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PINE WOOD CRIB FIRES: TOXIC GAS EMISSIONS USING A 5m^3 COMPARTMENT FIRE

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Abstract. Toxic emissions from pinewood crib fires were determined using heated FTIR gas analysis from a 5m^3 compartment fire with an air opening equivalent to 5% of the compartment cross-sectional area ($V^{2/3}$) in the floor of the compartment and a vent in the ceiling layer, with the air inlet controlling the flow. A 20mm square pine wood crib size of 400 x 400 x 260 mm was investigated. The crib was ignited using a small ethanol pool fire. The flaming fire had a peak HRR of 40 kW and average ceiling temperature of 400^{o}C. The fire was lean overall at the peak HRR and the fire self-extinguished through lack of air with subsequent smouldering combustion. In spite of the lean combustion in the fire, very high toxic emissions were determined with an FEC LC_{50} of > 6. The peak toxicity occurred just before the fire self-extinguished and the key toxic emissions were CO and formaldehyde for deaths, while formaldehyde and acrolein were the most important for impairment of escape.

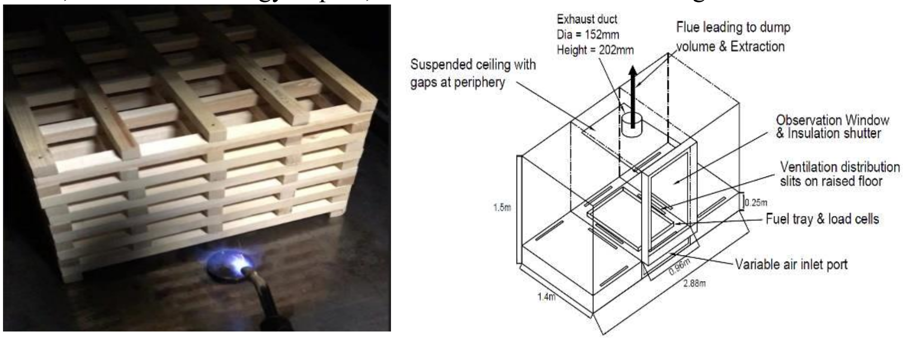
Keywords: Toxicity, Compartment Fires, FTIR.

1 Introduction

About 56 % of fire incidents in the UK occur in buildings [1] and most deaths as are caused by the inhalation of toxic smoke. Despite this, no legislation requires toxic gas measurements from fires for any building material, apart from visible smoke production. This work investigates the toxic gas emissions in a pine wood crib ventilation controlled fire in a 5m^3 compartment, larger than the 1.6m^3 compartment previously used by the authors [2-4]. In compartment fires, not only does smoke reduce visibility to occupants, but it is also an irritant which causes respiratory problems, leading to slower movement of people and eventually death [5-8]. Purser [5] showed that the main toxic products in fires are CO, HCN and irritant or acidic gases. The authors have shown [2-4] for pine wood crib fires in a 1.6 m^3 enclosure that the main toxic gases were CO, acrolein, formaldehyde and benzene. The most common method of assessing the toxicity of fire products is the LC_{50} 30 min exposure concentration at which 50 % of rats died in a test fire for 30 minutes exposure [6]. COSHH [9] is the European statutory law on occupational exposure limits equivalent to the US short term (10 mins.) impairment of escape limits AEGL2. The $COSHH_{15\ min}$ toxic gas concentration represents a safe condition for 15 minutes for escape not to be impaired.

2. Material and Methods

A pine wood crib 400x400x260 mm was the fire load with 35 20mm square sticks' as shown in Fig. 1a. The pine had a GCV of 18.9 MJ/kg, a volatile content of 79.2%, fixed carbon of 12.3%, moisture of 6.2% and ash for 2.3%. Elemental analysis was used to determine the stoichiometric A/F by mass as 5.9. The 6.22 kg crib was supported on load cells in the centre of a 5 m^3 compartment with a floor area of 4 m^2 as shown in Fig. 1b. This corresponds to a fire loading of 29.2 MJ/m^2 or 223.6 MJ/m^3. Ethanol, at 1% of the energy in pine, was used as an accelerant to ignite the fire.



(a) (b)

Fig.1. Pine Wood Crib (a) and Schematic of the 5m^3 Compartment

An air distribution plenum located below the compartment was used to provide air into the compartment by the chimney effect of the hot gases in the compartment. The air distribution plenum inlet was fully open and this was equivalent to a ventilation factor ($A_v/V^{2/3}$) of 5%. The N-gas model for toxicity assessment was used by taking the ratio n of the concentration of all the toxic species measured by the FTIR and dividing by either the LC_{50} values or the $COSHH_{15\ min}$ values. Their sum is the total toxic gas N.

3. Results and Discussion

3.1 Mass Loss, Equivalence Ratio, Heat Release Rates (HRR), Oxygen Concentration and Mean Ceiling Temperature

Figures 2a and b show the mass loss and the mass loss rate as a function of time. A gradual decrease in mass loss was observed after ignition at 34s until 2000s when flameout occurred and smouldering combustion continued. The equivalence ratio (from carbon balance) in Fig. 2c was 0.5 during the period of maximum HRR of 42 kW at 400s with a peak ceiling temperature of 400^{o}C. However, the fire then began to decay to a HRR of about 25 kW with an equivalence ratio of 0.7. This was due to the large mass of 6 kg of air in the compartment at the start of the fire. The initial fire growth was as a freely ventilated fire and then the effect of the restricted ventilation occurred with reduced HRR and richer mixtures. The fire continued to decay until flame out occurred at 7% oxygen and 170^{o}C. There was then a long period of smouldering combustion with a HRR of about 1 kW.

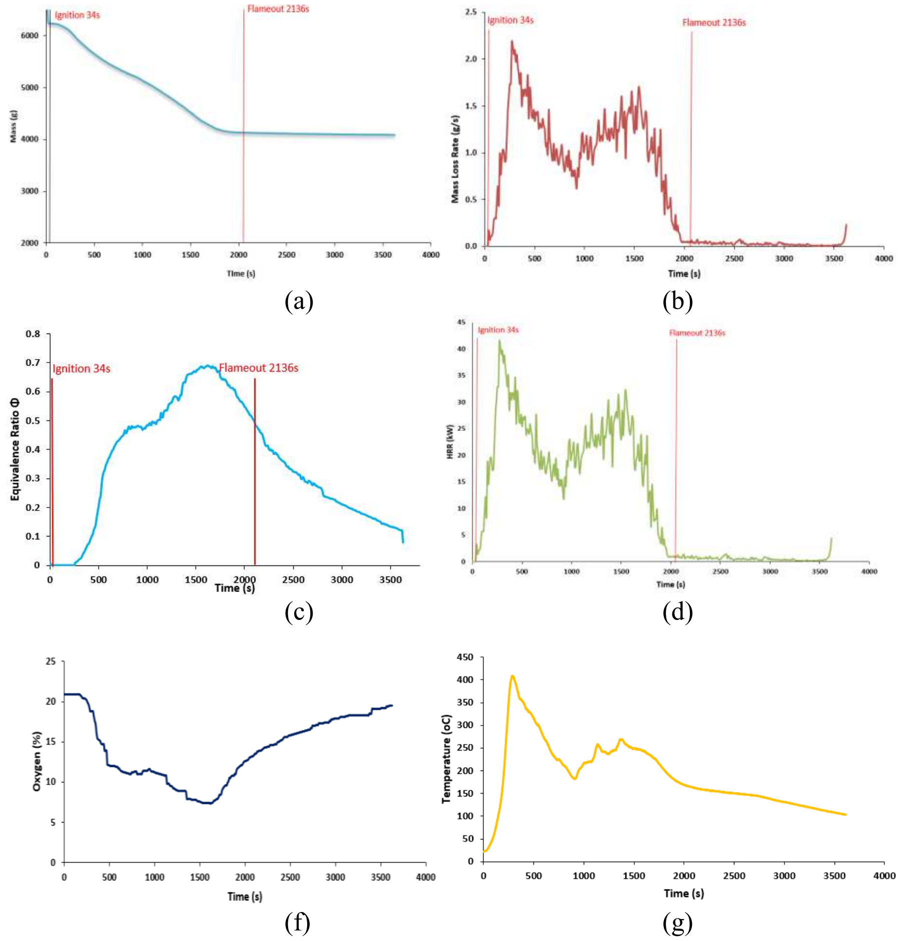


Fig. 2. Mass Loss (a) Mass Loss Rate (b) Equivalence Ratio (c) Heat Release Rate (d) Oxygen Concentration (f) and Mean Ceiling Temperature (g)

3.2 Toxic Gas Concentration

Figure 3 shows the most important toxic gas emissions, which had their highest concentration between 1500s to 2000s during the restricted ventilation phase of the fire. The transition from flaming to smouldering combustion with low oxygen concentration of < 10 % was associated with the release of peak levels of toxic gases. The main toxic gases were CO, Formaldehyde and Acrolein. Benzene was also found to be significant in this fire. This agrees with results obtained by the authors [2-4, 10] for a 1.6 m^3 compartment fire. CO exceeded the LC_{50} exposure limit by a factor of 3 while it exceeded the $COSHH_{15min}$ exposure limit by a factor of 40. Formaldehyde also exceeded the exposure limits on both the LC_{50} and $COSHH_{15min}$ basis. Although Acrolein did not exceed the LC_{50} exposure limit, it exceeded the $COSHH_{15min}$ limit by a factor of 5000. Even though the compartment was considered well ventilated with lean combustion, high concentrations of toxic gases were produced that will lead to the impairment of escape and eventual death.

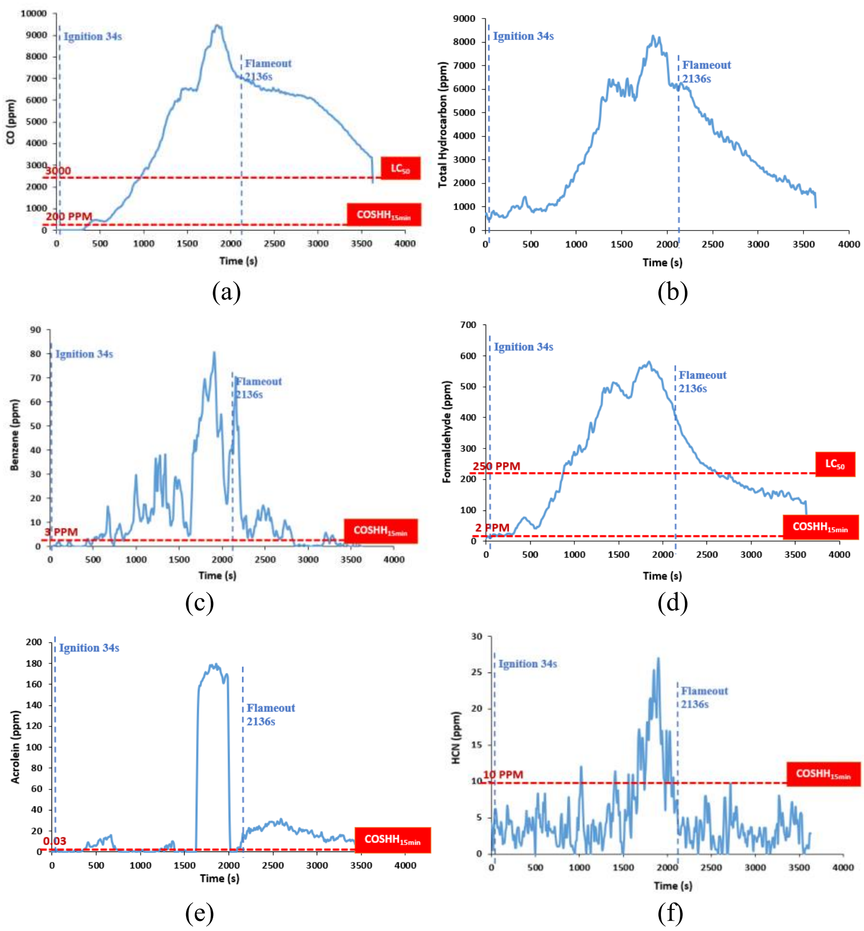


Fig. 3. Toxic gas concentrations; CO (a), Total Hydrocarbon (b), Benzene (c), Formaldehyde (d), Acrolein (e) and Hydrogen Cyanide (f)

3.3 Total Fire Toxicity N on an LC_{50} and $COSHH_{15min}$ Basis

Figure 4 shows that the peak **N** for LC_{50} was > 6 and the peak **N** on a $COSHH_{15min}$ basis was >2000, but they occurred at the same time in the transition from the flaming to smouldering combustion. The **N** values indicate that the toxic gases on escaping from the compartment would need to be diluted with air by a factor of > 2000 before escape was not impaired and by a factor of > 6 before deaths would not occur. Fig. 5 shows that on an LC_{50} basis the toxicity was dominated by CO, formaldehyde, acrolein and HCN and on a $COSHH_{15min}$ basis formaldehyde, CO and benzene. Between 1600s and 2000s there was a large increase in impairment of escape $COSHH_{15min}$ total toxicity and this can be traced to the large increase in acrolein in Fig. 3e. This period, as shown in Fig. 2d, coincided with the onset of fire decay with the peak HRR reducing to flame out over this period of high acrolein emissions. There was also a reduction in fire ceiling temperature as shown in Fig. 2g.

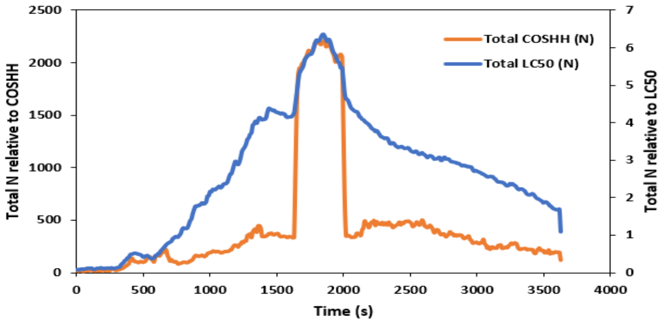


Fig. 4. Total toxicity N relative LC_{50} and relative to $COSHH_{15\ min}$

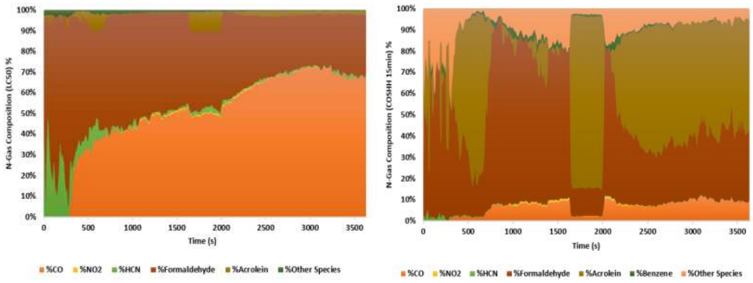
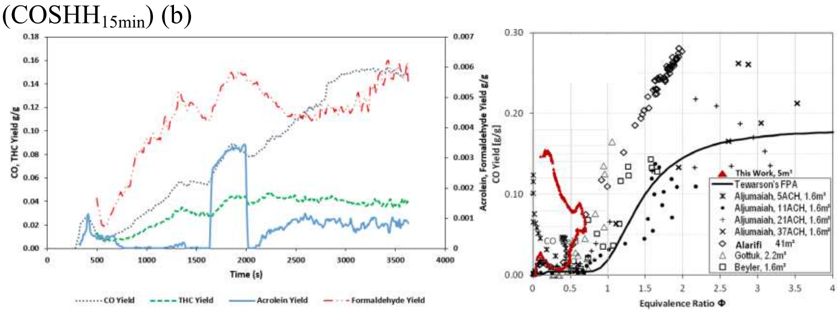


Fig.5. N-Gas Composition (LC_{50}) (a) and N-Gas Composition ($COSHH_{15min}$) (b)



(a) (b)

Fig.6. Toxic Gas Yield as a function of time (a) and Yield Comparison (b)

3.4 Toxic Yields

The toxic yields of the most important gases in Fig. 6a were high during 1500-2000s and increased during the smouldering combustion for CO and formaldehyde. CO had a peak yield of 0.15 g/g while formaldehyde had a peak yield of 0.006 g/g. Acrolein peaked at 0.003 g/g while the total unburnt hydrocarbon yield was at 0.04 g/g. The CO yield was compared in Fig.6b with the yield from wood in smaller compartments [3, 11], 41 m^3 compartment [12] and Tewarson's correlation [13]. The present result shows good agreement with the results in the literature for equivalence ratios 0-0.7.

4. Conclusions

High concentrations of toxic gases that would impair escape were produced in lean restricted ventilation compartment wood fires. Peak toxicity occurred just before flame out.

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