Silo fires require special

The replacement of fossil fuels with renewable fuels has an impact on fire safety issues in many ways. In *IFJ* number 80, the challenges with the increased use of ethanol were discussed. However, the use of solid biofuels also presents new risks and challenges for the industry and first responders. One common type of refined solid biofuel is wood pellets which are often stored in large silos after production or shipping. In the case of a silo fire, it is important to understand the nature of the fire and to use appropriate tactics and equipment. This article, written by Henry Persson from the SP Technical Institute of Sweden, presents new research on silo fires and silo fire fighting, and some experience from real silo fires.

In the past 10 years, the use of solid biofuels, and in particular wood pellets, has increased dramatically. In year 2000, the annual production of wood pellets in Europe and North America was about 1.5 million tons while the expected production for 2010 is in the range of 16 million tons[1]. Sweden is the largest wood pellet consumer with an expected consumption of about 2.2 million tons 2010[2]. The production in Sweden is estimated to be about 1.8 million tons, while the remaining part is imported by ships, normally from North America and the Baltic countries. However, pellet consumption is increasing dramatically in several European countries as well, e.g. Denmark, Belgium, Netherlands, Germany, UK. As a consequence, handling and storage of wood pellets is also increasing.

Figure 1; due to lack of knowledge many silo fires have developed into very serious fires placing firefighters at great risk and resulting in a total loss of the silo complex.

As wood pellets are a dry product, with a moisture content of 6-10%, they need to be stored indoors. Large stores are found both at the production site and on-site at large consumers such as power plants. Imported pellets are transported by large ships which could also be considered as temporary bulk storage. The most common storage is probably in so called A-framed buildings but the use of silos has increased. The advantage of silo storage is that the handling can be completely mechanised, reducing the amount of manpower required. The sizes of these silos are also constantly increasing. In Sweden, several old concrete silo complexes, previously used for grain storage, have been converted for pellets storage. However, all new silos are built as single, large diameter structures. The diameter of these silos is often in the range of 20-30m with a storage volume of about 5 000-15 000 m^3 but even larger silos are under construction.

Solid biofuels are porous materials which are generally susceptible to heat generating processes and are prone to self heating and spontaneous ignition. This is also true of wood pellets, which are a processed and rather dry wood fuel, and often exhibit self heating from oxidation[3]. Indeed, spontaneous ignitions in large scale stores have been reported rather frequently in Sweden. There is also a risk for various external ignition sources during handling and transport which might cause a fire inside the silo. A preparatory study on the extinction of silo fires[4] in 2004 revealed the risks with silo fires and the lack of knowledge among both silo owners and the fire rescue services concerning proper extinguishing practices. This has often resulted in very complex firefighting situations with total loss of the silos involved. Since the report was published in 2004, a number of fires have occurred in silos with wood pellets due to spontaneous ignition, giving further proof of the need for more information directed to the fire brigades, see Figure 1.

Research and experience

In order to improve our knowledge of fire development, detection and extinction techniques in silos, two main tests series have been conducted at SP Technical Research Institute of Sweden in 2006 and 2008, respectively, which are briefly summarised in this article[5,6]. Experience from these projects has resulted in recommendations concerning proper extinguishing practice. The proposed extinguishing technique has also been used successfully in a number of recent silo fires[7,8,9].

Figure 1

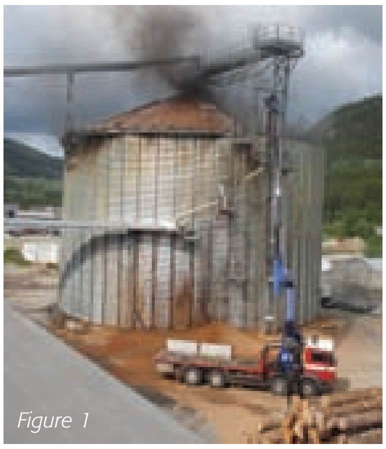

Figure 1

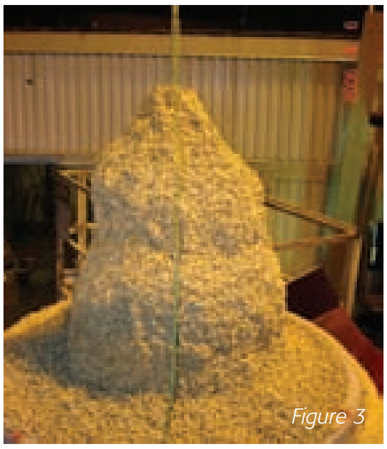

Figure 3

tactics and equipment

Silo extinguishing tests

The main purpose of the first project conducted in 2006 was to study fire extinction techniques in silos and to provide a basis for guidelines concerning the tactics to be used. The project also provided valuable information about the initial fire development of a simulated spontaneous ignition in the stored material and the possibility for early detection of such a fire. The silo used for the tests was 1m in diameter and 6m high. Close to the bottom of the silo, a ventilation duct was installed, which was used both to provide ventilation to the silo during the "pre-burn" phase and for injection of inert gas during the extinguishing phase. The silo was filled with wood pellets up to a height of 5m during the tests. Local auto-ignition was simulated using a coiled heating wire placed in the pellets, located centrally in the silo. The pyrolysis was allowed to develop freely with the ventilation openings in the bottom and the top of the silo open. The silo included a significant amount of instrumentation, with almost 100 thermocouples as a means to follow the development of the pyrolysis zone and later the efficiency of the extinguishment. Four tests were conducted and in all tests the extinguishing/inerting process was started after allowing the pyrolysis process to develop for about 30 hours, using gas injection of nitrogen and carbon dioxide, respectively

As shown in Figure 2, the extension of the pyrolysis zone was mainly downwards, towards the air inlet while a heat/moisture wave, with a temperature less than 100 °C, slowly moved upwards. Although the distance from the point of ignition to the pellet surface was only about 2.5m, it took about 20 hour before the fire could be detected by gas analysis in the top of the silo.

During dismantling of the silo after the tests, it could be verified that there had been a transport of moisture upwards from the pyrolysis zone as the pellets had "glued" together forming a something akin to a termite pile, see Figure 3. However, the pile was fragile and could easily be broken. It was also verified that the pyrolysis had only spread downwards from the ignition source and that the pyrolysis zone was very distinct and had a limited spread in the horizontal direction. These observations corresponded well with experience from real silo fire situations.

Figure 3: photos taken during dismantling of the silo. Opposite left, the pellets formed a "termite pile" in the top of the silo. Below: the pyrolysis zone about 0.5m below ignition source.

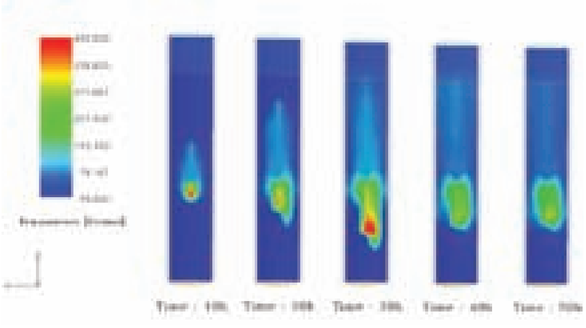

Figure 2: visualisation of the recorded temperatures inside the silo during one of the fire tests.

Gas filling tests and simulations

The purpose of the second project, conducted in 2008, aimed to investigate how nitrogen should be injected into a real silo during extinction in order to achieve optimal gas distribution and thus ensure that the entire silo was efficiently inerted. The experiments were performed in a 300m³ steel silo with a diameter of 6m and a height of 10.5m and filled with about 260m³ of wood pellets, see Figure 4. In total, five gas filling tests were conducted where the gas was injected from the silo bottom, in the centre of the silo, or alternatively at one point along the silo wall. All tests were conducted in a "cold" silo (no fire) as the main interest was to study the gas distribution in the bulk material. The tests showed that the gas distribution was significantly influenced by the gas

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New: very early smoke detection line – now with gas detection and environmental monitoring

Ideal for applications in warehouses, manufacturing facilities, battery room, boiler rooms and tunnels (amongst others) is the new VESDA ECO from Xtralis.

Xtralis has taken smoke detection to a new level by expanding its range of VESDA (very early warning smoke detection) aspirating smoke detection systems with gas detection and environmental monitoring. VESDA ECO uses new or existing VESDA pipe networks to reliably detect smoke in addition to hazardous/combustible gases to ensure air quality.

It has been designed to easily integrate with other building management systems to provide real-time situational awareness and intelligent emergency response – and that includes the activation of demand-controlled ventilation.

The system has been launched to tackle head on the fact that invisible hazards can originate from the release of toxic gases, oxygen deficiency, or the presence of combustible gases/vapours.

Xtralis President and CEO Samir Samhouri told IFJ that VESDA users could now fully realise the value of their systems beyond smoke, by also including gas detection and environmental monitoring.

Since the launch of VESDA ECO a few months ago the system has already been deployed in power plants in South America; car parks in Europe; and data centres, national laboratory, wireless telecom facility and historical relic displays in the US.

Benefits of the new system is that the VESDA ECO detectors are installed on the VESDA pipe network; this delivers continuous active air sampling, better area coverage over conventional fixed spot gas detectors, the ability to detect gases in harsh environments by conditioning the air to remove moisture, dirt and other particulates, as well delivering reduced installation and maintenance costs – all advantages over traditional fixed point gas-detection systems.

Each VESDA ECO detector can house up to two gas sensors, and additional detectors can be added easily to the pipe network to monitor more gases if required.

A wide range detectors are available to protect personal and property from combustible, toxic, and oxygen deficient environment. Additional detectors are available that can be used to reduce energy cost when deployed in demand controlled ventilation applications where ventilation only occurs when the gas of interest is present preventing continuous 24/7 ventilation. An example of available gases include; ammonia (NH_3), carbon monoxide (CO), hydrogen (H_2), hydrogen sulphide (H_2S), methane (CH_4), nitrogen dioxide (NO_2), oxygen (O_2), propane (C_3H_8) and sulphur dioxide (SO_2).

Point, zone or total-area coverage can be provided to suit different applications, and the system easily integrates with fire alarm control panels (FACP), programmable logic controllers (PLC), heating ventilation and air conditioning (HVAC) systems, and building management systems (BMS) to provide real-time situational awareness for intelligent emergency response.

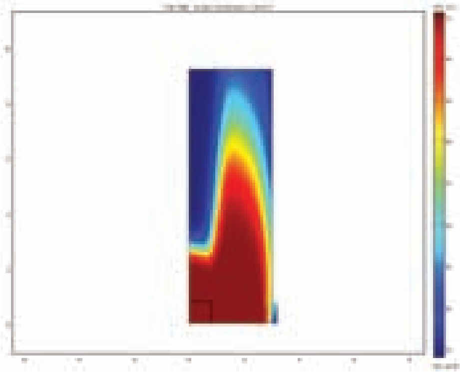

Figure 4, left: the 300 m^3 test silo used for the gas distribution tests. Right: simulated nitrogen distribution inside the test silo assuming a higher amount of fine fraction in the silo centre and an injection rate of 4.5kg/m^2h. Red colour – 100 % N_2, blue colour – air (21% O_2). The silo centre and the gas inlet are located in the lower left corner of the figure.

flow rate, the location of the inlet and the properties of the bulk. At a low flow rate (about 1.0 kg/m^2 h), the radial gas distribution was limited and an effective inerting of the material was only obtained in a part of the silo cross section. Using a higher gas flow rate (about 4.5 kg/m^2 h), the radial distribution was improved. It was also observed that the bulk had a lower permeability in the silo centre due to a higher amount of fine fraction which had a significant influence on the gas distribution.

As a complement to the gas filling tests, mathematical simulations of the gas distribution inside a silo were also made. Some of the simulations carried out were intended to give an idea of the expected gas distribution in the test silo (see Figure 4), and others to study the gas distribution in very large silos under a variety of conditions. The simulations assumed axi-symmetry conditions which means that only one half of the silo was simulated. The main conclusion from the tests and simulations is that several inlets are recommended if the silo diameter exceeds 6-8m.

Experience from real fire incidents

The results from the first silo project were successfully applied to a real silo fire in 2007 in Sweden[7]. Auto-ignition occurred in a silo, 47m high and 8m in diameter, filled to about 40m with wood pellets, see Figure 5. Elevated temperatures had been noted for some period of time and it was planned to empty the silo within the next few days. However, before such action was

Figure 5: the silo on fire (second from right) was 47m high, 8 m in diameter, and filled to about 40m with wood pellets. A vaporisation unit was used to ensure that the gas was injected in gaseous phase.

taken, smoke was seem emerging from the top of the silo and the fire brigade was called to the location. A first extinguishing attempt was made using the application of CO_2 in liquid phase to the top volume of the silo. During approx 18h, about 35 tons of CO_2 was applied intermittently. The application seemed to control the fire but there were no possibilities to verify how much of the gas was penetrating into the bulk material and how much was lost immediately through the opening in the top of the silo. Consequently, it was not possible to make any judgment of the extinguishing effect and when a discharge operation could be safely started.

Preparations were therefore made to inject nitrogen close to the silo bottom according to the recommendations from the silo experiments in 2006[5]. A gas tank with liquefied nitrogen and a vaporization unit was ordered. A hole was drilled close to the bottom of the silo and an injection probe was manufactured which was introduced into the hole. In order to control the effect of the gas injection, temperatures and concentrations of CO, CO_2 and O_2 were measured in the top of the silo.

The gas measurements were started just before commencement of nitrogen injection and showed a very high concentration of CO(>10%), verifying an ongoing pyrolysis activity. About 3.5 hours after start of gas injection, the first indication of a decreasing CO concentration was seen. After about 18h, the CO-concentration had been reduced to about 2% and the O2-concentration was 0%. At this point it was decided to begin discharge of the silo in combination with a continuous injection of nitrogen. The unloading work continued for about 48 hours but had to be stopped on several occasions for safety reasons due to high temperatures and increasing oxygen concentration in the top of the silo. This was probably due to the fact that the seat of the fire became exposed on these occasions. In total, nitrogen injection continued for almost 65 hours without interruption, with approximately 14 ton of nitrogen used, corresponding to an average injection rate of about 4 kg/m^2h. The gross volume of the silo was about 2500m^3 which gives a total gas consumption of approximately 5.6 kg/m^3 which is well in line with the recommendations from the research project[5].

Summarized guidelines

Below is a very brief summary of the recommended measures to be taken in case of a silo fire:

- Make an initial risk assessment of the situation. There might be very high levels of carbon monoxide in indoor areas in the vicinity of the silo. Further, consider the risk for dust and gas explosions in the silo and in any connected conveyer belt systems.
- Close all openings of the silo and turn off ventilation so that air entrainment into the silo is minimized. However, there must be a released hatch or similar in the silo top for gas and pressure relief while still preventing any inflow of air.
- Inject nitrogen close to the bottom of the silo. The nitrogen should be injected in gaseous phase, and an evaporator must be used. Assume an injection rate of 5 kg/m^2 hour (cross sectional area) and a total gas consumption of 5-15 kg/m^3 (gross volume) of the silo.
- If possible, measure the concentration of CO and O_2 at the top of the silo during the entire extinguishing and discharge operation.
- Do not start discharging the silo until there are clear signs (low levels of CO and O_2) that the fire is under control.
- Be aware of that the discharge capacity might be considerably reduced compared to a normal situation and that the discharge operation might take several days to complete.
- The discharged pellets must be inspected for glowing or burning material and extinguished with water if necessary.
- The gas injection should continue during the entire discharge process.

Important to remember!

- Do not open the silo during the firefighting operation. This will cause air entrainment which will increase the fire intensity and might cause dust and gas explosions and a severe fire situation.
- Do not use water inside a silo filled with wood pellets. Water application will cause considerable swelling (see figure 6) of the pellets which could both damage the silo construction and cause significant problems for the discharge operation.

Conclusions

Renewable fuels are an important issue both nationally and internationally. Clearly there are risks associated with large changes in the use and handling of new fuels or even old fuels in new applications. The use of solid fuels, such as wood pellets produced from low grade wood material not suitable for more refined uses, is increasing with no visible decline foreseen in the near future. Risks associated with their storage have been investigated in the two studies presented in this paper and a set of recommendations defined to assist in the efficient and safe extinguishment of storage facilities should spontaneous ignition occur. These recommendations have been successfully applied to a number of real fires and should provide a sound basis for the design of future facilities or retrofit of existing facilities to enable their rapid application in the event of a fire.

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