AIR QUALITY ON BIOMASS HARVESTING OPERATIONS

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ABSTRACT

The working environment around logging operations can be very dusty. But, air quality around logging operations is not well documented. Equipment movements and trafficking on the landing can cause dust to rise into the air. The addition of a biomass chipper creates different air flow patterns and may stir up additional dust. This project addresses two topics related to air quality on biomass harvesting operations.

The first topic addresses the quantity of dust in the air during biomass harvesting operations related to human health. Wood and other dusts can cause eye irritation, and in severe cases, may scratch the cornea. Exposure to wood dust may also cause allergic respiratory reactions, especially in people who suffer from asthma. During this study, the measure of particulate matter in the air is compared to the OSHA standards for nuisance dust (particulates not otherwise regulated) in a working environment.

The second topic addresses the impact of air quality on biomass feedstock characteristics. Analysis quantifies the amount of dust in the air and estimates the impact that it could have on the amount of ash in biomass. The research goal of the overall project is to provide a thorough analysis of air quality on landings of various biomass harvesting operations to determine the potential impacts of nuisance dust on human health and biomass feedstock quality. This paper documents findings from an initial project installation in Alabama.

Keywords: biomass harvesting, air quality, air sampling, biomass ash content, human health

INTRODUCTION

It is widely accepted that logging operations are a dusty work environment. This is clearly evident from accumulated dust in cabs and on machine surfaces. However, air quality on biomass harvesting operations is not well understood, nor documented in existing literature. A variety of activities occur on the landing and each may contribute to poor air quality.

Soil type and moisture content may impact air quality and ash content in processed biomass. When soil moisture content is high, fewer particles may become airborne as a result of equipment movements. Particle sizes associated with different soil types may impact the amount of dust that becomes airborne. Soils with smaller particles, <0.1 mm diameter, that rise more than 30 cm into the air may stay suspended for longer periods than larger particles (White 2006). Larger particles (>0.1 mm) do not usually rise over 30 cm, and usually fall back to the ground.

The impact of dust concentrations on air quality of the work environment of forest workers on biomass harvesting operations is unknown. Although personal exposure to dust can be measured, it may be highly variable due to differences in operational characteristics between logging sites, site differences, and a host of other variables. Dust concentration measurements on biomass harvesting operations are needed to quantify air quality and determine the impact that it may have on the health of forest workers.

Chippers and grinders may change the air flow on a landing, and the volume of air flow varies between machines. In a dusty working environment, dust will also be present in the air flow and may get deposited on processed biomass. The impact of dust concentrations on biomass feedstock qualities is also not documented in existing literature.

This introduction provides a brief summary of air quality as it relates to the working environment and human health. It also examines the potential impact of air quality on biomass feedstock quality.

Human Health

Standards for air quality in the working environment are regulated by the United States Department of Labor, Occupational Safety and Health Administration (OSHA). The Occupational Safety and Health Administration (OSHA) was created to ensure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance. ‘"Standard" means a standard which requires conditions, or the adoption or use of one or more practices, means, methods, operations, or processes, reasonably necessary or appropriate to provide safe or healthful employment and places of employment’ (OSHA 2011). As such, air quality standards are addressed by OSHA (1910.1000, Air Contaminants). OSHA sets enforceable permissible exposure limits (PELs) to protect workers against the health effects of exposure to hazardous substances. PELs are regulatory limits on the amount or concentration of a substance in the air. Forestry does not have any industry-specific PELs, however some other industries do. The general air quality standards for all inert or nuisance dusts (whether mineral, inorganic, or organic) not listed specifically by substance name are covered by the limits set for Particulates Not Otherwise Regulated (PNOR). The limits for PNOR are 15 mg/m^3 for total dust, and 5 mg/m^3 for the respirable fraction (OSHA 2011).

There are health issues related to nuisance dust in the working environment. Potential symptoms from exposure to nuisance dust include irritation to skin, throat, or upper respiratory systems. Dust may also cause irritation to the eye, and in severe cases, may scratch the cornea. Exposure to wood or inorganic dusts may also cause allergic respiratory reactions, especially in people who suffer from asthma. However, not all dusts pose the same level of health hazards. OSHA (2011) lists the following factors that can make inorganic dust particles harmful:

- Dust composition
  - Chemical
  - Mineralogical
- Dust concentration
  - On a weight basis: milligrams of dust per cubic meter of air (mg/m3)

    - On a quantity basis: million particles per cubic foot of air (mppcf)
- Particle size and shape
    - The particulate size distribution within the respirable range
    - Fibrous or spherical
- Exposure time

Forest workers on biomass harvesting operations can be exposed to nuisance dust in many ways. On a whole tree chipping operation, most workers operate in enclosed machine cabs. Windows and doors are often opened during normal operations. One of the primary reasons to open doors or windows is to communicate with other workers on the job site. These communications are considered administrative delays in productive environments, so operators do not allow the 'dust to settle' prior to opening a window or door. Modern equipment cabs have a positive pressure which keeps dust out, but open windows bypass the machine's cab air filtration system and may negatively impact the interior air quality.

Truck drivers are also in the landing area during active operations and exposed to nuisance dust. If a chip van has an open top, the truck driver often exits the truck's cab to watch the operation and move the truck/trailer forward to achieve a full payload. If the chip van is loaded from the rear, chips are 'blown' in and fine airborne particles exit the trailer through screened openings in the van. Nuisance dust that becomes airborne due to machine activity near the chipping operation may affect the work environment for truck drivers.

Many of the other workers on biomass harvesting operations are exposed to nuisance dust. Measurements of dust concentrations are needed on a variety of biomass operations.

Ash Content/Biomass Quality

Inorganic elements in wood are often referred to as ash content in biomass. Some of these elements occur naturally in trees because they are brought into the tree from the soil through the root system and sap stream (Koch 1972). In processed biomass, inorganic soil particles that adhere to the tree are included in ash content.

Ash generally constitutes less than 0.5 percent of oven-dry loblolly (Pinus taeda) or longleaf pine (Pinus palustris) stemwood (Koch 1972). Needles of loblolly pine have been found to have an ash content of 2 percent (Metz and Wells 1965). Although this amount seems very small, it results in a residue after energy conversion processes. When biomass is burned in a boiler, everything that doesn't completely combust can fuse together. This non-combusted material includes impurities, such as metal, sand and plastic; and the inorganic substances from biomass. This fused material can block the burning ports in a boiler so that the boiler doesn't heat evenly or efficiently. Ash content is also very important when pelletizing woody biomass. The ash in biomass can cause wear on pellet die, reducing die life. In addition, residential pellet customers want premium pellets with low ash content to reduce the maintenance of removing ash from their wood stoves.

Ash content is often measured through destructive analysis by grinding the material very finely, then drying it in a muffle furnace (ASTM D-1102 2007). In the furnace, the organic material in the biomass burns off and the inorganic components are left in the bottom of the crucible. Ash content is usually reported as a percentage of the oven-dry weight of wood. The resultant ash can be further analyzed for mineral content.

In 2006, pulp mills in Alabama were beginning to add limits to the ash content in their biomass delivery specifications (Mitchell 2006). Later, in 2008, biomass deliveries from land clearing operations were blocked from a mill using biomass as boiler fuel due to the high levels of ash in the material. The land clearing operation included pulling the stumps and grinding them along with other biomass material from a land clearing operation. Samples from this land clearing operation were found to contain an ash content range of 1 to 36 percent (Mitchell unpublished data). In another study, a front-end loader was used to feed biomass into a tub grinder and resulted in high ash percentages ranging from 20 to 65 percent (Rummer unpublished data). In these examples, equipment selection impacted the ash content in processed biomass.

Other sources of inorganic elements (ash) may occur as a result of the harvesting system. A variety of research is currently being conducted in the Research Work Unit to quantify the impacts of harvesting on feedstock characteristics. Researchers are studying whether the process of skidding whole trees from the stump to the landing increases the ash content in processed whole-tree biomass as opposed to trees that were forwarded or fully suspended during the extraction phase of harvesting. Another research topic related to ash content is quantifying the amount of ash in bark, stemwood, limbs and needles of sampled trees. These topics and more can provide information that can lead to improved harvesting techniques to increase the quality of biomass by reducing the ash content.

In this project, nuisance dust will be examined. Specifically, this project will address safety issues (human health) related to air quality on landings of biomass harvesting operations. These dust measurements will be compared to the OSHA standards to determine whether they are within the defined PEL. It will also analyze the impact of air quality on processed biomass by measuring ash content, which may negatively affect the value of the forest product. The results from a short, introductory field study are reported in this paper to share the methodology and initial findings from the study.

SITE LOCATION/LOGGING OPERATION

Data were collected for two days on a logging operation in Butler County, Alabama. Equipment on the landing consisted of a Precision Husky WTC-2366 used in combination with a ForestPro flail. A TigerCat 240 tracked loader fed the flail machine and removed residues from between the flail and the chipper. A rubber-tired HydroAx 411E with a brush blade was used to pile flail and chipper rejects at the edge of the cleared landing. The study was installed in April, 2011.

Although the study was planned for installation on a biomass harvesting operation, this paper summarizes data from a clean chipping operation. The observed logging operation usually processes biomass, but current markets and production-limiting quotas required that the logging business owner purchase a flail and swap between clean chipping and biomass processing as markets dictate. Data from this clean chipping operation may prove to be advantageous by providing a comparison point between clean and dirty chip processing.

METHODOLOGY

An air sampler was used to measure the volume of particulate matter (mg m^{-3}) in the working environment during active chipping operations. One air sample was collected for each load, resulting in one observation per load of chips. The sampler was located close to the chipper in order to get a base line, or worst case, measurement. Exposure time for individual workers was not collected in this initial study installation.

Methodology outlined in NIOSH (2003) was followed for determining total dust using an Airchek model 224-PCXR7 air sampling system. Sampling was performed during the processing of nine loads of chips from a single clean chipping operation.

Airborne particles were collected in cartridges attached to an Airchek model 224-PCXR7 sampler. Each cartridge contained a polyvinyl chloride (PVC) filter (37 mm diameter, 5.0µm pore size) and was sealed to protect against external contamination. Filters were exposed on the sampler for the duration of time that it took to process one load of chips. Once an observation was completed, the sample cartridge was sealed (plugged) and stored upright in a cooler for transport to the laboratory.

Sampler airflow was measured and calibrated at the beginning and end of every observation using a Bios DryCal primary flow meter air calibrator. Any air flow differences in the calibration readings between the start and end of each observation were used for corrections. Due to the filter's sensitivity to oils and dust, some prepared cartridges were exposed on the landing to quantify any handling and storage of the prepared cartridges that could have impacted the results of the observations. These blank cartridges were used to determine if a correction factor was needed for the filter weights.

Soil moisture content testing followed the methods outlined for standard bulk density testing methods (Grossman and Reinsch 2002). A soil sample was collected during each air sampling observation. Core soil samples were collected by driving 50 mm diameter metal corers into the soil. The samples were cut to 25 mm depth, labeled, sealed and stored in a cooler for transportation to the laboratory. The samples were cut to only include the top 25 mm depth of soil to better characterize the soil moisture on the soil surface. Samples were dried at 105°C for 24 hours, then reweighed. Soil type information was obtained using USGS soil maps.

Wood chips were collected to determine if there were any relationships between dust concentration, soil moisture content, and ash content in processed chips. Samples were collected in accordance with laboratory analysis procedures outlined by the National Renewable Energy Lab (Sluiter 2005). Chip moisture content was determined using methodology described in ASTM (2006) standard E-871 (standard test method for moisture analysis of particulate wood fuels). Ash content of the wood chip samples was determined using ASTM standard D-1102 (standard test method for ash in wood).

RESULTS AND DISCUSSION

The basic descriptive statistics shown in Table 1 were calculated from the limited initial data collected. The current dataset was limited to nine observations because of the small tract size and limited delivery quota during the first study period.

Table 1. Descriptive Statistics

	N	Mean	Standard Deviation
Biomass ash content (%)	8	0.305	0.146
Biomass moisture content (%)	9	56.9	2.4
Soil moisture (%)	9	19.4	2.2
PNOR-area (mg/m^3)	8	1.3	1.34

Air Quality

Exposure levels of the 9 air quality samples ranged in value from 0 to 11 mg m^{-3}. The exposure level measured for load 5 was higher than the rest, and may be attributed to a blown hydraulic hose that sprayed fluid onto the air sampler. Removal of load 5 from the analysis resulted in an average exposure level of 1.3 mg m^{-3} for the remaining 8 observations, as shown in Table 1. These remaining 8 observations had exposure levels ranging from 0 to 4 mg m^{-3} (95 percent CI = 0.264 to 2.329 mg m^{-3}). Exposure levels measured during this initial test are well within the PEL of 15 mg m^{-3} (OSHA 2011) for a working area, or less than 1 percent of allowable PNOR. Accuracy of these exposure levels could be increased in the future by using a 5-place balance as opposed to the 4-place balance used in this initial testing.

Temperatures during the study ranged from 21 to 24 ^{0}C (70 to 76 ^{0}F). Relative humidity ranged from 40 to 73 percent. Relative humidity is usually low (<70 percent) during dust storms (Hagen and Woodruff 1973), therefore it is expected that dust levels would have been low during the initial field study.

Ash

The mean ash content analysis for 8 samples of clean chips (chip samples were not collected for load 5) was 0.31percent (95 percent CI = 24.7 – 36.2 percent). Low ash content was expected since the chips were processed through a flail prior to chipping (minimal bark and needles).

Since this initial field study includes only limited data, and was collected on a clean chipping operation, a simple analysis was performed to determine how much dust concentration would be necessary to impact the ash content in a load of biomass chips. An assumption of this analysis is that the total dust on the sampling filter is inorganic and considered ash. During the initial data collection, processing times ranged from 39 to 81 minutes with an average time of 52 minutes.

Therefore, the analysis includes a variety of processing times. Longer observation times may impact the amount of dust particles captured on the sampling filters.

The sensitivity analysis began by considering three levels of ash content acceptable in the delivered load. Pellet mills are sensitive to ash, so the lower limit for the analysis was set at 2 percent. Additional amounts of 5 and 10 percent ash were also included. Assumptions necessary for the analysis were that a load of biomass weighed 23.6 tonnes (26 tons) and contained 50 percent moisture. Ash is calculated on a dry biomass basis. At 2 percent ash, the load would contain 236 kg (520 lbs.) of ash. At 5 and 10 percent, the ash in a load would be 590 kg. (1,300 lbs.) and 179 kg. (2,600 lbs.), respectively. The Precision Husky WTC-2366 has an air flow rate of 311.485 $m^3 min^{-1}$ (11,000 $ft^3 min^{-1}$) and at various loading time periods, different total volumes of air would be blown through the chipper. Table 2 displays the dust concentrations that would have to be sampled in order to reach various ash concentrations from accumulated total dust in the working environment, and without consideration of the ash in and on the biomass.

Table 2. Total accumulated ash (percent) based on dust concentrations and loading times

Dust Concentration ($mg\ m^{-3}$)	**Processing Time**					
	15	**30**	**45**	**60**	**75**	**90**
2	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
17000	0.7	1.3	**2.0**	2.7	3.4	4.0
42000	1.7	3.3	**5.0**	6.7	8.3	10.0
84000	3.3	6.7	**10.0**	13.3	16.6	20.0

Longer loading times may contribute to higher ash contents solely based on the dust concentration in the working environment and the volume of air moved. However, the PEL for total dust concentration (OSHA 2011) is much lower than would be required to attribute 2 percent of ash content to nuisance dust. Based on this analysis, a load of chips should not have any discernable ash content due to dust in the working environment.

Soil

The soil type on this first test site was Luverne, sandy loam, on 5-8 percent slopes. This is a well drained soil type. Sandy loam soil types usually contain more sand than clay or silt. Sand particles are larger than clay or silt and could possibly explain the lack of ash collected on the air sampling filters.

Approximately 3.8 cm (1.5-inches) of rain fell on the test site the day before data collection began. Rainfall data were estimated using NOAA rainfall maps and the nearest weather station data. The Luverne soil type is characterized as being well-drained, and there was no standing water present on the site during chipping operations. The landing area had been cleared a week earlier in preparation of moving onto the site during the morning of the first day of data collection. Laboratory testing revealed that the average soil moisture on the site during data collection was fairly low, 19.4 percent. However, when equipment trafficked in the landing area, there were no visible signs of soil lifting into the air. One would expect clouds of dry matter to rise into the air with such low soil moisture. This may be partially explained by the type of chipping operation. Flail residues coupled with the chipper overs and unders created a layer of material that formed a mat on the operational area of the landing. This mat may have reduced the aerial soil dispersion.

SUMMARY

Analysis during somewhat favorable conditions had levels that were less than one percent of allowable nuisance dust for a working area. Future studies on a variety of soil types may indicate whether soil particle size has an impact on the air quality on biomass chipping operations. The mat of residues on the landing of this clean chipping operation may have helped the air quality on this study site by limiting airborne particles. Further testing on a variety of sites should also provide further insight into the relationship between soil type and biomass ash content.

Dust in the air sampler filters could be further analyzed using an ash test. This test would determine whether the source of the nuisance dust was organic or inorganic. The inorganic component would be considered an impurity in the biomass, whereas the organic component could include wood dust and other particles that would not negatively impact the quality of the biomass produced.

The results of this analysis of air quality on biomass chipping operations are expected to be useful to land managers, loggers, and the biomass industry. Land managers could use the results of this study to determine whether dust abatement techniques would be warranted on their land during logging operations. Loggers, and their employees, could benefit by understanding the health exposure risks associated with biomass chipping operations. The biomass industry could benefit from the knowledge gained about the impact of air quality (nuisance dust) on biomass feedstock quality.

Further analysis is needed to fully address the objectives of this study. This study will be replicated on other sites and further investigate the variables that are determined to be significant to human health or biomass quality. Additional information regarding the biomass source (whole tree, delimbed/debarked, residues-only), species, and chipper type will be documented for each field investigation.

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