DANISH TECHNOLOGICAL INSTITUTE

Guideline: Storage and Handling of Wood Pellets

Resultat Kontrakt (RK) Report

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December 2012

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Contents

1 INTRODUCTION

The use of solid biofuels i.e. wood pellets and briquettes has increased significantly during the last 15 years. Biomass briquettes are mainly used by small scale consumer's i.e. private households while biomass pellets are used both within the private sector and for commercial heat and power production in large scale, industrial plants. During the past 10 years wood pellets have become an important energy carrier to substitute coal in the Danish energy sector. Today most pellets used in Denmark are produced abroad and shipped to Denmark in large container vessels where they are used as fuel in combined heat and power plants (CHP-plants), for district heating and small scale pellet boilers. The pellet consumption in Denmark is expected to increase strongly within the next 10 years and it is therefore necessary to provide a guideline for secure handling of solid biofuels. Recently different guidelines have been published by the Association of German Engineers [1], German pellets institute [2] or the Nordic Innovation Centre [3] dealing with safe handling and storage of solid biofuels. Safety considerations of biomass handling have been picked up in several journal articles and books dealing with solid biofuels [4-11].

A number of serious incidents have been reported across Europe in connection with false handling of wood pellets. Some of them have resulted in injury or even death of the handling personnel and some resulted in great damage and financial loss for the companies handling the pellets. Table 1 provides examples of accidents in relation with handling and storage of solid biofuels during the last 10 years. Most people consider wood materials as harmless, natural products and underestimate the risk potential, especially when storing it in closed compartments i.e. silo, storage room or transport vessels.

Table 1: Examples of accidents related to the storage and transportation of solid biofuels [4]

Year	Place	Accident
2002	Rotterdam	A ship loader on board of the "Weaver Arrow" loaded with wood pellets went down in the storage compartment and suffocated
2005	Gruvön	A seaman suffocated on board of the wood freighter "Eken" when he went down the stairs to the cargo room that was filled with pulpwood.
2006	Helsingborg	A seaman on board of the "Saga Spray" suffocated when he went down the stairs to the storage compartment filled with wood pellets. A ship loader and a rescue team rushing for assistance got severely injured
2006	Skelleftehamn	A seaman on board of the "Noren" died when he entered a storage compartment filled with wood chips
2007	Timrå	The captain and one seamen of the wood freighter "Fembria" died when they walked in the storage compartment filled with timber wood.
2007	Finland	A person died when walking into a small (10 t) wood pellets silo.
2008	Finland	Another person died when walking into a small (10 t) wood pellets silo.
2009	Bornholm	Two seaman on board of the "Amirante" died when they entered the cargo room filled with wood pellets. The pellets were loaded one day before.
2010	Germany	A person suffocated in a pellet storage (150 t)
2010	Ireland	A person suffocated in a pellet storage (7 t)
2011	Switzerland	A person suffocated in a pellet storage (100 t)

2 SCOPE

The intention of this guideline is to provide recommendations for the handling of solid biofuels in a responsible and safe way, minimizing risks for health and safety. The guideline is addressing both large and small scale producers, transporters and end users of solid biofuels. Focus is set on wood pellets and wood chips since they are by far the most common type of solid biofuels in Denmark.

3 TERMINOLOGY AND DEFINITIONS

Terms and terminology of this guideline apply as given in EN 14588. Specifications of different types of solid biofuels are defined according to EN 14961-1

4 SOLID BIOFUELS

Solid biofuels cover a wide range of sizes and shapes from wood pellets to straw bales. Solid biofuels and their typical dimensions and preparation method are specified in the European standard EN 14961 as shown in Table 2.

Table 2. Major trade form of solid biofuels according to EN 14961-1 [1]

Name	Typical particle size	Preparation
Whole tree	> 500 mm	No preparation or delimbing
Wood chips	5 to 100 mm	Cutting with sharp tools
Hog fuel	undefined	Crushing with blunt tools
Log wood/firewood	100 to 1000 mm	Cutting with sharp tools
Bark	undefined	Debarking residues from trees, can be crushed, shredded or unshredded
Bundle	undefined	Lengthwise oriented & bound
Fuel powder	< 1 mm	Milling
Sawdust	1 to 5 mm	Cutting with sharp tools
Shavings	1 to 30 mm	Planning with sharp tools
Briquettes	Diameter > 25 mm	Mechanical compression
Pellets	Diameter < 25 mm	Mechanical compression
Small square bales	0.1 m^3	Compressed and bound to cubes
Big square bales	3.7 m^3	Compressed and bound to cubes
Round bales	2.1 m^3	Compressed and bound to cylinders
Chopped straw or energy grass	10 to 200 mm	Chopped during harvesting or before combustion
Grain or seed	undefined	No preparation or drying except for process operations necessary for storage
Shells and fruit stones	5 to 15 mm	No preparation or pressing and extraction by chemicals
Fiber cake	undefined	Prepared from fibrous waste by dewatering

5 GENERAL RISK EVALUATION OF BIOMASS HANDLING AND STORAGE

Major problems that can arise when handling large amounts of biomass are connected to dust formation, off gassing, self-heating and biological hazards. The quality of biomass is subject of large variation and depending on biomass origin, size, shape, composition and moisture content different problems can occur during handling and storage. The most common problems are summarized in the following section:

5.1 Self-heating and self-ignition

Self-heating of biomass can occur either by chemical oxidation reactions and/or microbiological decay. The more fresh the biomass and the higher the moisture content the greater is the risk for self-heating and potential self-ignition. Self-heating of biomass is a serious problem and has been cause of several incidents.
Oxidation reactions require oxygen and the oxidation rate of the biomass seems to depend on the age of the biomass and generally decreases with storage time. The reactions go along with oxygen depletion which is a potential risk for pellet handling personal. The mechanism behind the oxidation reactions are not completely understood but it is likely connected to the biomass extractives. Heat development due to microbiological decay is to large extent depending on the moisture content and the surface area [5].

There are some general recommendations to avoid self-heating and self-ignition of biomass. According to Obernberger and Thek they can be summarized as follows [5]:

- Avoid storage and transport of large volumes if the fuel's tendency for self-heating is unknown
- Be conscious of the risk of self-heating and spontaneous ignition in large storage volumes
- Avoid mixing of different types of biomass fuels in one storage
- Avoid mixing of biomass fuels with different moisture content
- Avoid large parts of fines in the fuel bulk
- Measure and monitor the distribution temperature and gas composition within the stored material
- Prepare (large) silos for gas injection at the bottom of the silo in case a fir should occur
- Pellet storage units must be equipped with size dependent, appropriate means of ventilation control to remove carbon monoxide and carbon dioxide

In case a fire occurs it has to be noted that fire fighting procedures are difficult since water cannot be used in many cases, especially when pellets are stored in a silo. Pellets absorb moisture quickly and swell to about 3 to 4 times of their size, forming a cake like structure that can become very hard and is difficult to remove from the silo. The pellet expansion can in worst case result in a burst and collapse of the pellet silo. Self-heating occurs usually deep inside the bulk and the fire source is therefore difficult to reach.
Gases such as nitrogen and carbon dioxide and foams are usually the methods of choice to extinguish fires in pellet silos. Fire fighting operations, especially in large silos can be very complex and expensive operations. The technical research institute of Sweden (SP Sveriges Tekniska Forskningsinstitut) has published methods for extinguishing fires in wood pellet silos [17,18].

5.2 Off-gas formation and oxygen depletion

Biomass releases CO and CO_2 and oxygen is consumed in chemical oxidation processes and microbiological processes. CO and CO_2 are odourless toxins and can be lethal at low concentrations. Low oxygen concentrations can lead to suffocation of the handling personal when entering closed biomass storage without proper ventilation. Several death cases have been reported in connection with wood pellet storages during the last years both in large silos and container vessels but also in relatively small pellet storage in private homes. A closed biomass storage i.e. pellet storage room should never be entered before it has been ventilated with fresh air. CO and CO_2 are heavier then air and will accumulate at higher concentrations at the bottom of the storage. Furthermore does biomass contains various different volatile organic compounds (VOCs) i.e. terpenes and terpenoids, esters, ethers and aldehydes. A lot of these VOCs can evaporate from the wood and in some cases they might accumulate in concentrations that may cause a health and safety hazard.

5.3 Dust formation

Handling of biomass can liberate significant amounts of dust. Especially dry biomass particles have often a low density and a high drag coefficient and can easily be dispersed in the air. Airborne dust particles pose a great risk to anyone coming into contact with them, mainly through inhalation. Dust can have different impacts on health, but the main effects of biomass dust are on the lungs and the respiratory system. The inhalation of an excessive amount of dust particles can result in irritation of the lungs, nasal and respiratory system. It can give raise to allergic reactions and severe illness such as cancer when exposed repeatedly over a longer period of time. Apart from that dust can irritate the eyes, causing sourness and conjunctivitis. There are clear limitations for dust exposure of working personal on national and international level. For Denmark the Danish Working Environment Authority (Arbejdstilsynet) can be contacted for further information.

The second great risk connected to biomass dust is the risk for dust explosion. Dust has a very large surface area compared to its mass. Ignition of biomass can only occur at the interphase between biomass and air and this causes dust to be much more flammable then bulk material. Depending on biomass type, size and shape of the particles, explosive suspensions can be formed at different mass to oxygen ratios. Those explosive mixtures can be ignited by electrostatic discharges, friction or hot surfaces and can result in fatal damage. There are strict regulations in place to prevent dust explosion accidents. In some cases it might be necessary to classify biomass handling processes according to the ATEX directive. For Denmark the Danish Technological Institute (Teknologisk Institut) can be contacted for further information and help regarding risk evaluation and safety procedures. Table 3 shows an example of the ignition/explosion properties of dust from wood pellets (white dust), bark pellets, coal and a fungi and the used testing standard [5]. The pellet handbook from Obernberger and Thek [5] should be consulted for further reading.

Table 3. Ignition and explosion properties of dust from wood pellets (white dust), bark pellets, coal and a fungi. Data taken from Obernberger and Thek [5].

Test mode	Test parameter (dust < 63 µm)	Unit	White dust	Bark dust	Coal dust	Lycopodium spores	Testing standards
Dust cloud	Auto-ignition Temp (T_C) (Godbert-Greenwald)	°C	450	450	585	430	ASTM E1491
	Min Ignition Energy (MIE)	mJ	17	17	110	17	ASTM E2019
	Max Explosion Pressure (P_{max})	bar	8.1	8.4	7.3	7.4	ASTM E1226
	Min Explosion Pressure Rate (dP/dt_{max})	bar/s	537	595	426	511	ASTM E1226
	Deflagration Index (K_{St})	bar.m/s	146	162	124	139	ASTM E1226
	Min Explosible Concentration (MEC)	g/m³	70	70	65	30	ASTM E1515
	Limiting Oxygen Concentration (LOC)	%	10.5	10.5	12.5	14.0	ASTM E1515 mod
Dust layer	Hot Surface Ignition Temp (5 mm) (T_s)	°C	300	310			ASTM E2021
	Hot Surface Ignition Temp (19 mm) (T_s)	°C	260	250			ASTM E2021
	Auto-ignition Temp (T_L)	[illegible]	[illegible]	[illegible]			[illegible]
	Dust Class (> 0 to 200 bar.m/s)		St 1	St 1	St 1	St 1	[illegible]
	Dust Class Explosion Severity (ES > 0.5)		Class II	Class II			[illegible]

5.4 Biological hazards

Biomass is a natural product and as such a potential feedstock for different types of microorganisms i.e. fungi and bacteria. The risk of microbiological decay of the biomass depends on the biomass properties i.e. size and composition, moisture content and temperature. The major source of decay is caused by fungal infections. Fungi can digest the biomass and form large colonies commonly known as mould. Fungi produce toxins when growing on biomass i.e. mycotoxines and they can be released as dust into the air. Airborne fungal spores and toxins can cause irritations and allergic reactions along the respiratory system. Inhalation and direct contact should be avoided.

6 HANDLING OF WOOD PELLETS

Large amounts of wood pellets are transported by land and sea way, and the intercontinental trade of wood pellets is likely to increase by factor 10 within the next decade. It is therefore important to look on the overall risks involved in handling wood pellets. Mechanical forces during transportation of pellets cause fractures and breakage of the pellets, resulting in fines and dust. Although there are high quality standards (i.e. EN 14961-1) ensuring that pellet producers produce pellets with a high strength and abrasion resistance this problem cannot be eliminated completely. Especially pellets used in large scale applications such as heat and power plants are usually not following those standards. In those cases the quality standards are often agreed directly between the pellet producer and the large scale consumer. The mechanical durability of wood pellets is usually determined in a tumbler, simulating the impact forces that pellets experience during transportation. A standardized method exists to measure pellet durability, and this can be consulted for further reading (EN 15210-1).

To prevent the formation of fines and dust, handling should be as gentle as possible. The more handling steps the more degradation of the pellet. Important factors for handling are the drop height, elasticity of the impact surface and the number of times the pellets are dropped. Pellet degradation is a function of number of impacts and impact force (i.e. drop height) and they should be limited to a minimum to prevent dust and fines formation. There are many different ways of transporting pellets. The most common ways to move pellets from/to storage and transportation vessels are conveying and vacuum pumping. Especially large scale bulk handling of pellets exposes high mechanical load onto the pellets. This can be the case when loading pellets into an ocean vessel or into a large pellet silo at the producer/consumer site. Drop height are usually high (up to 25 m and more). It also has to be considered that pellets drop on each other and that a high weight load is exposed to the pellets lying in the bottom of the vessel/silo.

Pellet abrasion and dust formation takes place along the whole supply chain of the wood pellets from the pellet mill to the customer. Fines and dust formation during handling can occur during all of the steps during the supply chain. The most prominent ones are listed below:

- Conveying the pellets from the pellet plant to storage
- Packing of pellets i.e. big bags
- Conveying to transport vehicle
- Filling transport vehicle
- Discharge transport vehicle
- Conveying to another transport vehicle or to storage
- Filling into storage

Pellets are usually conveyed or transported by pneumatic pumps. The latter one might do severe damage to the pellets when the pressure (velocity of the pellets) is too high and if there are sharp turns in the transport pipe or potential impact sites for the pellets.

Pellet transport can take place either in trucks, trains or ships depending on the transport distance. Trucks are usually used to bridge short distances while trains are used for longer distance. Ship are used to transport large amounts of pellets either directly to the end customer or to a harbor were the pellets are unloaded and distributed to smaller transport vessels. A lot of large scale users are located close to the water so they can receive pellets by ship.

6.1 Loading and transport (in closed vessel)

Large volumes of pellets from oversea are transported in ocean vessels. Especially on the trans-Atlantic route from Northern America to Europe bulk carriers are used. The size varies and is usually ranging from 1.500 to 50.000 deadweight tons (dwt) [5]. During shipping the pellets are kept dry under hatch covers with tight seals. To avoid the penetration of moisture into the storage compartment, ventilation is usually turned off. The storage of large amounts of pellets in a closed compartment on a ship is similar to the risk in a pellet silo and the same safety measures should be taken (see chapter 7).Trucks are a used to transport small amount of pellets (up to 40 tons) to small scale customers. Pellets are loaded either as bulk or in bags. Bulk trucks are sometimes equipped with vacuum pump systems that allow pumping of the pellets and thus a comfortable way to transfer the pellets to a storage compartment. Rail cars and containers are also used for transport if available

6.2 Unloading and internal handling

During receiving and internal operations, the risk of dust generation, ignition and explosion should be minimized. Special precautions should be taken to avoid increase of fines and wear during unloading and receiving pellets. The precautions generally should focus on avoiding over-heated or burning loads, spark detecting and fire extinction systems.

6.3 Conveying

Conveying shall be conducted with a minimum of wear and damage to the solid biofuel. Fuel pellets, in particular, are very sensitive to physical wear and shall be handled with care. Precautions shall be taken to avoid moisture uptake in pellets. Minimal length of belt conveyor line should be applied and many crossings and high drops should be avoided, which raise the content of fines in a batch of pellets.

7 STORAGE OF SOLID BIOFUELS

Due to seasonal fluctuations with periods of high demand (winter) and periods with moderate or low demand (summer months) pellet producers and intermediate traders need large storage space. Also consumers i.e. heat and power producers have a high demand for securing their energy supply and thus keep storage big enough to be able to deal with unforeseen bottlenecks and shortages of supply. Wood pellets are sensitive to moisture uptake and when exposed to rain they swell and lose their pellet structure. High moisture content also promotes microbiological decay and this can result in dangerous conditions such as self-heating and self-ignition. Wood pellets are therefore always stored indoors, either in flat storages i.e. frames, storage halls or in silos. Indoor storage of biomass is a challenge with respect to self-heating of the biomass, dust formation and off-gassing of the biomass. A range of safety measures have to be taken to grant safety. Recent accidents have shown that improper handling of biomass can result in severe damages and risk for life and health of handling personnel.

7.1 Storage types

7.1.1 Silo

Silo storage is the most common way of storing pellets at power plants, pellet producers and harbors. Silos are consuming less space as storage halls and can be filled and emptied easily using screw conveyors. The size of the silo depends on its function. Large silos with several thousand cubic meter volumes are common as intermediate storage at harbors or at large scale pellet consumers. From there pellets are distributed to transport vessels, or feeding bins.

Large scale silos can be different in size and shape depending on the function and construction year. Typically older silos that have previously been used for agricultural products are high and have a small diameter. Newer silos that have been designed and built from wood pellets storage usually have a larger diameter compared to their height. In general there are two different types of pellet silos, silos with a tapered bottom and silos with a flat bottom.
Vertical silos with a tapered bottom can be emptied by gravity using a discharge tunnel and a conveyor. These type of silos are widely used to store agricultural products i.e. grains and are to some extend also used for pellet storage. Agricultural silos usually range from 50 to 10.000 m^3. Dark colors and corrugated metal should be avoided since they increase heat absorption and lower heat transfer. Vertical silos with a flat bottom are emptied using a circulating auger for center feed to a discharge tunnel. They require less space due to their flat bottom and are therefore cheaper to build. However do they require more maintenance and take longer time to empty.

7.1.2 Flat storage

Flat storage building i.e. A-frames, are used for bulk storage of pellets and are used for large storage of pellets in a range from 15.000 to 100.000 m^3. They are used at the pellet producer's site, for intermediate storage at harbors and at the end users i.e. power plant site. Pellets are conveyed into the building and dropped down onto the floor forming a pile and/or moved by front loaders onto a pile. Emptying of this kind of storage is made by front loaders either into a feed system for a boiler (power plant site) or onto trucks, vessels or rail cars for further transportation. Especially moving pellets with a front loader bears the risk for fines and dust formation and as such a risk for health and dust explosion.

7.2 Self-heating and ignition risk

Fires in wood pellet silos due to self-heating are not uncommon and several incidents have been reported during the last years. Also dust explosion incidents have been reported from several plants and facilities handling wood pellets. Fires and explosions can occur along the whole supply chain of wood pellet production and delivery and can take place in the production plant, transport vessel, transfer facilities and at the consumer site. However fires and explosions are not known to be a problem in the bagged pellets marked [5].

The sources of ignition can either be externally from sparks generated by metal pieces or stones coming in contact with the biomass or by overheating of motors, conveyer belts, bearings due to high friction. An accumulation of dust and fines due to improper maintenance and cleaning can increase the risk of fires and dust explosions. Measure to reduce these risk are control measures to remove impurities i.e. stones and metal from the biomass, spark and heat detectors along the transport conveyors, extinguishing systems and fixed control schemes for checking the state of the conveyor belts and bearings to prevent overheating and removal of dust and other debris. The utilization of antistatic and fire resistant material as well as proper grounding of the transport conveyors can reduce the risk of external ignition too.

Pellets in a closed storage environment can heat up due to microbiological and/or chemical reactions. The bulk mass act as insulation and therefore heat is usually built up deep inside the bulk. Microbiological decay requires moisture and it is therefore usually a problem occurring when the moisture content of the biomass is too high or in case of water (rain) coming in contact with the biomass. Microbial decay results in a temperature increase in the stored fuel and peak temperatures of microbial self-heating can be up to 80 °C depending on the type of microorganism [19]. Chemical degradation usually starts to have influence at about 40 °C and at temperatures above 50 °C chemical degradation reactions will exceed the biological ones [19]. Due to poor heat transfer within the bulk mass and the insulating properties of biomass, heat is accumulated inside the bulks that can result in self ignition. The main factors affecting the temperature in a pellet silo are the ambient temperature, moisture content, moisture gradients, size of the bulk and density.

7.3 Monitoring of temperature, off-gasses and moisture

Temperature in a pellet silo should be monitored continuously by sensors embedded in the stored product. An alternative and/or addition to direct temperature measurement can be equipment sensing carbon monoxide, hydrocarbons, radiated heat and smoke as precursors for overheating [5]. Even at low temperatures low temperature oxidation of pellets will result I the formation of carbon dioxide, carbon monoxide, aldehydes and methane and these gasses will deplete the oxygen in the silo. One option to cool and ventilate a pellet silo at the same time is to ventilate a storage silo whenever the ambient outside temperature is lower than the temperature inside the storage. In case of too high temperatures (> 80 °C) emergency procedures should be in place. This could be emergency discharge of the pellets by relocating them into a different storage or outside and thus breaking up the hotspots and cool the pellet bulk. In general the temperature in a pellet silo should be kept below 45 °C.

7.4 Safety measures for handling personnel

Gasses formed in a close pellet silo are a threat for the life of handling personnel and therefore measures should be taken to avoid contact with handling personnel. This can be done by ventilation systems, gas monitoring, warning signs and strict working procedures when opening and entering a pellet silo.

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