hrs$. Nine percent had accumulation between 320 and $1000 g/m^2/8hrs$. Eighteen percent had accumulations between 1000 and $5000 g/m^2/8hrs$. Finally, 19% of the collected samples had accumulations greater than $5000 g/m^2/8hrs$, which is approximately 50mm or more of wood dust in 8 hours. It is important to note that this cannot be used to assess risk since other factors such as the upward-facing surface areas covered were not examined in this project.

Fine particles smaller than a few millimetres were targeted and successfully collected. Forty-five percent of the mass of these particles were retained on the 1000µm sieve and classified as larger than 1000µm; 30% were between 425 and 1000µm; 13% were between 250 and 425µm and 11% were between 75 and 250µm. The particles smaller than 75µm were very difficult to collect even after repeated attempts – they made up only 1% of collected particles.

A comparison of the three species/sources groups (MPB, SPF and DFC) showed that there were differences in moisture content and particle size composition of the collected sawdust. Dust accumulation rates were very similar with the SPF sawmills having a slightly larger proportion of high accumulation rates. The DFC sawmills had the highest proportion of samples classified as Wet at 55%, which is not surprising given the processing of green timber and the common practice of transporting and storing logs in water. MPB sawmills had the driest wood with 60% of samples classified as Dry or Very Dry while the SPF sawmills had 47% of their samples classified as Dry or Very Dry. The dust collected from MPB sawmills also showed a significantly higher proportion of particles between 75µm and 250µm; 20% versus 10% for SPF and 5% for DFC. This generally seemed to be offset by a smaller proportion of particles in the 425 to 1000µm range; 23% versus 30% for SPF and 37% for DFC.

The sawmill groupings by Coast, Southern Interior, Central Interior and Northern Interior appeared to show similar trends to those of the species comparisons. The Coast sawmills had the highest proportion of samples classified as Wet and the Central and Northern Interior samples, where the MPB sawmills in this study were all located had the lowest. The Central and Northern Interior sawmill samples also had higher proportions of dust of 425µm and smaller, and of 250µm and smaller similar to the MPB sawmill results. Southern Interior sawmill samples had the highest percentage of high dust accumulation measurements and also the highest proportion of SPF sawmills.

Within the sawmills, trends were observed for wood dust moisture content, accumulation and particle size. Within two metres of the dust source, High and Basement elevations tended to have drier dust samples. At a further distance from the dust source, the dust was likely accumulating from multiple sources generating mixed results. Dust samples collected earlier in the breakdown process, such as the log In-feed, Primary breakdown and Secondary breakdown, also tended to be higher in moisture content than samples collected from machine centres further along the production process.

The highest accumulation rates were generally found on the Main floor where the lumber processing occurs but it was in Basements where the majority of the fine dust below 1000µm and 425µm was accumulating at higher rates. Basements accounted for 40% of the collected dust samples. Although 60 samples were collected at High elevations only two had sufficient accumulations for particle size analysis.

This is not intended to suggest that fine dust does not exist at High elevations but rather that the accumulation rates are low and consequently within the 6 to 8 hours' collection period sufficient quantities were not available for analysis. One of the High elevation samples had one of the highest proportions (96%) of dust 425μm or smaller. On the Main floor, 43% of the sampled wood dust was 1000μm or smaller and 14% was 425μm or smaller. In the Basement, 62% of the collected wood dust was 1000μm or smaller and 31% was 425μm or smaller.

By machine centre, the highest accumulation rates were from samples at the Trim-sort followed by the Basement, Secondary breakdown, Primary breakdown and Transfer systems. The Planer had lower accumulations, but its results and the In-feed were based on fewer samples. The particle size followed the opposite trend with the machines earlier in the process generating a higher proportion of large particles with the smaller particles being found near the Trim-sort, Transfer systems and Basements.

Observations were made during the dust collection to compare against the results of the dust sampling data analysis. Bandsaws and other Primary breakdown machines are machine centres generating more dust than others and Conveyor and Transfer systems are dropping dust into Basements. The dust generated by Primary breakdown machines could be reduced through improved enclosures and guarding. In some cases, dust collection using suction may also help reduce dust dispersal. Belts, chains and other Transfer systems are responsible for generating much of the collected fugitive dust. Dust gets trapped in these systems creating unintentional drops upon the chain or belt return. In addition, wood particles that get into the slides, between wheels and under belts are being ground to smaller sizes. This dust is then often dropped along the entire run of the belt and chain.

Locations where boards drop or dust and chips change directions, and in chip screens are also common sources of dust generation. Wood particles become momentarily airborne, gaining energy and drifting beyond the machine. Wind or other air flow can exacerbate this problem by adding even more energy to the dust.

Explosion Severity tests (Maximum Pressure - P_{max} and Deflagration Index - K_{st}) were conducted on 31 wood dust samples collected by grab sampling. Ignition Sensitivity tests (Minimum Dust Cloud Ignition Energy–MIE, Minimum Dust Cloud Ignition Temperature–MIT cloud and Minimum Explosible Concentration–MEC) were conducted on 28 of the 31 samples since there was no ignition in three of the samples in the Explosion Severity tests. The 31 samples included sources from MPB, SPF and DFC. Two western hemlock / amabilis fir (hem-fir) grab samples were also collected to increase the number of samples from BC Coastal sawmills. The hem-fir samples were included in the DFC group. The moisture content of the 31 samples ranged from Low (generally 5%) to Medium (17 to 20%) and High (>=24%) on a wet basis and the average particle size ranged from 183 to 210μm, 244 to 313μm, 356 to 513μm, and 726 to 1276μm. As noted above, in 28 of the 31 samples there was ignition. The three samples that did not ignite were combinations of larger average particles and higher moisture contents, 420μm and 30% MC, 993μm and 20% MC and 1276μm and 29% MC.

Usually, dust explosion testing concentrates on determining the worst case, and therefore typically fine (smaller than 75μm) and dry (less than 10% moisture content) dusts are tested. In this study, such fine particle sizes were not represented; the data points for the smallest particle sizes are missing as there was very little of this particle size available in the mills that were sampled. However, the general trend as a function of particle size does compare well with that expected of other materials.

For the Maximum Explosion Pressure most data points are in the same range, except for very high moisture contents and very large particle sizes. Except for the larger particle sizes, the maximum pressures are also in the range that would be expected for similar materials. For practical purposes, the differences in the values found are not very important since the pressure resistance of normal dust handling equipment and of buildings is far below the maximum pressures measured. The Deflagration Index, i.e. the speed of the explosion, is more important because it determines the necessary explosion protection measures and it is usually a more sensitive parameter.

Compared to the values reported in the literature, the K_{st} values are fairly low: no more than about 60 bar*m/s compared to literature values up to and sometimes above 200 bar*m/s. The trend clearly suggests that such K_{st} values would be expected if finer dusts were tested. In terms of practical interpretation, about 60% of the dust that has ever been tested, and the vast majority of natural products, fall in Dust Explosion Class St1. Some interesting conclusions can be drawn:

- It is clear that even at average particle sizes of more than 400 or 500µm explosions still occur.
- Within the species groups, both for SPF and MPB, the results do not depend strongly on the moisture content for average particle sizes up to about 250µm. For larger particle sizes, the effect of moisture content becomes more pronounced, especially for MPB.
- Comparing the species, in particular the SPF, MPB and DFC low MC data, there is not much difference among them. This finding is significant since it suggests that timber killed by MPB infestation does not change the dust properties to create a more severe dust explosion hazard. It may be that the MPB-killed timber leads to more dust creation, or dust is easier to raise into a cloud, or similar effects. But based on the results of this research, the resulting dust cloud, at least with dry dust in the particle size range investigated, will explode with comparable severity.

Unfortunately, the results in this project yielded MIE values of between 1,000 and 10,000mJ for all samples tested that did ignite in the Explosion Severity tests. This means that no trends can be detected in the spark sensitivity for the range of particle sizes and moisture content tested. In terms of interpretation, a Minimum Ignition Energy of more than 1,000mJ indicates a moderate to low sensitivity to spark ignition, and static discharges from smaller objects, including people, would not be able to ignite such a dust cloud.

Some Minimum Ignition Temperature data showed a great range in the results for samples with similar average particle size and moisture content. They may therefore be artificially low or high, depending on whether uncharacteristically low or high data are included in the averaging. If one considers the data for all species and all moisture contents, but only the finest sample tested, the Minimum Ignition Temperature data are very similar and range between 445°C and 480°C. Considering this data it is obvious that larger particle sizes generally lead to increased Minimum Ignition Temperature values, as would be expected.

It would appear that all fine and dry samples from SPF, MPB and DFC have similar Minimum Explosible Concentrations, around 150g/m^3. Increasing the particle size of dry SPF and MPB seems to have the same effect on the Minimum Explosible Concentration, if the outlier data are disregarded. There are not enough data points for the high moisture content samples to be certain, but it would appear that at least qualitatively they show the same trend.

To assess the potential higher risk samples, the dust samples were evaluated with two criteria. Accumulation rates of at least 320g/m^2/8hrs (3.2mm accumulation in 8 hours) and particle size content of at least 40%, based on mass, of 425µm and smaller. The 320g/m^2/8hrs threshold is important because it is the rate that is conservatively estimated to generate 3.2mm (1/8-inch) accumulation in 8 hours, which is a depth noted in NFPA 664. It would suggest that inspection and possible clean-up might be required during a production shift to prevent coverage over 5% of the upward-facing surfaces. Since this is not always possible, it suggests the need for design or process changes in the sawmill. Moisture content was excluded from the risk assessment criteria since the explosibility results suggested that moisture content is not a significant factor for smaller particle sizes.

Application of the potential higher risk criteria focussed attention on 20, or 7% of the 295 samples that were collected and were available for accumulation rate analysis. Eleven of these samples were collected under conveyors, three were collected where conveyors dumped into other transfer systems and one was collected next to chip screens. The majority of these were collected in Basements. The other problem areas were on the Main floor with three samples collected next to Bandsaws and two collected next to Trimmers.

Differences were also identified in sawmills processing MPB-killed lodgepole pine, SPF and DFC (Douglas-fir and western red cedar). SPF sawmills were found to have slightly higher accumulation rates compared to MPB and DFC but as noted previously, in many instances these accumulations were of larger particles exceeding 425μm and 1000μm. When the samples with accumulation rates of at least 320g/m^2/8hrs and particle size content of at least 40% of 425μm and smaller were examined, 14 of these samples were found to have been collected in MPB sawmills. Each MPB sawmill sampled had at least one of these samples and the accumulation rates of these samples in MPB sawmills in general were higher than in SPF and DFC sawmills. One of the DFC sawmills was also found to have a dust sample with these characteristics but at lower accumulation rates. Only half of the SPF sawmills were found to have a dust sample with accumulation rates of 320g/m^2/8hrs or higher and at least 40% of the particles passing through the 425μm sieve by mass.

Areas with 40% of the particle mass of 425μm or smaller but with accumulation rates less than 320g/m^2/8hrs are also very important to consider for mitigation. When the threshold is decreased to 320g/m^2/8hrs, two additional samples were highlighted, one near the chip screens and the other near the Bandsaws. The accumulation rates in these samples suggest the requirement for daily inspection and possible clean-up. None of the potentially higher risk samples were collected from High elevations but one sample was found to have one of the highest proportions of fine dust (96%) of 425μm or smaller size. High elevations and other factors such as the effect of moisture content and the explosibility of wood particles greater than 500μm require further examination.

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