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Explosivity and Flame Propagation Characteristics of Pulverised Woods

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Woody biomass fire & explosion hazards

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At least one dust fire or explosion incident is reported every day in biomass plants (Abbasi and Abbasi, 2007). Some recent incidents related to biomass dust explosions are given below as examples (Industrial Fire World, 2016).

- ***Weyerhaeuser Plant in Columbia [May 7, 2016]***

  Fire started in the dust collection system. No injury was reported with minimal physical loss.

- ***Timeless Frames plant [March 5, 2016]***

  Fire started in 40ft tall silo. No injury was reported with some physical loss. Third fire incident in this silo.

- ***Krabi biomass power plant [April 8, 2015]***

  Two workers injured due to massive fire. Damage was estimated at about Bt 100 million.

- ***Biomass power plant managed by Eco Sustainable Solution Ltd. at Southampton dock[January 03, 2015]***

  20 ft flame and thick cloud of billowing smoke due to woodchip pile fire. No injury was reported.

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- ***Biomass power plant managed by Eco Sustainable Solution Ltd. at Southampton dock[January 03, 2015]***

  20 ft flame and thick cloud of billowing smoke due to woodchip pile fire. No injury was reported.

- ***Tandil Argentina grain silo agricultural plant [January 28, 2013]***

  An explosion occurred in a grain silo at an agricultural plant that killed 1 and injured another.

- ***Fire and explosion at New England Wood Pellet LLC [October, 2011]***

  It took 100 fire fighters and 15 hours to put down the fire. The company had to pay fine of $100,000.

- ***Explosion at the RWE's 750,000 ton wood pellet factory, Georgia, USA [June, 2011]***

  An overheated roller/bearing assembly in a pelletizer sparked the blast at the factory that damaged some of the processing equipment. No injury was reported.

Recent Bosley mill explosion, Macclesfield

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- A very recent incident of wood floor mill explosion in UK (17 July 2015) was reported with physical and human loss (4 deaths were reported).
- Temperature reached 1000^{o}C in the fire following the blast.
- HSE finds dust issues at blast site (BBC news).

Biomass is utilized in pulverised form for their efficient and effective combustion. This pulverised form has fire and explosivity hazards associated with them that need to be contained in the safe working boundaries for safety.

12 Sept 2016 – dust hopper explosion in furniture plant - Canada

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http://www.cbc.ca/news/canada/british-columbia/abbotsford-fire-dust-explosion-1.3759400

Fire fighting (water jets) disturb the dust creating dust cloud

Biomass Wood Dusts

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- Wood processing plants including wood finishing plants, panel-board plants and wood pellet facilities have fire/explosion hazards that needs to be assessed for safe working environments.

- Woody biomass is increasingly being used as a renewable and sustainable fuel for low carbon power generation.

- Different pre-treatments help to refine and improve its burning properties for its commercial applications but there is insufficient data in the literature to enable safe design of systems.

In this work we will show that

- Woody dusts are more sensitive to explosion than coal, gaseous and liquid fuels with leaner flammability limits and no defined rich flammability limit.

- Coarse woody dust in the presence of fine size particles can propagate the flame with significant build up of pressures.

Characterisation of biomass compared to coals

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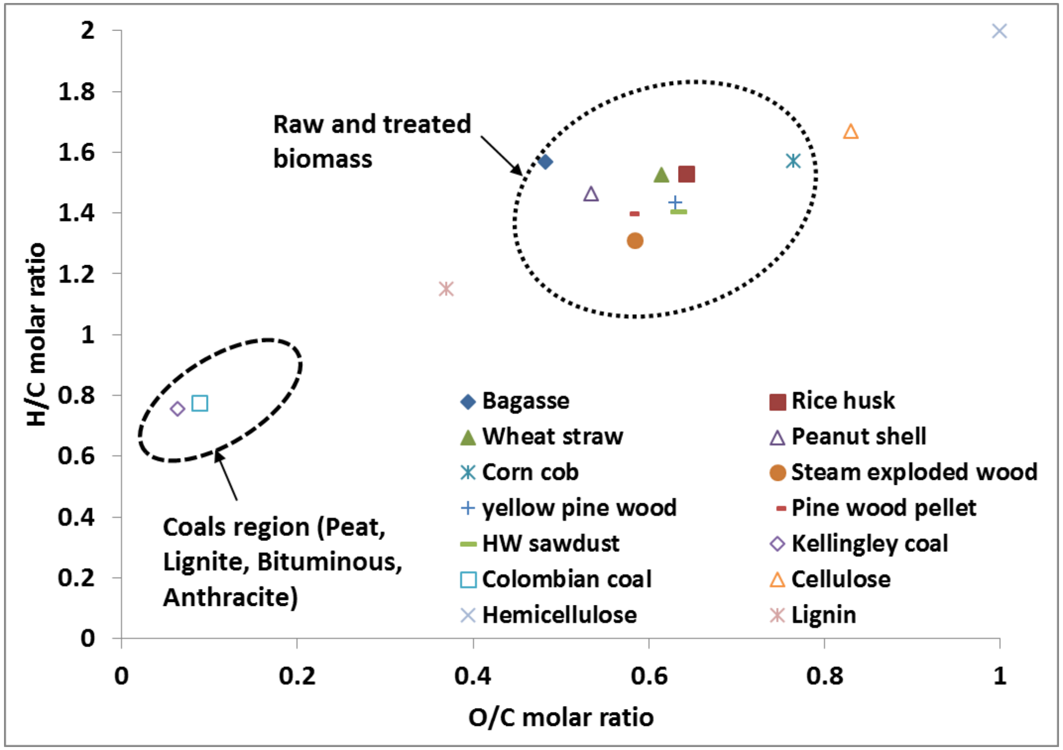
- Biomass dusts have inherent oxygen in their structure with higher O/C and H/C molar ratios compared to coals.

Variations of O/C and H/C molar ratios is dependent on the proportions of hemicellulose, cellulose and lignin contents in the biomass samples.



Role of volatiles rate in the flame propagation

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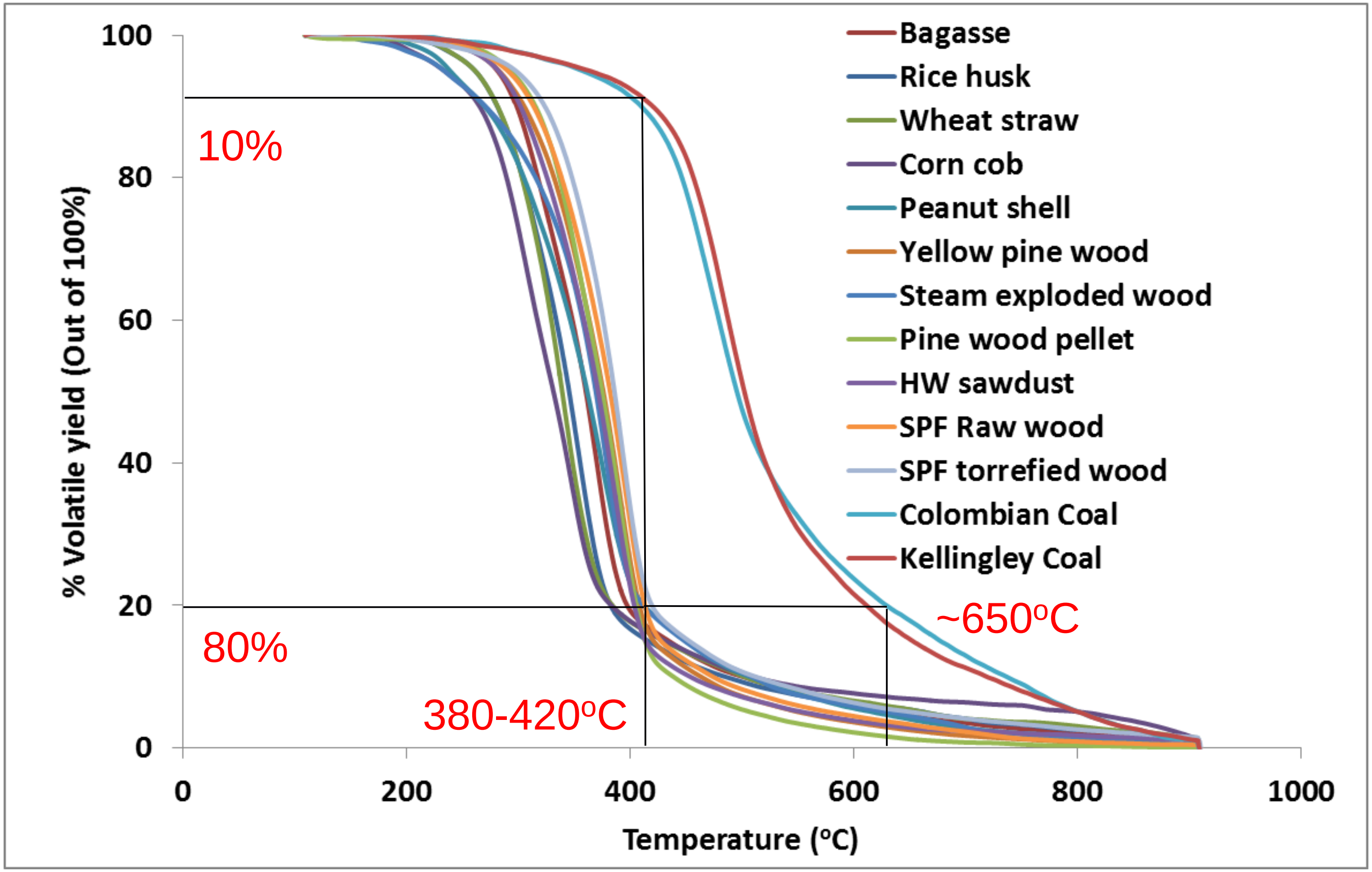
- Biomass dusts also have higher volatile contents that release in the lower temperature range assisting their efficient burning compared to coals.



Experimental methods

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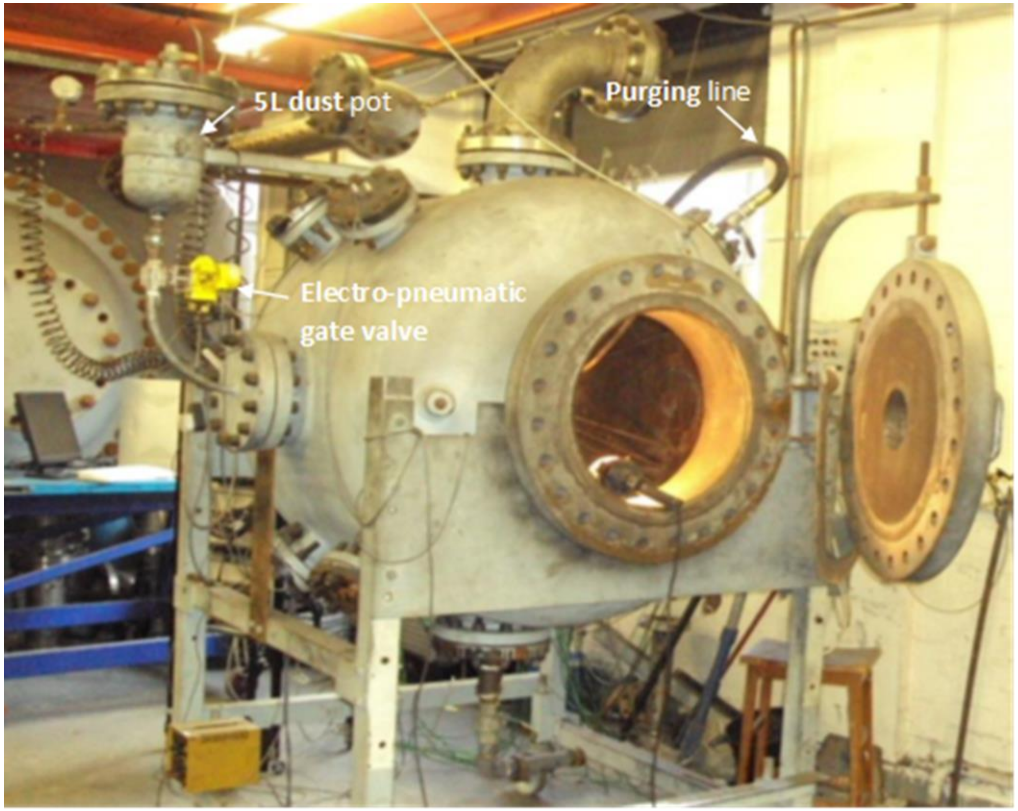

Modified Hartmann dust explosion tube

Modified 1 m^3 dust explosion vessel

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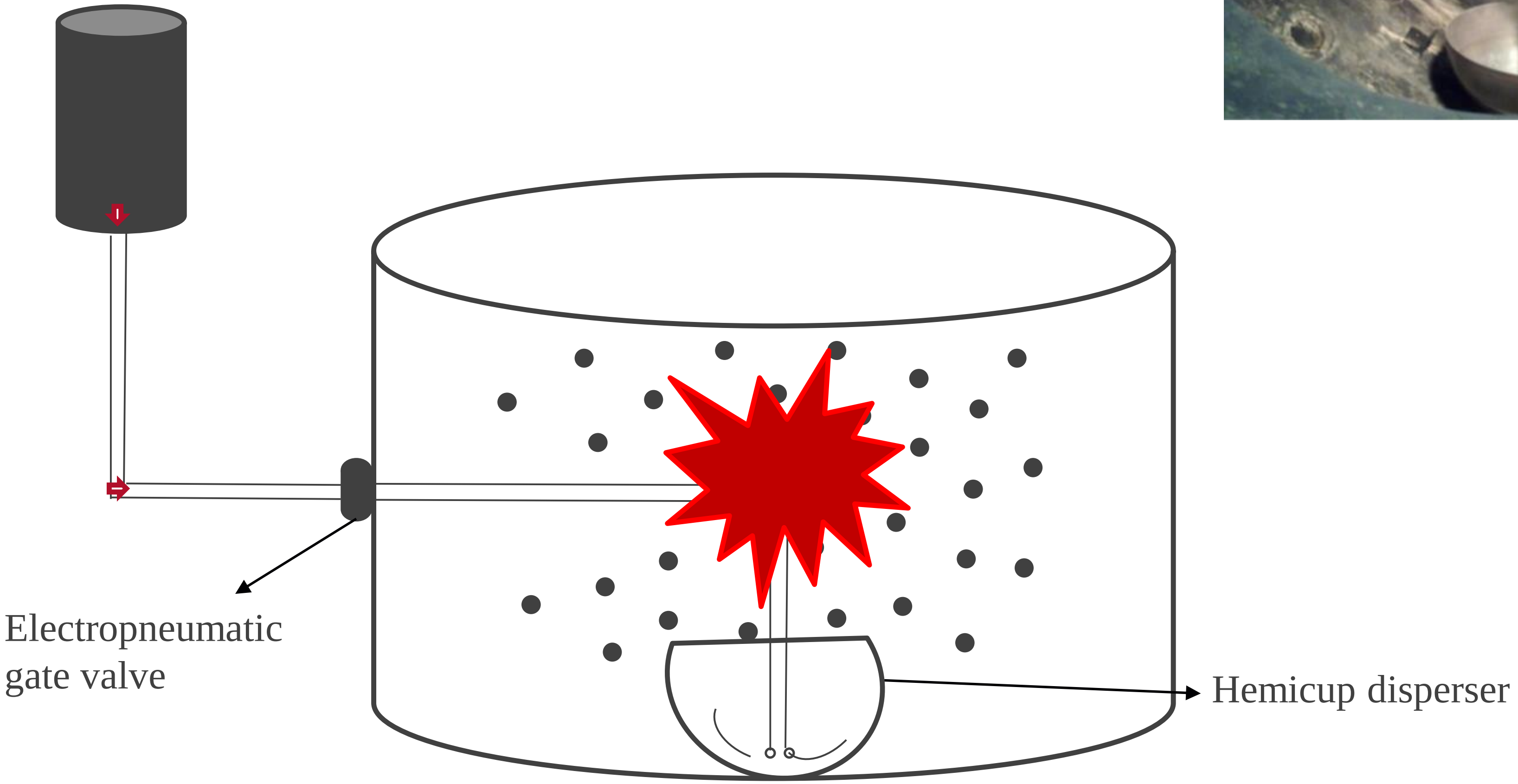
- Hemispherical disperser was calibrated using standard corn flour and Colombian coal samples based on explosivity parameters and the mass burnt compared to std. system.



Calibrated Conditions

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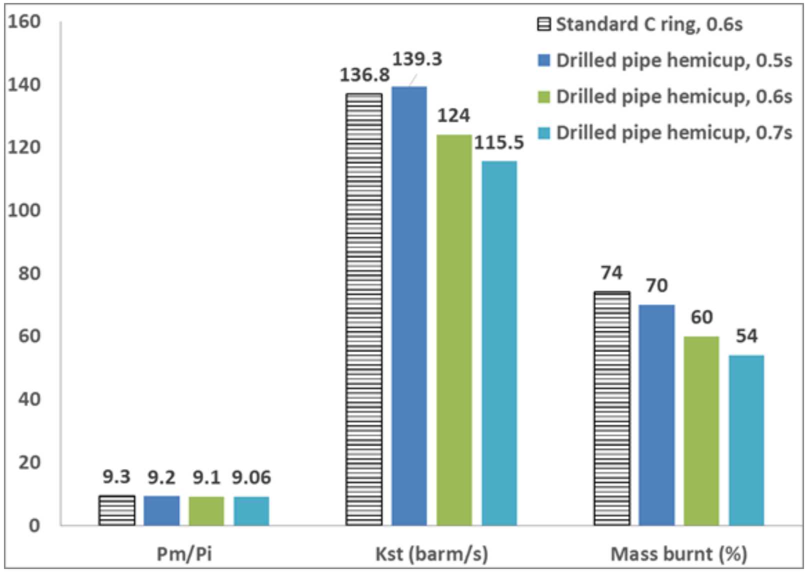
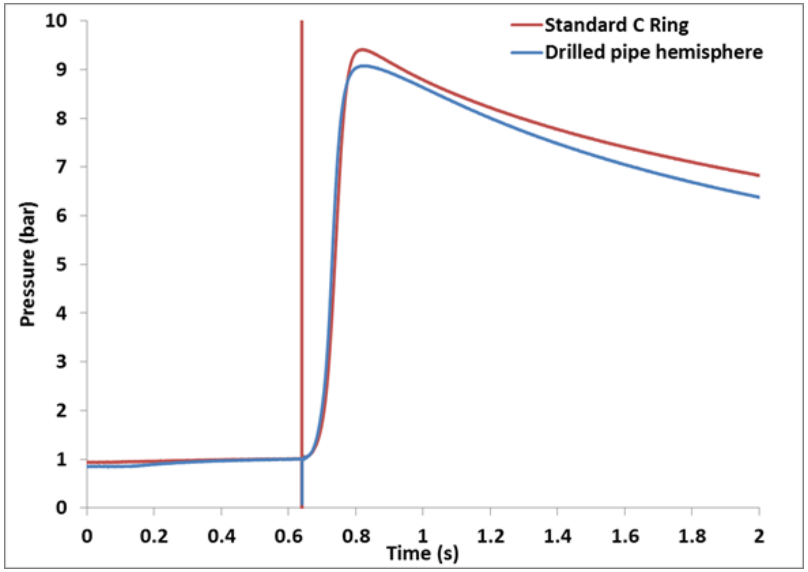
	Calibrated Hemispherical disperser	Standard C-ring disperser
Ignition delay (s)	0.5s	0.6s
Valve off timing (s)	0.64s	0.65s
Dispersion pressure (bar,g)	20bar for 10L	20bar for 5L
10% Methane ($Turbulence\ factor = \frac{Kg_{,turbulence}}{Kg_{,laminar}}$)		
Turbulence factor	4.7	4.0





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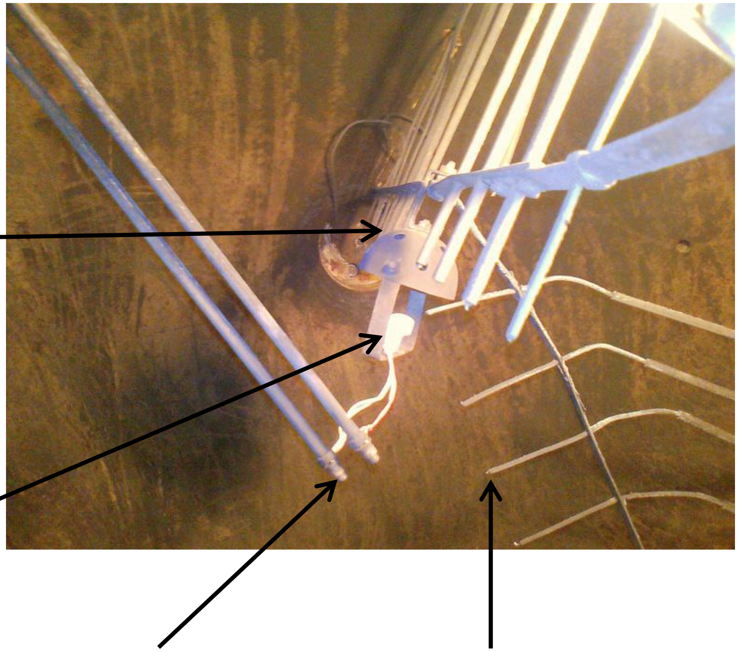
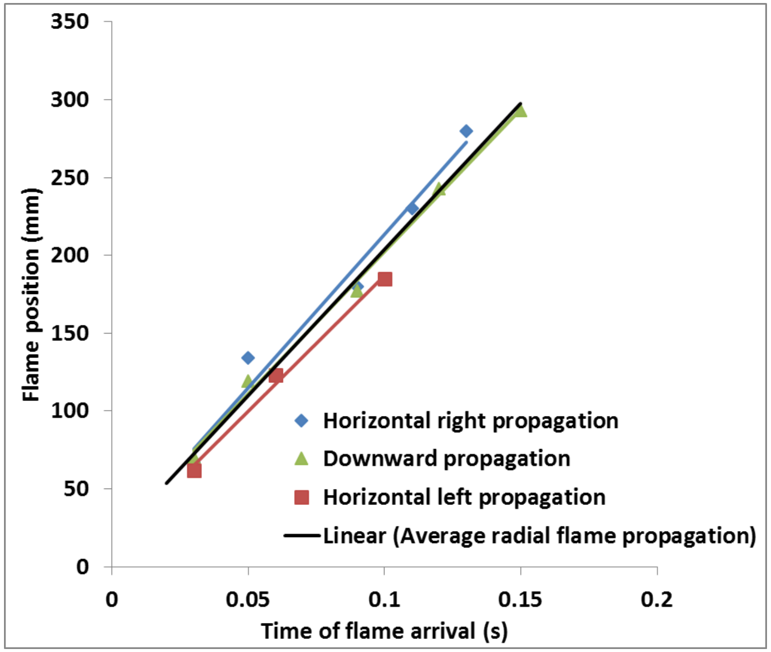
- 2D arrays of thermocouples were used to measure the time of flame arrival for flame speed measurements and to determine the uniformity of the dust cloud.





Flammability limits and poor resolution for MEC

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- MEC resolution was not clearly defined for dust in the existing standards however a procedure was adopted for testing of subsequent dust concentration 50% of the previous one such as;

…………,1000, 750, 500, 250, 125, 60, 30,………….. g/m^3

- Based on this, a poor resolution of 50% means that if 60 g/m^3 ignites and 30 g/m^3 does not then MEC is 60 g/m^3 based on ignited concentration and 30 g/m^3 based on non-ignited concertation.
- In that scenario, MEC should be considered for non-ignited concentration for extra safety.
- In past, the concentration of the solid dusts have been reported in terms of 'g/m^3'. With this, it is difficult to compare their properties with gaseous and liquid fuels.

Cont.

- Another concentration parameter known as 'Equivalence ratio' is more sophisticated as it also helps to estimate and compare the limits of combustion for solid, liquid and gaseous fuels (Andrews and Phylaktou, 2010). It is calculated based on the simple elemental and proximate analysis.

$$\left(\frac{Air}{Fuel}\right)_{Stoichiometric} = \frac{\left[\left(1+\frac{y}{4}\right)-\frac{z}{2}\right]\times 137.94}{(12+y+16z)} \qquad (by\ mass) \qquad (1)$$

Where y=H/C molar ratio , z=O/C molar ratio

$$Burnt\ equivalence\ ratio, \emptyset_{burnt} = \frac{\left(\frac{Air}{Fuel}\right)_{Stoichiometric}}{\left(\frac{Air}{Burnt\ Fuel}\right)_{Acutal}} \qquad (by\ mass) \qquad (2)$$

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- Most HC's fuels have their lean flammability limits half of their stoichiometric concentration.
- Oxy-fuels like biomasses were found to have MEC of about 1/5th to 1/3rd times their stoichiometric concentration.

Gas	A/F Ø=1	daf. g/m^3 Ø=1	MEC Ø	Method [1,2,3]	Dust	A/F Ø=1	daf. g/m^3 Ø=1	MEC Ø	Method [4,5,6]
Methane	17.2	70	0.46	EU Tube	Polyethylene	14.8	81	0.25 0.37	Hartmann 1 m^3
					Torrefied Wood	7.17	167	0.20	Hartmann
Propane	15.7	76	0.43	EU Tube	Torrefied Norway Spruce	6.61 8.70	181 138	0.17 0.22	Hartmann
Ethylene	14.8	90	0.38	EU Tube	Wood 95 µm	5.63	213	0.14	1 m^3
n-Hexane	15.2	79	0.47	EU Tube	Bark 57 µm	6.03	199	0.14	1 m^3
1,3,5 TMB 70 ^{0}C			0.50	EU Tube	Forest Residue 102 µm	4.78	251	0.22	1 m^3
Hydrogen	34.5	34.8	0.12	Tube	Bagasse	6.45	186	0.27	Hartmann
CO	3.45	350	0.41	Tube	Rice Husks	6.24	192	0.35	Hartmann
					Wheat Straw	6.03	199	0.55	Hartmann

[1] BSEN 1839, 2003 [2] Schroder and Molnarne, 2005 [3] Razus et al., 2004 [4] Maisey, 1965 [5] Wilen et al., 1999 [6] Saeed et al., 2015

% Inert vs. Minimum Explosive Concentration

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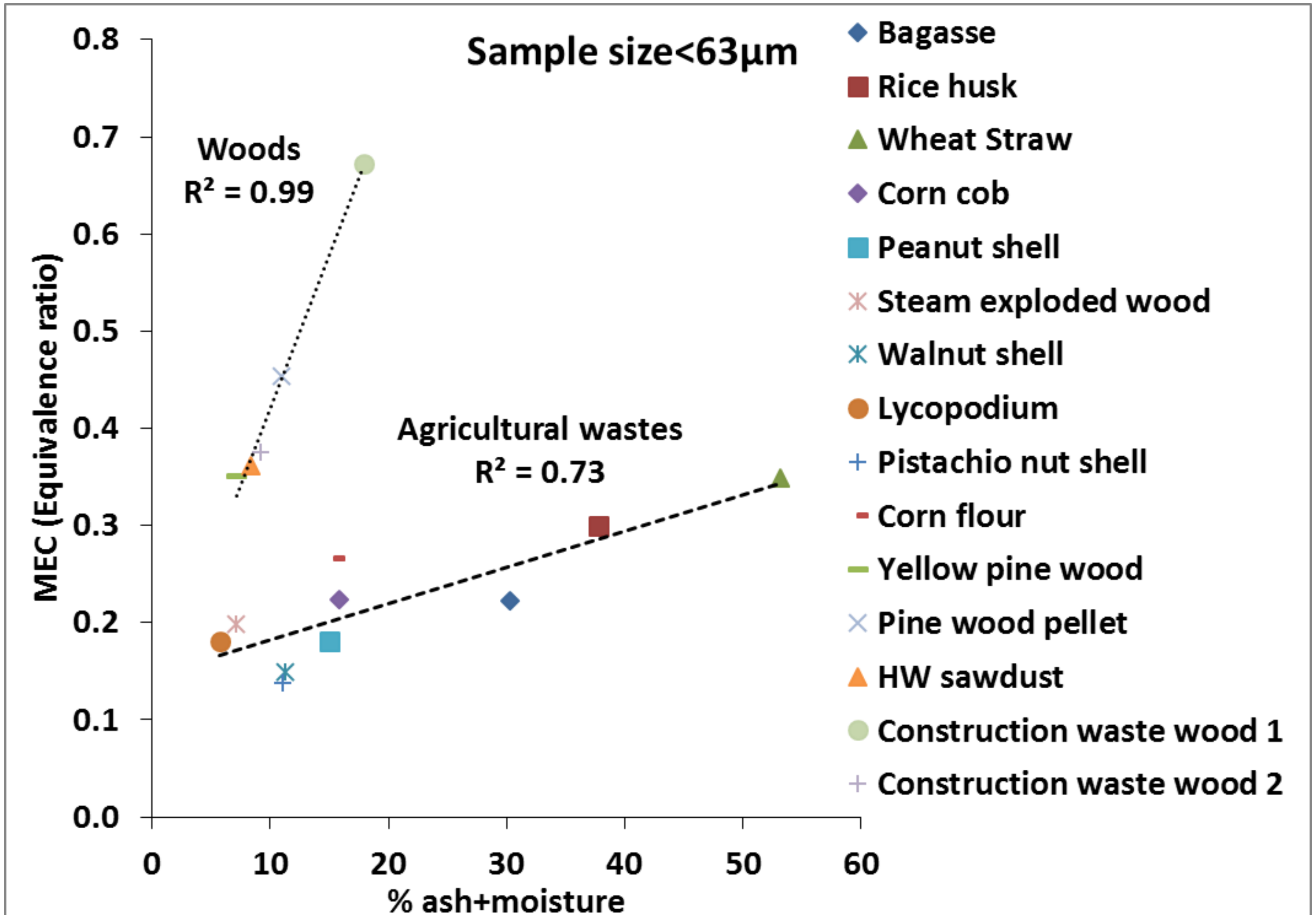

Flame propagation of fine and coarse size dust mixtures

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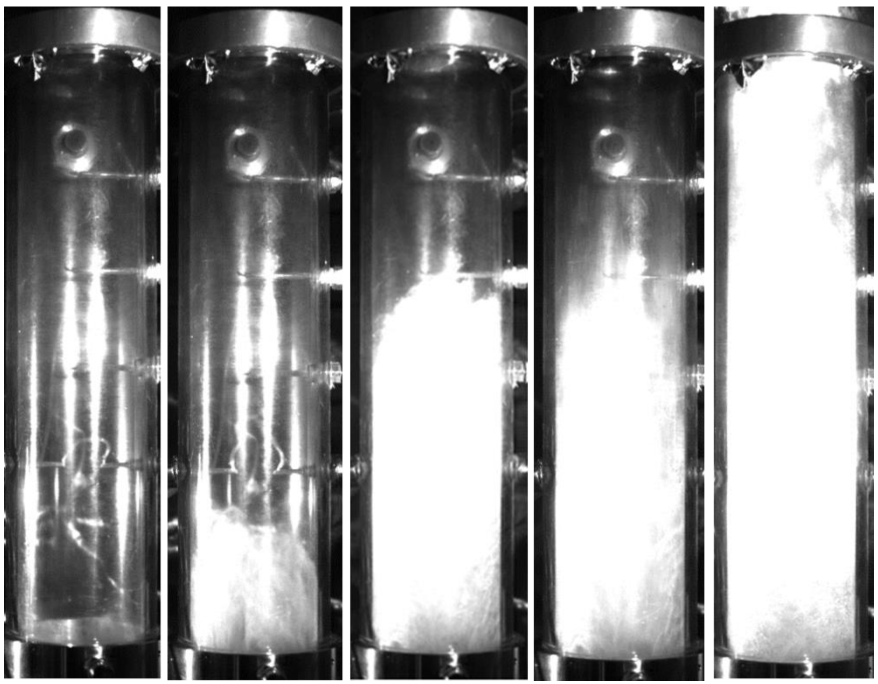
Particles distribution of fine and coarse size dust mixtures

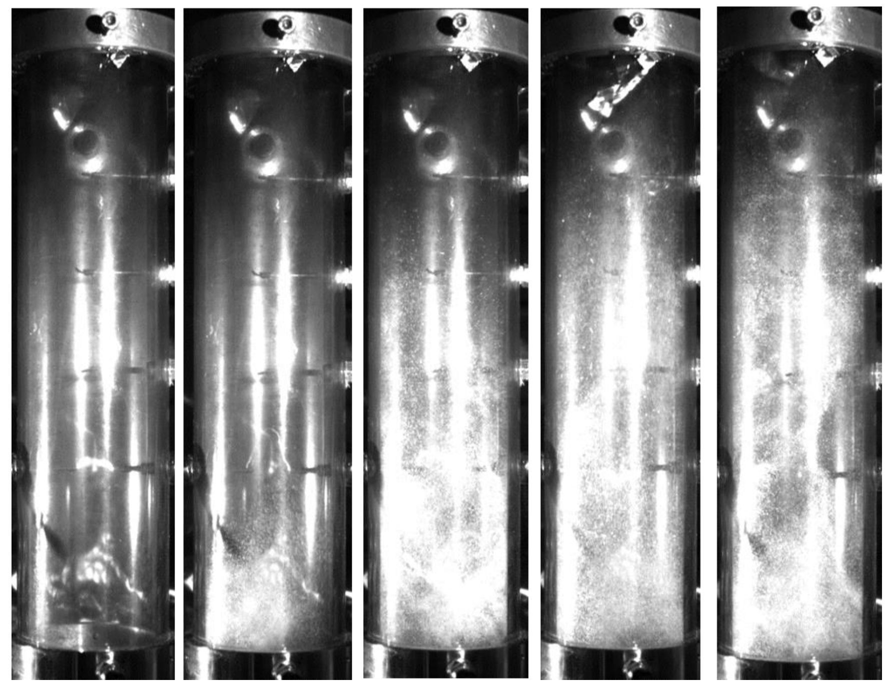
Fine size wood dust



Dust introduction	Propagation	Max. solid distribution	Vent rupture	Burnt mixture
0ms	14.8ms	67.4ms	69.6ms	180.4ms

Timings from activation of spark

Coarse size wood dust



Dust introduction	Propagation	Max. solid distribution	Vent rupture	Burnt mixture
0ms	55ms	420ms	1056ms	1273ms

Timings from activation of spark

Flame propagation comparison of fine wood and coal samples

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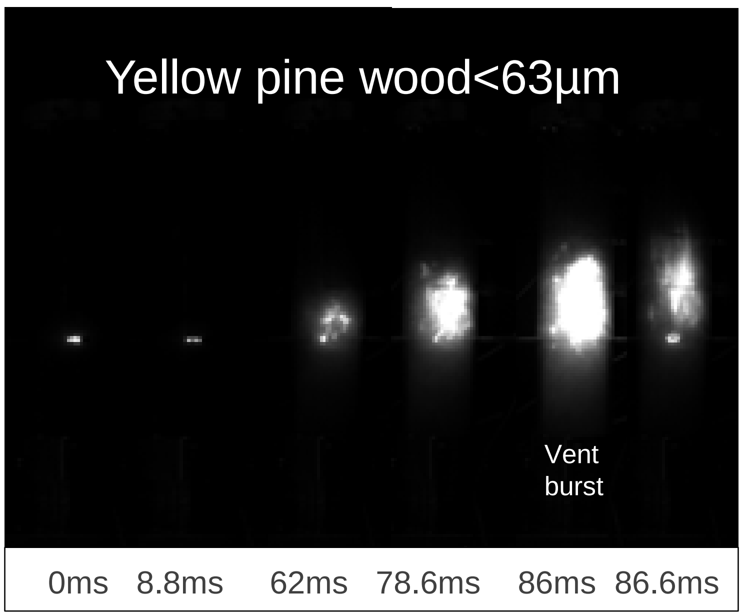
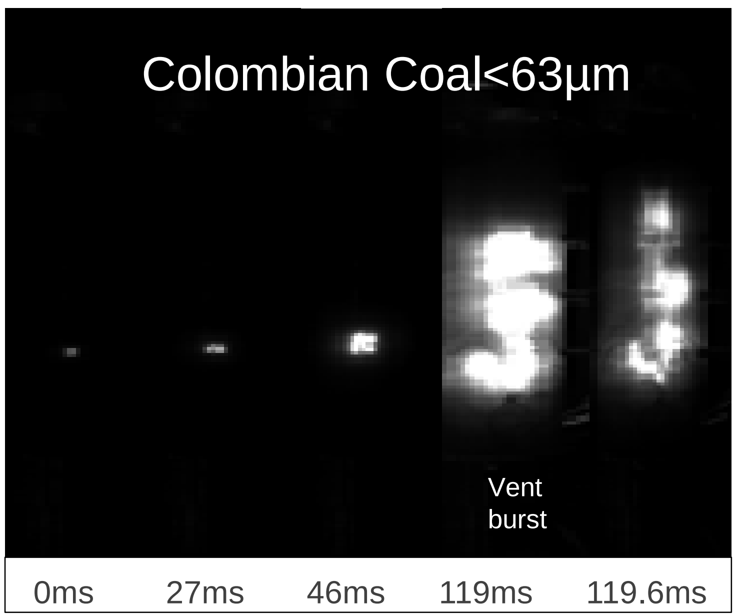
- Fast burning with small delay
- Apparently uniform burning
- Upward flame propagation

- Slow burning with large delay
- Non-uniform burning
- Irregular flame propagation





Surface morphology of raw, steam exploded and post explosion residue (<63μm)

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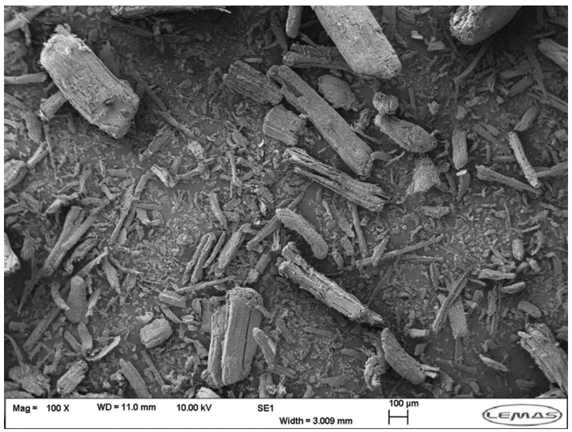
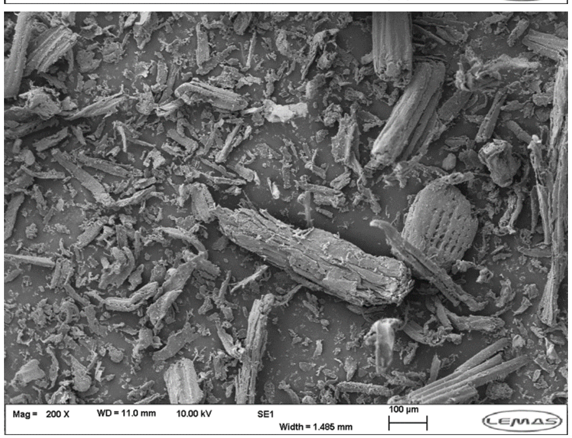
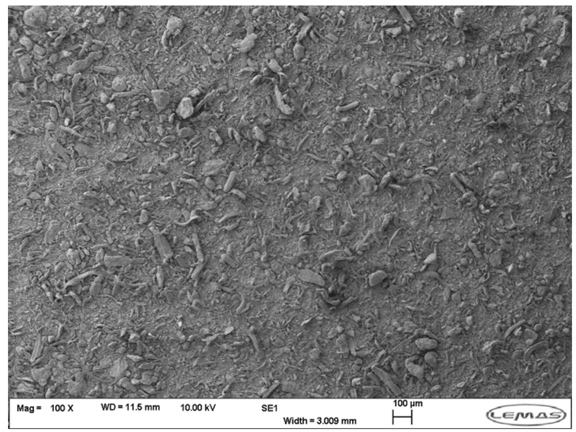
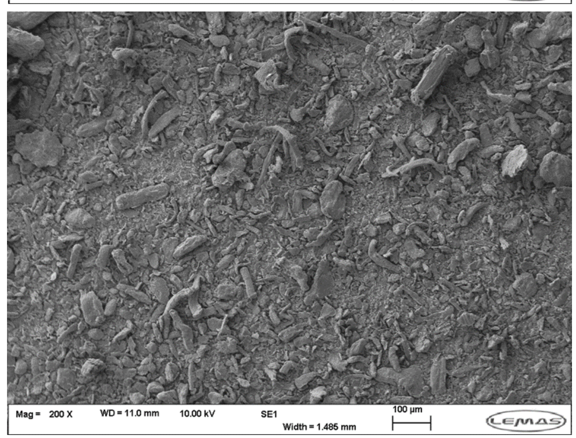
Raw pine wood (YPW)



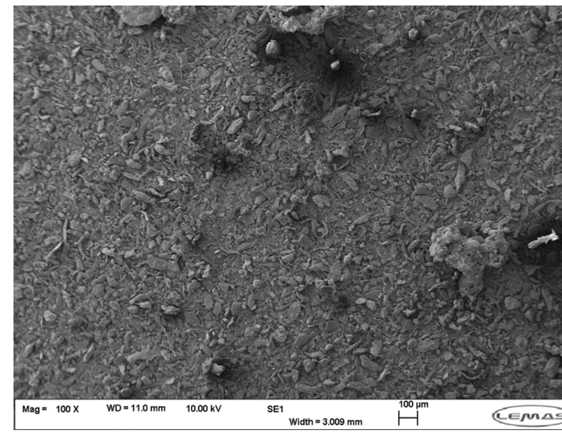


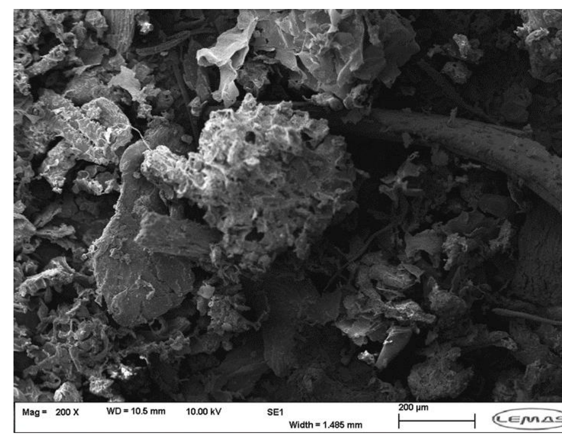
Steam exploded wood (BP)





Steam exploded wood (Post explosion)





Flame propagation of fine and coarse size thermally treated pine wood

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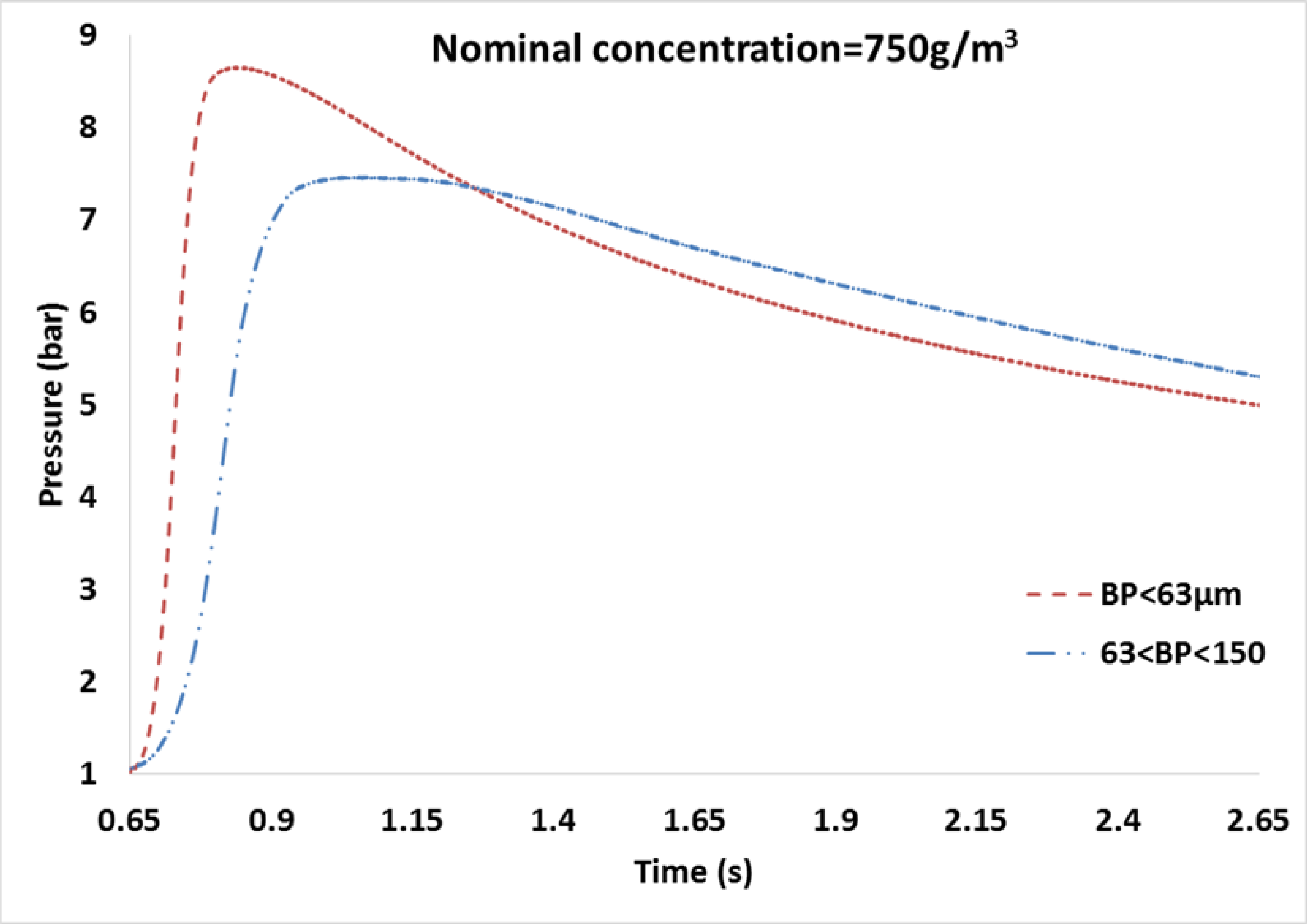

Correlations of explosibility characteristics and flame speeds against particle size

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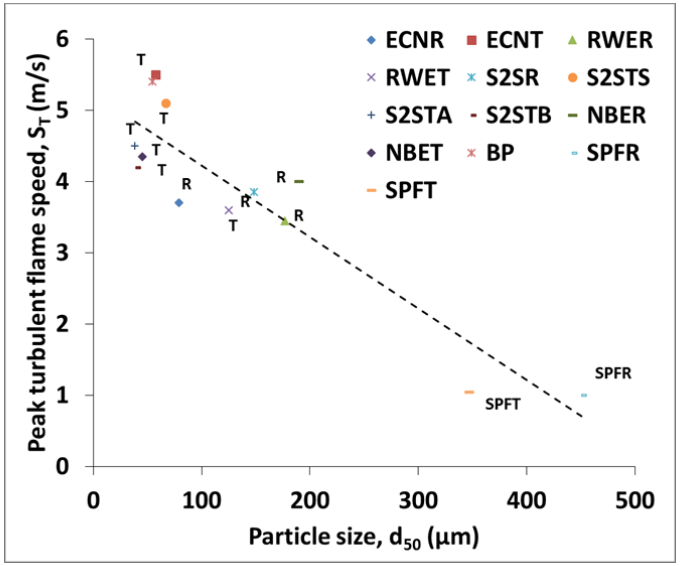
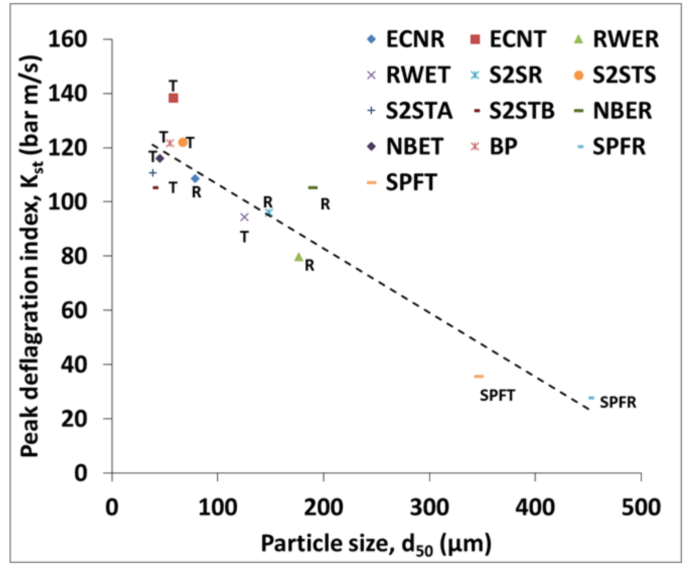
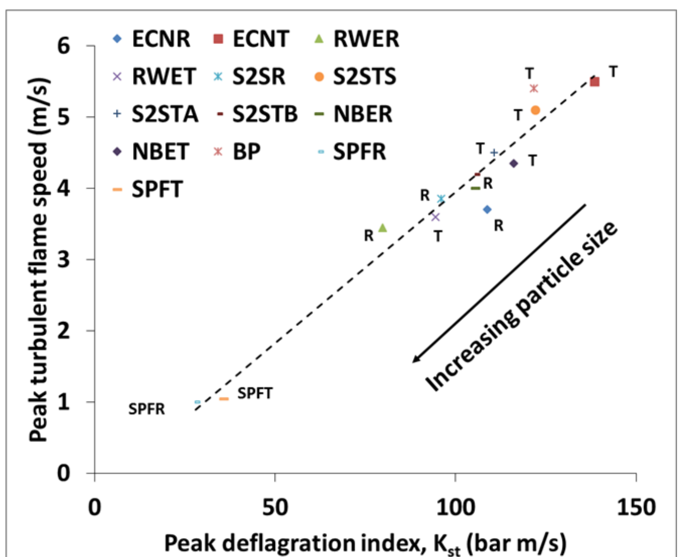
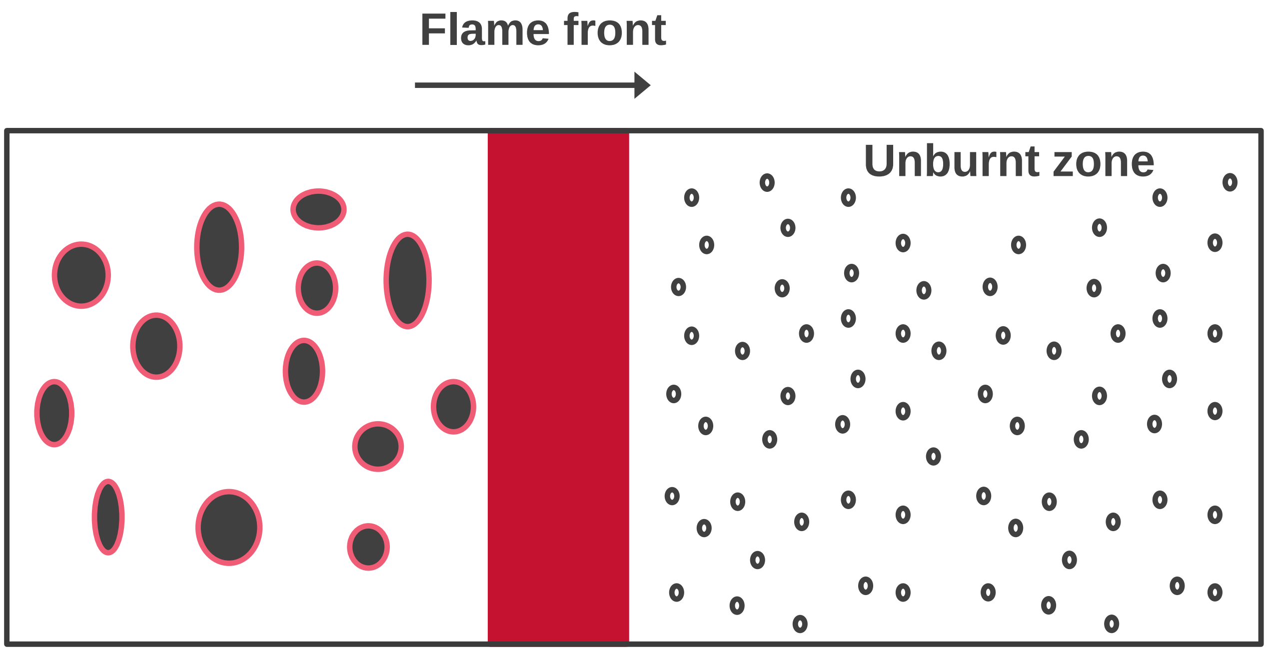






Proposed Model for Coarse Particles Gasification



Coarse particles lagging
and gasifying behind flame

Fine particles
ahead of flame

Conclusions

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- Biomass dusts (<63µm) release almost 80% of their volatiles at around 400^{o}C assisting for their fast burning contrast to coals with only 10% release of volatiles that make biomass more reactive.
- Minimum explosive concentration resolution for dusts is crude/ poorly defined (50%) in the literature. The last ignited and first non-ignited concentrations should be reported togather.
- Biomass dusts were determined to have leaner MEC (compared to gases) and no upper flammability limits.
- Fine size biomass wood dusts carry greater explosion potential with higher severity than the coarse size dusts.
- However, the **woody biomass of coarse size range (sieve size less than 1mm) also propagated the flame and produced high overpressures.**
- These data and understanding, should contribute to better interpretation of wood dust explosion incidents and to the design of better safety systems.

Thanks