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Additives to Mitigate Against Slagging and Fouling in Biomass Combustion

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Background

- 4 year MSc/PhD as part of Bioenergy CDT, University of Leeds
- Project commenced October 2015
- Project aim – to investigate the behaviour of biomass ash when an aluminium silicate-based additive, coal PFA, is added, with the goal of producing a useful predictive model using these results

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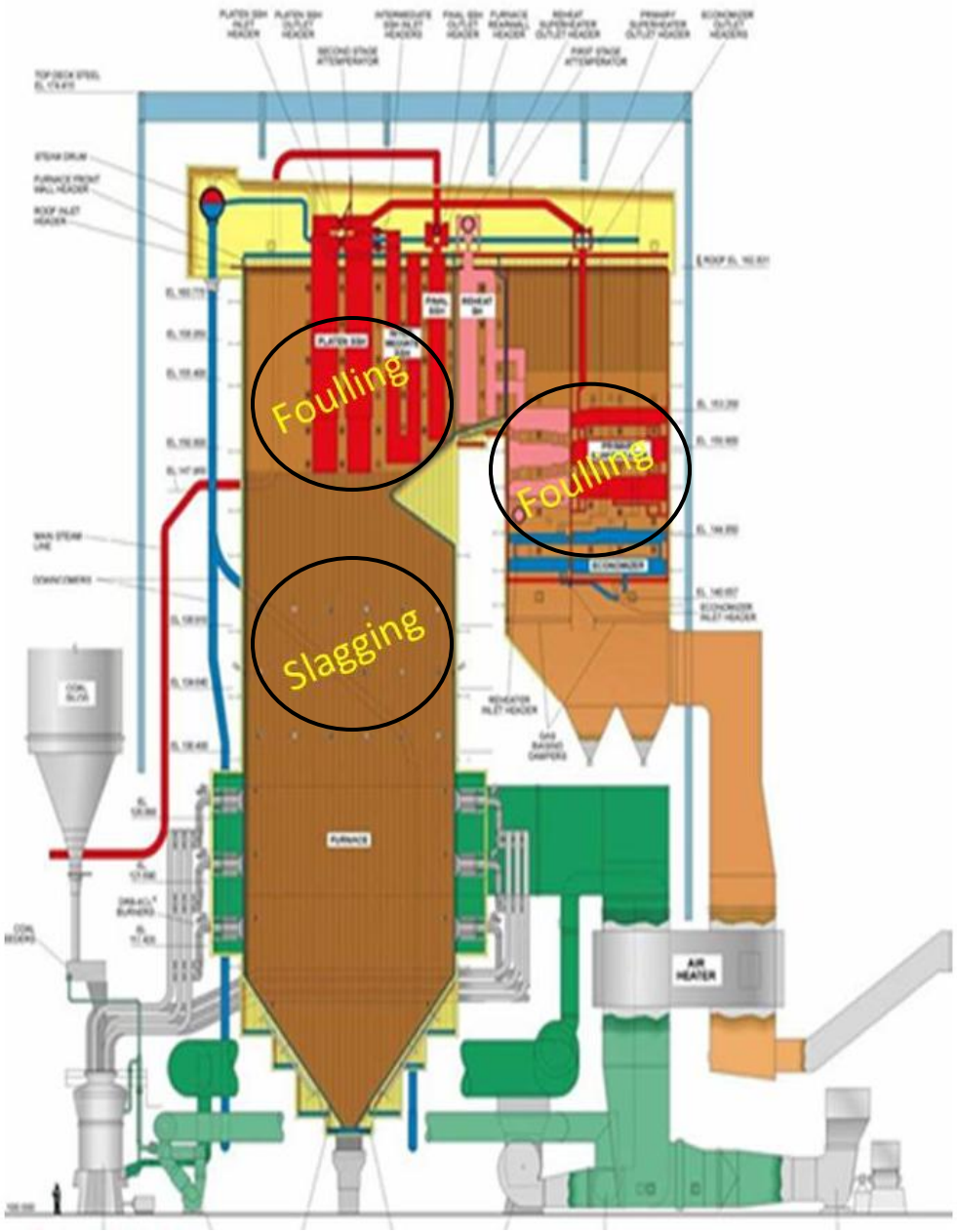
Background



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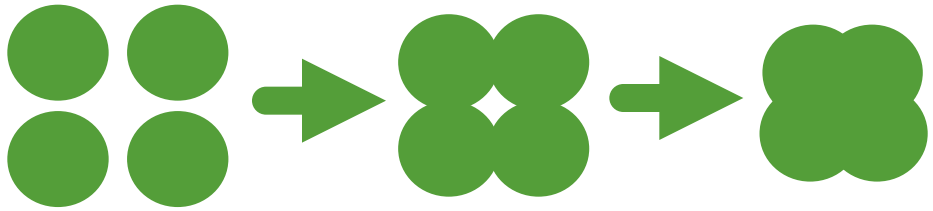
Background

- Slagging – occurs within high temperature regions of boiler, high radiant heat transfer present
- Fouling – occurs within lower temperature convective regions of the boiler, away from combustion zone
- Both are the result of particles becoming sticky and sintering at high temperatures



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The problem

- The extent of deposition depends heavily upon the composition of the ash – particularly when alkali salts are present

Constituent	Coal Ash %	Straw Ash, min %	Straw ash, max %	Wood ash, typical %
SiO_2	59.8	19.7	38.9	10
Al_2O_3	19.1	0.24	0.52	2
Fe_2O_3	8.1	0.13	0.19	1
CaO	2	6.35	8.45	35
Na2O	0.6	0.29	1	3
K_2O	2.2	28.7	34.6	20
Cl	<0.1	4.55	7.06	-

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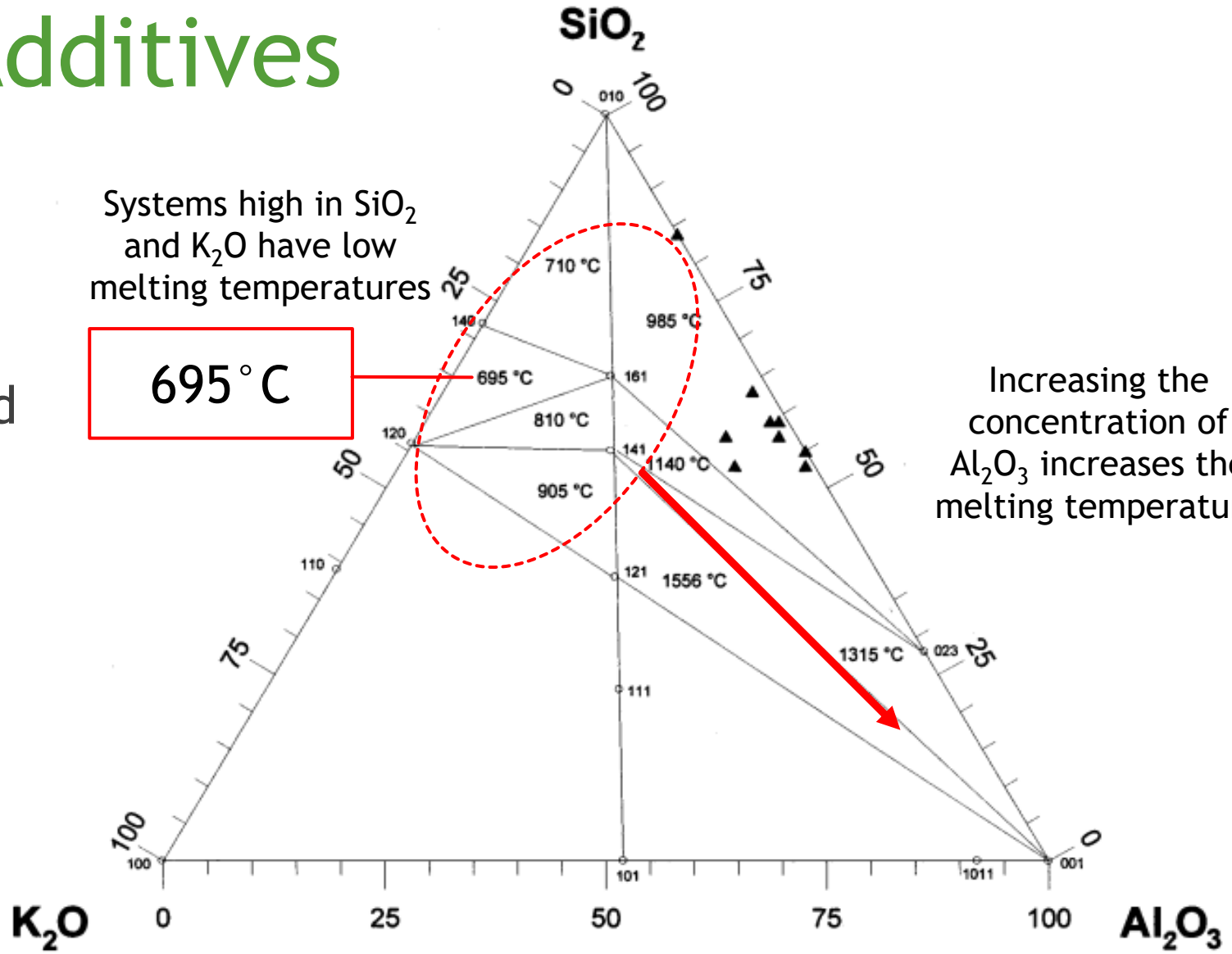
(Van Loo and Koppejan, 2003)

The solution - Additives

- Coal PFA is an aluminium silicate-based additive
- Converts vapour and liquid phase KCl and KSiO3 to potassium aluminium silicates

Systems high in SiO_2 and K_2O have low melting temperatures

695 °C



Increasing the concentration of Al_2O_3 increases the melting temperature

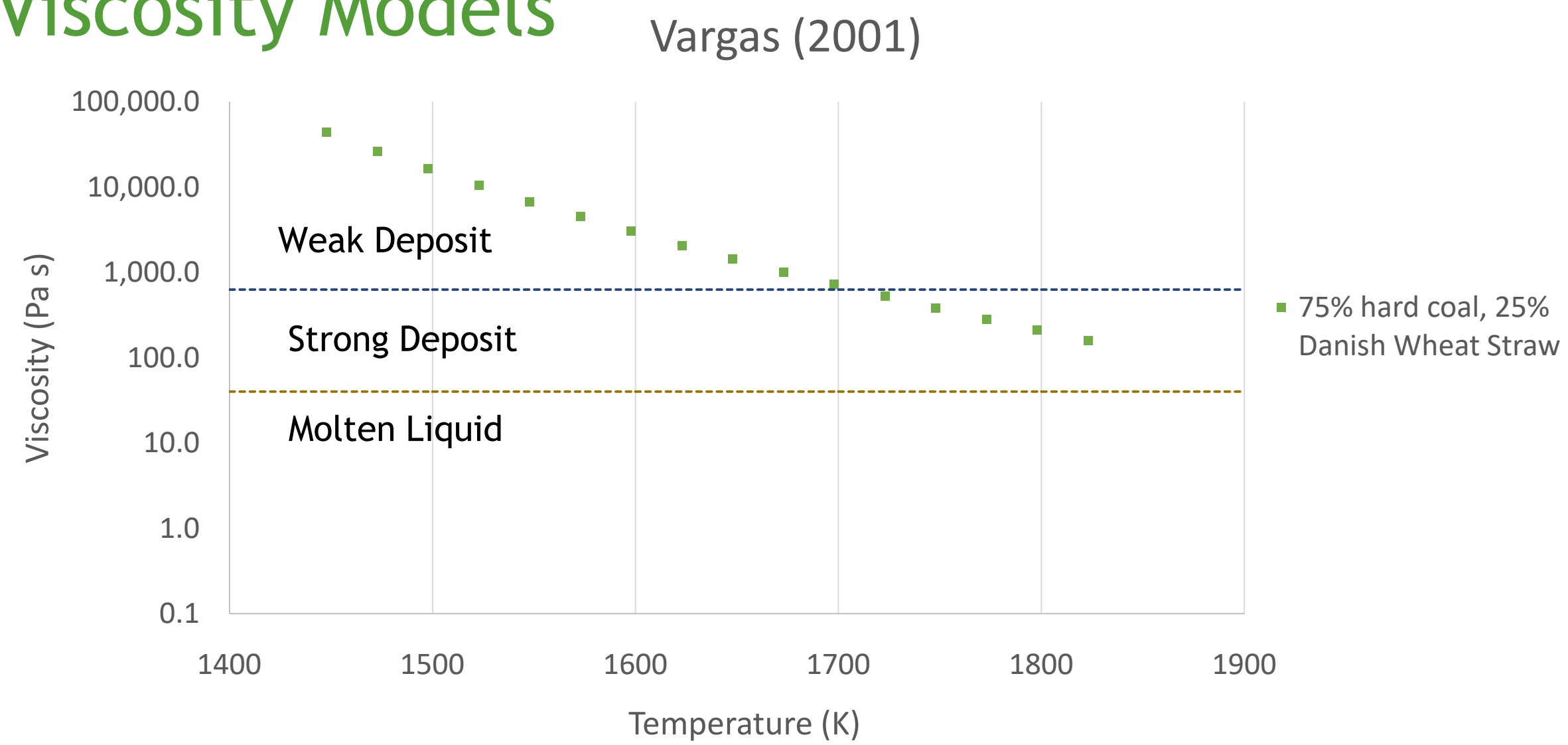
(Öhman and Nordin, 2000)

Viscosity Models

- Ash viscosity has a direct effect upon the nature of the deposit – lower viscosity results in a glassy, difficult to remove deposit

- Viscosity models typically developed using coal slag compositions
- Empirically fitted data from viscosity experiments
- 7 models tested against compositions from literature – performance compared to experimental results

Viscosity Models



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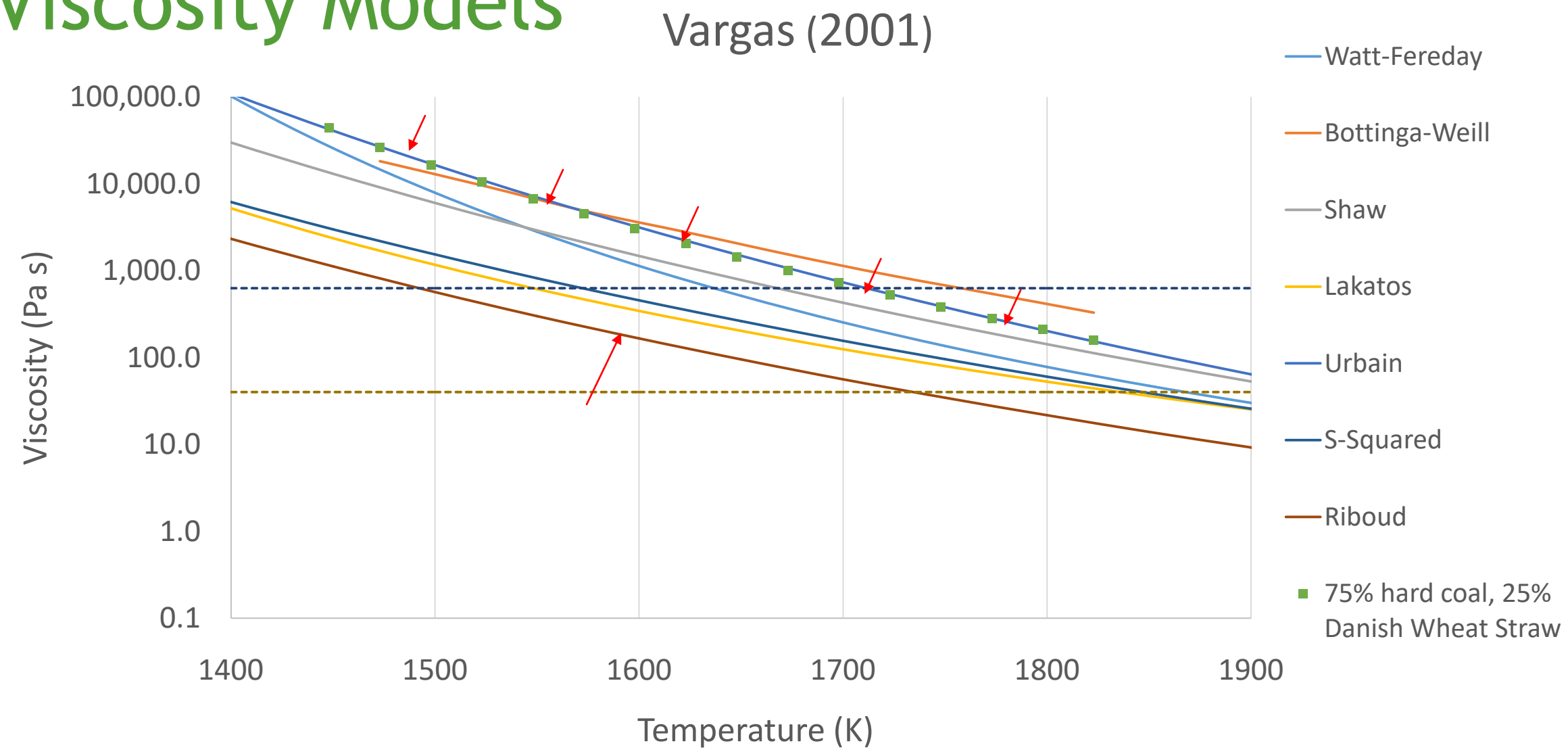
Viscosity Models



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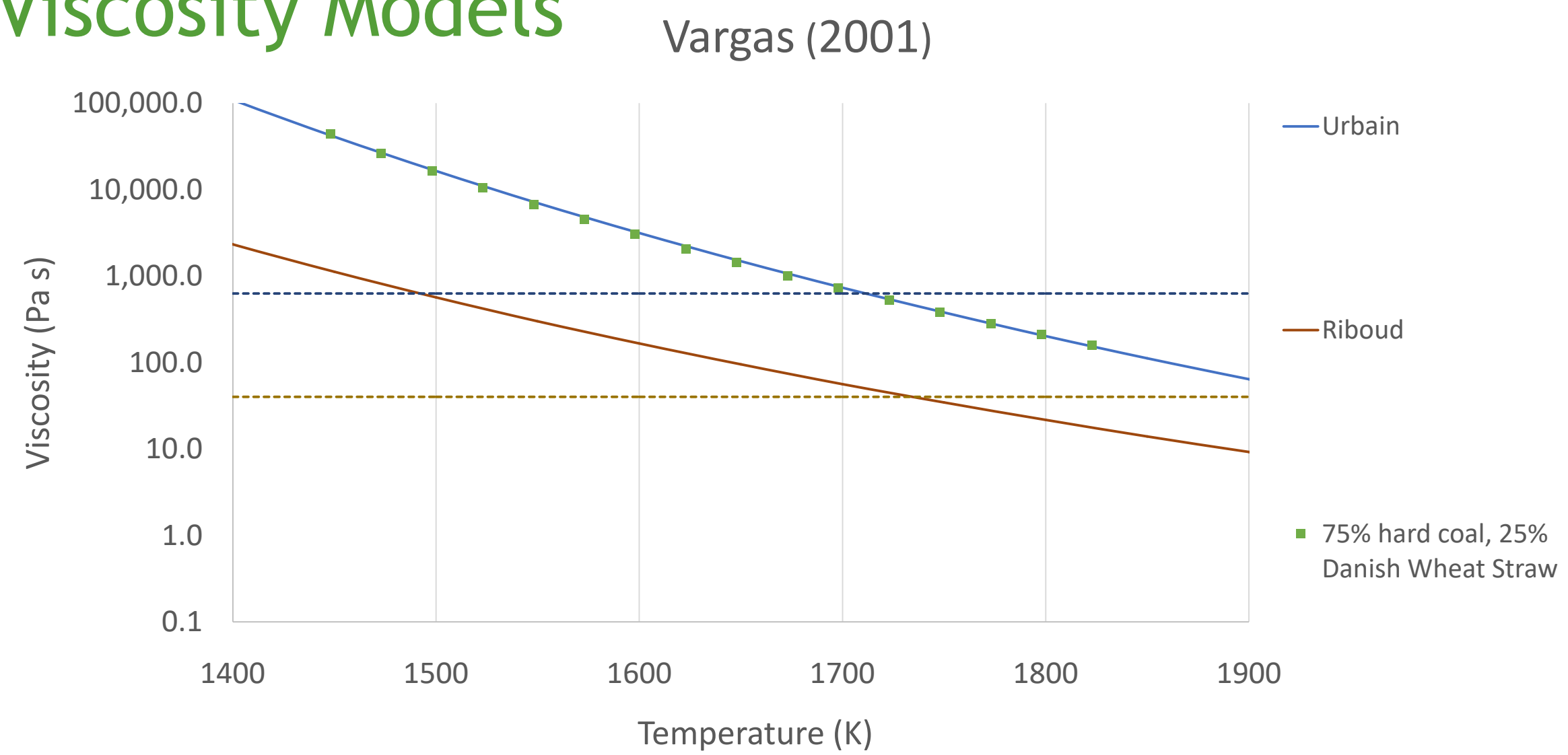
Viscosity Models



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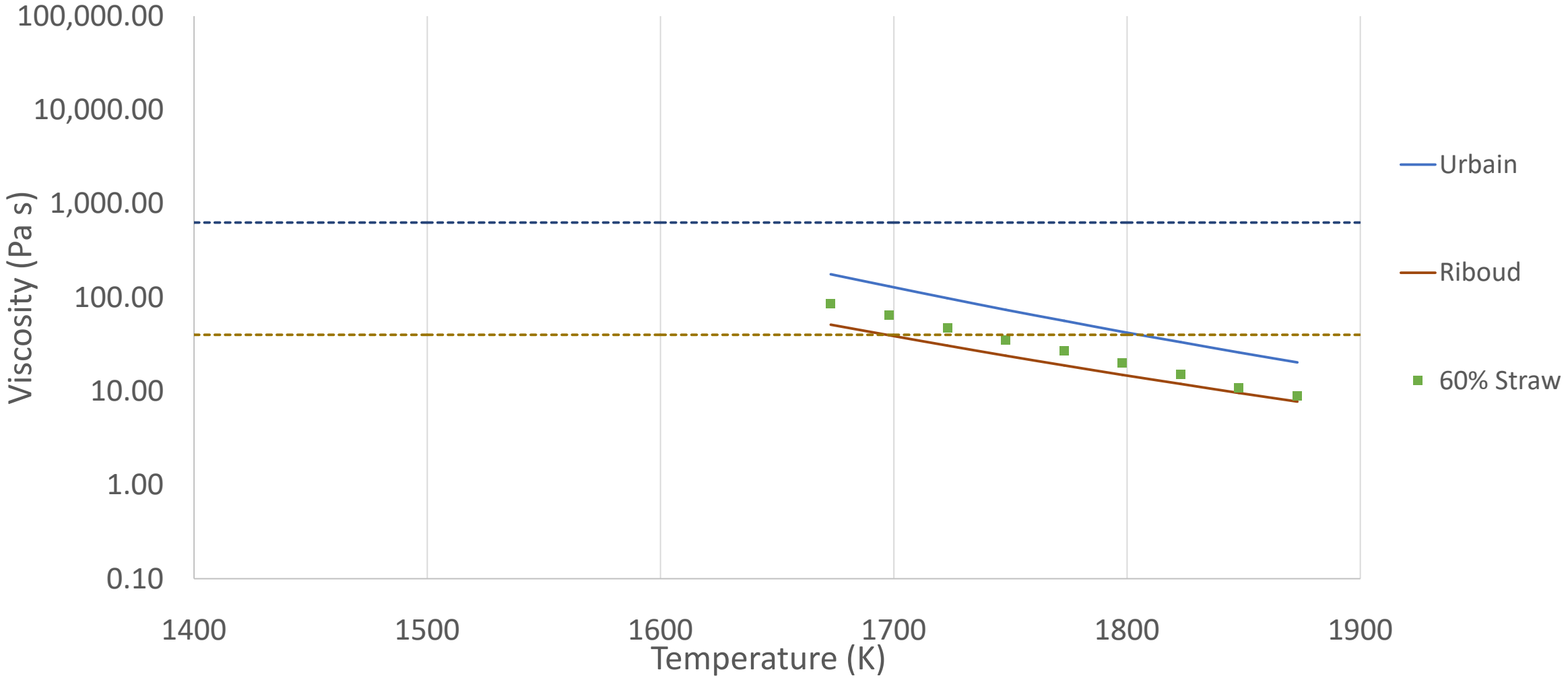
Viscosity Models

Xu, et al. (2014)



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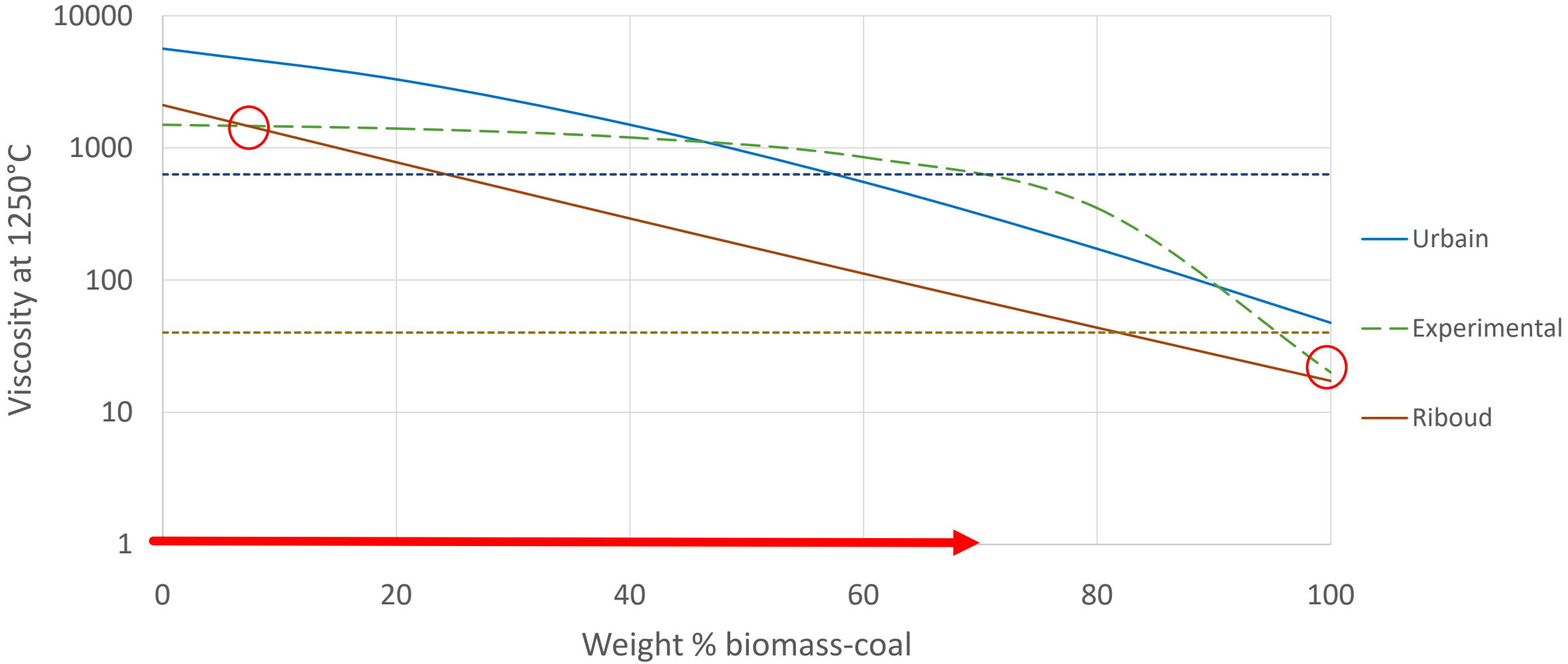
Viscosity Models

Wigley, et al. (2007) - Miscanthus



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Viscosity Models

In summary:

- Ash viscosity has a direct effect upon the nature of a deposit
- Models are developed using experimental data of coal viscosities – models may fail with compositions outside of those studied
- Developed for liquid phases – fail to predict behaviour of multi-phase slags

Experimental Results

Two main experiments conducted so far:

- Ash Fusion Temperature (AFT) testing – to determine the melting temperature of various ash compositions
- Ash Resistivity Testing (ART) – to determine the effect of the additive upon the electrical behaviour of the ash

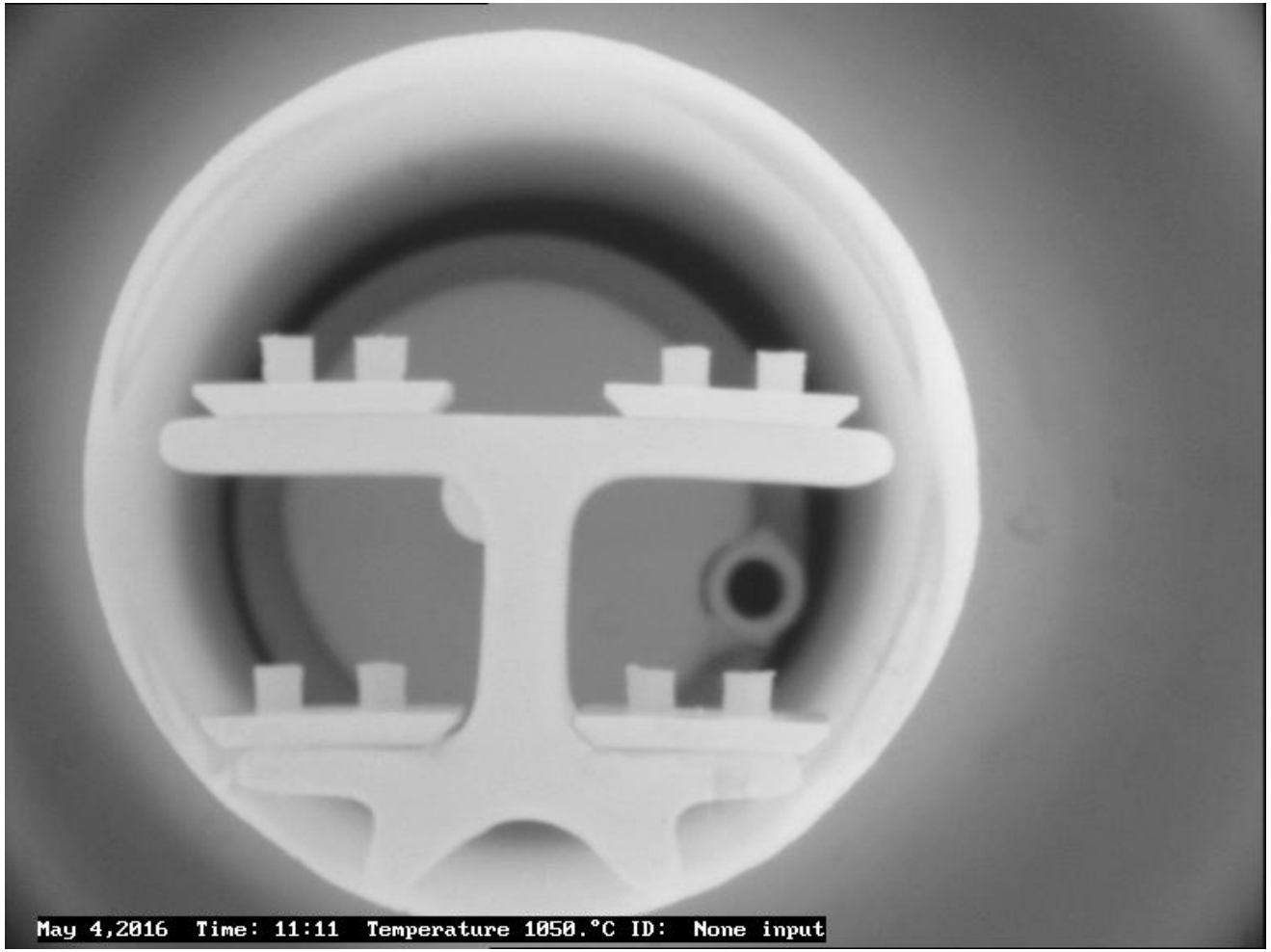
Ash Fusion Temperatures

- Four samples tested (°C):

Sample	Initial Deformation	Softening Temperature	Hemisphere Temperature	Flow Temperature
Olive Cake Ash	1050±10	1235±5	1330±5	1370±5
Olive Cake/ 5% pfa	1230±10	1290±10	1370±5	1390±5
Olive Cake/ 10% pfa	1205±5	1340±20	1400±10	1410±5
100% pfa	-	1250±20	1390±20	1415±10

Ash Fusion Temperatures – 1050°C

100% Olive Cake ash



100% Coal pfa

95% Olive/ 5% pfa

90% Olive/ 10% pfa

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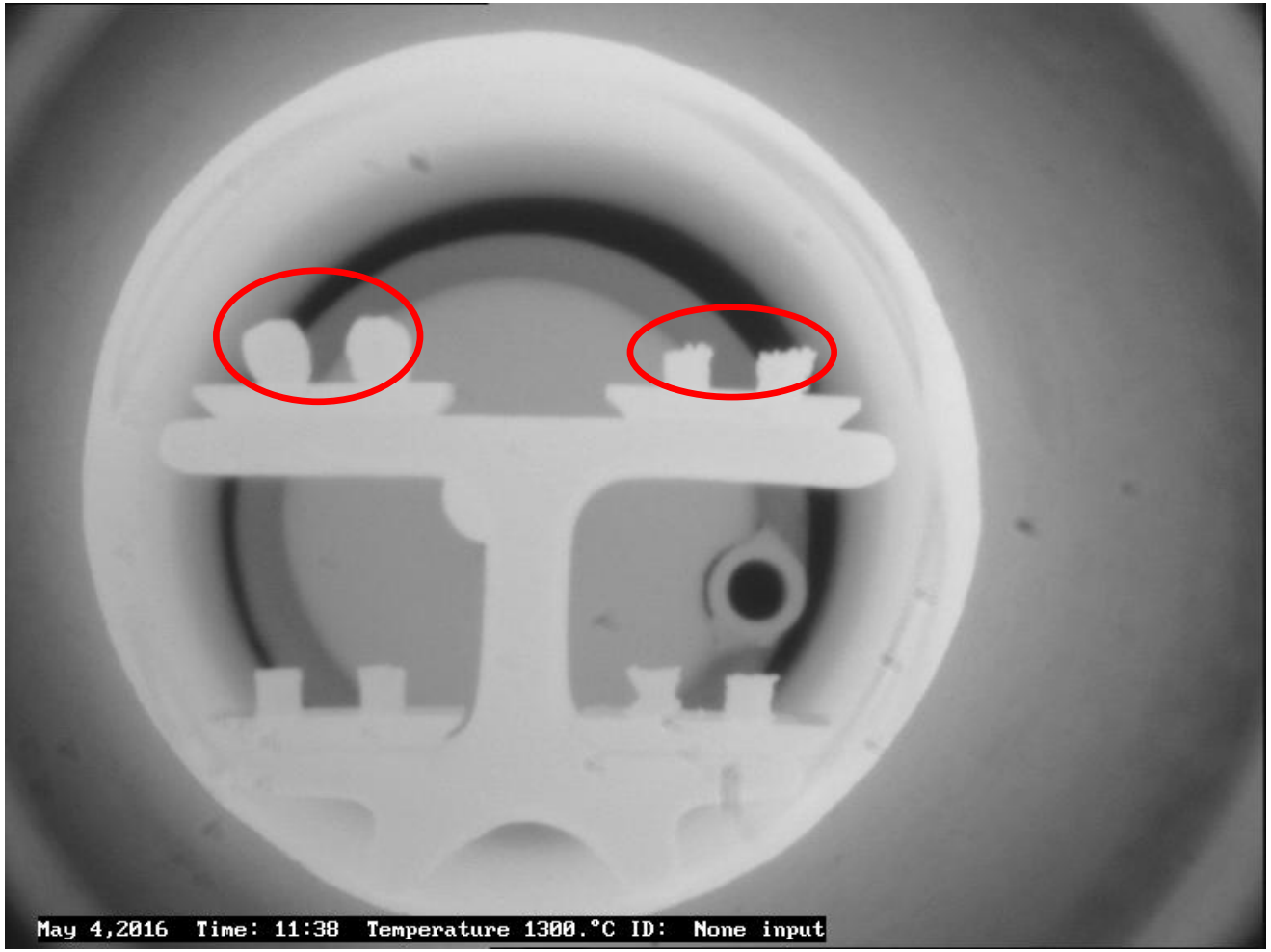
Ash Fusion Temperatures – 1300°C

100% Olive Cake ash

100% Coal pfa



95% Olive/ 5% pfa

90% Olive/ 10% pfa

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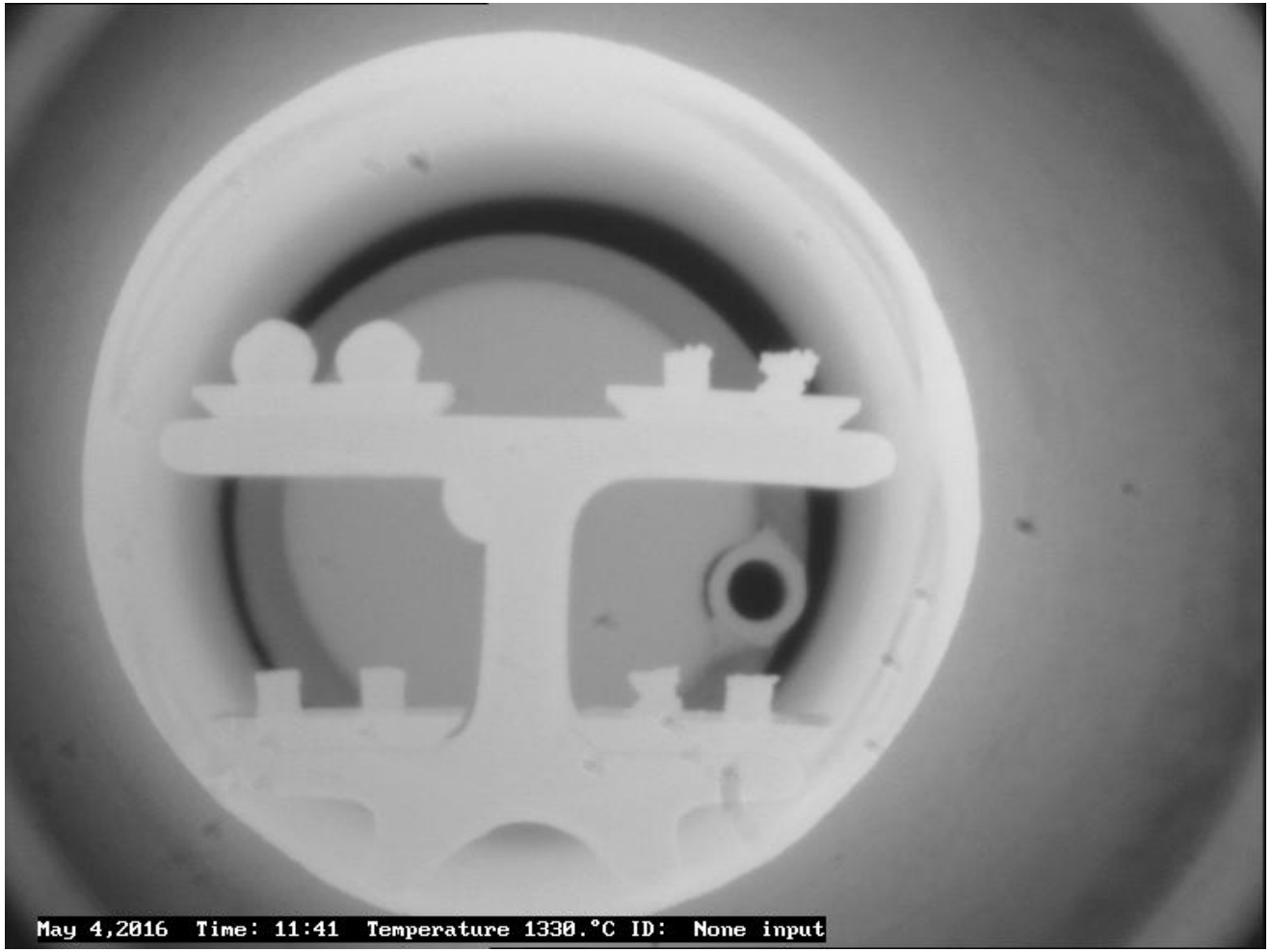
Ash Fusion Temperatures – 1330°C

100% Olive Cake ash



100% Coal pfa

95% Olive/ 5% pfa

90% Olive/ 10% pfa

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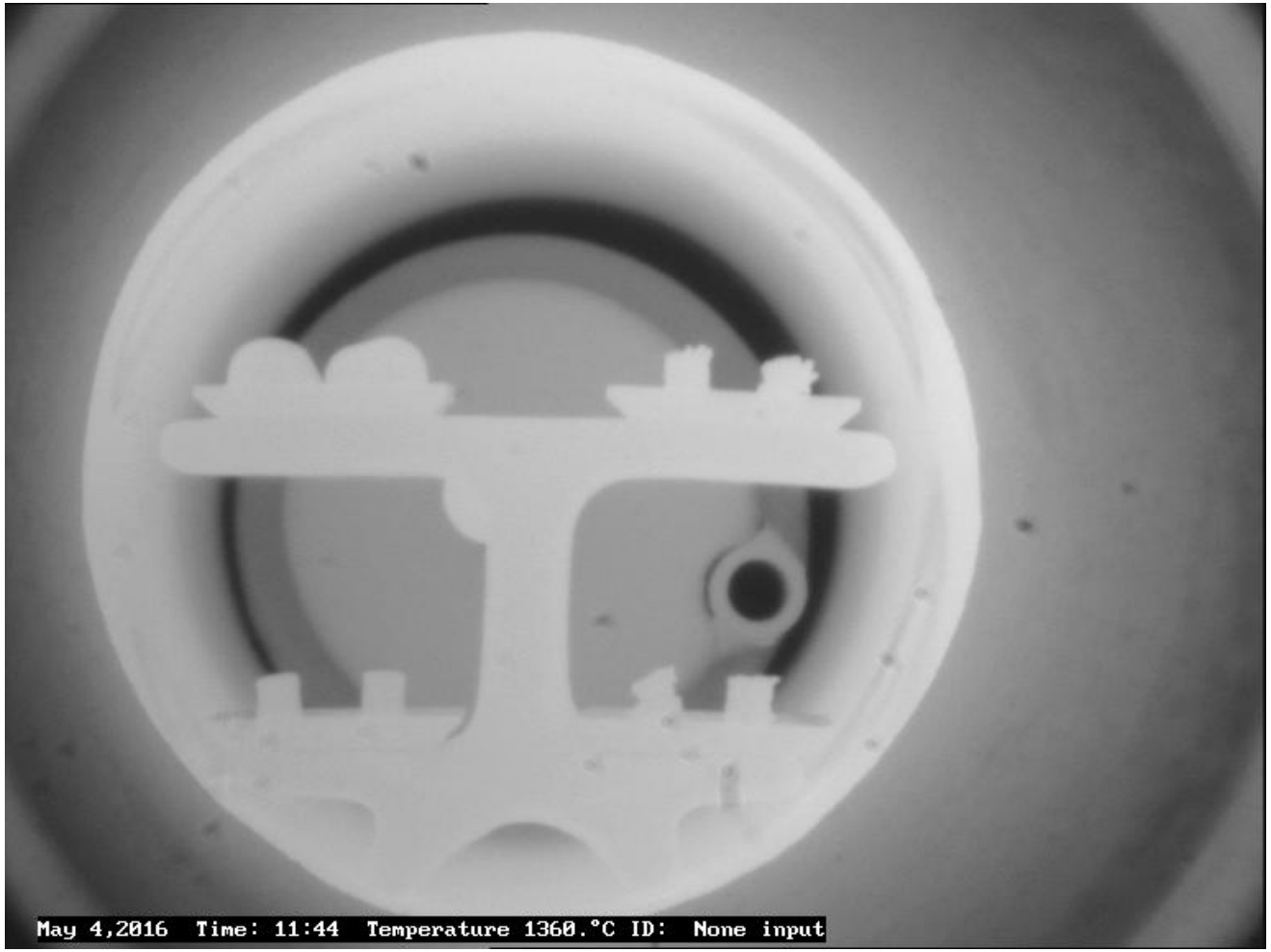
Ash Fusion Temperatures – 1360°C

100% Olive Cake ash



100% Coal pfa

95% Olive/ 5% pfa

90% Olive/ 10% pfa

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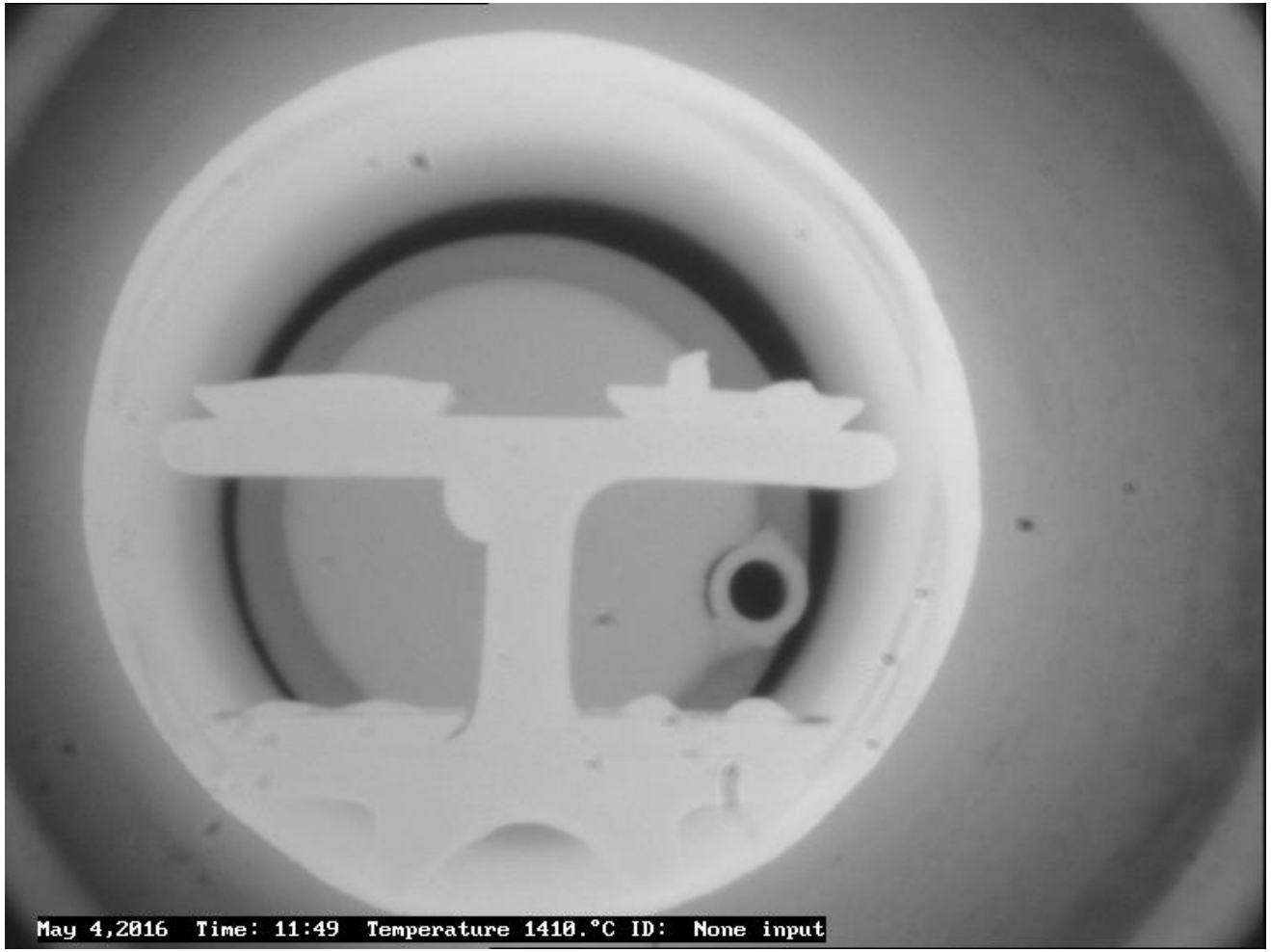
Ash Fusion Temperatures – 1410°C

100% Olive Cake ash

100% Coal pfa



95% Olive/ 5% pfa

90% Olive/ 10% pfa

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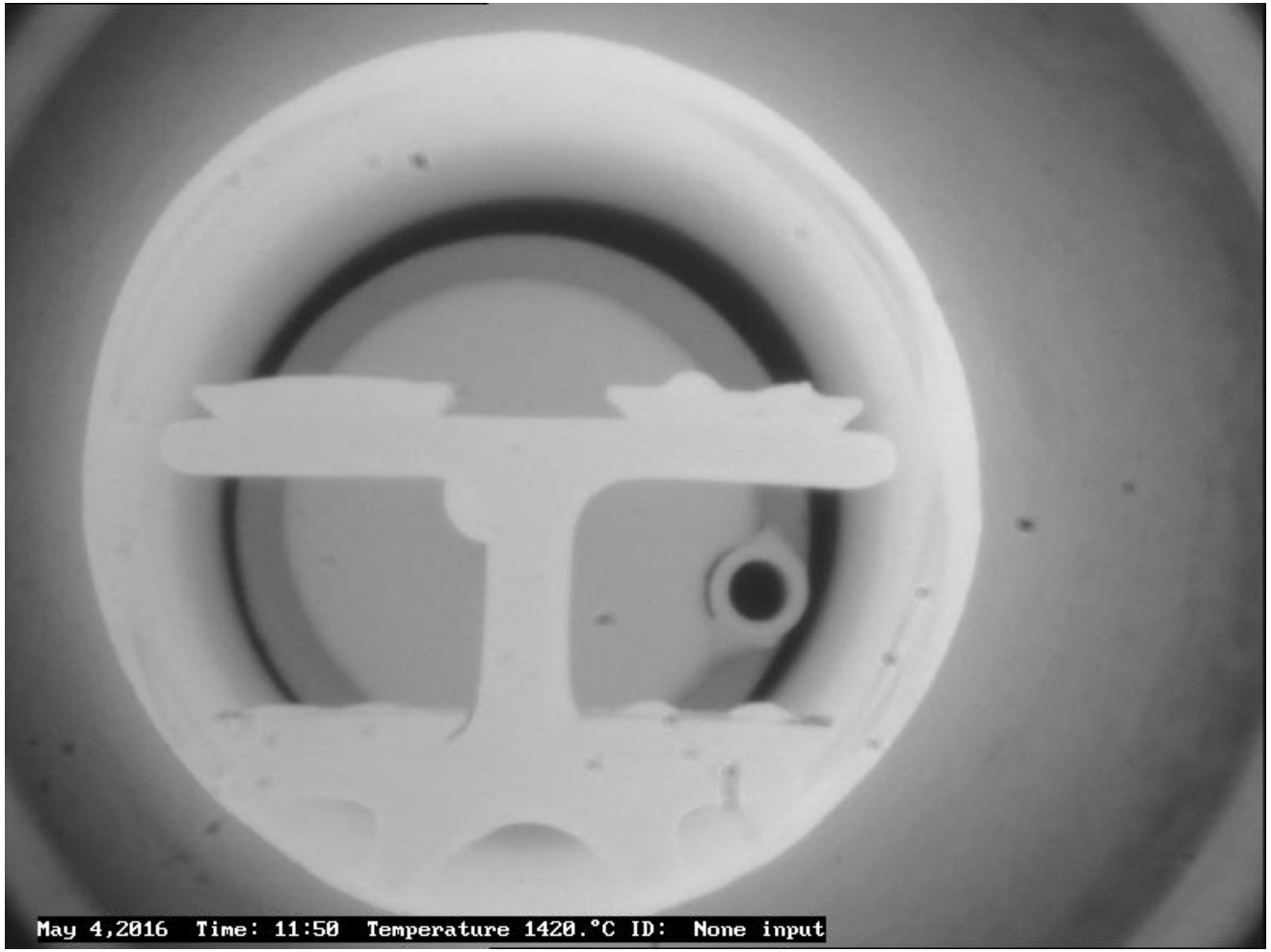
Ash Fusion Temperatures – 1420°C

100% Olive Cake ash



100% Coal pfa

95% Olive/ 5% pfa

90% Olive/ 10% pfa

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Ash Fusion Temperatures

In summary:

- Addition of PFA to olive cake ash increases flow temperature

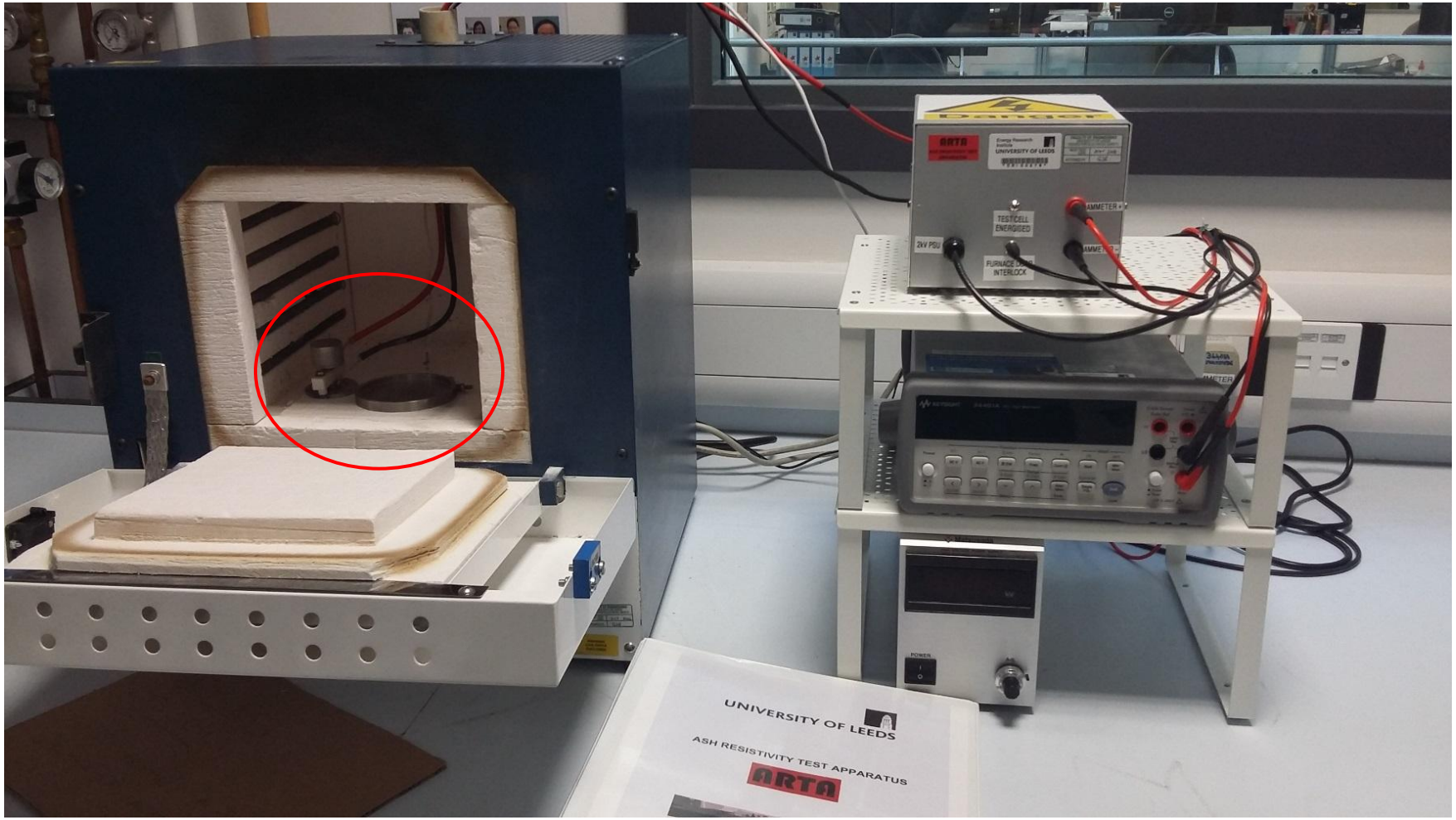
- Initial deformation temperature less clear – more testing needed

Ash Resistivity Testing

- Electrical behaviour of fly ash impacts performance of electrostatic precipitators (ESPs)

- Resistivity governs for how long a particle will hold an applied charge – lower resistivity can result in particles passing through ESP

Ash Resistivity Testing



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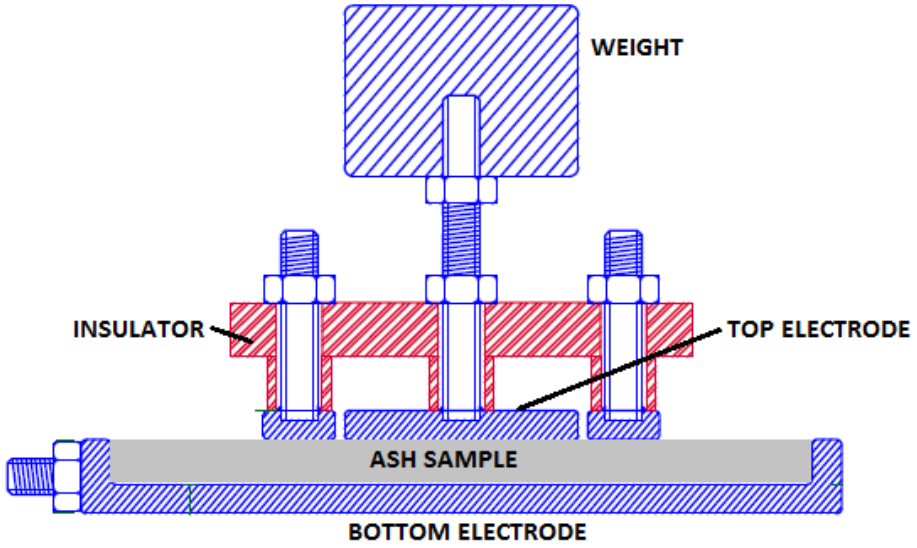
Ash Resistivity Testing

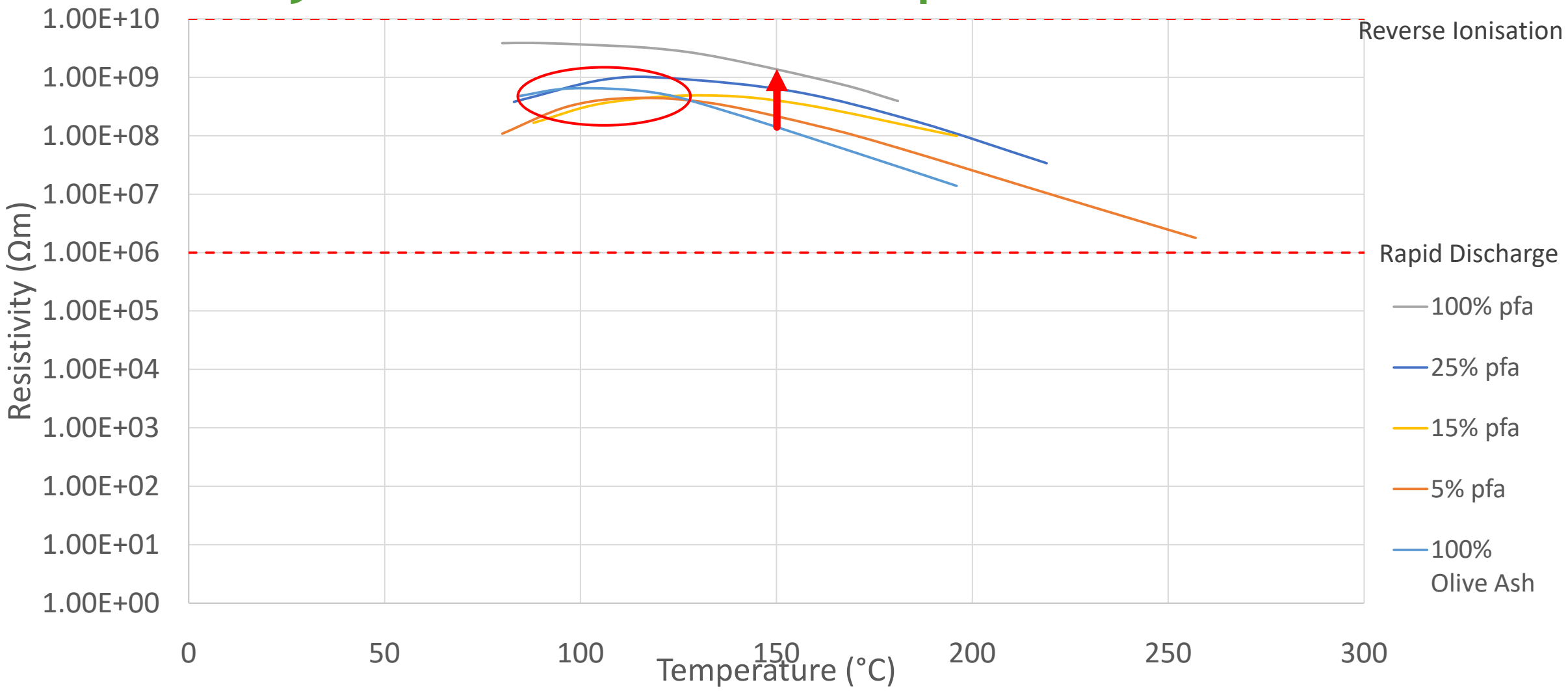
- Test cell constructed in accordance with IEEE Standard 548-1984



Ash Resistivity Testing

- Test cell constructed in accordance with IEEE Standard 548-1984
- Connected to 2kV variable power supply and ammeter. From current resistivity is calculated.
- Test cell situated inside furnace to allow for current measurements over a range of temperatures.

Resistivity of Olive Cake Ash/pfa blends



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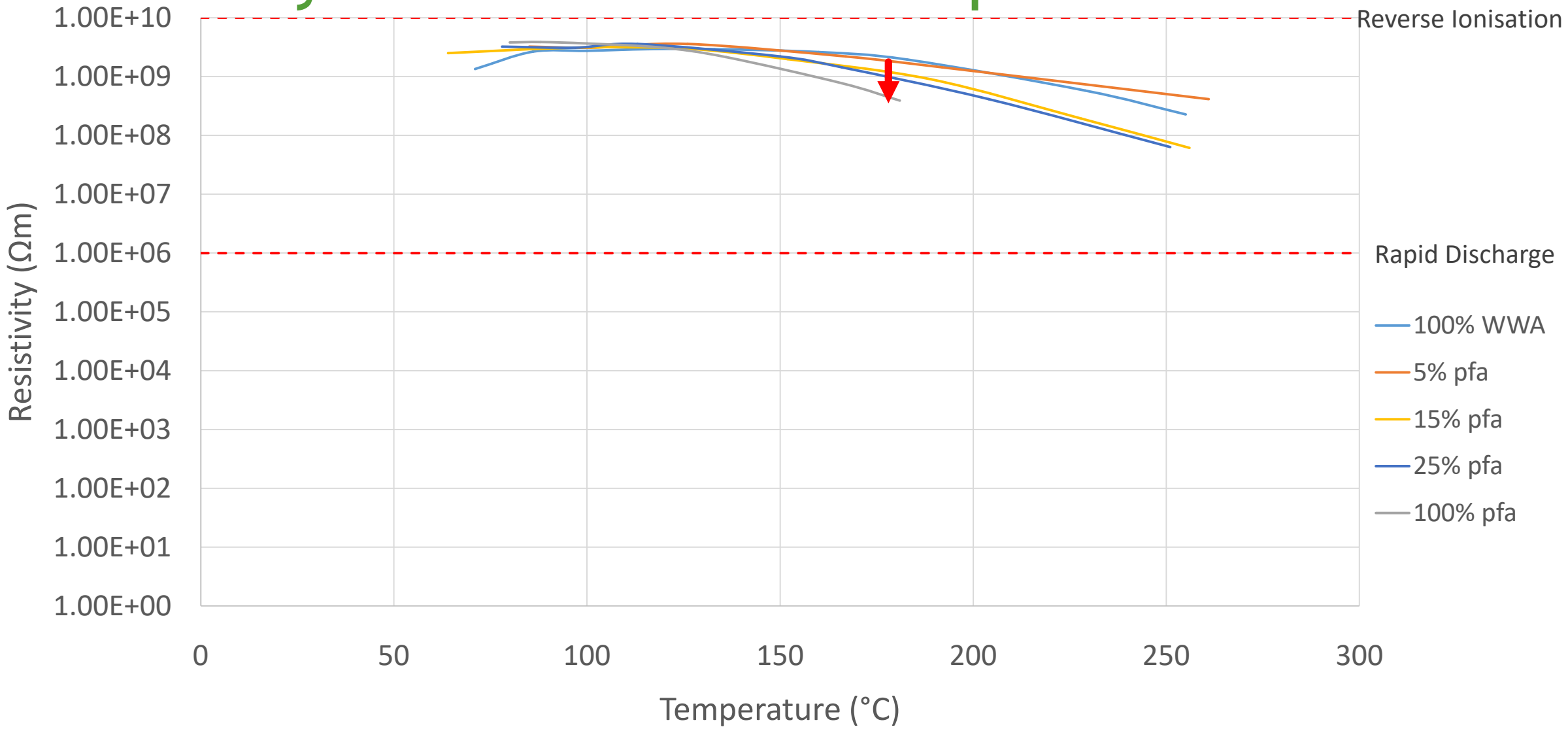
Resistivity of White Wood Ash/pfa Blends



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Ash Resistivity Testing

In Summary:

- Use of additive increases resistivity of olive cake ash – particles retain charge for longer
- Peak resistivities for white wood ash are unaffected
- Pfa may lower white wood ash resistivity at higher temperatures – resistivity remains within safe working levels

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Future Work

- Sinter Strength testing
- Pilot scale combustion tests – PACT
- Modelling using FactSage

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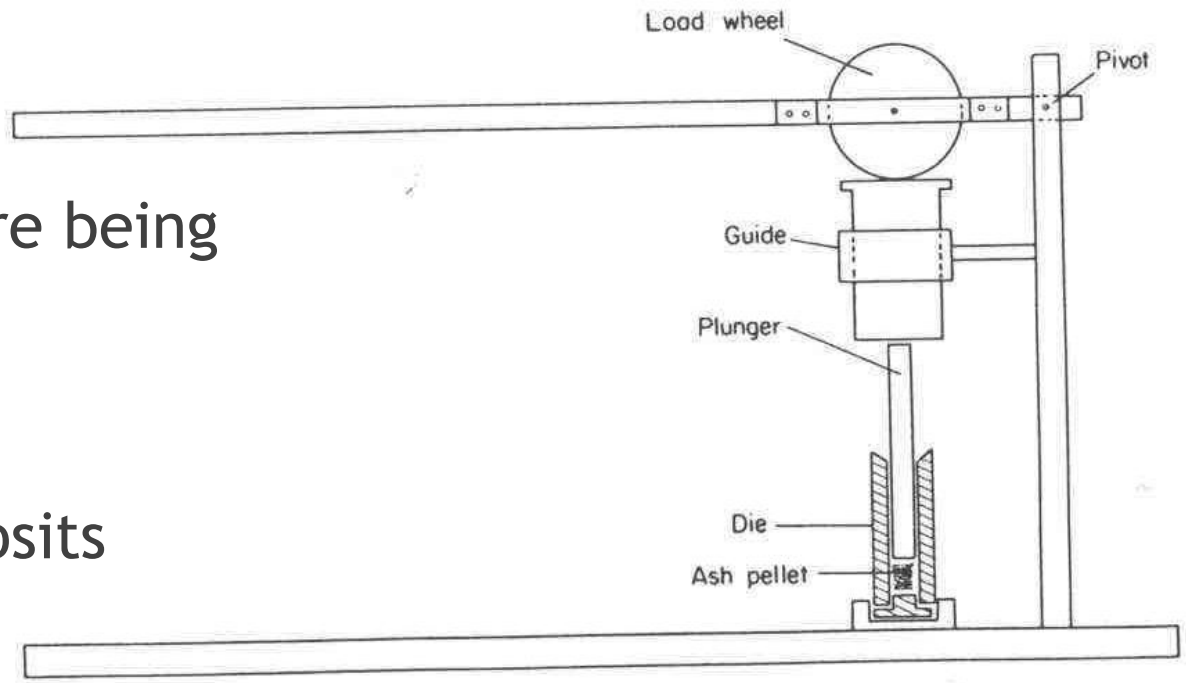
Sinter Strength Testing

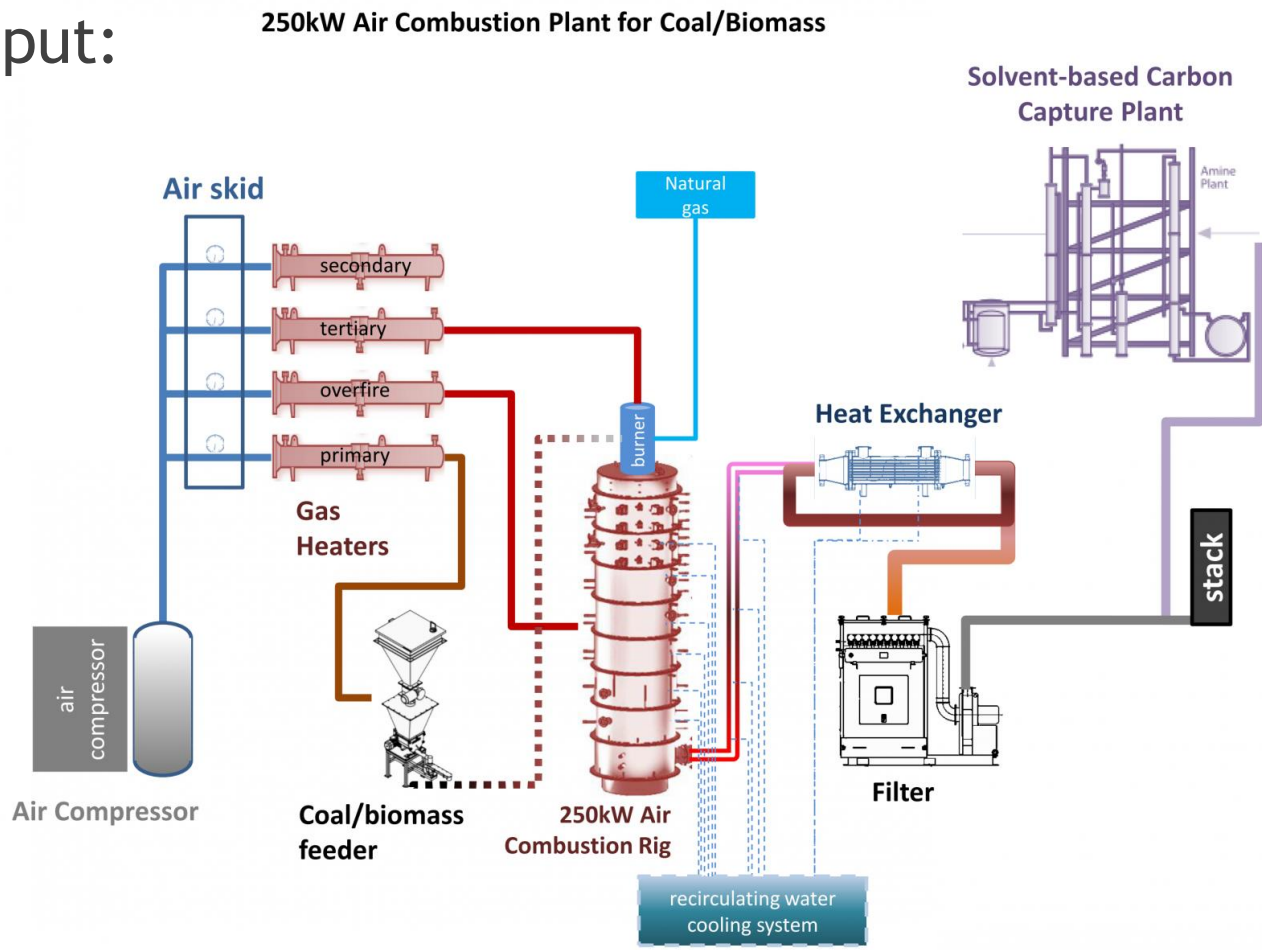
- Ash pellets prepared using a cast, before being sintered at different temperatures
- Sintered pellets are then cooled, before being crushed using a tensometer
- Greater force required = stronger deposits



(W.H. Gibb, 1981)

Pilot Scale Testing at PACT

- Two tests planned, at 250kW thermal output:
  - White wood pellets
  - White wood pellets with PFA
- System is monitored throughout testing
- Bottom and fly ash will be collected for further analysis of deposits



(www.pact.ac.uk)

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FactSage Modelling

- A series of information, database, calculation and manipulation modules

- With these modules, a wide variety of thermochemical calculations are possible, which can in turn generate predictions for behaviour of substances under different conditions

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Acknowledgements

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