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Impact of fuel bed permeability on feasibility of fire detection in waste and recycling materials

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Abstract. Waste fire testing of deep-seated fires in a variety of materials identified that waste material fuel beds may be categorised by the permeability of the fuel bed with regards to the products of combustion including heat and flames. Current works experimental measurements showed that permeable fuel beds allow for the passage of heat through the fuel bed while impermeable fuel beds hinder the movement of a fire and of fire products. It is proposed, based on the observed differences in heat spread through and to the exterior of an impermeable versus a permeable fuel bed, that typical fire detection methods are less effective on impermeable fuel beds.

1. Introduction

As the UK moves towards low carbon targets and invests further in recycling and as the overall quantities of waste produced in the UK increase [1], the volumes of waste and recycling materials in storage or processing across the country increase as well.

Materials that have been collected and await processing, materials part-way through a sequence of processes and materials awaiting transport or long-term storage may be kept as loose-piled materials. An immediate example is regular household bin collection services which transport household waste to a local site where it is piled up to await processing.

These piles are a source of large-scale fire incidents for the waste and recycling sector. Fires can begin deep within a pile of material – as deep-seated fires – which can then grow undetected and are difficult to extinguish quickly once the hazard does become evident to workers or fire detection systems on site. Best practice information advises that piles be limited depending on access arrangements to areas of 20 m by 20 m, or 10 m by 10 m in area, with heights of 4 m or more [2]. This means firefighters must displace large volumes of material to get to the core of a fully developed pile fire to extinguish it. This entails significant risk to life, property damage and business disruption.

This problem is also increasing in severity as there is a documented increase in the rate of occurrence of waste fires due to the increased presence of lithium batteries [3] in waste streams. These batteries can short out and provide rapid ignition in a waste pile or accelerate fire development. Waste fires contain a broad range of materials and can therefore produce a wide range of combustion products including toxic and polluting byproducts.

To prevent an increase in the number of large-scale pile fires in waste handling facilities, reliable and early fire detection is necessary. A fire identified in the incipient stages of development can be extinguished by on-site staff and facilities. A developed fire can burn for days [4] or weeks [5] despite fire service intervention and result in pollution by smoke and by water run-off.

Fire detection is a requirement in all waste and recycling facilities [6], where deep-seated fires are not detected until they are fully developed, it is not due to the omission of any fire detectors. Common fire detection methods such as point heat or smoke, beam, aspiration, or flame detection systems are in use in waste and recycling facilities but are noted by industry guidance as being less effective for pile fires [2]. Why these detection methods are less effective is however not documented in this guidance, however.

2. Fire Fuel Beds

The UK Health and Safety Executive formed the Waste Industry Safety and Hazards Forum (WISH) to address key safety issues such as fires in the industry. WISH also sponsors experimental testing where needed. A previous sequence of WISH waste fire tests looked at whether deep-seated fires began inside or on the surface of piles and how such fires could be extinguished quickly and safely. These tests are detailed in a summary test report [7] which addresses primarily the question as to where deep-seated fires begin in or on a pile but also provides test data that is not directly related to this topic. Part of the sequence of test fires involved replicating common pile fire scenarios using a variety of materials to observe and record fire progression characteristics and trial a variety of firefighting methods and media for practical real-world use. These tests were thus replications of real-world storage scenarios and the resulting fires and were demonstration tests rather than laboratory-standard experiments.

Outside of the primary findings of the experiments, the tests also provided a way of categorizing waste piles by the permeability of the pile. Piles were labelled permeable, semi-permeable or impermeable. Permeability is described as a result of the average ‘porosity size’ - the average gap size between the distinct fragments forming the pile - compared to the experimentally observed flame height generated by combustion in the given material fragments. Small porosity sizes where the average value is close to or equal to 0 will result in an impermeable pile, large gap sizes equal or greater than the flame height result in a permeable fuel bed and porosity sizes lower than the flame length value but not approximate to 0 will result in a semi-permeable fuel bed [7].

3. Experimental configuration

Two deep-seated fire tests were carried out at National Fire Service College, Gloucestershire using: pre-crushed wood (18 October 2017) and refuse-derived fuel (RDF) (23-24 October 2017) as fuels; see Figure 1 for test piles. Surface fire tests were carried out in wood fines, solid recovered fuel (SRF), shredded types, fragmentizer fluff, pre-crushed wood, and plastic bales in two batches of previous tests prior to the deep-seated fire tests.

Pre-crushed wood was considered a permeable fuel bed. Other materials that result in piles of large, rigid elements are likely to also form permeable fuel beds due to the open matrix with large gaps of such a pile. RDF was considered an impermeable fuel bed. Materials featuring smaller particle sizes and also more flexible particles are more likely to form impermeable fuel beds. The test fires were all carried out outside in the open, meaning that traditional fire detectors such as smoke or aspiration detectors were not present. Ignition for both the wood and RDF pile fires was using an oxy-propane lance, inserted into the centre of the pile via a hole in the rear bay wall. To avoid overly slow ignition in the RDF, a small core of pre-crushed wood was placed around the lance to help with ignition of the RDF, this is shown below.

(a) (b) (c)

Figure 1. Permeable (a), impermeable (b) fuel beds tested. RDF ignition wood shown (c).

Internal type-K thermocouples were used: 5mm diameter – 6m long with 4m of stainless-steel sheathing protecting the power coated electrical wires and 2m of PVC sheathed wire for weather protection. For the wood test, four thermocouples located 1m in from the back of the pile, at 0.5m increments in height along the same vertical plane starting at 100mm above the ignition point with TC4 at the bottom and TC1 at the top of the pile. For the RDF test, thermocouples were arrayed in layers throughout the pile for each test with 10 strings of 10 sensors and 5 strings of 5 sensors, as shown in Figure 2 with strings staggered to go through the mortar between rear-wall blocks which results in only select thermocouples being in the same vertical or horizontal plane as other thermocouples. Thermal video camera footage was taken for key parts.

Both tests were carried out outdoors, exposed to weather and wind, environmental factors could not be entirely controlled. Moisture content and prevailing air flows, for example, were weather driven. The wood pile fire took place with humidity between 88 and 94%, wind speeds peaking from 0 to 3mph over the time of the testing [8]. The RDF fire took place with humidity between 83 and 94%, wind speeds from 5 to 18mph over the entire duration of the test. As there were concerns about biological self-heating in the RDF pile, it was left in place for over a week prior to testing to monitor this. Hence, moisture content data is available. The wood ignition material had a moisture content of less than 20% while the RDF itself averaged 35% moisture content but this varied throughout the pile and over time [8].

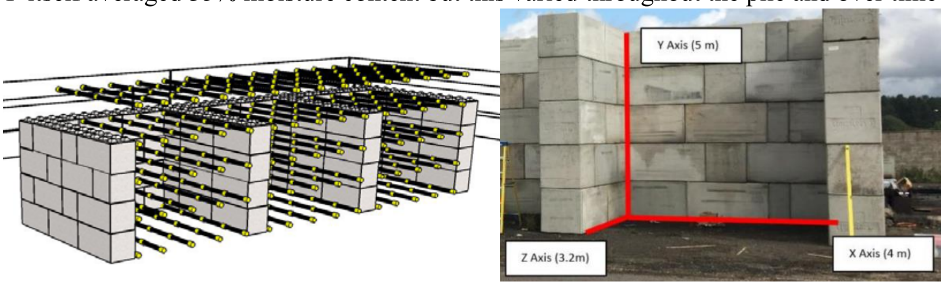

Figure 2. Thermocouple positioning during the experiments (left), bay dimensions (right).

4. Results and discussion

4.1 Wood Pile Fire - Permeable

The wood pile fire was allowed to burn for six hours until the pile was fully involved in a developed fire, after which point it was extinguished due to fire service policy preventing fires being left unattended overnight. For the permeable fire, there was no difficulty in determining when the fire had started within the pile, smoke and flaming were easily identified and observed from the exterior of the pile (Fig. 3).

(a)  (b)


(c)

Figure 3. Wood pile fire burn at approx. 60 mins (a), 180 mins (b), and 210 mins (c) of burn time.

Thermocouples inside the pile show the change in internal pile temperatures as the fire progresses. All thermocouples in the wood pile showed the same overall trends as the increasing internal temperatures in the pile were detectable by all four of the thermocouples. Temperatures increase steadily for the most part, with thermocouples throughout the pile being involved in the fire and showing climbing temperatures as the fire develops. TC1 being the closest to the surface was likely the last to be affected by the fire and most affected by the external conditions such as wind.

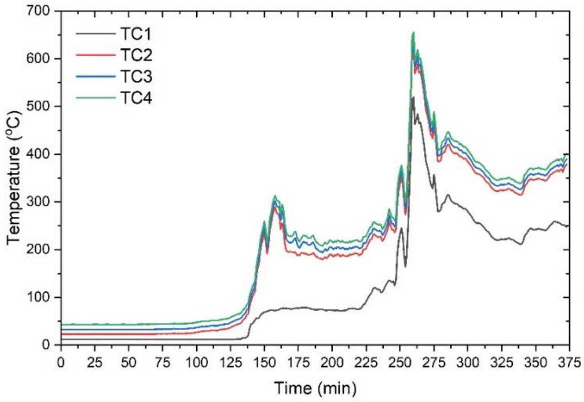

Figure 4: Thermocouple readings of peak internal temperatures for wood pile fire

4.2 RDF Pile Fire – Impermeable

The RDF pile fire was monitored overnight to allow for it be kept burning from Monday (23/010/2017) at approximately 12pm through to 5pm Tuesday (2/10/2017) when the attending fire service extinguished the fire. As the fire was intended for fire service training, to ensure a suitably intense fire, accelerants were applied after 12pm on Tuesday creating an artificial surface fire on the pile, so only the pre-accelerant data is included here.

For the impermeable fires, there was significant difficulty in determining whether the required fires had ignited fully, whether the fires were then developing inside the material pile, and after the given test completed there was difficulty in observing whether the fires were properly extinguished also. There were no visual signs from the exterior of the pile that significant levels of combustion were present inside the material pile (Fig. 6).

Internal thermocouple readings from the impermeable fuel bed fires were also affected, with thermocouple readings from inside the pile not showing significant increases in temperature even once the fire was known to be progressing and detected by adjacent thermocouples. Thermocouples over a certain distance in the pile from the core of the fire did not show the same or similar readings as thermocouples inside or directly adjacent to the burning zone (Fig. 4). In the below graph of thermocouple readings, the second thermocouple (TC7) is 0.8m above the first (TC6). Whilst TC6 exceeds 400°C for most of the test duration, TC7 does not exceed 100 ° C, suggesting a relatively strong insulation effect inside the pile of material (Fig. 4) even as the fire is burning steadily. The spread of heat through the pile is limited.

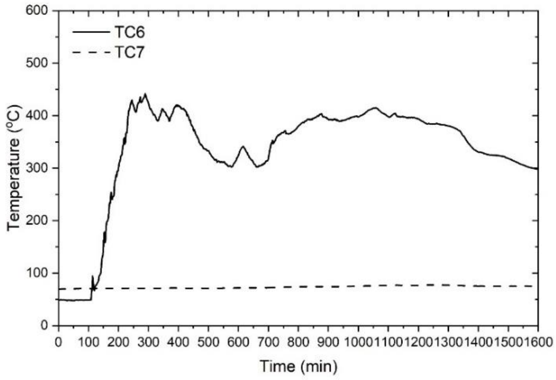

Figure 5: Temporal evolution of temperature from core (TC7) and above-core (TC6) thermocouples for RDF pile fire.

Likewise, the footage taken of the given tests on the thermal video camera does not show elevated temperatures as would indicate a fire. When viewed through the open channel into the bases of the pile through the wall behind the pile, elevated temperatures were seen on thermal images (Fig. 7) and the presence of a developed fire was confirmed, but the fire is not visible on the thermal camera from the exterior of the pile (Fig.6).

Figure 6: Thermal imaging of pile surface (left) and standard photo (right), Tuesday 8:00 am and 11:00 am respectively.

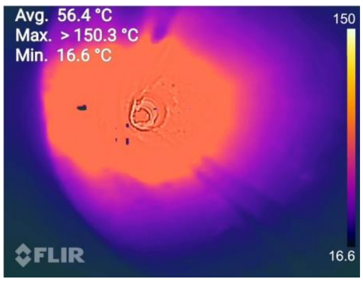

Figure 7: Thermal imaging of pile core – maximum temperature exceeds camera range (>150°C), Tuesday 11:00 am.

4.3 Permeability Compared to Detectability

It is suggested that impermeable fuel beds do not allow for the passage of sufficient quantities of heat or flames for common heat or flame detection methods to detect a deep-seated pile fire until the fire has reached within a certain distance of the pile surface. It is then considered likely that an impermeable pile would also be impermeable to hot gases and smoke particulates such as are detected by smoke and aspiration detectors.

This is suggested as the cause of deep-seated fires in certain materials being difficult to detect before fires are well developed and hazardous. While other materials allow for easy detection of fires based on radiated heat, visible flaming or visible smoke, the materials identified as forming impermeable fuel beds may trap heat and combustion products inside the fuel bed sufficiently well as to make traditional fire detection methods ineffective.

5. Future Work

Where traditional fire detection methods do not work, other methods and technologies may be able to replace them. For example, hidden coal seam or coal pile fires may be detected by seismic-acoustic monitoring and by gas-flux measurements [9], neither of these detection methods are in common use in the waste and recycling industry but may in fact be able to detect deep-seated waste fires in impermeable fuel beds.

As traditional and common fire detection methods are not effective on fires in impermeable fuel beds, alternative methods of fire detection should be researched in order to provide early fire detection methods to the waste and recycling industry. Methods used in similar situations in other sectors may be applicable, such as coal fire detection methods, and also technologies not previously used for fire detection such as X-ray computed tomography [10].

To lower the rate of occurrence of significant deep-seated pile fires, it is proposed to undertake another sequence of trial pile fires, with the intention of trialling a broad variety of potentially effective technologies and methods in order to identify avenues through which the waste and recycling sector may develop targeted detection methods for use on sites handling materials which form impermeable fuel beds and thereby catch incipient fires before they reach life-threatening sizes.

Acknowledgments

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Fire detection: Section 2.11 and Appendix 4, section 2
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