



Research article

Some characteristics of the self-heating of the large scale storage of biomass

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ABSTRACT

Increasingly large quantities of biomass are being transported and stored for use in bioenergy applications. This large storage of biomass is liable to undergo self-heating sometimes leading to ignition and fire. Numerous studies on both the laboratory scale and by using theoretical analyses have been made in order to predict their behaviour but these are made on the basis of a number of simplifying assumptions. It is clear from studies reported here of self-heating in 40 kt storage piles of wood pellets that the process is much more complex than the simpler models suggest since thermal waves are observed.

1. Introduction

Stored combustible fuels such as coal [1] and biomass [2–5] are liable to self-heat which can, under certain conditions, lead to ignition. This phenomenon has been known for many years and the first theoretical studies on the ignition of cellulosic materials [2–6] were based on earlier work relating to explosive ignition of gases; this work, particularly by Frank-Kamenetskii, is cited in these references. In view of these hazards, regulations have been developed in most countries to govern the transportation and storage of these materials, and appropriate testing methods established to estimate the fire risk e.g. [7,8]. In recent years, biomass is being used in much larger quantities, particularly for power generation [9], than was envisaged when these test methods were developed and this poses a number of additional safety issues.

The technology for the safe handling of coal is well established, but this is not the case for the large scale transportation and storage of biomass. In addition there are a variety of types of biomass fuels which may be in the raw state, or processed into the form of pellets, or may be washed or torrefied. Although biomass shares many properties with coal, there remain many disadvantageous features such as a larger content of volatiles that can evolve at lower temperatures than for coal. In addition, the porous nature of biomass, particularly in the pellet form, permits the ingress of oxygen and moisture which can increase the susceptibility to bacterial attack; this in turn can increase the possibility of self-heating and ignition. As biomass stockpiles increase in size this becomes even more of an issue and there have been several instances of fires in storage silos. Consequently, there is a need to improve our knowledge of the underpinning chemistry and physics of

these events.

Both experimental and theoretical approaches have been made of the ignition process which should be complementary, but often look at different aspects. In the former, self-ignition temperatures and associated ignition induction times have been assessed by a standard method which utilizes different basket or heap sizes with the aim of extrapolating fuel behaviour to large volumes representative of industrial silos or storage piles [7,8]. Thermogravimetric analysis techniques, which are less time intensive but use small samples, have been conducted and compared with this standard method to determine the relative ignition risks of different fuels [10–15].

The second approach is the use of theoretical studies which involve mathematical analysis of heat conduction and kinetic parameters in geometrically simple and isotropic systems [2,4,5]. More recently, detailed analyses have been made of large quantities using CFD methods [16–18]. These models, representing real situations are complicated by the fact that in addition to heat released by the oxidation of the fuel by the ingress of molecular oxygen, the role of moisture [19–21] and heat released by microbiological action have to be considered [19,22–27].

This paper aims to examine experimentally the pre-ignition behaviour of large scale (40 kt) storage units and to examine how it compares with theoretical analysis and laboratory tests.

2. Materials and methods

2.1. Materials used

Most of the experiments were undertaken using compressed pine wood pellets but some laboratory measurements were using

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Table 1
Typical data for ultimate and proximate analysis of wood pellets.

	As received	Dry basis
Moisture %	4.8	
Ash %	2.5	2.5
Volatile matter %	76.8	80.7
Fixed carbon.%	16.1	16.8
Carbon %	48.87	51.33
Hydrogen %	5.61	6.1
Potassium %	0.12	0.13
Chlorine %	0.01	0.01
Nitrogen %	0.28	0.29
Sulphur %	0.02	0.02
Gross CV MJ/kg	19.76	20.76

agricultural residues (Miscanthus, wheat or barley straw), and torrefied pellets consisting of mixed wood materials. The proximate and ultimate compositions of typical wood pellets are given in Table 1. The moisture content is 4.8 wt%. The size range of the pellets used is that typically 97 wt% of the pellets are in the range of 6.3 to 10 mm with a diameter in the range 6–10 mm, and their compact density as received is 698 kg/m³.

2.2. Laboratory studies

The temperature changes resulting from the addition of water to the samples of pellets were determined using a thermocouple and a FLIR Model 6 infrared camera. The biomass samples were weighed into 1 L polyethylene vessels and water added up to 40% (w/v). After the addition of the water, images were taken with an infrared camera monitoring the heating profile in each sample vessel for a period of 2–4 h.

Measurements were made of the pH of water after it was added to the biomass. 10 g of biomass samples were weighed into a 100 mL glass beaker and 50 mL of demineralised water (at 20 °C) was then added to the beaker. pH measurements were made for 520 min using a Mettler Toledo SevenMulti pH meter.

Thermogravimetric (TGA) analysis was undertaken using a Perkin Elmer STA6000 instrument. Samples of ground pellet (< 80 µm) were used, and the sample sizes used for the experiments were approximately 5 mg. An initial temperature ramp of 2 °C/min from 30 to 900 °C was used in a stream of nitrogen gas and the sample was then held at 900 °C for 30 min in an air stream. The results were plotted using derivative weight loss (% loss/min) giving the characteristic peak temperatures, and the estimation of apparent first order pyrolysis kinetics as previously described [13,14].

2.3. Studies with large scale (40 kt) biomass storage

Two large biomass stores, Pile A and Pile B, were studied each containing 40 kt of biomass but with slightly different depths (6–8 m and 10–13 m respectively). A schematic aerial view of the geometrical shapes is shown in Fig. 1.

The volume in each case is about 52,600 m³ and the moisture content for these samples when loaded into the store was 7%. Both stores, which measured 30 m × 50 m, were filled to an even depth on three sides of the stores and take the natural angle of repose for biomass down to the base of the store (approx. 60°), the edge of the biomass is shown by the red line. Measurements of temperature and gas composition within the piles at varying depths were made by bundles of 5 mm internal diameter PVC sampling tubes and K-type thermocouples. Temperature measurements were made from the floor (0 m) to the top of the pile at 1 m intervals and gases at every 2 m intervals. Results are presented here from the sampling bundle, located in Pile A at location 11 and in Pile B at location 13, as shown in Fig. 1. Samples were also taken above the bed at 1 m intervals. The external ambient temperature was measured as were the relative Humidity and temperature at 1 m

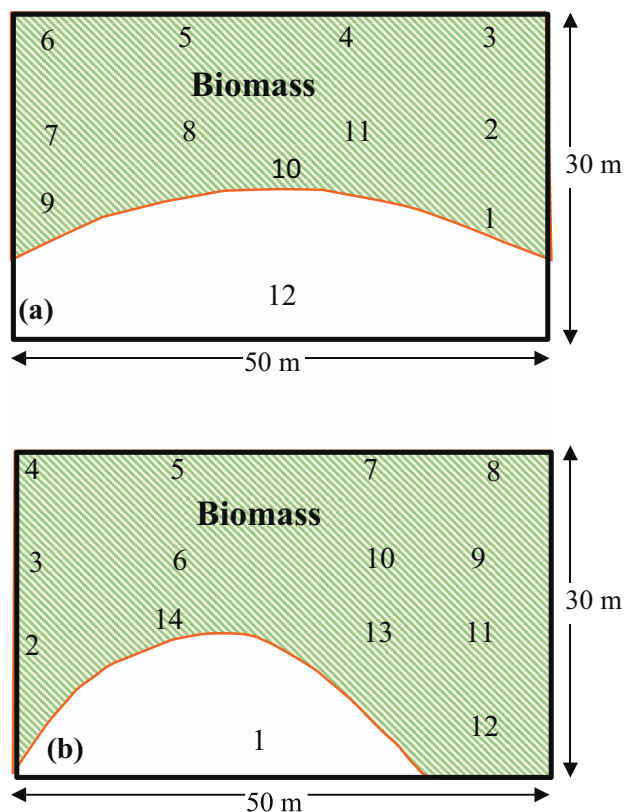


Fig. 1. Diagrammatic aerial view of the biomass stores. (a) Pile (A) depth: 6–8 m over monitored area. (b) Pile (B) depth: 8–10 m over monitored area. Numbers refer to sampling positions (in or above the bed).

above the bed.

Samples of the volatile organic compounds emitted from the two piles were measured above the surface and within the bed using the ppb RAE 3000 Gas Detector. The concentrations of CO, CO₂, O₂, SO₂ and flammable gases were analysed using a Dräger Xam 7000 instrument. Volatile organic compounds (VOC) were analysed by sampling tubes for formaldehyde, acetaldehyde, *n*-pentanal, *n*-hexanal, furfural and glutaraldehyde at a flow rate of 0.3 L/min for 45 min, and charcoal sampling tubes for terpenes, acetone, and butanoic and octanoic acids at a flow rate 0.2 L/min for 60 min.

The microbiological activity on spot samples of pellets taken at random from within Pile A and other Piles where heating was not observed were measured using dip slides. 10 g of milled biomass sample was weighed with 40 mL of demineralised water in a 50 mL centrifuge tube at room temperature, and agitated for 2 min. The supernatant was then decanted on to the dip slides. Two types of were used, a sterile nutrient agar which grows bacteria, and a second which grows fungi, bacteria and yeasts. They were incubated for 48 h (72 h for yeast) at 30 °C. The results are then compared visually with the growth guide supplied with the dip slides.

The microbiological contents in air samples taken 0.5 m above the centre of the wood Piles at location 11 in Pile A and location 13 in Pile B were determined using a Sartorius AirPort MD8 portable air sampler. The total viable bacteria count (TVC) was made using Tryptone Soya Agar (TSA) and fungi (Sabourguard) agar plates for sample collection. The samples were taken at 125 mL/min for 4 min. The plates were incubated at 22 °C for 3 days and provided information on the in-colony forming unit/plate for bacteria and the number/plate for fungi.

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