BF2RA



Low Temperature Ignition of Biomass Jenny Jones, Alan Williams, Abby Saddawi Ben Dooley, Eddie Mitchell, Joanna Werner, Steve Chilton



Introduction



Ignition risk is a significant hazard in the utilisation of biomass and is present in all aspects of its use:

•Processing

- •Transporting
- •Storage
- •Milling
- •Conveying
- Accumulation on hot surfaces
- •Ignition sources (e.g. spark, static discharge)
- •Dust explosions

In comparison to coal, biomass has higher volatile content and the volatiles evolve at lower temperature, presenting an increased ignition risk.



- To develop laboratory-scale methods for assessing ignition risk.
- To characterise and measure the ignition properties and temperatures for a range of relevant biomass fuels.
- The data will be used to categorize the biomass in terms of its ignition risk in both storage and conveying

Approaches 1. Ignition of dust layers



 Determine the minimum temperature (to within 10 °C) at which ignition occurs within 30 min.









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2. Thermal analysis methods

100 ----- 0.0E+00 90 Char burnout -2.0E-03 80 On-set of -4.0E-03), 70 S 60 M 50 Burning profile combustion -6.0E-03 -8.0E-03 -1.0E-02 40 -1.2E-02 Mass loss curve 30 -1.4E-02 20 Air -1.6E-02 10 0 -1.8E-02 100 500 600 700 0 200 300 400 Temperature (°C)

Determine:

Temperature for onset of combustion (devolatilisation),
The temperature for the maximum combustion rate
Temperature at which process becomes exothermic.
Rates of pyrolysis



3. FTIR and pyrolysis-GC-MS



- Identification of low temperature volatiles
- Release of oily material at low temperature
- Volatile composition during pyrolysis, and lower flammability limit of volatile mixture.







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4. Single Particle Ignition

Measure:

- minimum furnace temperature for ignition
- Ignition delay time
- Combustion characteristics





5. British Standard method for dust accumulations





• Different volumes/area of fuel are tested for critical temperature for self ignition and combustion induction time.

BS EN 15188:2007 Determination of the spontaneous ignition behaviour of dust accumulations

Fuels

Olive cake,

Mesquite,

Plane,

Pine heartwood,

Sunflower husk

Red berry juniper

Miscanthus

- Moisture contents in the range 4.7-7.4 % (a.r.)
- Ash contents vary from 2.1% (pine) to 11% (olive cake)
- HHV: 19-22 MJ/Kg.



Results – Dust Layer

- Full set of test results shown for 5mm pine dust layer on a heated plate
- Temperature is decreased in 10 °C intervals (fresh dust layer added)
- Lowest temperature of ignition, and ignition delay at each temperature is recorded.
- Smouldering spread from edge of ring, flaming combustion was not observed





Mesquite

Red berry juniper

Sunflower

Pine dust progression of ignition





Dust layer test results

Sample	T Hot Plate . °C	Description	Time (mins)	Ignition Seen	
Pine Heartwood	350	Ignition	5	Visible Glowing	
	330	Ignition	7	Visible Glowing	
	320	Ignition	9	Visible Glowing	
	> 310	no ignition	30	-	
	310	no ignition	30	-	
Plane	.2 300	Ignition	10	Visible Glowing	
	ರ 290	no ignition	30	-	
	290	no ignition	30	-	
Red Berry Juniper	310	Ignition	6	Visible Glowing	
	300	no ignition	30	-	
	300	no ignition	30	-	
Mesquite	300	Ignition	5	Visible Glowing	
	0 290	no ignition	30	-	
	290	no ignition	30	-	
Sunflower Pellets	O 300	Ignition	4.5	Visible Glowing	
	2 90	no ignition	30	-	
	290	no ignition	30	-	
Olive Cake	300	Ignition	7	Visible Glowing	
	290	Ignition	5.5	Visible Glowing	
	280	No Ignition	30	-	





- All fuels show complex degradation
- Olive cake, in particular, begins to degrade at very low temperature
- On the heating plate, temperature where ignition is detected before 30 min is towards the end of devolatilisation



Pyrolysis-GC-MS at low T

Low T pyrolysis products contain:

- Essential oils
- Long chain fatty acids and esters (olive cake)

High T pyrolysis products contain:

- Lignin decomposition products
- Cellulose and hemi-cellulose decomposition products

May contribute to ignition risk, since fats and resins increase the self-heating risk.







Initial decomposition temperatures

The three methods (below) assume that reactivity (or ignition risk) is related to the temperature at which degradation <u>begins</u>





Volatile composition

TGA-FTIR during pyrolysis enables estimation of main volatile composition



wt% daf	Pine
Acetaldehyde	6.31
Acetic Acid	1.54
Acetone	0.74
Ammonia	0.12
Carbon Dioxide	3.45
Carbon Monoxide	2.49
Char	22.93
Ethylene	0.10
Formaldehyde	1.07
Formic Acid	2.15
Hydrogen Cyanide	0.01
Methane	1.84
Methanol	0.97
Phenol	1.37
Tar	34.44
Water	20.46
Total	100

Lower flammability limits of volatiles



 Lower flammability limit of the volatile mixture can be evaluated from:

$$LFL_{mix} = \frac{1}{\sum_{i=1}^{n} \frac{y^{i}}{LFL_{i}}}$$

	Willow	Olive	Red Berry	Mesquite	Sunflowe	Pine	Plane
		Cake	Juniper		r		
LFL (% in air)	18.0	33.7	22.0	19.3	18.4	17.7	15.4
Combustible Fraction	0.293	0.316	0.384	0.383	0.368	0.388	0.457

• Lower flammability limit is very rich (but this neglects the less volatile tars).

Single Particle Combustion



- Video shows common features for single particle combustion tests:
- 1. Particles blacken as pyrolysis proceeds, and smoke is produced, but no flame.
- 2. After a delay period, if the furnace temperature is high enough, the resultant char ignites and an exotherm is detected.





Ignition delay time was measured for ~ 10 particles at each temperature

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Ignition delay and temperature



The lower the furnace temperature, the longer the ignition delay



Note that ignition of a very reactive char happens (rather than ignition of volatiles)

This is seen in single particle, dust layer and basket tests.

Volatiles have low flammability because of high fraction of inerts (water vapour and CO₂)

Therefore, ignition risk (in absence of external ignition source) depends on how quickly the char can form at any given temperature (i.e. global decomposition rate – rather than initial decomposition rate).

Note that ignition delay time increases as temperature decreases.

Predicted conversion with time at 150 °C





Time to reach 90% conversion

[assuming isothermal conditions]

Fuel	70 °C		100 °C		150 °C		200 °C
	h	day	h	day	h	day	h
Miscanthus	1970	82	389	16	44	1.8	8
Sunflower Husk	2651	110	438	18	39	1.6	6
Red Berry Juniper	1821	76	371	15	43	1.8	8
Plane	6058	252	958	40	79	3.3	11

- High activation energies for decomposition mean the fuel has a lower risk of ignition at slightly elevated temperatures.
- Low activation energies for decomposition mean a higher risk of ignition at slightly elevated temperatures.



400 ♦ olive residue* 380 anthracite* ▲ Wheat mix* Low risk 360 ✗ icing sugar[∗] 340 TMWL peak (°C) X Sub-bit. coal* × ж • bit. coal* 320 Medium risk + wheat* 300 Olive Cake 280 Mesquite High risk Sunflower Husk 260 Miscanthus ж 240 × Plane Very high risk 220 × Pine 45 55 65 75 85 35 95 X Red Berry Juniper Activation energy for pyrolysis (KJ/mol)

Adapted from Ramirez (J. Hazardous Materials)

Risk ranking

Risk ranking based on fuel type and reaction rate





- A novel, single particle, method has been developed for assessing ignition delay and probability of ignition.
- This, together with other rapid, laboratory-scale methods have been used to compare 7 fuels from the project partners.
- Risk ranking must include a global reaction rate parameter preferably an activation energy (since this will dictate the rate at low temperature).
- Laboratory scale methods provide useful insight and parameters to enable the prediction of (comparative) ignition delay of fuels at slightly elevated temperatures.
- Methods for scaling up (e.g. basket tests) are needed for assessing ignition risk in storage of heaps, since other tests neglect the self-insulating.
- Further work is recommended to extend the data base, measure critical ignition temperatures, and characterise ignition delays in dust-layers at lower temperature.



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