STORAGE OF FOREST RESIDUE WOOD CHIPS FOR ENERGY USE

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INTRODUCTION

This literature review is made as a pre-research for an actual study about storage of wood chips made from wood residues. This literature review is made for BEST -project (*Sustainable Bioenergy Solutions for Tomorrow*). The study is made to gather information about storage of wood chips and how storing affects wood chips energy use.

In the practical part of this study a 5000m^3 stack is formed from forest residue wood chips. During the experiment several different samples are taken and analyzed. Samples are gathered during the storage time period from different places of the stack to determine dry matter losses. Microbes and molds are analyzed using the same samples which are used for dry matter analysis. This is done to find possible correlation between microbes and dry matter losses. Self-heating of wood chips is analyzed by thermometers which are placed inside the wood chip stack. Stack is non-ventilated pile which is located at center of Finland, approximately at 62° on northern latitude. Stack is uncovered so it will be exposed to seasonal changes. Experiment is done from October 2015 to spring 2016.

In an ideal case trees would be cut down in early spring and left to by the roadside. In autumn trees would be brought to heating plants where they would be chipped. In this case wood would be only used when it is at its driest point. The problem is that energy and heat is most needed at winter time so wood chips or logs need to be stored at the power plant to ensure fuel availability at coldest times.

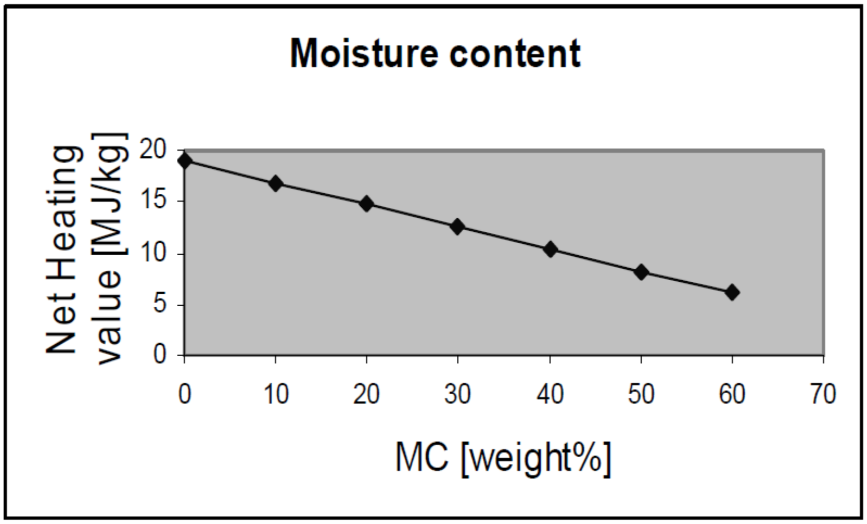
Wood chips are usually stored close to heating plants to ensure fuel availability during winter time when harvesting wood is difficult. Storing of wood chips in an open pile has many known issues. These are dry matter losses, heat development and health risks caused by microbes. Heating is caused by biological, physical and chemical processes.

Wood chips are usually stored outside in big stacks or in big barns. Wood chips are usually not stored in silos, because they have relatively low calorific value so wood chips need a lot more storage volume than dry biofuels. Extra moisture doesn’t do as much harm as it would do for dry wood fuels like pellets.

FACTORS EFFECTING FUEL QUALITY FOR ENERGY USE

For lignocellulose biomass six different parameters effect its energy use: moisture content (intrinsic and extrinsic), calorific value, proportions of fixed carbon and volatiles, ash/residue content, alkali metal content and cellulose / lignin ratio. (McKendry, 2002)

Intrinsic moisture content describes the amount of moisture in material when influence of weather conditions are not considered. Extrinsic moisture content describes the total moisture content of biomass. Extrinsic moisture content is the actual moisture content which has effect on calorific value of wood chips. When stating calorific value extrinsic moisture content needs also to be stated, because higher moisture content decreases the calorific value (*Lower Heating Value, LHV*). In case of higher heating value (*HHV*) moisture content is redundant. (McKendry, 2002)



Picture 1 Moisture content effect on calorific value (Eriksson, 2011)

Fixed carbon (*FC)* and volatile matter (*VM)* proportions are determined in laboratory. Volatile matter is the portion of driven-off matter as a gas when solid fuel is heated to 950 °C for seven minutes. Fixed carbon content is the remaining mass after volatiles are released, excluding the ash and moisture that is left from volatiles.

Alkali metal content describes the total amount of alkali metals in biomass (e.g. Natrium, Kalium, Magnesium, Potassium and Calcium). Alkali metal content is important for combustion and thermo-chemical conversion processes. A reaction between alkali metals and silica (SiO_2) produces a sticky compound that can stick to super-heater and furnace pipes. This causes corrosion and lowers heat conductivity which decreases the total process efficiency. (McKendry, 2002) Cellulose / lignin ratio is important factor for biochemical conversion processes, for example ethanol fermentation. Cellulose is more biodegradable than lignin. Plants with higher cellulose content are then more suitable for biochemical processing. (McKendry, 2002)

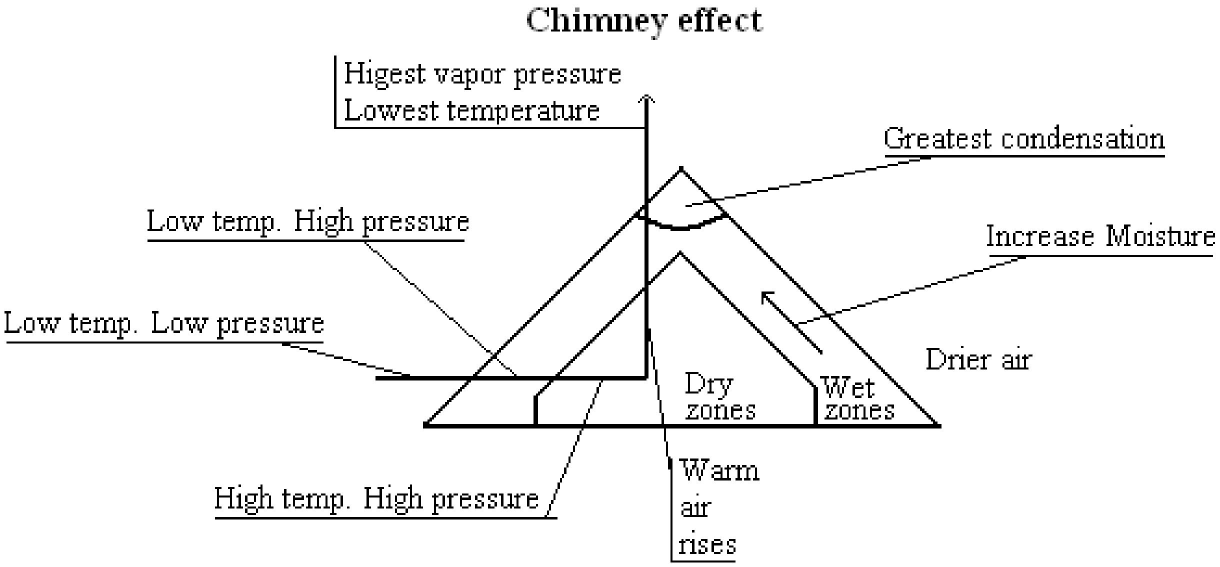
FACTORS NEEDED TO CONSIDER WHEN DESIGNING STORAGE OF WOOD CHIPS

Storage area

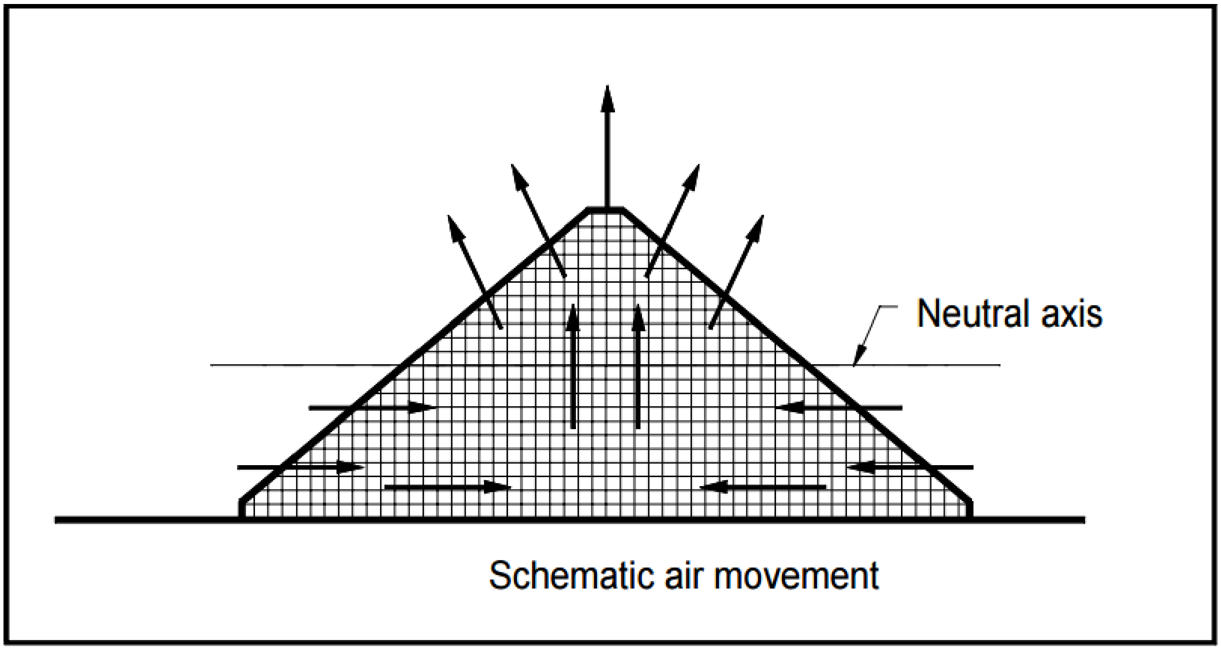
Stored wood is weakly acidic with pH ranging from 4 to 5. This has to be taken care of when designing storage areas. Some concretes can't stand acidic materials which can cause problems. Steel parts that are in touch with wood should be acid resistant, for example ductwork, conveyors and so on. Acidic material will cause faster corrosion in the long run if not preventive maintenance is taken care of. (McGowan, 2011)

Chimney effect

Self-heating of wood chip pile will also dry the material. Heating starts at the center so evaporation will push moisture towards outer layers of the pile. This will cause dry zones in the heart of pile and more moist zones on the outer layers of it. In the heart of pile under pressure generated heat will also increase pressure. Heat dissipation is greatest at the top of pile, so it will have lowest temperature. Temperature difference will cause the heat and moisture to rise towards the top of pile. This causes so called chimney effect. (Eriksson, 2011)



Picture 2 Chimney effect described (Eriksson, 2011)



Picture 3 Air movement inside stack according to mathematical model (Garstang;Weekes;Poulter;& Bartlett, 2002)

Compaction

Compaction of pile can be divided into natural and forced compaction. Higher stacks have more natural compaction due to increased pressure inside the stack due to more material. Forced compaction depends on used bulldozer. Rubber-tired vehicles will increase compaction compared to tracked vehicles because of smaller contact area. Smaller chips tend to compact tighter than larger chips. Also size segregation has effect on actual compaction. For example wind pushes finer particles to one side of pile. (Janzé, 2011)

Compacting chips decreases the airflow through pile. Decreased air flow increases generated heat inside the pile. Studies show disagreement between each other whether decreased air flow decreases biological action or not. Some state that compaction doesn't have an effect on biological processes and it only decreases the heat dissipation which increases internal temperature. (Janzé, 2011)

Compacted stacks will dry slower because of restricted air flow. So compaction isn't preferred method for storing wood chips because of increased heating inside pile.

Chip size

Wood chips should be stored as big size as possible to handle with conveyors and other instruments. Bigger chips are not so vulnerable to biological degradation which decreases heating value losses. Optimum wood chip size is 3 – 30 mm. (Garstang;Weekes;Poulter;& Bartlett, 2002) Chips should be as uniform in size to ensure proper combustion if chips are not ground before combustion.

Heat development in finer particles is less related to ambient conditions than bigger pieces of wood. Smaller particles also absorb rain easier. Stack in open air can develop a 1 – 3 m deep wet layer. This layer will be insulating layer to decrease heat dissipation. This increases internal temperature which leads to greater microbial action and again more heat build-up which in the end can lead to spontaneous combustion. (Janzé, 2011)

Smaller boilers require higher quality wood fuel with lower moisture content and smaller particle size. When boiler size increases also quality requirements for fuel quality loosen. Large boilers (>1 MW) can handle wider chip size range than small household scale boilers. (Kofman, 2015)

STORAGE OF WOOD RESIDUE FOR ENERGY USE

Storing wood as chips has many know issues. In order to minimize the negative effect of self-heating and dry matter losses their mechanisms have to be known.

Self-heating

Sap wood is living material. When trees are cut the cells can still be viable for long periods of time. When wood is chipped living cells of wood rays start to respire in order to heal the tree. This respiration consumes oxygen and releases heat. This respiration reaction happens during the first 5 – 7 days after chipping of wood. This reaction will go until nutrient or moisture is extinct or until temperature has raised approximately till 25 – 50 °C. Increased temperature provides a good growth conditions for microbes. (Carbolea, 2015)

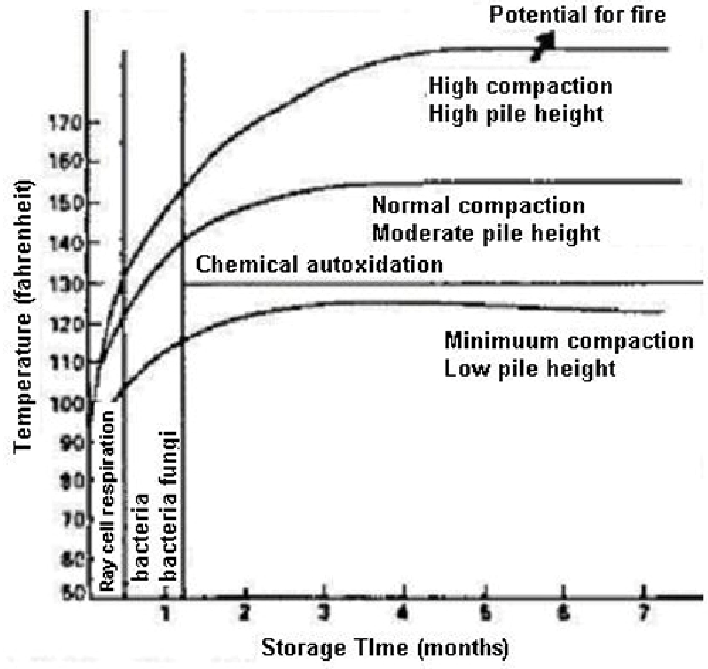
After first two weeks temperature has typically raised to 60 – 70 °C inside the stack and chemical reactions start. In this part acetyl group is cleaved from cellulose molecules and acetic acid and heat is formed. Formation rate of acetic acid increases with temperature, so reaction speeds up if the heat is not dissipated from the stack. (Fuller, 1985) Water catalyzes this reaction. For dry material speed of reaction increases significantly beyond 80 °C, but with moist material in lower temperatures (Carbolea, 2015).

Formation of acetic acid increases the acidity of the pile. Even though acetic acid isn’t a strong acid (pK_a = 4,76) it still causes shortening of cellulose molecules. This shortening darkens the wood and makes it crumble as it would have been burned. Sometimes it’s misunderstood that chips have gone through slow pyrolysis, because of darkened color and crumble form.

Slow pyrolysis can still occur. It start generally at 65 – 70 °C and decomposes cellulose, hemicellulose and lignin. It requires oxygen and water, and produces CO2 and heat. Carbon dioxide dissolves to water and forms weak acid, which then accelerates the increase of piles acidity. (Carbolea, 2015)

Low pH of wood chips at pile exposes cellulose molecules to exothermic auto-oxidative reactions. These reactions can rise the temperature of pile to over 80°C. Biological organisms can’t stand such a temperatures so all biological activity will stop. When temperature rises even higher to approximately 90 – 150 °C and oxygen level is low fast pyrolysis reaction can occur. When the temperature from pyrolysis isn't dissipated away from stack an ignition may occur. (Fuller, 1985)

Rather than deflagrating it's more usual that wood chips start to smolder. The actual temperature spontaneous combustion differs, but is usually between 150 – 200 °C. When oxygen is unavailable smoldering will occur, but in case of sudden aeration deflagration can happen. This can happen for example if wood chips are removed from pile for combustion. (Carbolea, 2015)

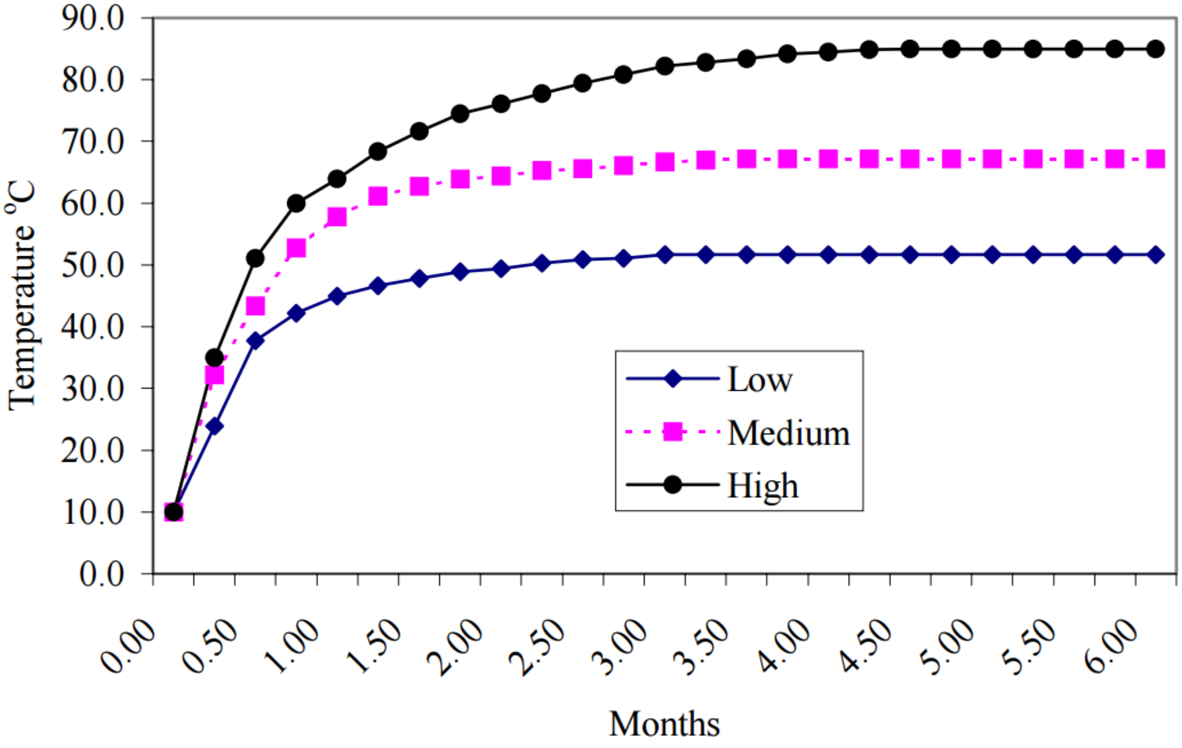


Picture 1 Graph describing heating mechanisms over storage time

Smaller particles have higher surface-area to volume, called SA/V ratio. Oxidation reactions take place on surface of the chips, so smaller chips have higher SA/V ratio compared to their mass. This means that smaller chips have higher heat generation rate compared to bigger chips. Smaller chips also absorb water more, which increases fungal activity and thus heat generation. Smaller particles can pack more tightly which decreases the amount of air circulation inside stack. This will decrease heat generation. (Carbolea, 2015) Even though if fine chips are blown or either compacted tightly with external force it increases the risk of self-ignition since small particles stratify so that it reduces free air between chips and decreases heat dissipation and thus increases self-ignition risk. (Garstang;Weekes;Poulter;& Bartlett, 2002)

Higher stacks generate more heat, because heat generation is directly proportional to the volume of pile. Thus, higher stacks have smaller radiative area compared to shallower stacks with same volume. Radiative area is the area of boundary layers of the stack. So short piles with flat tops would have less radiative area compared to tall and narrow based stacks. In order to minimize self-heating tall and narrow based piles should be prepared. (Carbolea, 2015)

In picture 2 is described the effect of stack height on internal temperatures. It shows that higher stacks have higher internal temperature. They generate more heat but also the heat isn't dissipated so effectively which increases internal temperature. Volume of stack increases X^3 where X is linear dimension of stack.



Picture 4 Stack height effect on stack temperature

Higher moisture content will decrease temperature rising inside the stack. Increased moisture content will increase fungal activity and thus heat generation, but increasing heat will go to evaporation of moisture instead of increasing pile temperature.

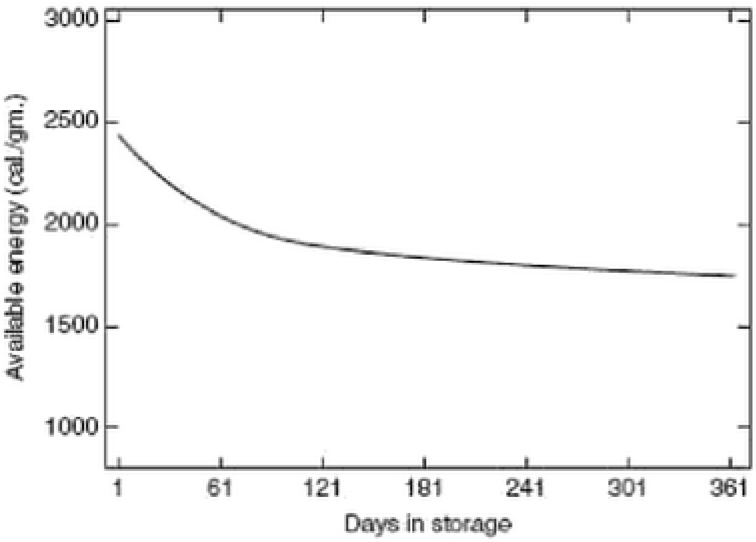
The moisture content has an effect on temperature behavior. According to studies, the temperature rises rapidly in wood chip piles with moisture content of 40 wt%, but decrease after

1 – 2 months. When moisture content is 50 – 55 wt% temperature rises, but it doesn't decrease. It stays high during whole storing period. (Wihersaari, 2005)

Dry matter losses

Young trees are biologically active material, so changes occur in material during storage. According to studies biodegradation of organic matter is a function of temperature. Respiration increases until temperature reaches 40°C, while optimum temperature for aerobic deterioration is 20°C – 30 °C.

Microbial organisms consumes low energy components cellulose and hemicellulose. This increases the percentage of higher heating value components lignin and extractives. Even though this increases woods heating value, since it's expressed in MJ/kg, it still lowers the total energy content of the pile, because dry matter is consumed. Ash content will also increase due to same reason, even though the actual amount of ash is unchanged. (Eriksson, 2011) This means that chips that are stored first, should be used first in order to minimize energy losses during storage. Picture 3 describes who the energy content of wood chip pile varies during storage. (McGowan, 2011)



Picture 5 Available energy content during storage

To minimize dry matter losses only dry material should be stored. Moisture content should be less than 20% on weight basis to minimize dry matter losses. The problem is that 20 wt-% moisture content isn't possible without artificial drying. Studies made in Sweden showed that increases in initial moisture content increased dry matter losses.

Initial Moisture Content	Monthly dry matter loss	Total dry matter loss on 6-month period
42 %	1,1 wt%	6,6 wt%
51 %	2,2 wt%	13,2 wt%
58 %	2,6 wt%	15,6 wt%

Picture 4. Initial moisture content effect on dry matter losses.

Material losses are highest in the beginning of the storage period, right after the temperature has risen. Highest losses are estimated to be 3,6 wt% per week and after that it slows to 0,4 – 0,7 wt% per week. (Wihersaari, 2005)

HEALTH ISSUES

As described before in this study storing of moist wood chips increases the growth of microorganisms. When wood chips are handled microorganisms can be airborne and when inhaled they can cause health problems. Normal outdoor air concentration for microorganisms are 10 – 1000 per m3 air. Researches have showed 100 – 1000 times bigger amounts next to fuel feeding inlet.

The health risk of microbial growth depends on the amount of airborne microorganisms. The amount of airborne microorganisms is dependent on three factors: (Eriksson, 2011)

- **Total amount of spores** – The amount of spores that are bonded to wood chips
- **Moisture content of material** – Drier material will cause more spores to airborne. Moisture content will bound spores to woodchips so they won't be airborne so easily
- **Weather** – Rainy days will lower the amount of airborne spores. When spores are dry they will be airborne for longer time.

To minimize microbial growth storing time should be short. So firstly stored chips should be used first, this is called first-in first-out method. Material should also be stored only short times at plant site. When stored at roadside microorganisms will grow, but they don't cause health hazard since there is no workers.

Microorganisms are main health concern when storing wood chips. If a lot of bark and needles are stored volatile hydrocarbons like terpenes and isoprene's can emit. They can cause irritation to skin, tissues and mucosa. According to studies made in 1998 this is quite rare health hazard if wood chips are stored outdoors. (Eriksson, 2011)

Inhaling fungi or actinomycetes spores can cause a hypersensitivity reaction called allergic alveolit. The disease can be acute, sub-acute or chronic form. Possible symptoms are high temperature, shivering, headache and muscle pain. Symptoms normally show up a couple of hours after the exposure. People infected by an acute form are generally recovered in a couple of days after exposure. However they can be sick again if exposed again. In sub-acute or chronic form it takes more time to be infected and recovered. If daily expose is 15 – 30 minutes sub-acute or chronic form can be developed. (Eriksson, 2011)

CONCLUSION

Efficient storage of wood chips really important to minimize economical losses and minimize the risk of potential self-ignition. Wood is biological material so most of the problems cannot be totally overcome, but with correct plant and storage design effects can be minimized.

Wood is weakly acidic so handling of wood can cause corrosion to conveyors and pavement of storage area. Preventive maintenance needs to be taken care of to minimize losses.

Air flow through pile is important in order to prevent rise of internal temperature. Temperature rise is a continuous set of different reactions. Right after wood chipping wood tries to heal itself. This respiration causes internal temperature to rise. Increased temperature provides good environment for bacteria to grow. Bacteria continues to grow and continues to increase temperature of pile. After one month of storage temperature has raised enough acetyl groups are cleaved from cellulose molecules and acetic acid and more heat is formed.

Since a lot of heat is formed it is important to make sure that heat is dissipated away from stack. To maximize heat dissipation compaction should be avoided. Compaction decreases airflow inside the pile so heat increases internal temperature. Natural compaction occurs from the shape of the pile. Higher stacks have more natural compaction. Shallower stacks have also more radiative area which increases the heat dissipation rate.

Growing of microbes will generate heat but will also cause health risk. When microbes come airborne and are inhaled they can have hypersensitivity reaction called allergic alveolit. Its symptoms can be high temperature and shivering. When exposed time is long chronic or sub-acute form of disease can develop. In these forms it takes longer to recover from symptoms. If daily expose is only 15 – 30 minutes sub-acute or chronic form can develop.

Issues found in storing of wood chips are not impossible to overcome. Minimizing storage time and possible self-heating issues efficient wood chip storage can be really efficient. Not all of the energy losses cannot be avoided, but they can be minimized. Good design before storing and efficient monitoring of temperatures are necessary.

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