# Cone Calorimeter Biomass Combustion with Particle Number Analysis

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# Introduction

The cone calorimeter is a standard test method for material behaviour in fires and this work shows that it could be used for the characterisation of the combustion of biomass.

The principle of the cone calorimeter is to use an electric radiant heater to raise the temperature of the combustion zone and ignite the fuel and 35 $kW/m^2$ was used in the present work, as this has been previously shown to be sufficient to establish fully developed combustion of biomass materials such as wood.

The radiant heater represents the surrounding heat for a piece of biomass in a larger combustion zone.

As one of the main fire loads is wood, which is the dominant biomass for energy generation, it is reasonable to use the cone calorimeter to characterize the combustion of biomass on a small scale and pine was used in the present work.

**The cone calorimeter was used in the controlled atmosphere mode with an enclosure around the test biomass that enabled the air flow for biomass combustion to be controlled and 19.2 g/m$^2$s was used in the present work. This corresponds to a combustion HRR of 57 kW/m$^2$, assuming all the oxygen in the air is consumed.**

**This air flow will be shown to generate rich combustion at a metered equivalence ratio, Ø, of about 2, which is comparable with the first gasification stage of biomass two stage burning in log burners and pellet burners, where air is added downstream of the gasification stage of biomass combustion.**

**Soot emissions are generated in this rich gasification stage burning and are shown not to be oxidized in the second stage burning.**

**The particle size distribution of the particulate emissions after second stage air addition were determined and shown to be very significant with a high number of nano-particles <20nm.**

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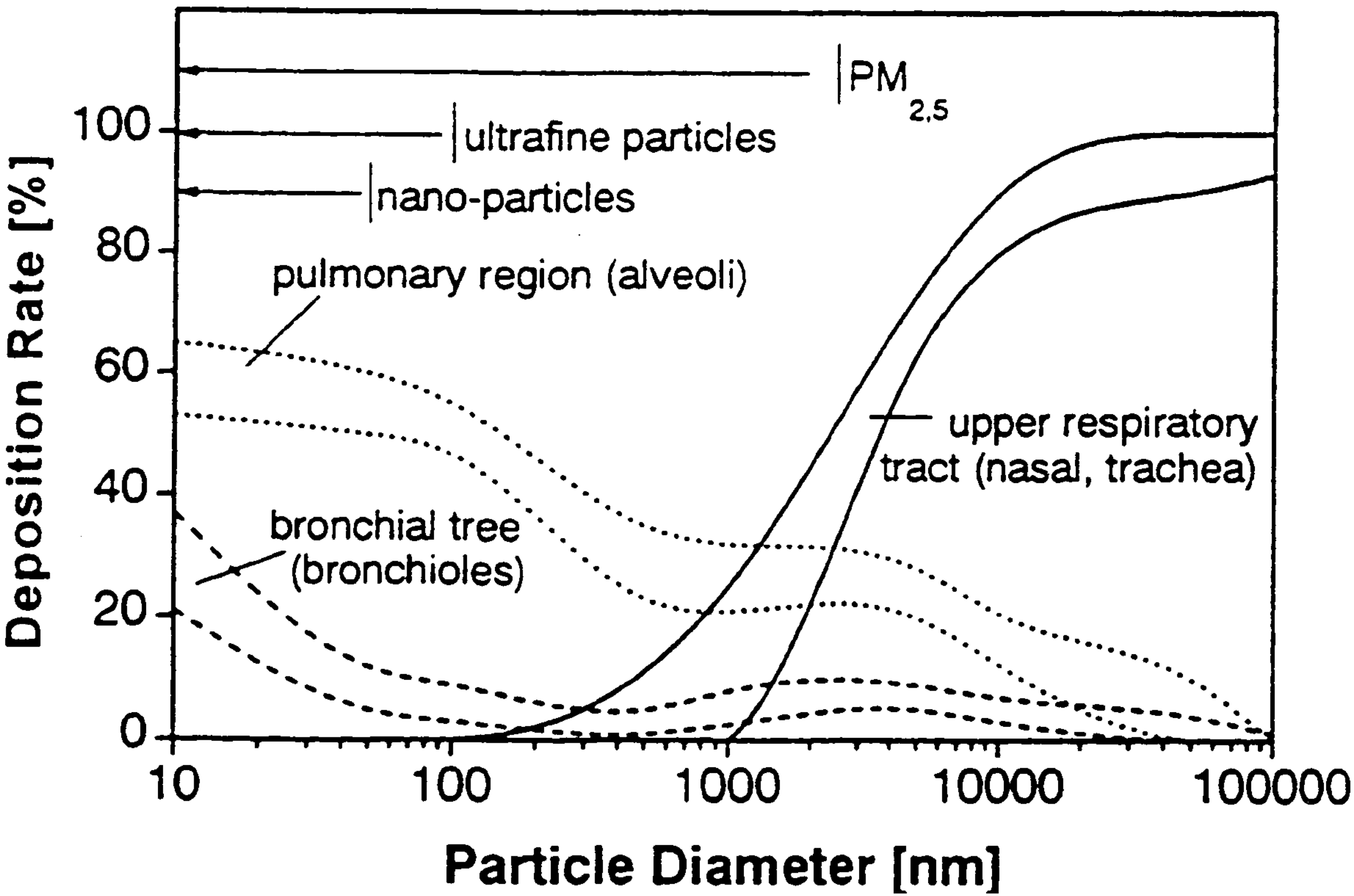
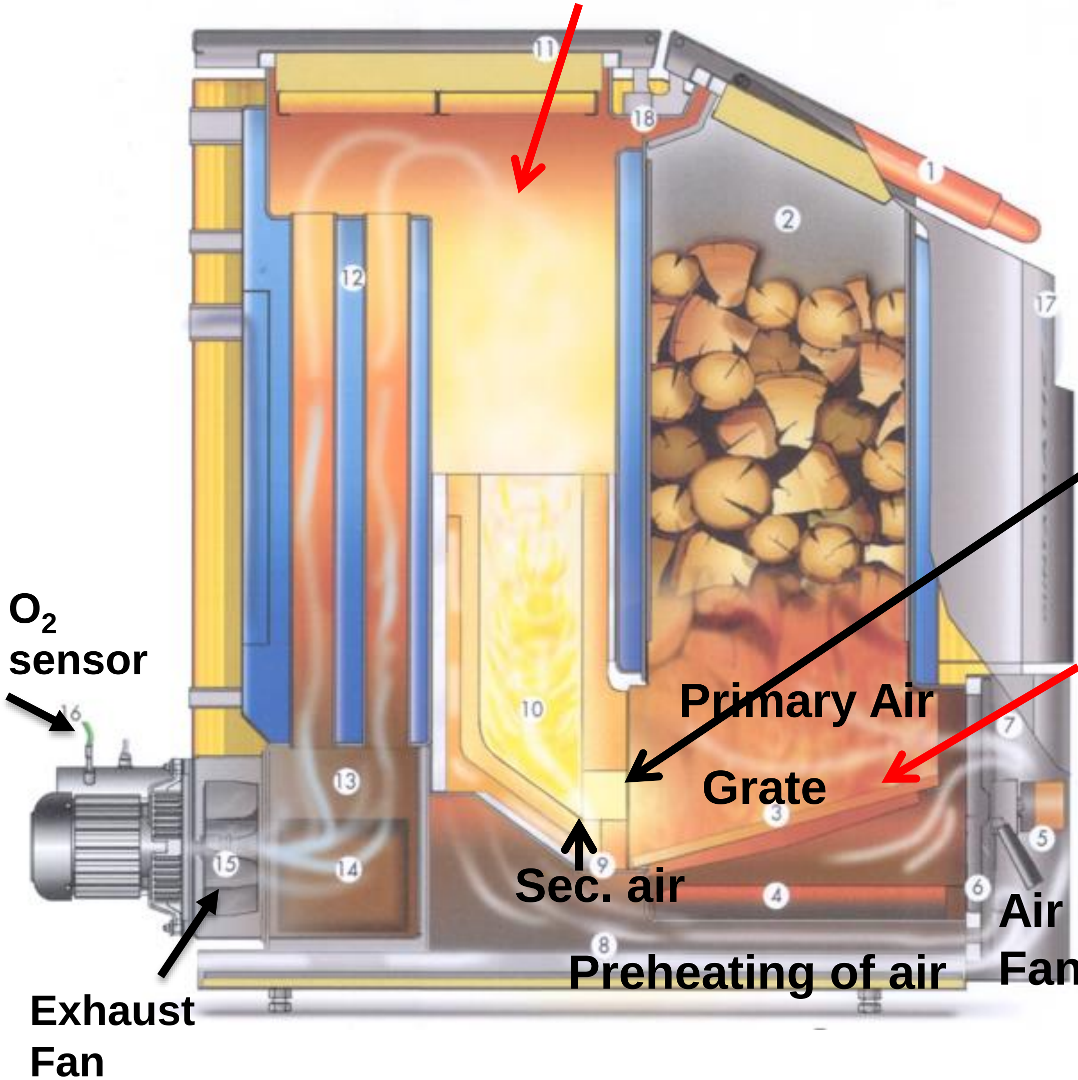



Deposition rates of inhaled particles in the respiratory tract.
*Air Pollution, The Automobile and Public Health, National Academic Press, 1988.*

Note that heat extraction does not occur until the end of secondary combustion heat release

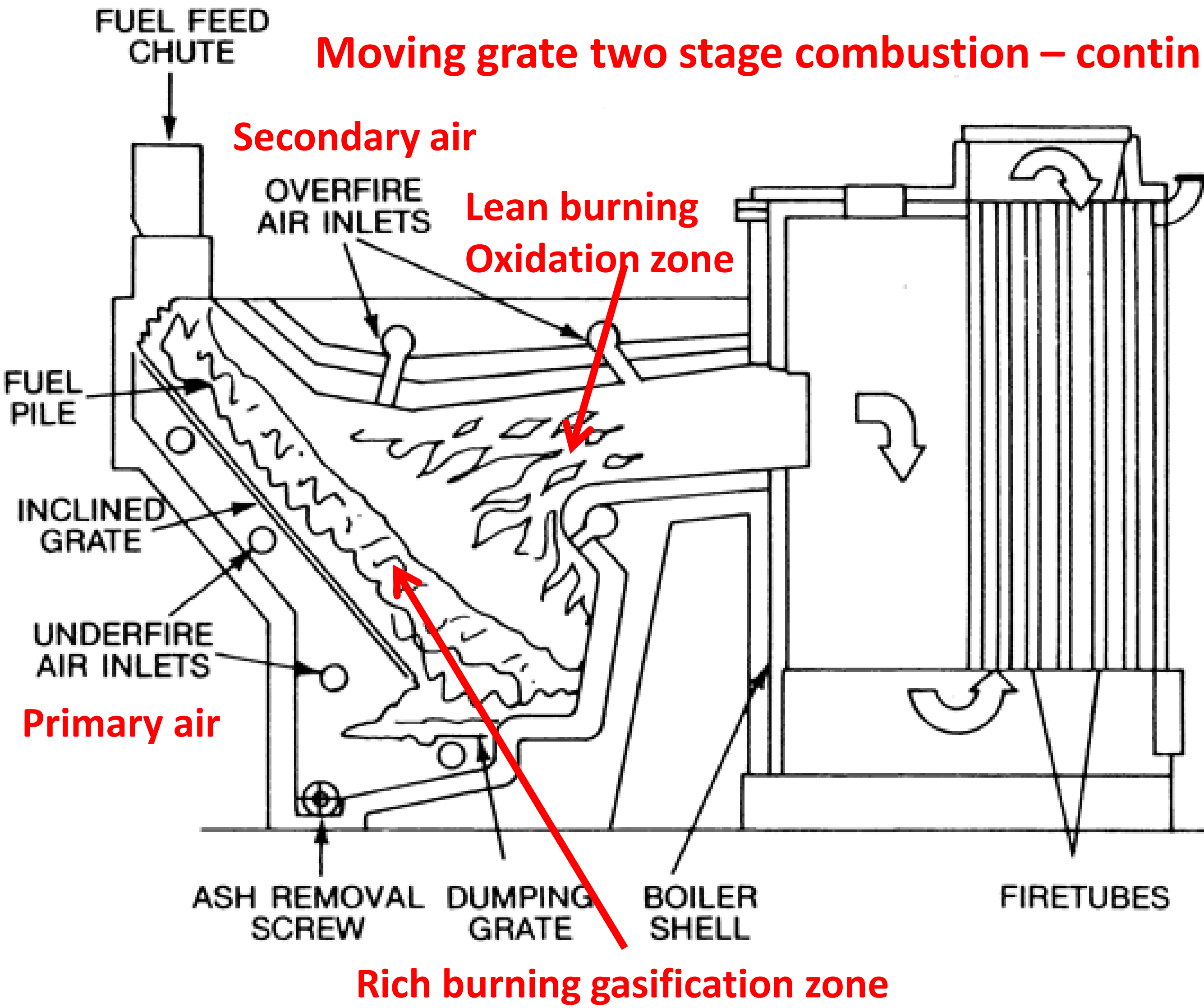



Hole that transfers the primary rich burn product gases to the second stage oxidation with air added.

This is the rich burning primary dombustion studied in this work.

Baffle to control the primary/sec. air split

# Moving grate two stage combustion – continuous fuel addition




- Moving grate systems
- Can use wood chips or pellets or logs
- Electricity production using steam turbine
- Two stage combustion with rich primary or underfire air and overfire or secondary air to complete the combustion.
- Used for generation of electricity in the 1 – 50 MW range.

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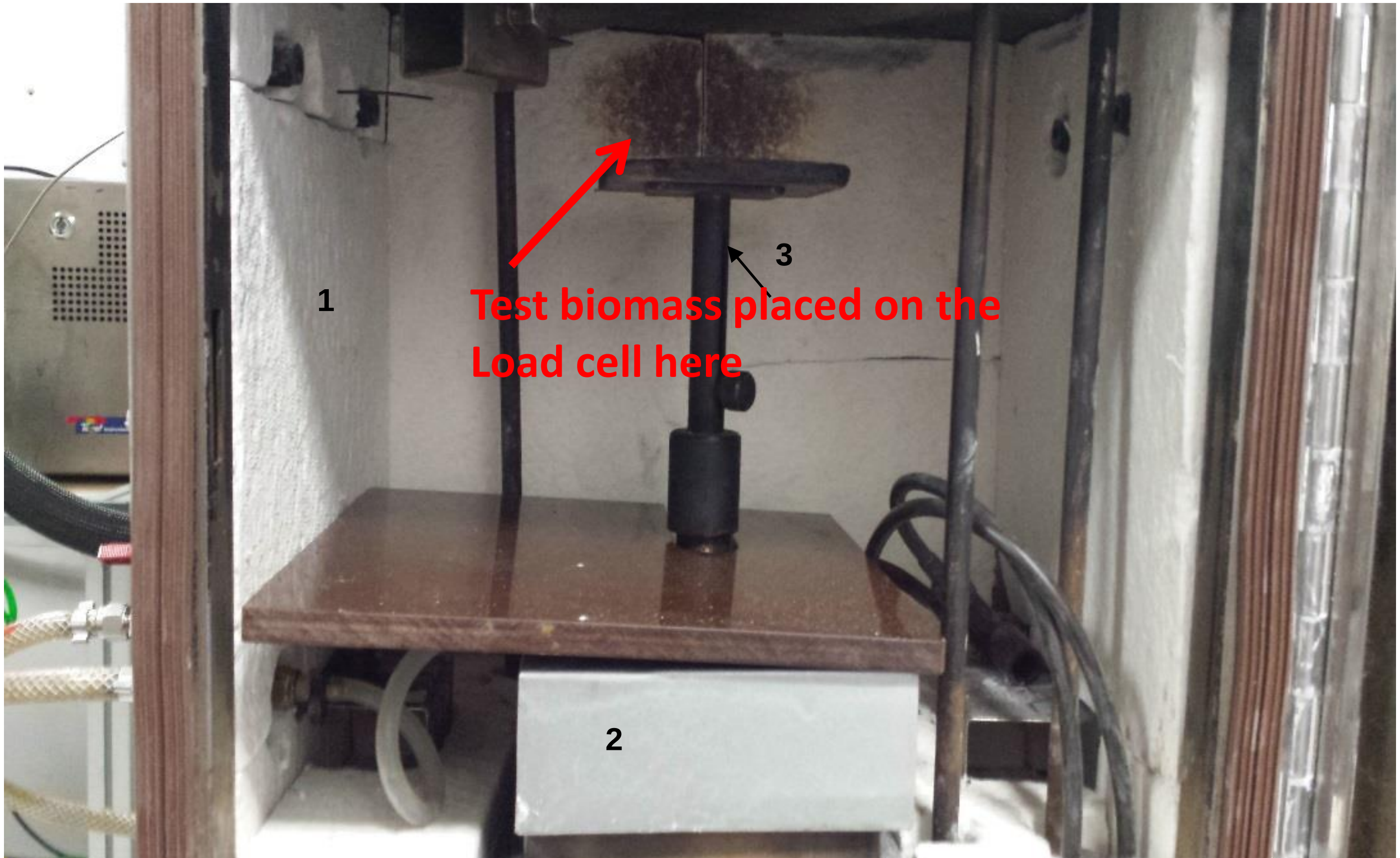


Air flow set to achieve rich combustion.
Gas composition is CO, hydrogen and hydrocarbons.
Effectively this is an upward flow gasifier.

1. insulation
2. cooling jacket on load cell
3. Load cell

Cone calorimeter insulated
Confined atmosphere air box
Air supplied through two pipes in
Bottom of the compartment

- **The Cone calorimeter was exposed to a radiant heat of 35kW/m$^2$ and a fixed ventilation rate of 19.2 g/sm$^2$**

**Biomass flame through observation window**

**Test sample of 100mm x 100mm**

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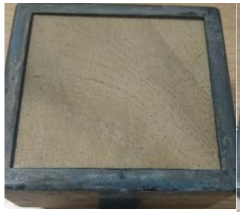
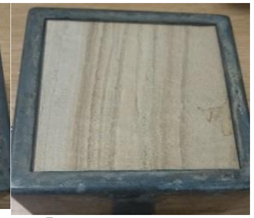
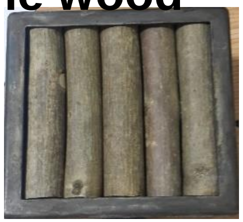



Pine wood Acacia wood Eucalyptus wood



Dry ash wood Wet ash Mountain ash pellets



Sunflower shell pellets

Torrified wood White wood pellets



Corn cobs

China's biomass black
China's biomass skin

The cone calorimeter has been used to characterise a wide range of biomass.
Pine has been used as the reference biomass to develop the experimental methodology.

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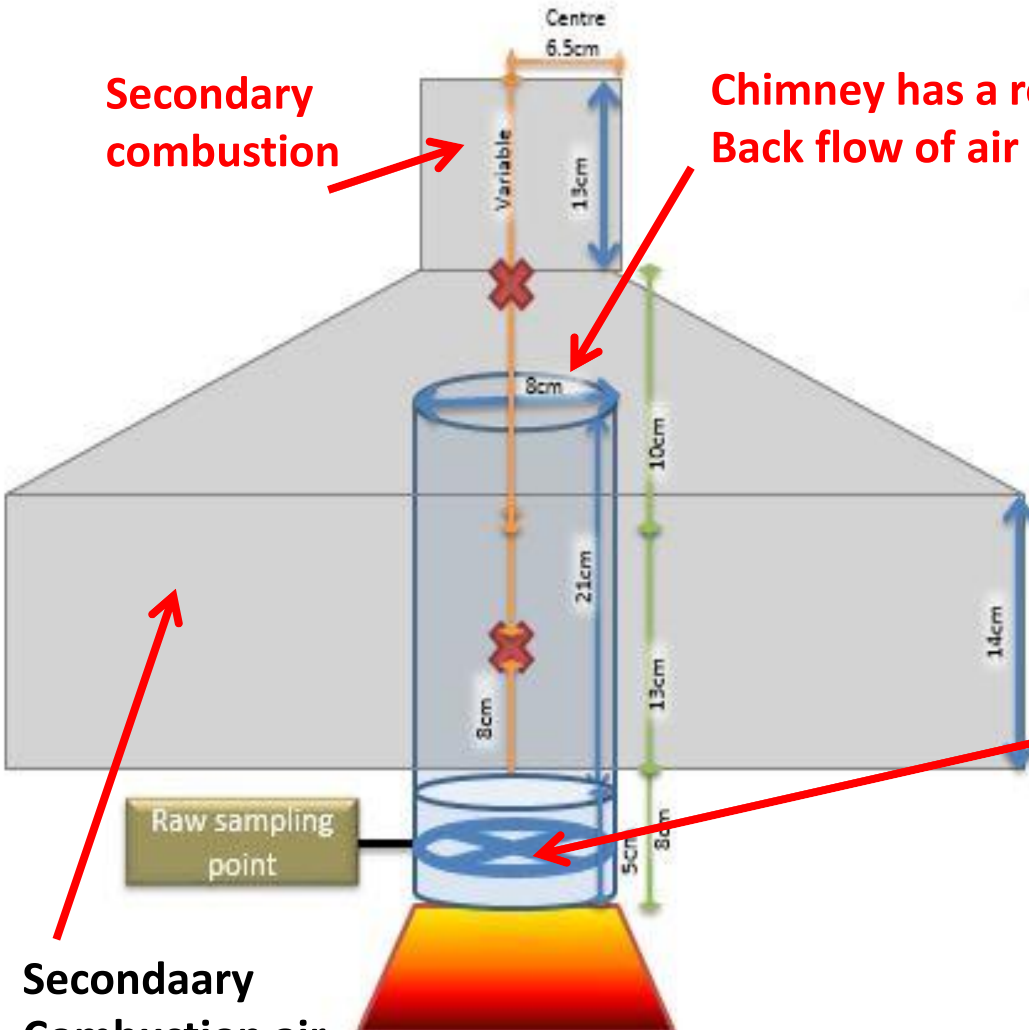
Secondary combustion

Chimney has a restricted outlet to prevent Back flow of air into the primary zone





Secondaary Combustion air

Primary combustion zone mean gas sampler

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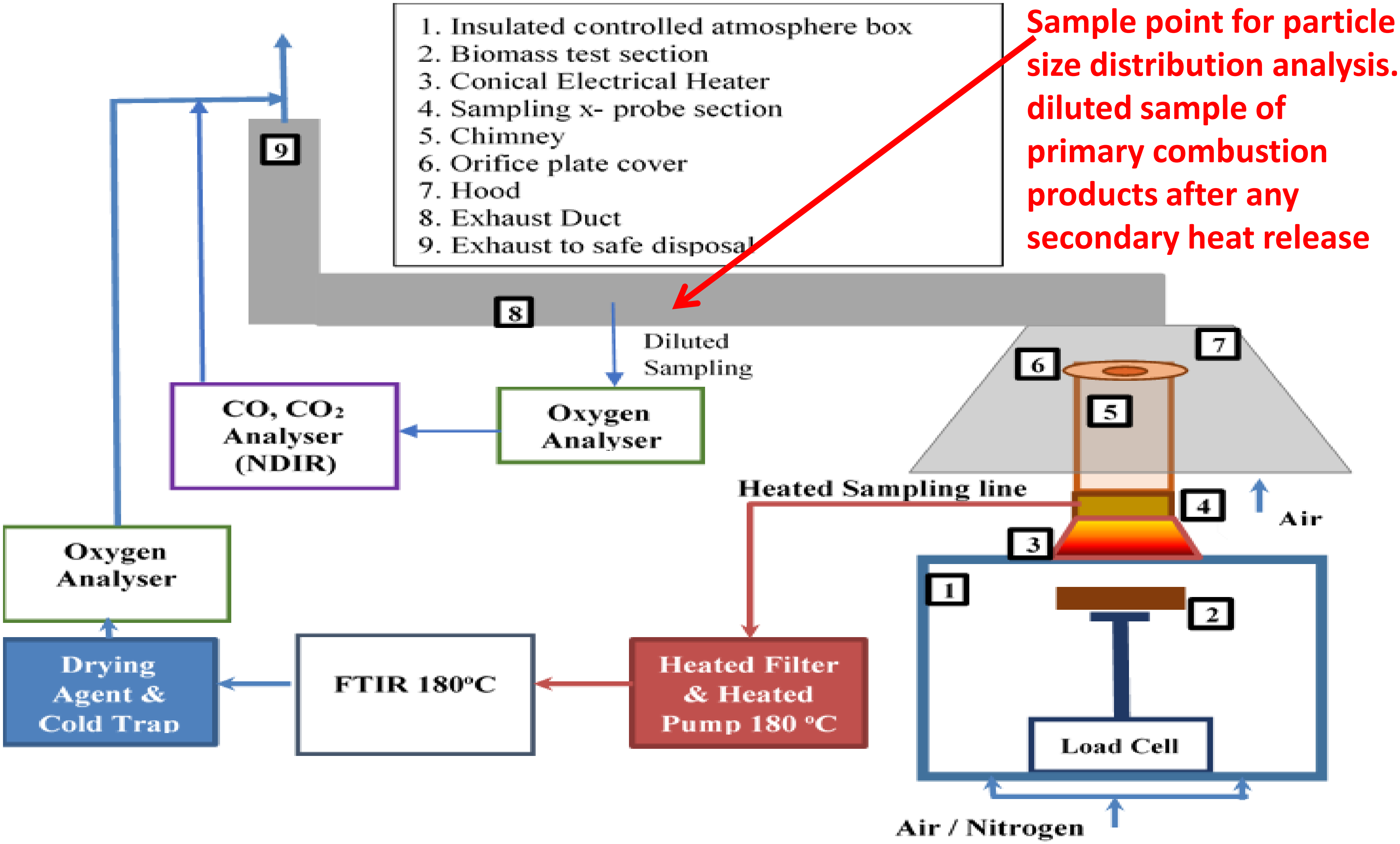

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In the cone calorimeter the heat release rate (HRR) is determined by oxygen consumption.

In this case two oxygen analysers were used, one measured the primary zone outlet oxygen and the other measured the oxygen after secondary dilution air flow and this is the total or overall HRR.

For all fuels there is 3.05 MJ/kg of air consumed which is the same as 13 MJ/kg of oxygen consumed.

Thus HRR is determined from the rate of consumption of oxygen.

Primary HRR in the gasification zone is controlled by the air flow into the enclosure around the test specimen.

This was varied, but in this work the results for one air flow is shown which is that for the most efficient conversion of solid biomass energy into gaseous CO, hydrogen and hydrocarbons.

# Analytical Instruments

1. Gasmet heated FTIR.

This was calibrated for 60 species which enabled a total hydrocarbon measurement to be made as about 50 hydrocarbons were calibrated for. Hydrogen was not measured and was calculated using the water gas shift reaction from the CO measurements – this was for the energy balance. The gas sample was taken from the cone calorimeter chimney exit for the primary combustion. The sample handling system was heated to 180°C and the FTIR detection chamber was heated to 180°C

2. Cambustion DMS 500

This measures the particle size distribution continuously as a function of time. It is based on the mobility of charged particles in an electrical field. The sample was taken from the diluted flow.

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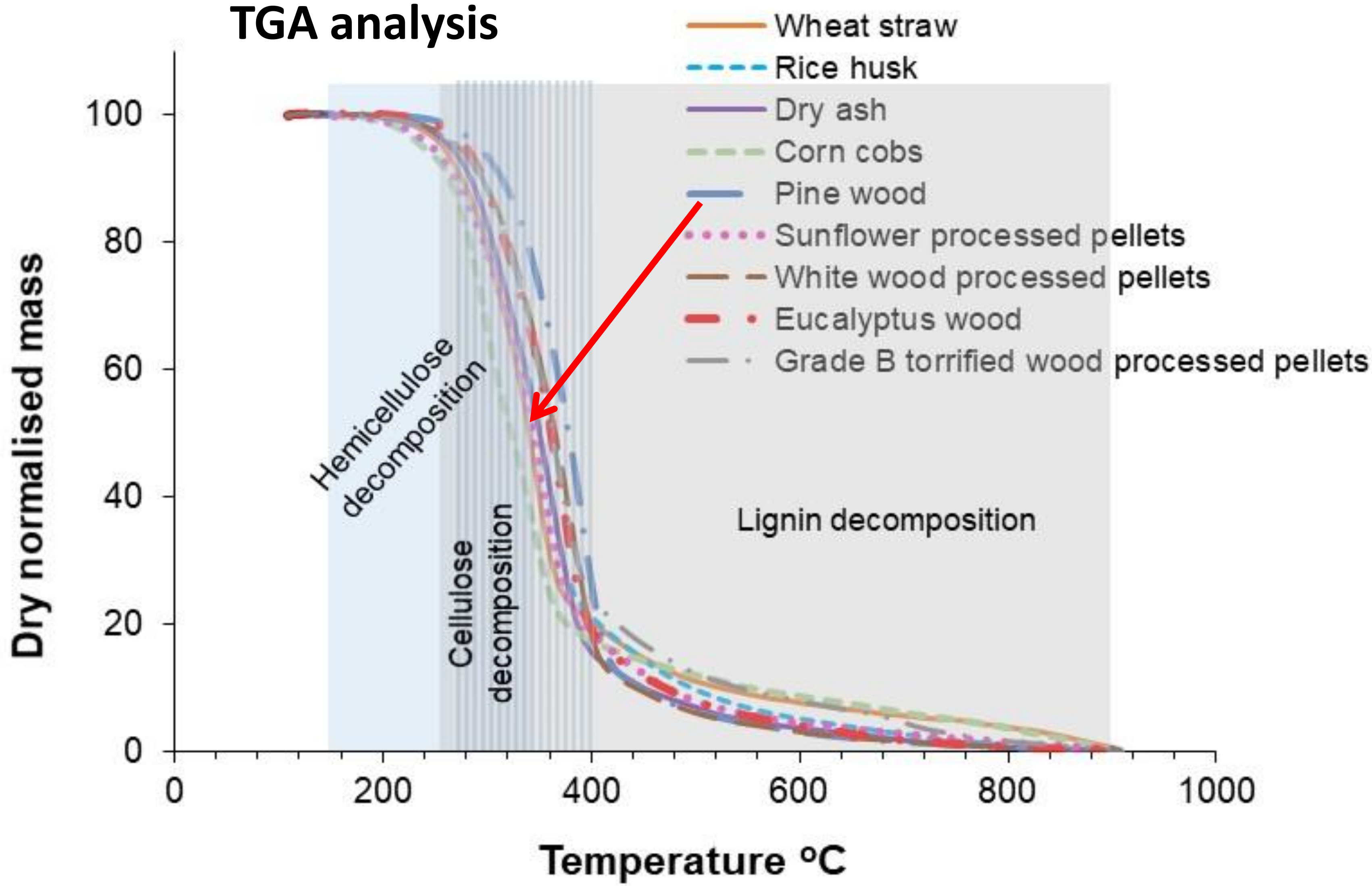
# TGA analysis



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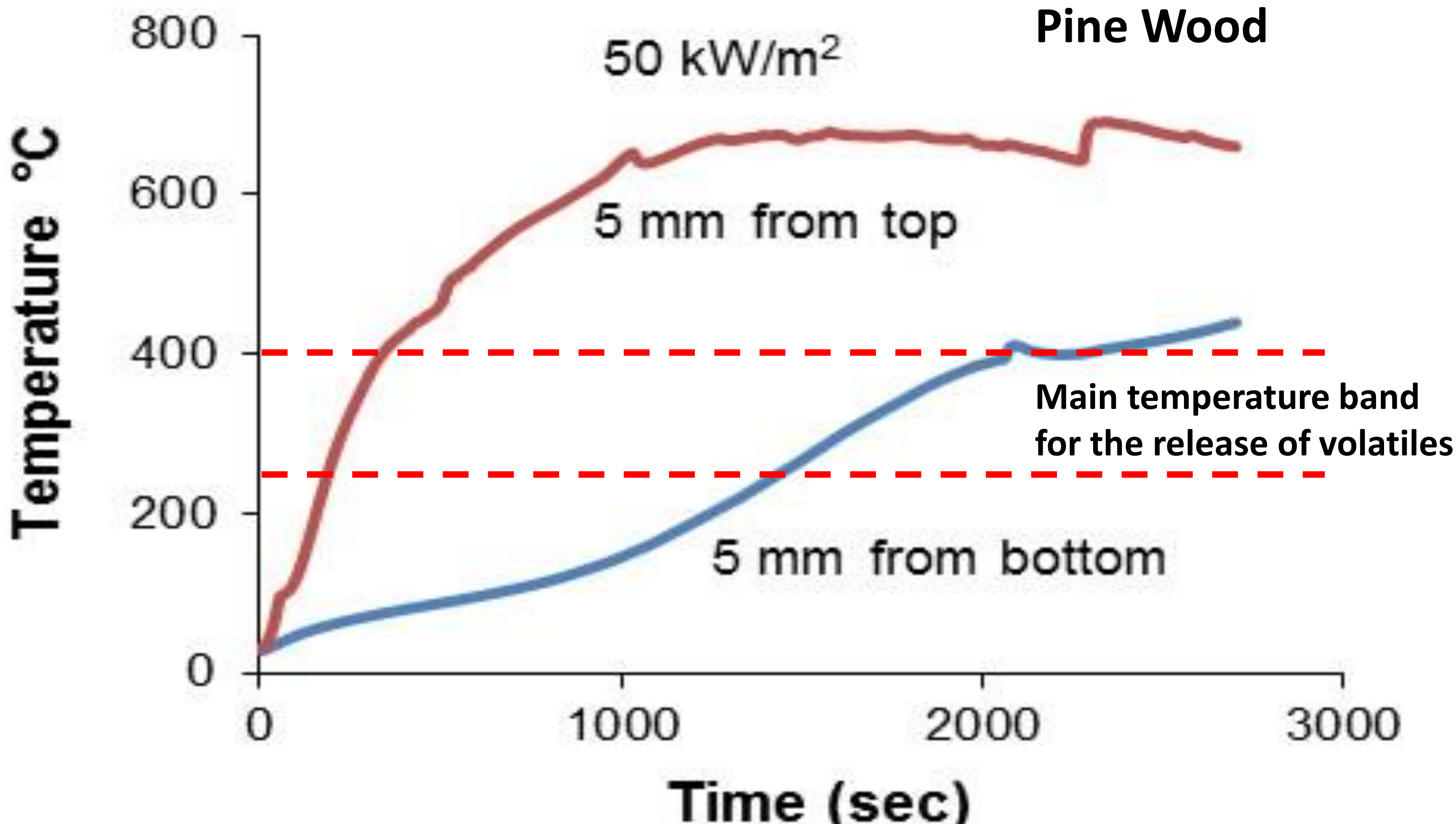


Temperature measurements using thermocouples inserted into the pine

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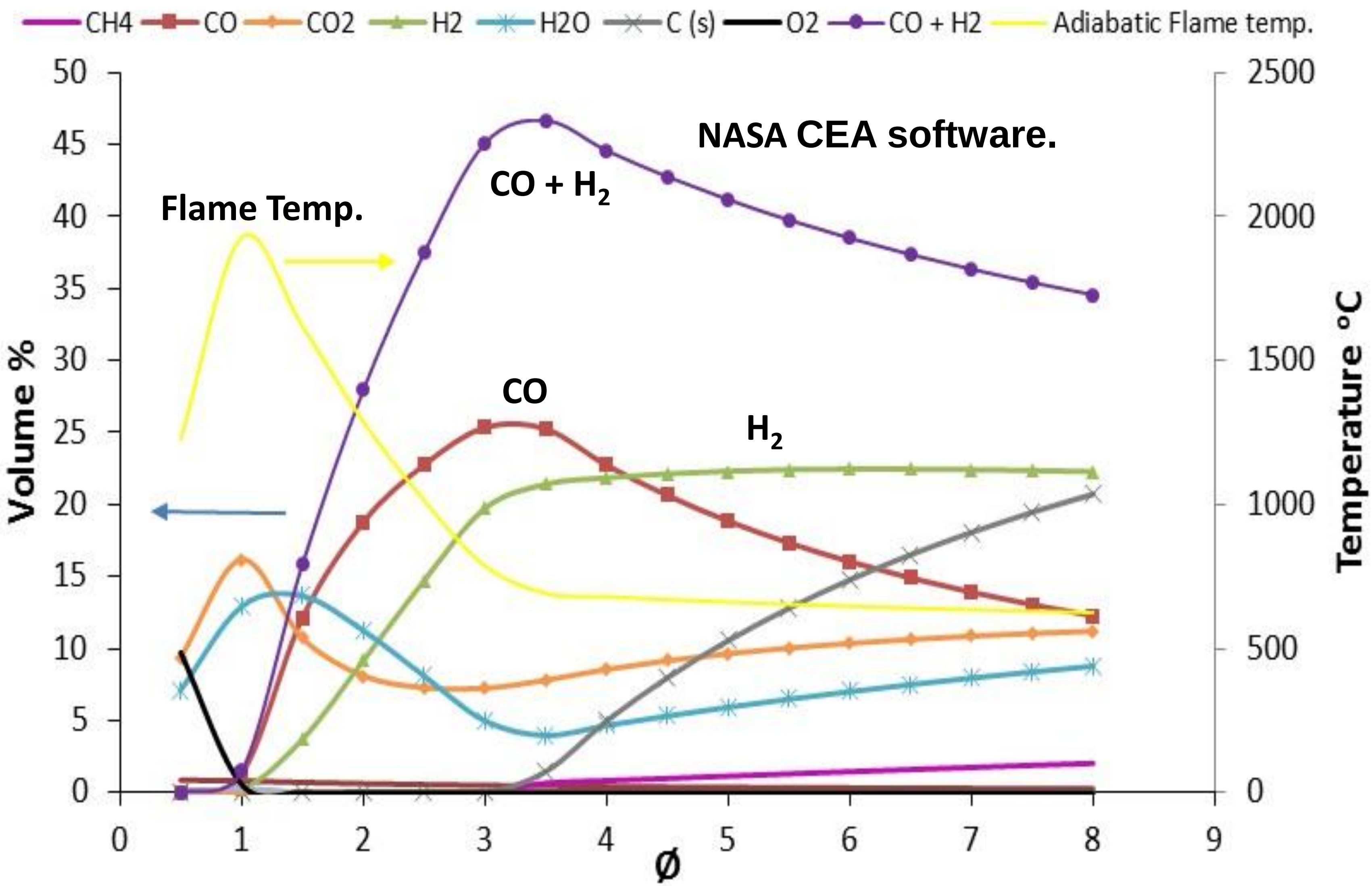
CH4
CO
CO2
H2
H2O
C (s)
O2
CO + H2
Adiabatic Flame temp.
NASA CEA software.
Flame Temp.
CO + H$_2$
CO
H$_2$
Volume %
Temperature °C
Ø
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
0
1
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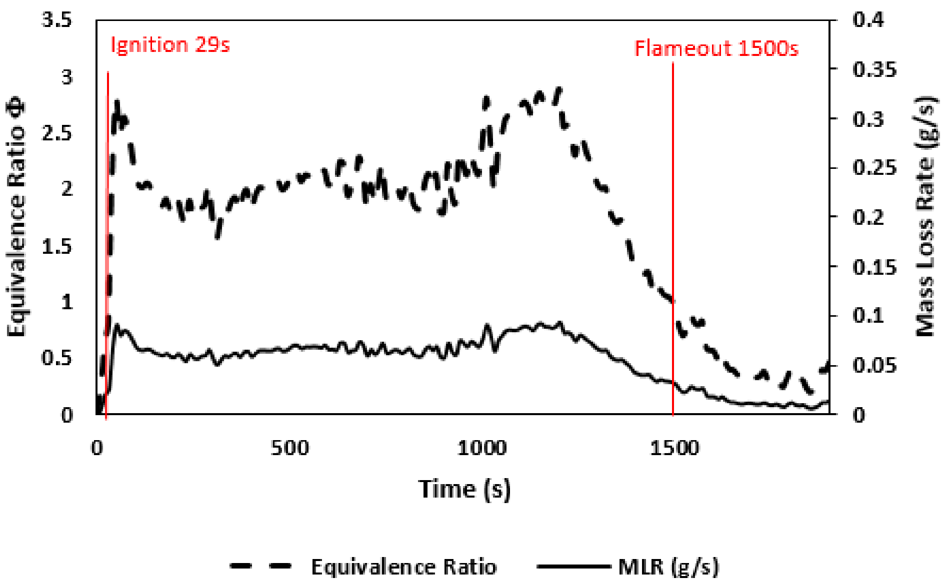


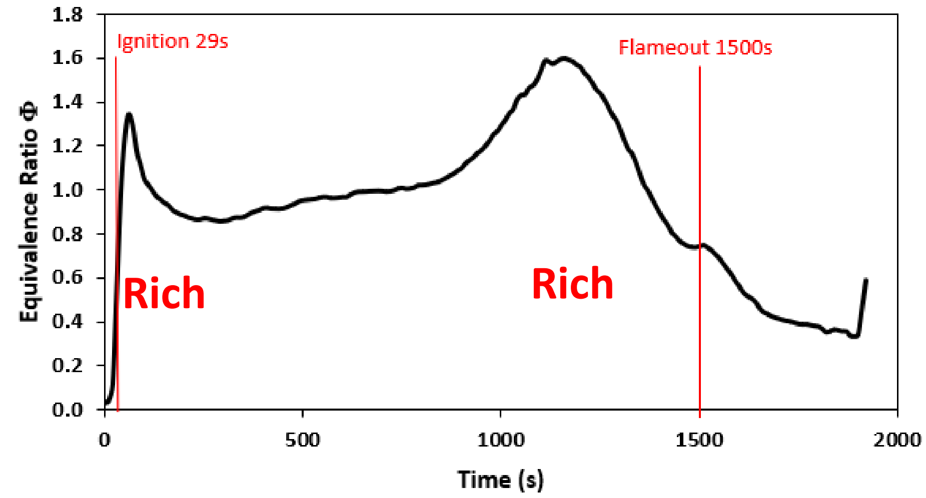


Metered Ø and mass loss rate

*Rich mixtures will give high CO and hydrogen for adiabatic equilibrium combustion.*

Ø by carbon balance with hydrogen calculated by the water gas shift reaction from the CO measurements.

**The metered and carbon balance equivalence ratios are different by about a factor of 2, apart from after the flameout when they are in agreement.**

**It is possible that in spite of the multi-hole gas sampler a mean sample is not being collected. Also, the very high levels of CO and hydrocarbons have an FTIR calibration problem as most Hydrocarbons were calibrated up to 500ppm and levels are higher than this and involved an Extrapolation. CO was calibrated up to 10% so this should be reliable.**

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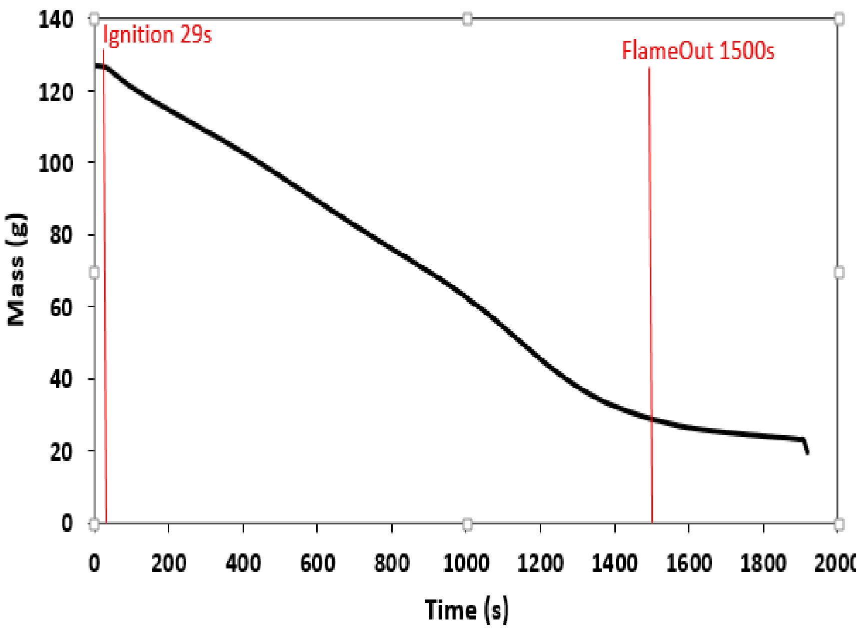
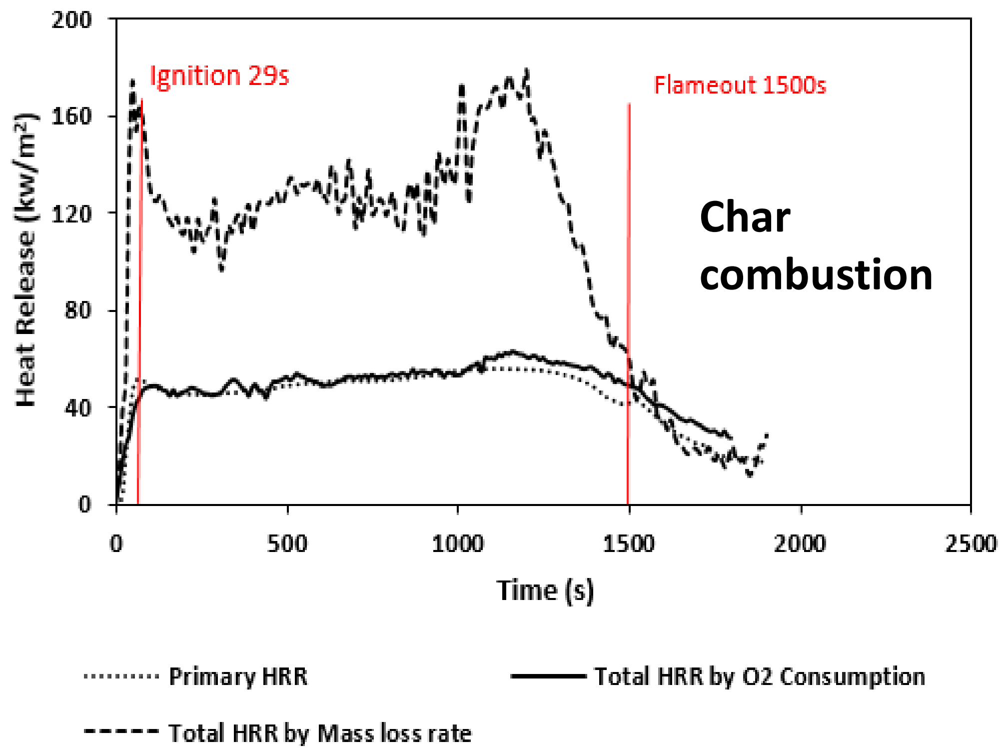



Mass loss as a function of time.




HRR based on mass loss and by oxygen consumption for primary and secondary combustion.

HRR from mass loss assume 100% combustion efficiency. There are high CO and $H_2$ emissions which are not burnt due to lack of oxygen., so the actual HRR is lower than that based on mass Loss. The difference between primary and overall HRR is small and is only significant in the 1000-1500s region. This indicates little secondary combustion.

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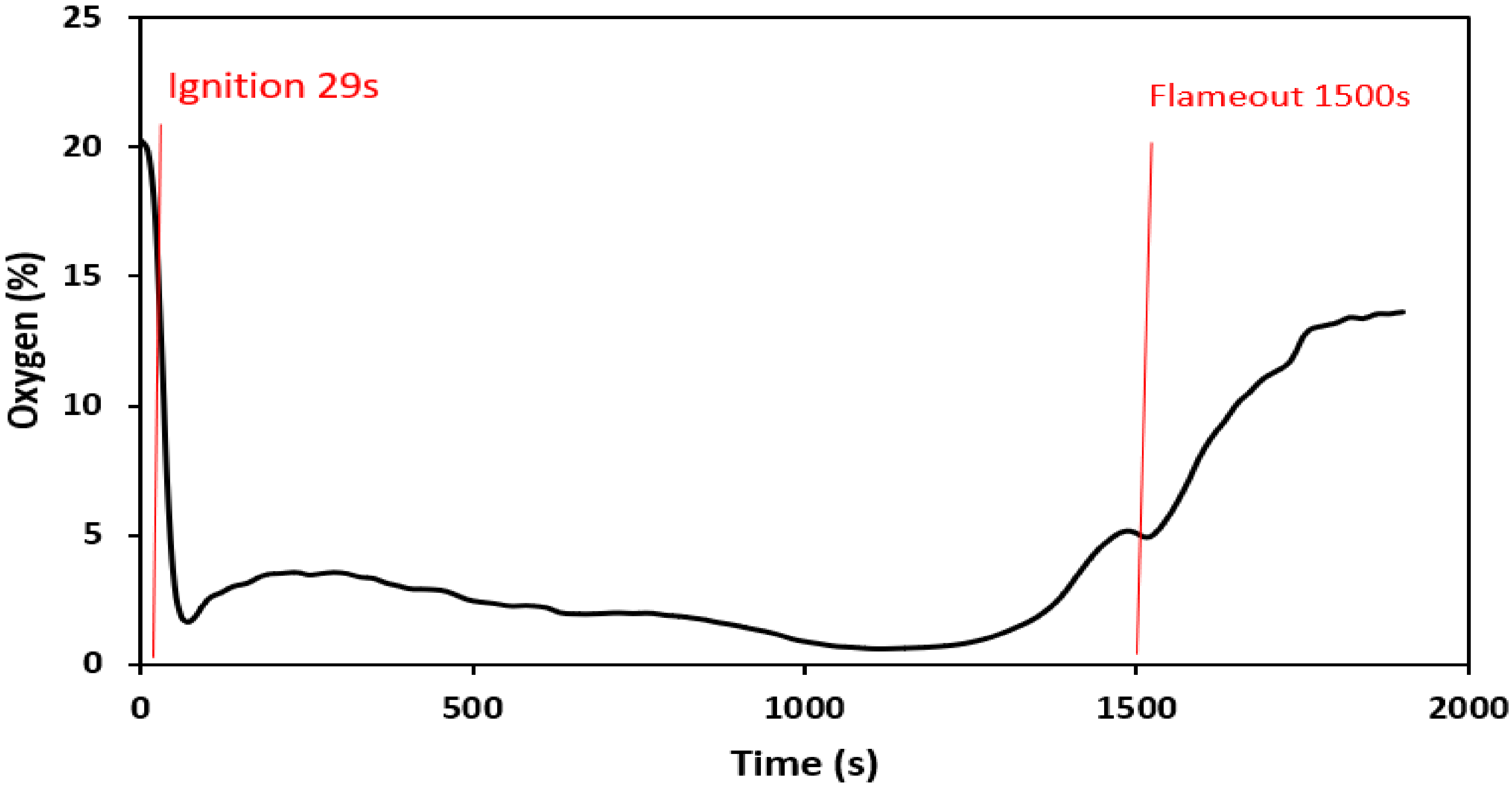


**The presence of oxygen in regions of the combustion that are rich, indicated that there are combustion efficiency problems.**

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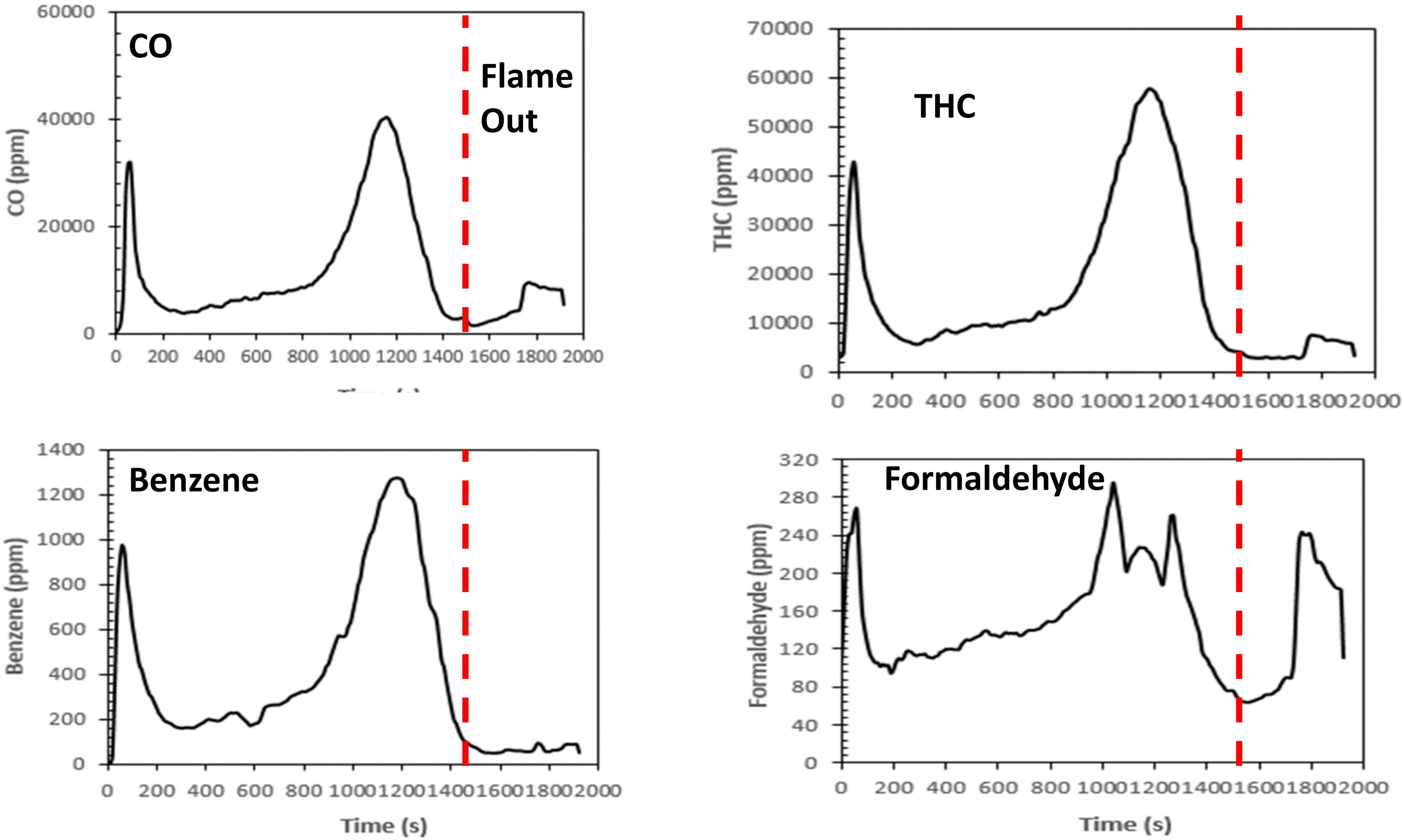

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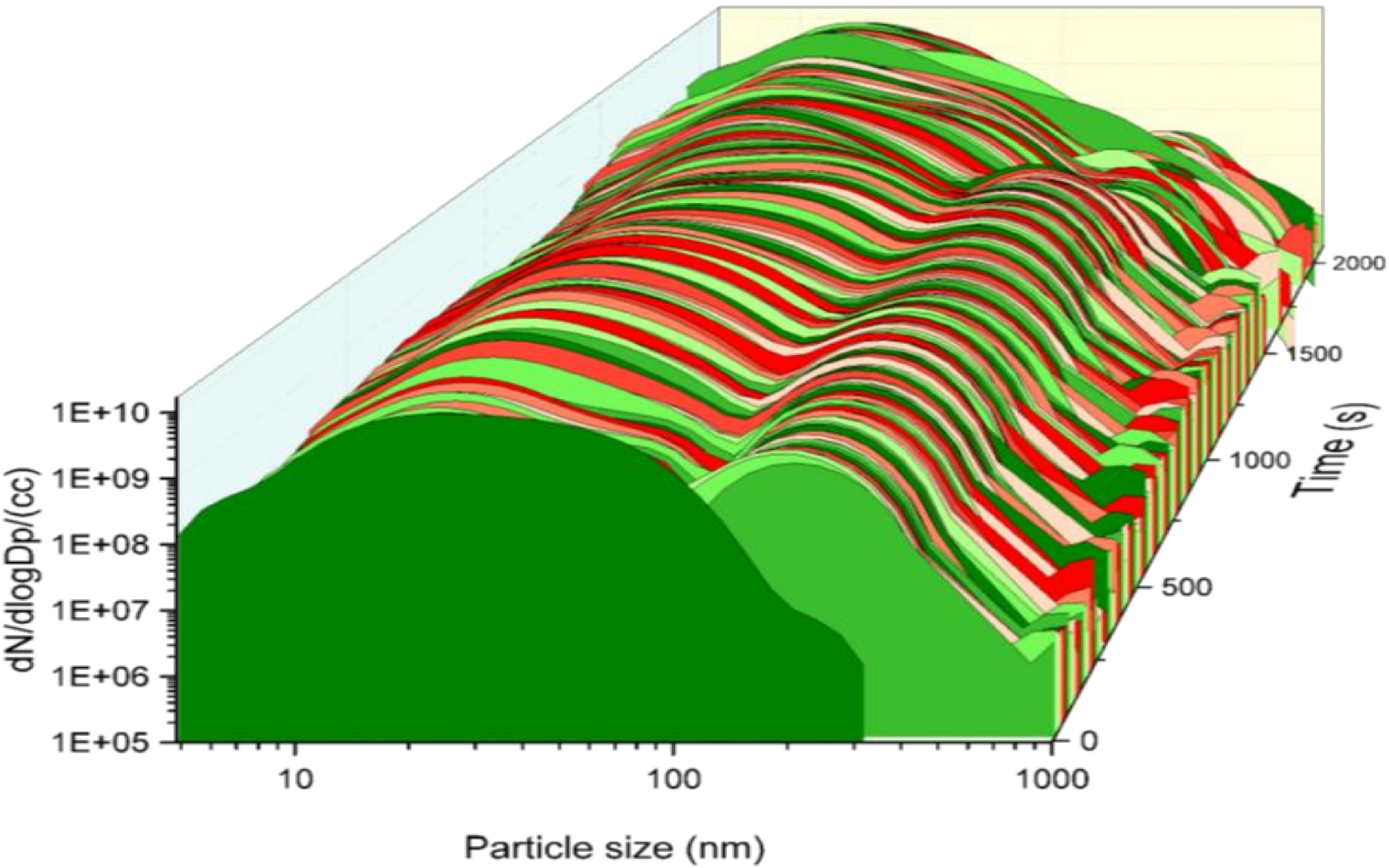

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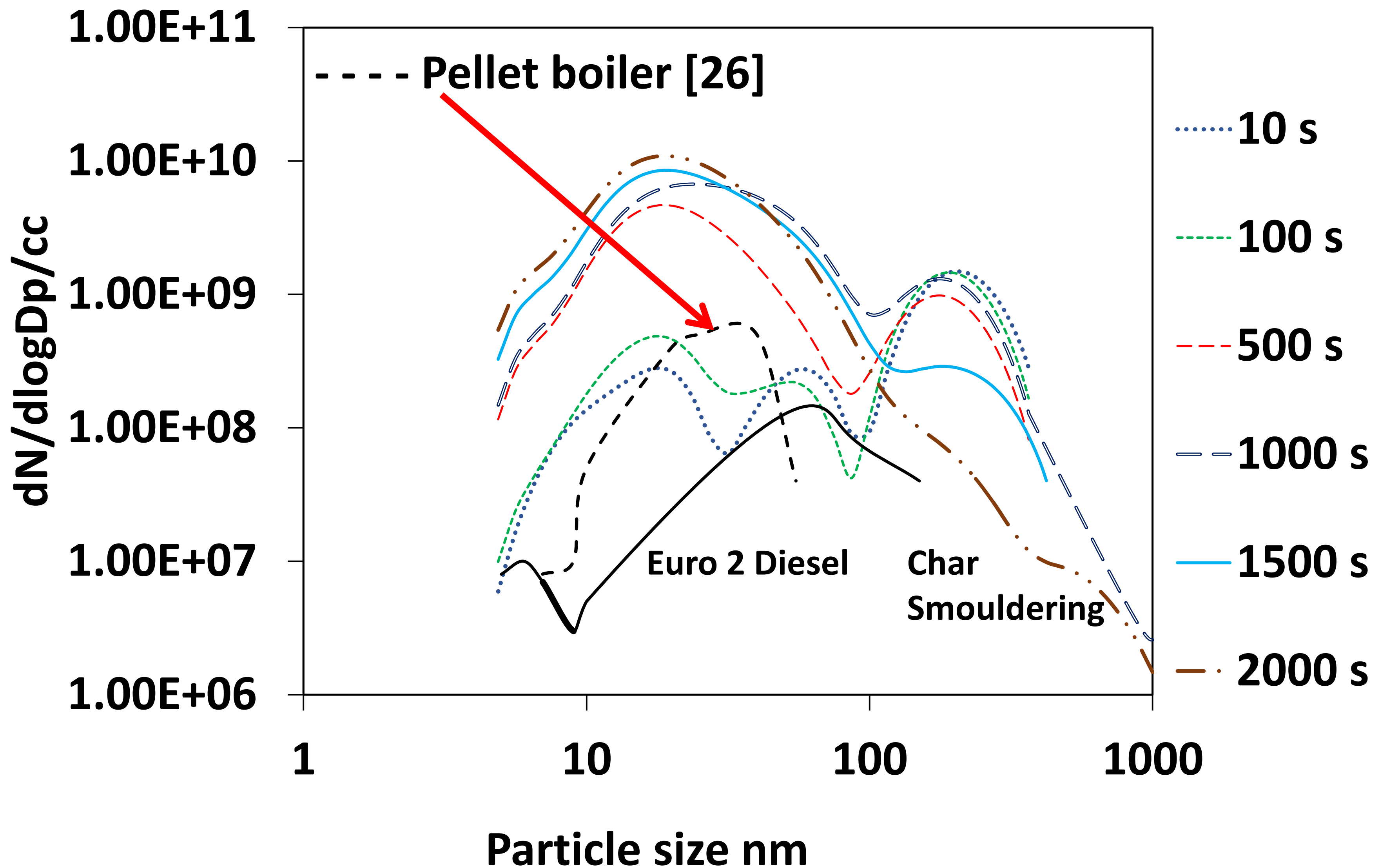

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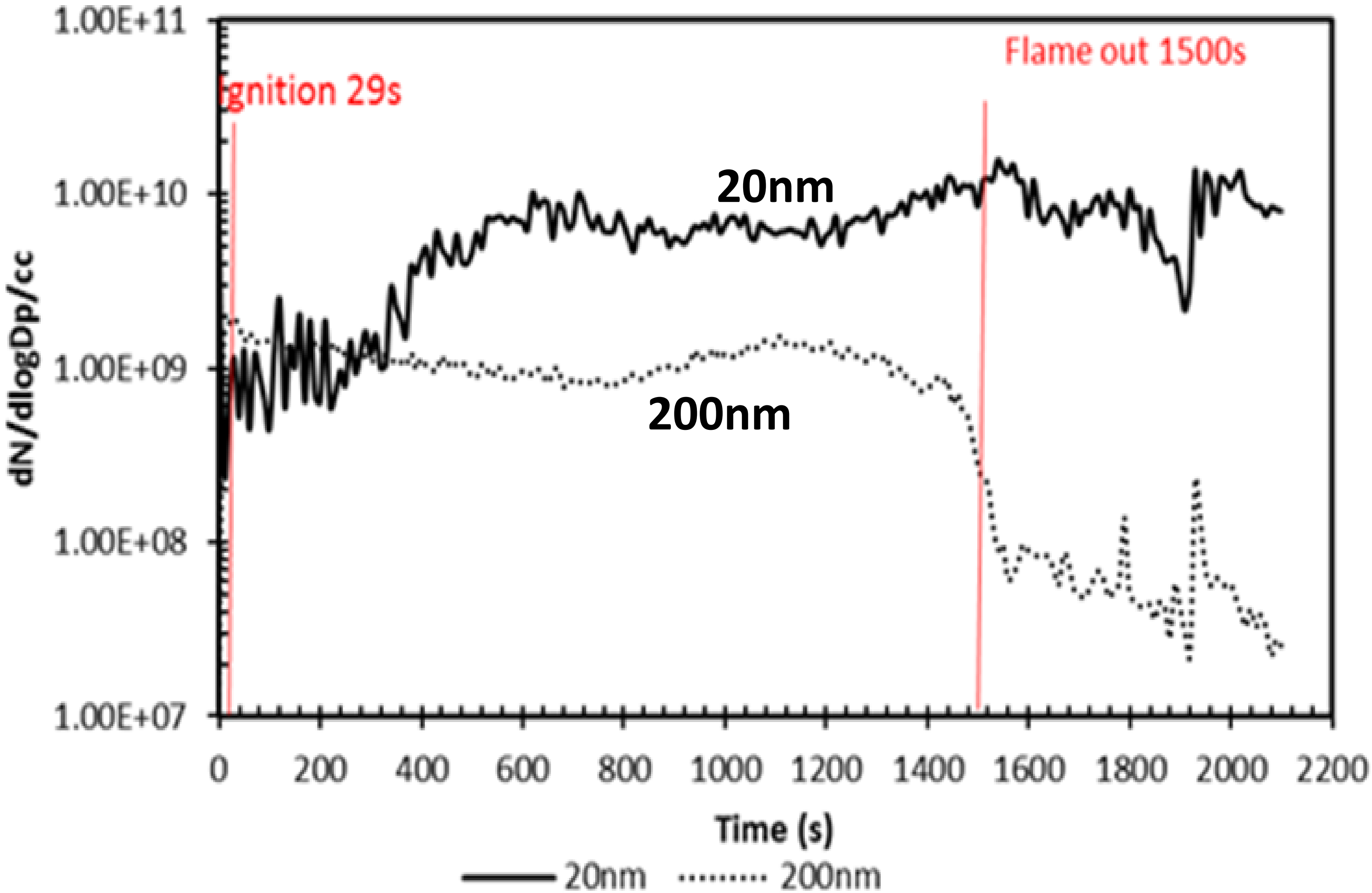

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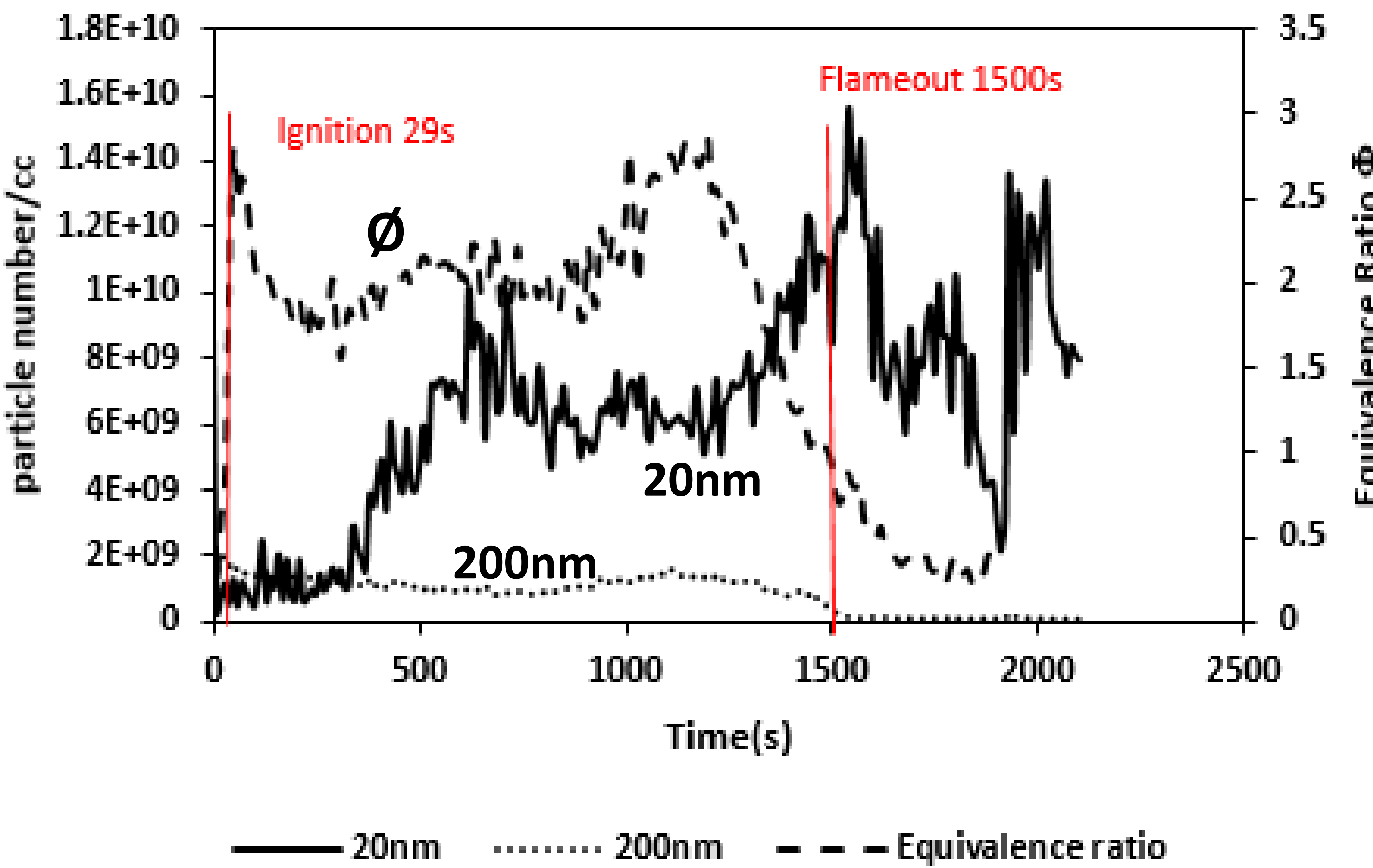

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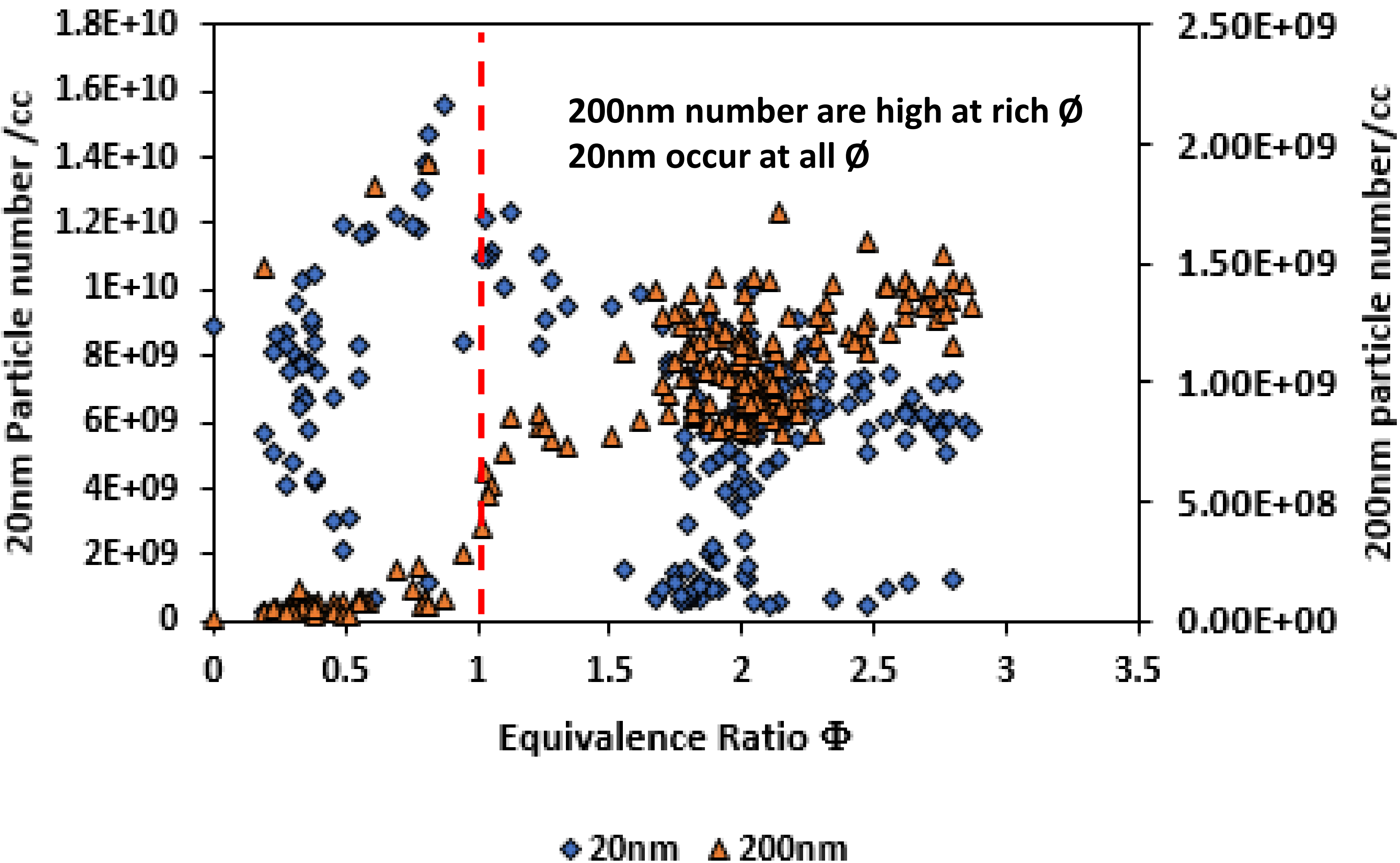

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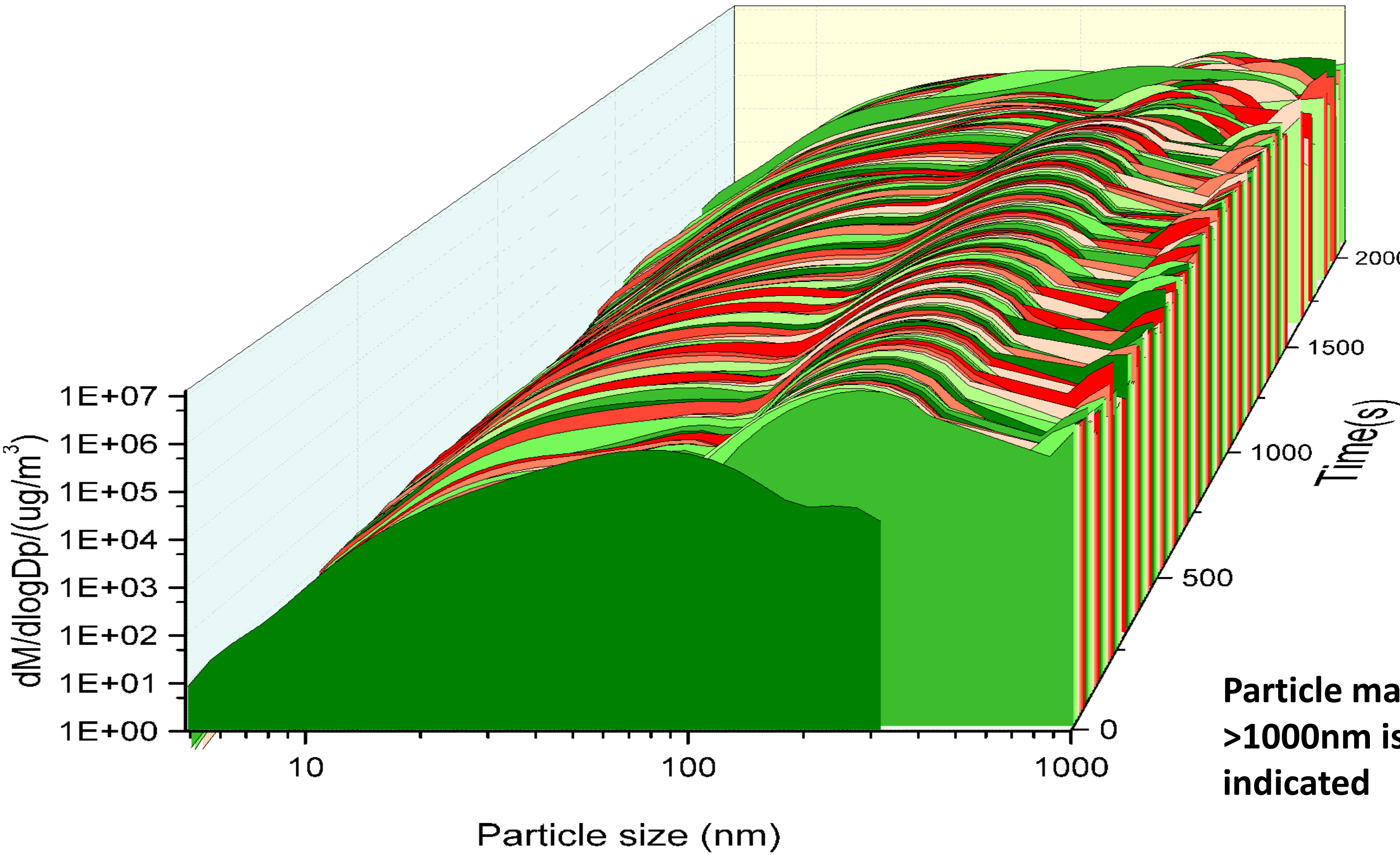


**Particle mass >1000nm is indicated**

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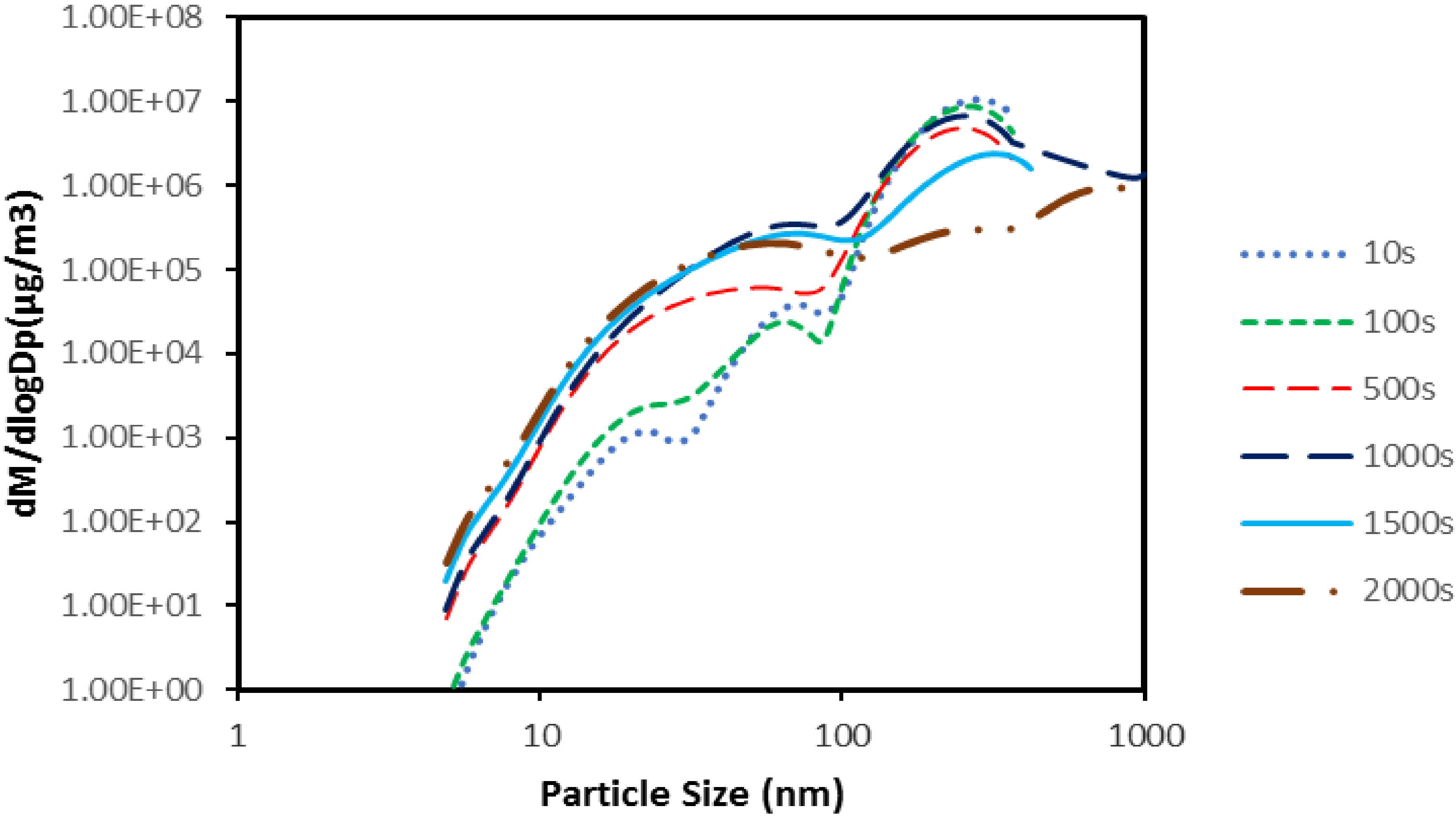

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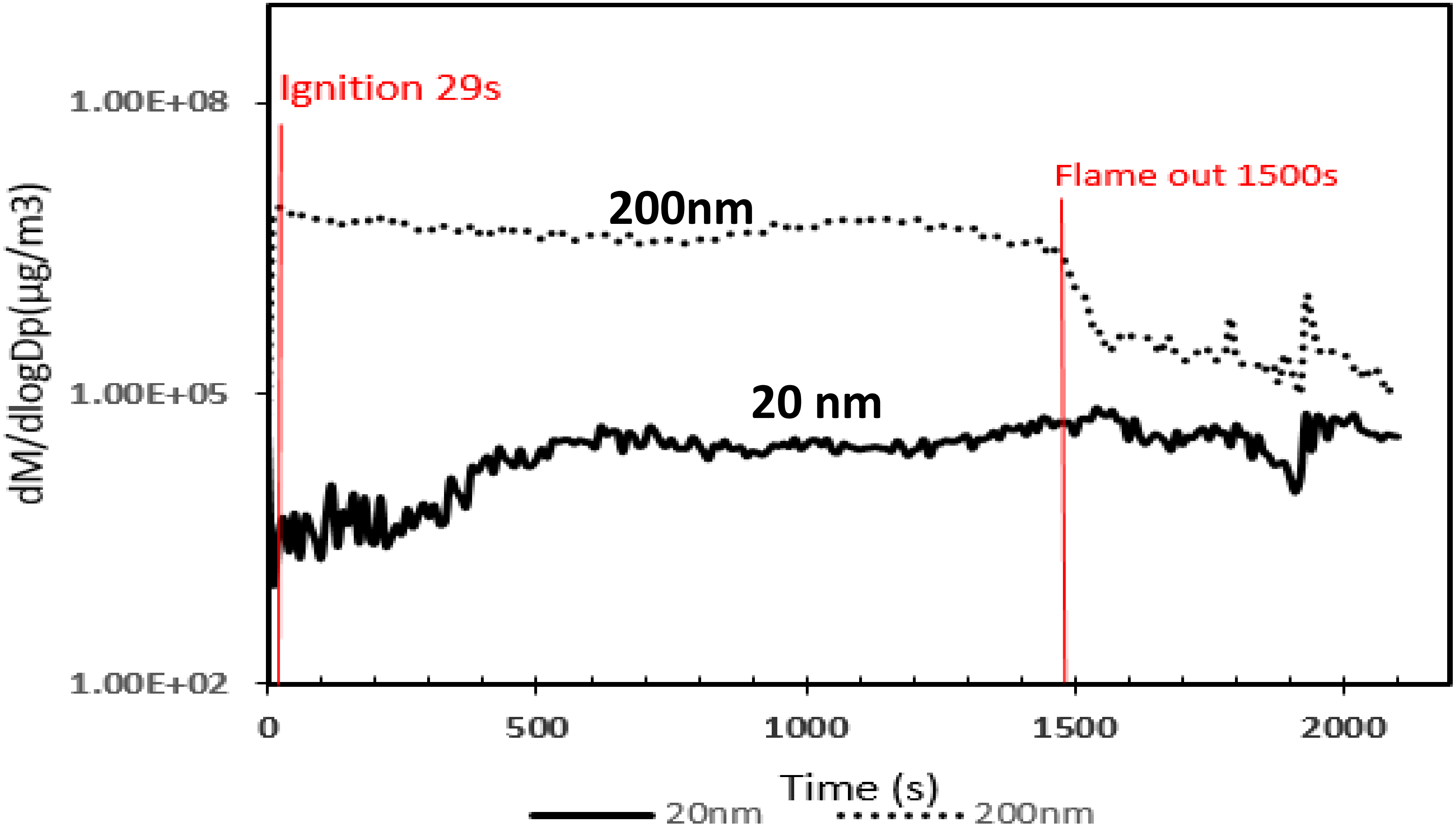

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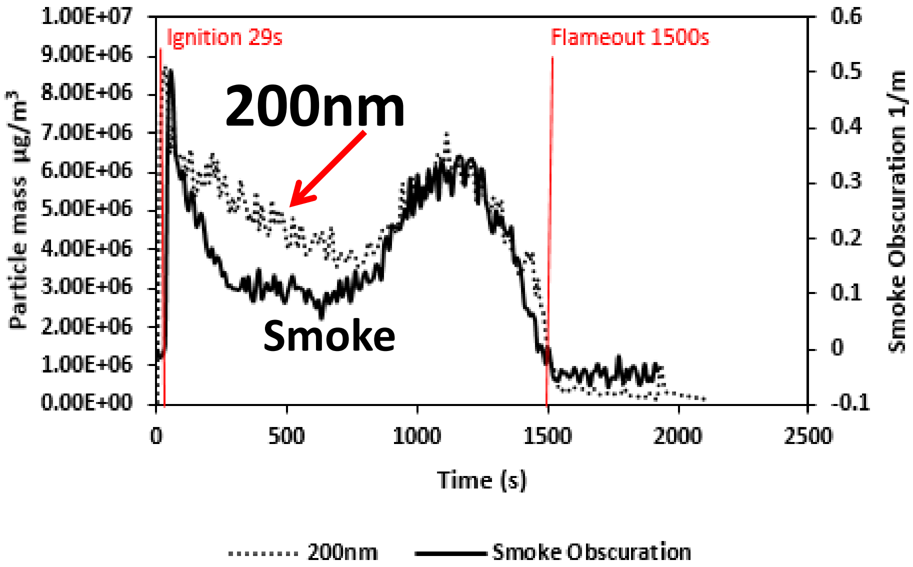
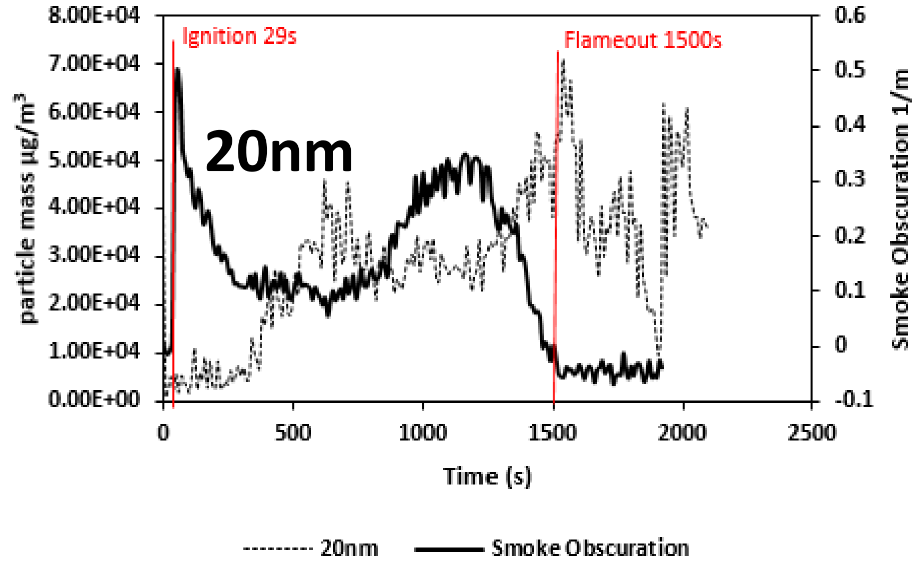
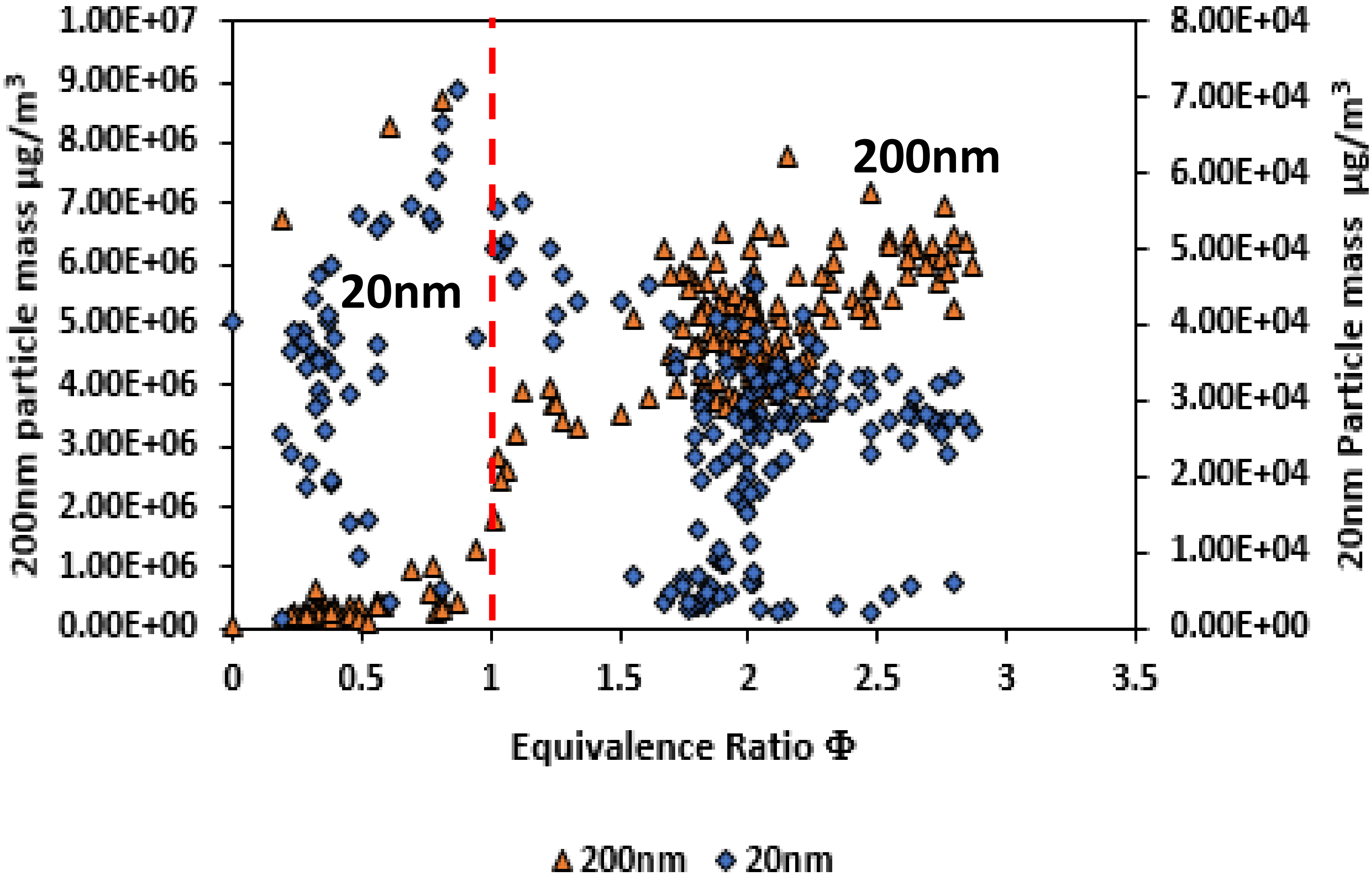



**The optical obscuration smoke correlates with the 200nm mass not with the 20nm mass.**

**Optical obscuration measurement of smoke thus gives little information relative to the health hazards of particulate emissions which are caused by the ultra-fine nano-particles with a 20nm peak in this work.**


1.00E+07
9.00E+06
8.00E+06
7.00E+06
6.00E+06
5.00E+06
4.00E+06
3.00E+06
2.00E+06
1.00E+06
0.00E+00
200nm particle mass μg/m³
8.00E+04
7.00E+04
6.00E+04
5.00E+04
4.00E+04
3.00E+04
2.00E+04
1.00E+04
0.00E+00
20nm Particle mass μg/m³
200nm
20nm
0
0.5
1
1.5
2
2.5
3
3.5
Equivalence Ratio Φ
200nm
20nm

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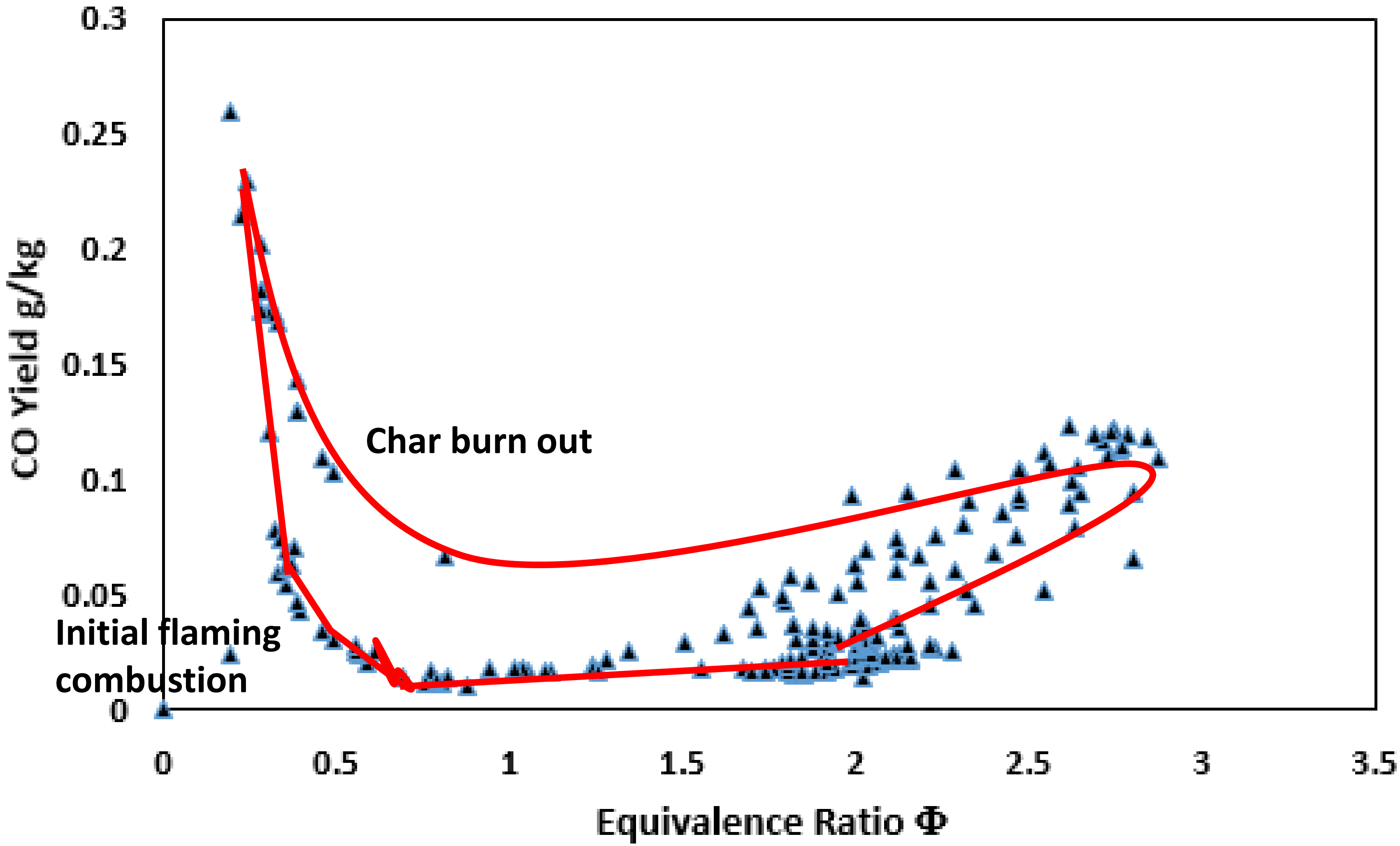
## CONCLUSIONS

1. The real - time particle size, number and mass distribution from pine wood biomass combustion was obtained showing a bimodal distribution representing a nucleation mode and an agglomeration/accumulation mode.
2. The particle size distribution on a number basis showed a peak of 20nm in the nano particle size range and a peak of 200nm in the agglomeration range.
3. Ultra – fine particles generated in solid wood combustion was higher than those generated by diesel engines or biomass pellet combustion.
4. The 20nm nano particles will penetrate the lungs leading to asthma and heart related illness due to the effects fine particles have on the lungs.
5. The modified cone calorimeter proved to be a good technique for realistic determination of particle size distributions for biomass when used with a heated FTIR and DMS 500.




Mass consumption metered Ø