Dangerous (toxic) atmospheres in UK wood pellet and wood chip fuel storage

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**ABSTRACT**

There is growing use of wood pellet and wood chip boilers in the UK. Elsewhere fatalities have been reported, caused by carbon monoxide poisoning following entry into wood pellet storage areas. The aim of this work was to obtain information on how safely these two fuels are being stored in the UK. Site visits were made to six small-scale boiler systems and one large-scale pellet warehouse, to assess storage practice, risk management systems and controls, user knowledge, and potential for exposure to dangerous atmospheres. Real time measurements were made of gases in the store rooms and during laboratory tests on pellets and chips. Volatile organic compounds (VOCs) emitted and the microbiological content of the fuel was also determined.

Knowledge of the hazards associated with these fuels, including confined space entry, was found to be limited at the smaller sites, but greater at the large pellet warehouse. There has been limited risk communication between companies supplying and maintaining boilers, those manufacturing and supplying fuel, and users. Risk is controlled by restricting access to the store rooms with locked entries; some store rooms have warning signs and carbon monoxide alarms. Nevertheless, some store rooms are accessed for inspection and maintenance.

Laboratory tests showed that potentially dangerous atmospheres of carbon monoxide and carbon dioxide, with depleted levels of oxygen may be generated by these fuels, but this was not observed at the sites visited. Unplanned ventilation within store rooms was thought to be reducing the build-up of dangerous atmospheres. Microbiological contamination was confined to wood chips.

**Introduction**

Use of wood pellet boilers in domestic, community, and commercial property as a renewable energy alternative to oil-, gas-, or coal-fired boilers in the UK is increasing, but this is still a comparatively new activity. This technology is already becoming established in Europe. There are concerns that the risks associated with wood pellets in the UK, particularly the release of carbon monoxide and absorption of oxygen during storage, are not understood, and that the health and safety information provided by manufacturers and suppliers to control the potential risks is inadequate. This prompted the UK Health and Safety Executive to issue an HSE Safety Notice.[1]

Since 2002 there have been at least nine fatalities caused by carbon monoxide poisoning following entry into wood pellet storage areas reported in the literature. These deaths occurred in ships’ holds, pellet silos, and domestic storage, and have been reviewed by Gauthier et al.[2] To date, there have not been any deaths in the UK. At present, UK boiler systems tend to be smaller scale than those used in Europe; however, wood pellets are also increasingly being considered for use in large-scale power generation. There are potential risks associated with each.

Further knowledge and evidence are needed to enable better guidance and information to be produced for duty holders in the wood pellet industry, including users, manufacturers, and suppliers of wood pellets, and those installing and servicing wood pellet boilers. The work was expanded to include fresh and dried wood chips which are comparable in use, and whose potential for gaseous production and absorption was also not fully understood.

Wood pellets are typically around 6 mm in diameter and contain less than 10% moisture with no additives or binders. Wood chips are typically 20–50 mm long and when freshly harvested can have a moisture content of more than 60%. Seasoning can reduce moisture content to 25–30% and kiln drying reduces it further. Both fuels need to be kept dry to maintain their calorific value and ease of ignition, and to prevent microbiological growth.
Additionally, moisture may cause pellets to swell and breakdown causing transportation problems.

There are a number of health and safety hazards associated with the transportation and storage of wood pellet and wood chip fuels, including airborne dust (wood and microbiological material), gaseous toxic emissions (carbon monoxide, carbon dioxide, methane, and a range of volatile organic compounds (VOCs)), asphyxiating and explosive atmospheres and spontaneous combustion. In the context of fuel storage, the often limited access, the free-flowing nature of the fuel and the fuel transportation machinery also present a hazard. Furthermore, there is a problem when fuel does not flow freely and voids are created, i.e., unstable structures possibly requiring intervention. Where fuel storage areas are enclosed and there is a reasonably foreseeable risk of serious injury or death these areas should be considered to be confined spaces, as defined by the Confined Space Regulations 1997.[4]

Carbon monoxide is a chemical asphyxiant and carbon dioxide is a simple asphyxiant which also has a physiological effect on breathing rate. The US National Institute for Occupational Safety and Health (NIOSH) has defined IDLH (Immediately Dangerous to Life or Health) values of 1200 ppm for carbon monoxide and 40,000 ppm (4%) for carbon dioxide.[5] These values do not take into account a possible simultaneous exposure to an oxygen deficient atmosphere, which would increase the effect. The HSE Approved Code of Practice (ACOP) to the Confined Space Regulations 1997,[4] states that there are substantial risks if the concentration of oxygen in the atmosphere varies significantly from normal (i.e., 20.8%); and very low oxygen concentrations (i.e., below 16%) can lead to unconsciousness and death. In the UK, carbon monoxide has workplace exposure limits (WELs) of 30 ppm and 200 ppm (8 hr time weighted average (TWA) and 15-min reference periods, respectively)[6] Carbon dioxide has corresponding WELs of 5000 ppm (0.5%) and 15,000 ppm (1.5%).

**Methods**

Seven sites were identified for investigation. Six had small to medium sized boiler systems (<250 kW) with associated storage (<15 tonnes), and included store rooms (purpose built and converted rooms) and silos (glass reinforced plastic and fabric). The sites included one wood chip store room. The sites were identified via the HSE manufacturing sector and were chosen primarily for the variety of storage types they represented. The seventh site represented large-scale wood pellet storage (8,000 tonnes), used for storing fuel for a power generation company.

During the visits, site representatives were interviewed to identify their knowledge of the hazard and risk associated with the storage of wood pellets or chips. Information was collected on delivery and storage of the fuel, operation and maintenance of any related heating system, and the risk management strategy in place. The storage areas were examined to establish and assess the controls present.

At four of the small sites, and at the large site, measurements were made as follows:

- air monitors were set up to assess real time changes in store room air composition;
- diffusive samplers were left to sample VOCs;
- the air change rate in the four small storage areas was determined; and
- bulk samples of fuel were taken for investigation of potential microbial activity and laboratory-based monitoring of air composition changes.

Staff at these sites were also asked to keep a log of relevant activities undertaken during the monitoring period.

No measurements were made at the other sites: one was a tower silo, outdoors, impermeable, and relatively inaccessible (Site 1), the other was not suitable for access for the planned work (Site 5). At two sites (Sites 4 and 6), access to the fuel area was not possible because the fuel was in a silo with no access hatch; therefore, air measurements were made in the room in which the silo was situated. These silos were both made from fabric and expected to be permeable to gases, and the rooms were readily accessible.

An Ion Science GasClam real time air monitor (Cambridge, UK) was left in the wood pellet/chip area to collect data on changes in air composition and air temperature over a four week period, at one measurement per hour. The GasClam was chosen because it was intrinsically safe and able to monitor carbon monoxide and oxygen using electrochemical sensors, carbon dioxide and methane using infra-red monitors and VOCs using a photoionization detector calibrated with isobutylene. The GasClams were calibrated by their supplier (Shaw City Ltd., Watchfield, Oxfordshire, UK), and were checked after use at the HSL laboratory.

Diffusive sorbent tubes (Tenax TA and Chromosorb 106) were left to sample VOCs. The tubes were analyzed by thermal desorption–gas chromatography with flame ionization detection and mass selective detection.

The ventilation rate or air change rate of the store rooms, or rooms containing silos, were measured using a modified version of the step-down method.[7] This involved injecting a tracer gas (10% SF$_6$, balance N$_2$) into the room, mixing it with the room air using a desk top fan to obtain a uniform concentration, and then monitoring the concentration as it was diluted by incoming clean air. The concentration of SF$_6$ was monitored using a Miran
1a infrared spectrometer (Thermo Scientific, Waltham, MA).

The bulk pellet and chip samples were analysed for potential microbiological activity. A sample of each fuel was suspended in ¼ strength Ringers solution. Dilutions of this suspension were used to inoculate nutrient agar plates for incubation at 25°C and 37°C, and Malt agar plates for incubation at 25°C and 40°C. Following incubation for seven days, any emerging colonies were counted and the results used to calculate the level of contamination.

**Laboratory-based monitoring of air composition**

Samples of fresh wood pellets (from the supplier to Sites 1, 4, and 5) and wood chips (from Site 3) were obtained to measure their gaseous emissions in laboratory tests. The samples were packed into air tight 60 L drums to maximize emission concentrations. Measurements were made of changes in oxygen, carbon monoxide, carbon dioxide, and VOCs in the headspace of the drums. Other researchers have previously used this approach to investigate wood pellets, but HSE were unaware of any similar data for wood chips. These tests also acted as a control and reference for the site measurements.

Tests were performed on the fresh pellets and chips shortly after collection. Logging MultiRae gas monitors (RAE Systems San Jose, CA) and Gemini Tiny Tag+2 temperature and humidity meters (Gemini Data Loggers, Chichester, UK) were placed inside the drums, which were then sealed and stored in a laboratory kept at 21°C. The MultiRae used were pumped monitors configured to measure carbon monoxide, carbon dioxide, and oxygen using electrochemical sensors individually calibrated with their respective gases; VOC, using a photoionization sensor calibrated with isobutylene; and flammable gases using a catalytic bead sensor calibrated with methane. Pressure was not monitored because previous studies have shown there to be minimal change at room temperature.

For comparison, a second set of tests was performed with dried wood chips. The wood had already been seasoned to some extent before chipping, but the chips were further dried by heating to 30°C in a climatic chamber for 20 hr while being flushed with dry air (<5% relative humidity, RH) at 4 L.min⁻¹. The average moisture content of ten randomly selected wood chips was measured using a GE Protimeter Surveymaster (Boston, MA). Moisture was reduced from 26.1 to 12.6%.

Initial testing had shown that the %RH and the carbon dioxide exceeded the upper working ranges of the sensors in the drum containing woodchips. Therefore, new samples of woodchips and pellets were tested in which the quantities were carefully selected in order to keep the gas concentrations and relative humidity within the gas monitor manufacturer’s recommended specifications. During testing, acceptable humidities of approximately 90% RH, 44% RH and 42% RH were obtained in the containers that held wood chips, dried wood chips, and wood pellets, respectively.

**Results and discussion**

**Activities**

At the smaller sites visited, workers were relatively remote from the delivery process. At the five small pellet sites, delivery was done pneumatically from a tanker via a flexible hose taking 15–20 min. This is an enclosed system which should also dilute any accompanying gases through entrainment of air. The wood chips were tipped from a trailer into a delivery pit, taking 20–30 min. At the large warehouse the pellets were tipped from lorries and then pushed into position using tractors. No examples of bulk bag delivery were encountered during this work.

If the transfer mechanism was working correctly, there should be little reason to enter the storage areas. Often, they could not be accessed until the level of fuel has decreased sufficiently. Viewing windows (with intrinsically safe lighting) or scales could be used to check levels. However:

- In the past, the Site 2 store room had occasionally been entered to check the transfer screws.
- Site 3 staff sometimes enter the wood chip store room when there has been a breakdown, to check fuel levels or the transfer sweeping arm, and to break up steep piles of chips. This occurred twice in 29 days during monitoring, taking around 10 min.
- The storage at Site 4 needed to be redesigned because the pellets did not slide properly to the auger. Since the new fabric silo system was installed there has only been one similar incident whereby a cavity was created after the pellets formed an arch. This was remedied by the site manager crawling under the fabric silo and hitting the wall with his hand. A sleeve on the front wall of the silo allows visual inspection. This occurred once in 34 days during monitoring.
- As the level of pellets in the Site 5 store room decreases it is necessary to periodically open a hatch in order to lean in and level the pellets with a garden rake to ensure they cover the auger screws.
- At Site 6 the room containing the silo is accessed regularly by cleaners.
- At the large Site 7 warehouse carbon monoxide and air temperature are monitored twice per week using...
a personal monitor, taking 30 min. This task involves walking along the top of the pellets.

The associated boilers are generally serviced twice a year by specialist companies who are also called out for repairs. At Site 3 the service engineer is required to enter the wood chip store room to check the sweeping arm. Once established, repairs generally relate to operation of the furnace and not the fuel storage or delivery systems; however, one service company reported that problems have been encountered with foreign objects (e.g., nuts and bolts) jamming augers. For major repairs to the fuel transfer system, the fuel would need to be removed to gain access. There were conflicting reports on whether residual dust needs cleaning out.

**Risk management**

**Information, instruction, and training**

There was limited awareness at the smaller sites of the potential risk presented by the storage of wood pellets or chips in a confined space. Silos are generally inaccessible; however, rooms containing fabric silos or boilers are potentially confined spaces and are accessed. Generally, information, instruction, and training were minimal and were often restricted to the operation and basic maintenance of the boiler system when it was first installed. The HSE Safety Notice[^1] had resulted in action at Sites 3, 4, and 6, and raised some awareness at Sites 2 and 5. Training on wood pellet storage with respect to health and safety was good at Site 7, with the external storage company being linked into the power generation company's safety regime.

None of the smaller sites (Sites 1–6) had a Manufacturer's Safety Data Sheet (MSDS) for the wood fuel. The wood chips burnt at Site 3 are produced on the estate, but are also supplied to other users. The MSDS for the imported Site 7 fuel was quite comprehensive. It included chemical, fire, and explosion hazards from wood dust, carbon monoxide, carbon dioxide, methane, and oxygen depletion. Advice on handling, storage, ventilation, and entering "enclosed" spaces was also given. Wood pellets in containment are recommended to be ventilated at “one air exchange per 24 hr at 20°C and a minimum of two air exchanges per 24 hr at 30°C and above,” and that pellets in “long period storage in large bulk containment” should be “as air tight as possible.”

**Management controls**

No relevant risk assessments were available at the smaller sites. Warning notices on the storage area doors at Sites 4 and 6 give some instructions on procedure for entry (i.e., checking the carbon monoxide alarm, keeping the door open whilst inside). Site 6 required ventilation of the room before entry, but the building design made this impracticable and this instruction was therefore unlikely to be followed.

At Site 7, workers have a safe working procedure and risk assessment of the dangers of working at the site. This includes information on personal protective equipment (PPE), the use of personal alarms for monitoring carbon monoxide, the dangers of combustible dust and oxygen, and lone working.

Access to the boiler rooms and fuel storage areas was generally restricted at all sites via lockable doors, with keys being held by a responsible person (although they were not always aware of confined space hazards). The Site 7 warehouse doors are kept locked unless the doors are opened for inspection or ventilation purposes in dry conditions. They may be then left open and unattended for long periods. The site personnel are aware of confined space entry controls: workers wear personal gas monitors, a buddy system was used when monitoring the warehouse, and personal radio communication is maintained with a person on the outside during entry. None of the sites had any form of temporary barrier, e.g., rope or mesh door.

There were warning signs on the pellet store room and boiler room doors at Sites 3, 4, 6, and 7. At Sites 4 and 6 there were signs on both sides of the door making them still visible when opened. At Sites 3 and 7 they were commercially produced, at Sites 4 and 6 the signs were homemade.

Air quality checks or forced ventilation were not generally made before entry to the smaller store rooms or rooms containing silos; however, Sites 4 and 6 had domestic carbon monoxide alarms by the room entrance. Carbon monoxide checks are made with a hand held monitor before entry at Site 7. Staff are instructed to limit exposure to carbon monoxide to no more than 15 min at 200 ppm. This would be exposure at the WEL. None of the sites checked oxygen levels.

**Planned ventilation**

The small storage areas did not have any planned mechanical or natural ventilation. The large warehouse had natural ventilation via louvered windows, and during dry conditions the doors were opened to increase ventilation.

The Site 1 silo was located outdoors. The Site 4 and 6 silos were situated in rooms with some natural ventilation via wall vents. The Site 4 room was also connected to a ventilated boiler room via a large gap in the internal wall. The Site 6 room also contained the boiler, and there was a non-return valve located in the flue which could draw air from the plant room into the flue to balance pressures. Boiler rooms containing silos are likely to have a high air change rate during operation; however combustion in
boilers may also be a source of carbon monoxide. There is evidence that boiler flue gases were a likely cause of a death at a domestic wood pellet installation in Ireland.\[^8\]

The rooms accessing the Site 2, 3, and 5 store rooms were ventilated via wall vents. The Site 5 room was also connected to the adjoining boiler room via a gap in the internal wall.

**Personal protective equipment**

None of the sites provided respiratory protective equipment (RPE) specifically for protection against exposure to gases and vapours generated by the fuel; however, RPE was available for dust hazards, in particular during boiler maintenance. At Site 4, when pellets were previously stored in a store room, a half mask respirator fitted with P3 filters was worn when entering the store room however not face fit tested. Staff working at Site 7 are supplied with P3 filters when entering the store room.

**Measurements**

Notes on the circumstances relating to the real time measurements were made, and the results obtained on site and in the laboratory are summarised in Tables 1 and 2 and Figures 1–4.

**Air quality**

The GasClam monitors did not identify any significant build-up of carbon monoxide, carbon dioxide or methane at any of the four small stores (Table 1). At two of the sites the GasClam monitors were positioned outside fabric silos. The GasClam at the Site 7 warehouse recorded a peak carbon monoxide concentration of 27 ppm, with a mean of 5 ppm (Figure 1). This was from a significantly larger quantity of pellets. Information supplied by the company indicated that, at times, these levels had been higher with readings as high as 106 ppm; and, at a different site, levels had been measured at greater than 200 ppm.

It has been reported that carbon monoxide production peaks during the first six weeks after wood pellet production.\[^2\] It is anticipated that pellets delivered in the winter will be freshly produced, in which case it is likely that monitoring at all the small sites would have included pellets within this period. However, the imported pellets at Site 7 were at least 120 days old, but, nevertheless still producing carbon monoxide.

The oxygen levels at Sites 2, 6, and 7 were similar to those in ambient air, but those at Sites 3 and 4 were more varied. At these sites oxygen fell to minimums of 15.4

**Table 1. Summary of site visit measurements.**

| Site | Sampling dates | CO (ppm) | CO₂ (%) | O₂ (%) | CH₄ (%) | VOC (ppm) | Temperature (°C) | Ventilation rate (air changes per hour) | Microbiological Analysis |
|------|----------------|----------|----------|--------|---------|-----------|------------------|------------------------------------------|------------------------|
| Site 2 Purpose built pellet store room. | 28/2/13 for 19 days (24 days after last delivery.) | 1 | 0.0 | 20.6 | 0.0 | <1 (0–1) | 18.1 (15.8–20.6) | 1.7 (1.5–2.1) | All tests: not detected |
| Site 3 Converted barn wood chip store room. | 20/2/13 for 28 days (1 day after last delivery & further weekly deliveries made) | 1 | 0.1 | 19.5<sup>a</sup> | 0.0 | 2 (0–29) | 5.6 (0.0–10.2) | 20.2 (12.8–25.9) | Bacteria (25°C): 1.81 × 10<sup>7</sup> cfu/g Bacteria (37°C): 2.61 × 10<sup>7</sup> cfu/g Mesophilic Fungi (25°C): 3.30 × 10<sup>6</sup> cfu/g All test: not detected |
| Site 4 Fabric pellet silo inside a former coal store room. | 5/3/13 for 27 days (6 days after last delivery, 2nd delivery 8/4/13) | <1 (0–3) | 0.0–0.1 | 19.1<sup>a</sup> | 0.0 | <1 (0–1) | 8.2 (5.6–10.8) | 8.8 (8.6–9.1) | |
| Site 6 Fabric pellet silo in a boiler room. | 11/3/13 for 31 days (33 days after last delivery, 2nd delivery 21/3/13) | <1 (0–3) | 0.0–0.1 | 20.9 (20.0–21.0) | 0.0 | <1 (0–1) | 23.9 (10.3–26.9) | 2.8 (2.0–3.5) | No sample collected, pellets inaccessible |
| Site 7 Large-scale pellet storage in a former grain warehouse. | 11/9/13 for 29 days (~68 days after delivery >120 days after production) | 5 (0–27) | 0.0–0.1 | 20.2 (19.5–20.8) | 0.0 | 1 (0–11) | 12.9 (5.8–22.1) | Estimated 0.5–2 | Mesophilic Fungi: (25°C): 125 cfu/g Aspergillus fumigatus: (40°C): low levels |

CO – carbon monoxide; CO₂ – carbon dioxide; O₂ – oxygen; CH₄ – methane; VOC – volatile organic compounds

Site 1 (outdoor GRP tower silo) and Site 5 (converted coal store room) not included in testing because of access problems.

Air measurements are means (ranges in brackets)

cfu/g – colony forming units per gram

<sup>a</sup>the reliability of these data is discussed in the text.
Table 2. Emission concentrations produced in laboratory headspace air composition tests and estimated indicative emission factors.

| Test                | Mass (kg) | Period (days) | Carbon monoxide | Carbon dioxide |
|---------------------|-----------|---------------|------------------|----------------|
|                     |           |               | Maximum (ppm)    | Minimum (%)    | Maximum (mg/kg) | Minimum (%) | Maximum (mg/kg) | Minimum (%) | Maximum (ppm) |
| Wood pellets        | 28.2      | 34            | >1042<sup>a</sup> | 15.42<sup>b</sup> | 21.8           | 0.1        | 47               |
| Undried wood chips  | 3.6       | 15            | 60<sup>b</sup>   | 35.57          | 650            | 5.7        | 2481              |
| Dried wood chips    | 3.0       | 11            | 543<sup>b</sup>  | 0.15<sup>b</sup> | 31.5           | 20.9       | 73               |

<sup>a</sup> instrument off scale.
<sup>b</sup> reading still increasing.
<sup>c</sup> unseasoned virgin pinewood dust.
<sup>d</sup> almost entirely seasoned spruce.

and 16.0%, respectively, in a number of depressions which did not correspond with any known events over the sampling period. Checks performed after sampling against air standards confirmed accurate calibration of the sensors. Nevertheless these results are to be treated with caution considering the high level of general, albeit natural ventilation, and the lack of a corresponding increase in the concentration of the other gases measured.

Peak total VOC concentrations at Site 3 of up to 29 ppm were detected coinciding with wood chip deliveries, typically lasting less than one day. Peak concentrations up to 11 ppm total VOC were detected at Site 7 and these were similarly short lived. The diffusive sorbent tube results indicated that the wood chips emitted terpenes (principally alpha-pinene and limonene), and wood pellets emitted predominantly aldehydes (C5 to C8), but also other oxygenated VOCs and some terpenes, all present at extremely low levels.

The temperatures recorded at Sites 3, 4, and 7 reflected the cold outside air temperature (means of 6, 8, and 13°C, respectively). At Sites 2 and 6 where the storage areas were situated inside better insulated larger buildings the temperatures were higher (18 and 24°C, respectively). At Site 7, historical records show that temperatures can rise to
51°C. Carbon monoxide production would be expected to increase with temperature.\(^{[9,10]}\)

The limited measurements in this study were not planned as a representative survey. For comparison, Soto-Garcia et al. measured carbon monoxide emissions in six storage areas (3–30 ton) in New York State and found peak concentrations between 14 ppm and 155 ppm.\(^{[11]}\) In contrast, in an Austrian study Emhofer and Pointner report 9% of air tight wood pellet storage areas may have carbon monoxide concentrations of over 1000 ppm (reported in Gauthier et al.\(^{[12]}\)) These measurements are substantially greater than those reported here and in Soto Garcia et al.

**Ventilation rate**

The ventilation rates determined at the four smaller sites were all higher than expected (based on the experience of the HSL specialist). The Site 2 store room had the least obvious natural ventilation and it is suspected that air could have been drawn for combustion by the boiler via the delivery auger. During testing the boilers were observed to increase and decrease their output consistent with variations in the ventilation rate. The Site 6 silo room contained the boiler and it is likely that ventilation is partially driven by air extracted via the boiler flue and by other areas of the building. The Site 3 store room air change rate test had the highest measurement (mean 20.2 air changes per hour) but with large variation between three tests, likely due to a strong dependence upon prevailing weather conditions.

Measuring the ventilation rate at Site 7 using the tracer gas method would have been problematic due to the large volume of the space and the dividing walls between storage bays. This would make it difficult to mix the tracer gas and maintain a uniform concentration. Typically, similar naturally ventilated spaces have air exchange rates in the range 0.5–2 air changes per hour, dependent upon prevailing weather conditions and assuming the doors were closed.

Air change rates measured were all greater than 1.7 air changes per hour, significantly higher than the one air change per 24 hr stated in the wood pellet MSDS obtained.

In comparison, wood pellet storage areas in Europe tend to have limited or no ventilation.

Reports of the fatalities that have occurred in wood pellet store rooms in Switzerland and Germany indicate that the store rooms were airtight.\(^{[2]}\) This is apparently to reduce the possibility of moisture from humid air having an adverse effect on the pellets. However, the inclusion of ventilation to reduce carbon monoxide has now been recognised by the industry in Central Europe.\(^{[12]}\)

**Microbiological analysis**

It was clear from the results that there is a difference in microbiological content in wood pellets compared to wood chips. No micro-organisms were detected in samples of wood pellets from two sites, and little in the third sample, however, there were significant quantities of fungi and bacteria in the sample of wood chips. For comparison, Svedberg et al.\(^{[13]}\) found <9 cfu/g bacteria and <9 cfu/g fungi in dry wood pellets, and 940,000 cfu/g bacteria and 710,000 cfu/g fungi in wood chips.

Reduced water content and the compression of material may have discouraged microbial colonisation of the pellets. At site 3, low temperatures and a high turnover of chips may have inhibited proliferation of bacteria during monitoring.

**Laboratory-based monitoring**

Results from the tests are presented in Table 2 and Figures 2–4.

In the tests on wood chips and wood pellets, the oxygen concentrations fell, carbon monoxide, carbon dioxide and VOCs increased, and the flammable gas sensors did not show any response. The carbon monoxide and VOC concentrations in the wood chip test peaked after less than two days and then fell significantly (Figure 3), and carbon monoxide went off scale in the wood pellet test (Figure 2).

The dried wood chips produced emission trends that were closer to those from wood pellets than from undried wood chips, i.e., an increase in carbon monoxide, carbon dioxide and VOC concentrations without any obvious maxima. However, there were some significant differences; the oxygen concentration did not change and the carbon monoxide concentration only started to increase during the second day.

The emission rates for carbon monoxide and carbon dioxide were estimated in terms of milligrams of gas evolved per kilograms of wood fuel and were based on the maximum concentrations measured and the wood pellet’s and chip’s weight and estimates of density.\(^{[9]}\) Wood pellets produced relatively more carbon monoxide than did the wood chips (>1.6 mg/kg vs. 1.1 mg/kg) but significantly less carbon dioxide (21.8 mg/kg vs 650 mg/kg). The estimate for the emission rate for carbon monoxide for pellets is a minimum because it is based on the maximum value that could be measured by the carbon monoxide monitor. The emission rates for dried wood chips were closer to those from wood pellets than from the undried wood chips.

The emissions of gases from wood pellets followed the expected pattern demonstrated by Kuang et al.,\(^{[9]}\) but the pattern for wood chips was more complicated. Chemical decomposition is believed to be the cause of emissions from pellets\(^{[9]}\) and emissions from wood chips are
predominantly from microbiological processes.[13] Wood pellets are produced by subjecting wood material to high pressures and temperatures resulting in a pellet that has been at least partially sterilised with a smooth compact surface. Wood chips are not exposed to such extreme conditions and therefore have a more open and porous surface. The greater surface area allows them to more readily outgas and be open to the effects of moisture and microbiological activity. Drying the chips would inhibit microbiological growth, however it does not prevent all the emissions.

These are laboratory tests, actual wood pellet store room concentrations would depend on ventilation as well as wood type, temperature, age, surface area, and relative quantity.[2]

Conclusion

These laboratory tests confirm that the pellets encountered during this work were capable of producing dangerous levels of carbon monoxide given suitable conditions. The hazard would be increased by the elevated carbon dioxide and reduced oxygen levels. Wood chips produce less carbon monoxide however there is still a hazard from carbon dioxide and low oxygen levels.

Information from site visits indicates that contact with the wood pellets or chips for operators of small boiler systems is varied. Some may have little or no requirement for access until a fault occurs, whereas those with badly designed fuel transfer systems may require more frequent access.

Knowledge of the hazards of dangerous atmospheres is limited amongst the operators of small boiler systems. The HSE Safety Notice[1] has led to some action to address the issues of control at some sites (e.g., posting of warning signs and fitting of domestic carbon monoxide alarms). Boiler rooms and fuel store rooms are usually kept locked, but there is little in the way of written risk assessments and prescribed safe working procedures. Site managers can be inexpert in matters of health and safety such as confined space entry. The industry (companies supplying and maintaining boilers and storage equipment, and the fuel suppliers) are themselves only just becoming aware of the issues involved and as yet have not provided comprehensive authoritative guidance.

Staff at the large wood pellet warehouse were more knowledgeable about health and safety requirements for storage of wood pellets, but they too are still developing expertise in this new technology.

The fundamental controls for preventing exposure to dangerous atmospheres and depletion of oxygen are:

- prevention of dangerous gas levels accumulating (including low oxygen) by ventilation;
- the recognition of these fuel storage areas as a confined space, i.e., restricting access except to authorized workers with the necessary training;
- having a safe system of work, including supervision, air quality checks (carbon monoxide and oxygen), etc. as defined by the Confined Space regulations 1997,[4] and
- giving consideration to areas where escaped gases may accumulate.

During examination of a range of differing types of small wood pellet and wood chip storage areas, no significant concentrations of carbon monoxide were detected. Each measurement location had a reasonably high ventilation rate (>1.7 air changes per hour) which was assumed to have controlled build-up of carbon monoxide. Ventilation was generally unplanned and may have been reliant on operation of the boiler. Ventilation therefore may be reduced for long periods during the summer if the boiler is unused. The design and location of the storage area can affect ease of access or accumulation of gaseous emissions in the vicinity.

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Disclaimer

This work, including any opinions and conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

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