Carbon Monoxide Off-Gassing From Bags of Wood Pellets

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Abstract

Wood pellets are increasingly used for space heating in the United States and globally. Prior work has shown that stored bulk wood pellets produce sufficient carbon monoxide (CO) to represent a health concern and exceed regulatory standards for occupational exposures. However, most of the pellets used for residential heating are sold in 40-pound (18.1 kg) plastic bags. This study measured CO emission factors from fresh, bagged-wood pellets as a function of temperature and relative humidity. CO concentrations increased with increasing temperature and moisture in the container. CO measurements in a pellet mill warehouse with stored pallets of bagged pellets had 8-h average CO concentrations up to 100 ppm exceeding occupational standards for worker exposure. Thus, manufacturers, distributors, and home owners should be aware of the potential for CO in storage areas and design facilities with appropriate ventilation and CO sensors.

Keywords: bagged-wood pellets, CO off-gassing, emission factors, exposure

Issue Section: Short Communication

Introduction

The worldwide wood pellet market has grown rapidly. Growth rates have been about 10% annually from ~19.5 million metric tons in 2012 to ~28 million metric tons in 2015 (WPAC, 2017). In 2016, the demand for industrial wood pellets was estimated to be ~13.8 million metric tons (WPAC, 2017). However, a problem exists with respect to the safe handling of wood pellets and that is off-gassing of carbon monoxide (CO) and aldehydes into storage bins and shipping vessels (Svedberg *et al.*, 2004, 2008, 2009; Arshadi and Gref, 2005; Hagström *et al.*, 2008; Kuang *et al.*, 2008; Arshadi *et al.*, 2009; Granström, 2010; Soto-Garcia *et al.*, 2015a). Fourteen fatal accidents have been reported since 2002 resulting from the storage or transport of bulk wood pellets (Gauthier *et al.*, 2012).

Soto-Garcia *et al.* (2015a) measured 8-h average CO concentrations up to 35 ppm in a residential basement. Recently, Rossner *et al.* (2017) measured CO concentrations in areas with indoor storage of bulk wood pellets in homes and reported that 6 of the 16 homes tested exceeded the 9-ppm American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2009) guidance concentration on multiple occasions. These studies were performed using bulk wood pellets, but most wood pellets in the United States are sold and distributed in plastic bags containing 10 to 25 kg (Safe Pellets, 2012). To store and transport the bagged pellets, they are normally stacked on pallets with typically a ton per pallet. The bags are perforated to allow for stacking on the pallets without the air in the bags inflating them and thereby preventing effective packing.

After purchasing bagged-wood pellets, consumers often store 1–3 tons of pellets in an inside storage room or in the basement until they are needed. Pellet manufacturers and distributors generate or store large quantities of bagged pellets in warehouses for extended periods before selling them to the customers. The perforations of the plastic bags suggest that the CO generated from these pellets can emanate from the bags, enter the storage area, and result in exposures to building occupants. There is currently no published information regarding the off-gassing of CO from the stored bagged-wood pellets and the resulting impacts on air quality in occupational or residential spaces.

Soto-Garcia *et al.* (2015b) measured the emission factors for CO off-gassing from loose hardwood, softwood, and blended pellets by storing pellets in steel drums and measuring the resulting CO under varying temperature and moisture conditions. Similar results have been obtained in other studies (Kuang *et al.*, 2008; Emhofer *et al.*, 2014). The objective of this present study was to understand the impact of storing bagged pellets by manufacturers, distributers, and consumers by estimating the emission factors for CO off-gassing. CO emissions from bagged pellets were studied as a function of temperature, and relative humidity (RH) that could mimic storage conditions in a warehouse, basement, or garage. Wood type (hardwood, softwood, and blended) affects CO emissions (Soto-Garcia *et al.*, 2015b) and off-gassing from hardwood, softwood, and hardwood/softwood blended bagged pellets was measured. To ascertain if these emissions represented an occupational hazard, measurements were made in the warehouse of an active pellet mill.

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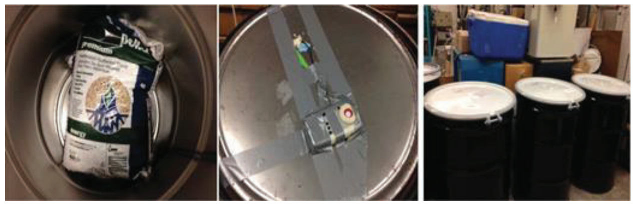
Methods

The experiments were conducted in a manner similar to that described by Soto-Garcia *et al.* (2015b) except using 55-gallon (208.2 l) carbon steel drums. The 55-gallon drums were sealed by a metal ring to maintain an airtight fit against a gasket. Two sealed bags of pellets were inserted into each drum for each experiment. A CO monitor (Model ZDL-500, Environmental Sensors Co., USA) and a temperature (T)/RH (EL-USB-2+, EasyLog, LASCAR electronics, China) monitor were attached to the inside bottom of the cover (Fig. 1). The drum was sealed for 20 days to continuously monitor the resulting CO concentrations as well as temperature and RH. The CO monitors measured from ~1 to 2000 ppm and they were calibrated using high purity CO gas (99.999%) diluted with zero air in a Model 146i multigas calibrator and a Model 111 zero air supply (ThermoScientific). Fresh (<2 days after production) bags of pellets (40 lbs, 18.14 kg) were obtained from a local manufacturer. The pellets were typically ~6 mm in diameter and 6–25 mm in length, with a bulk density of (40 lbs ft^{-3}, ~650 kg m^{-3}). Tests were run under different environmental conditions for each type of wood pellets. Three replicate tests of each type of wood pellet were performed. Measurements of CO were data logged every 3 min, and T and RH was measured every 5 min. Each set of measurements was performed for up to 20 days.

Figure 1.



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Experimental setup of the bag-pellets drum experiment.

Details of these experiments are provided in the Supplemental Information file (available at *Annals of Work Exposures and Health* online). CO emission factors were then calculated from the data. At constant temperature (T) and pressure (P), the concentration of CO off-gassing was converted to an emission factor, *f* (milligram of off-gas per kilogram of wood pellets) using the equation of Yazdanpanah *et al.* (2014) and Tumuluru *et al.* (2015).

$$f = \frac{PCVgMwt}{RTM} * 1000 \tag{1}$$

Where, T = temperature (K); R = gas constant (8.31 J $mol^{-1}.K^{-1}$); M_{wt} = gas molecular weight (g $mole^{-1}$); M = mass of the pellets in the drum (kg); V_g = volume of the gas in the drum (m^3); P = pressure in the container.

Field study

To monitor CO in a large-scale pellet storage, a CO logger was place in a large pellet warehouse (Rahman *et al.*, 2017). The warehouse can store 269000 bags (40-lbs bags), equivalent to ~5000 tons of pellets. The warehouse represents a volume of ~480000 ft^3 (13592 m^3). Measurements were made from 25 April to 21 July 2016 and 21 July to 26 October 2016. The break in measurements was to download the data and clear the memory. During these periods, the warehouse was being filled with ~5000 and 2500 tons of pellets, respectively, in anticipation of the 2016–2017 heating season. CO was measured at 5-min intervals in the middle of the storage area at 3.66 m (12 ft) and 1.52 m (5 ft) above the floor level with Lascar CO monitors. When pellets were being loaded into the warehouse or removed for shipment, one of the large doors was open. The warehouse configuration and sampling position are illustrated schematically in Supplementary Fig. S3 (available at *Annals of Work Exposures and Health* online).

Results and discussions

Laboratory study results

A detailed discussion of the laboratory results are provided in the Supplemental Information file (available at *Annals of Work Exposures and Health* online). The maximum CO emission factors are presented in Table 1. The results show that CO emissions increase with temperature at 30% RH for all types of bagged pellets. However, the emission rates are higher for blended wood (70% softwood, 30% hardwood) and softwood compared to hardwood (100%) pellets at all temperatures. Temperature has a significant effect on CO production for all wood pellet types as seen in prior studies (Soto-Garcia *et al.*, 2015b).

Table 1.

Summary of the maximum CO emission factors at different temperature and moisture.

Temperature (°C)	Hardwood		Softwood		Blended wood	
	Max. emission factor (mg kg^{-1})		Max. emission factor (mg kg^{-1})		Max. emission factor (mg kg^{-1})	
	30% RH	70% RH	30% RH	70% RH	30% RH	70% RH

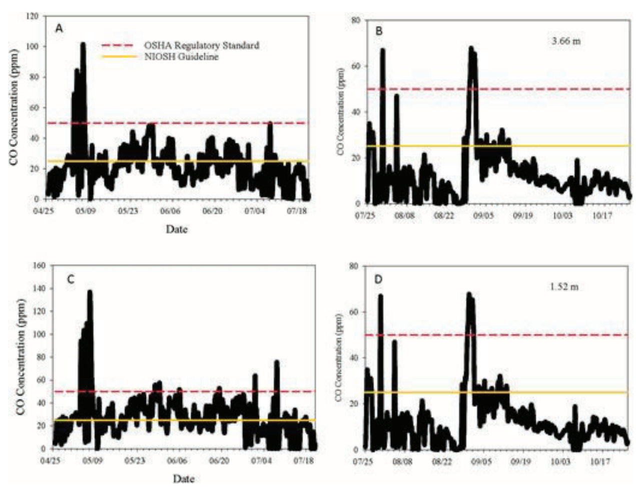
	Max. emission factor (mg kg^{-1})		Max. emission factor (mg kg^{-1})		Max. emission factor (mg kg^{-1})	
	30% RH	**70% RH**	**30% RH**	**70% RH**	**30% RH**	**70% RH**
0–6	0.35 ± 0.06	1.17 ± 0.08	0.42 ± 0.10	1.88 ± 0.06	0.99 ± 0.11	2.52 ± 0.15
22	3.18 ± 0.12	3.27 ± 0.11	5.73 ± 0.21	7.74 ± 0.41	7.66 ± 0.45	9.52 ± 0.55
30	4.47 ± 0.22	6.10 ± 0.14	9.66 ± 0.52	10.4 ± 0.6	9.95 ± 0.53	10.41 ± 0.49

In the United States, the Occupational Safety and Health Administration (OSHA, 1997) permissible exposure limits is 50 parts per million (ppm) averaged over an 8-h time period. Other guidance values like that of the ACGIH are lower (25 ppm over an 8-h period).The CO concentrations for all pellet types at room temperature (22°C) and elevated temperature (30°C) at both RH values were high enough to produce potential in-building concentrations that exceed the ACGIH health-based guidelines of 25 ppm (ACGIH, 2007) and OSHA-regulatory concentration of 50 ppm for occupational settings. In addition, the 9 ppm (ASHRAE, 2009) guideline for homes could be exceeded.

Measured CO concentrations in the warehouse

Fig. 2 presents the 8-h rolling average CO concentrations calculated from the 5-min data. Fig. 2A and B show the CO measured at 3.66 m above the floor while Fig. 2C and D show the measurements at 1.52 m. Temperature and RH were measured in the warehouse. The temperature during the April to June period ranged from 5 to 20°C and the opposite trend of 20 to 5°C during the July to October period. RH was ~30%, similar to what was observed in the drums without added water. These measurements confirmed that concentrations can reach concentrations of regulatory concern. The peaks occurred after a substantial mass of fresh pellets was brought into the warehouse. Workers would bring in a truck load, off-load it, and stack the pallets and leave so the space was not routinely occupied for a continuous 8 h. In April, the warehouse was about 30% full and in May, it was 50% full. In June, the warehouse was at capacity. The maximum 8-h value was 109 ppm exceeding both OSHA regulations and the ACGIH guidance value. Shipments reduced the inventory and additional fresh pellets then were added several times resulting in the peaks observed during the July to October period. There were no short-term spikes to extreme concentrations since the maximum 15-min CO concentrations at 1.52 m were 155 and 113 ppm, respectively, for the two sampling periods.

Figure 2.



Time series of rolling 8-h average concentrations of carbon monoxide measured in the storage warehouse of the pellet mill. (A) and (B) show the CO measured at 3.66 m above the floor, while (C) and (D) show the measurements at 1.52 m during the two measurement periods.

Conclusions

The results of this study demonstrated that CO emissions from wood pellets stored in plastic bags within a building are a concern with respect to undesirable exposures of the building's occupants analogous to the problems associated with stored bulk pellets. Environmental factors such as temperature and RH influence the CO emissions. Storage temperature affects CO off-gassing more than the moisture. Faster emissions and higher concentrations were observed with increasing temperature. Pellets stored at high RH showed increased emission rates and higher CO concentrations for all types of pellets than lower RH. Therefore, bagged pellets are best stored in cool and dry places. All types of bagged pellets could produce concentrations exceeding exposure health base limits and prior work in Europe had suggested there are limitations to the effectiveness of passive ventilation (Emhofer *et al.*, 2014), it is essential to design pellet storage spaces with active ventilation and CO monitors for both domestic and commercial buildings storing large quantities of wood pellets.

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Declaration

The authors declare no conflict of interest relating to the material presented in this Article. Its contents, including any opinions and/or conclusions expressed, are solely those of the authors.

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Supplementary data

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