Investigating the Effect of Coal Mineral Matter on Blast Furnace Coal Injection

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Julian Herbert (3rd Year PhD Student)

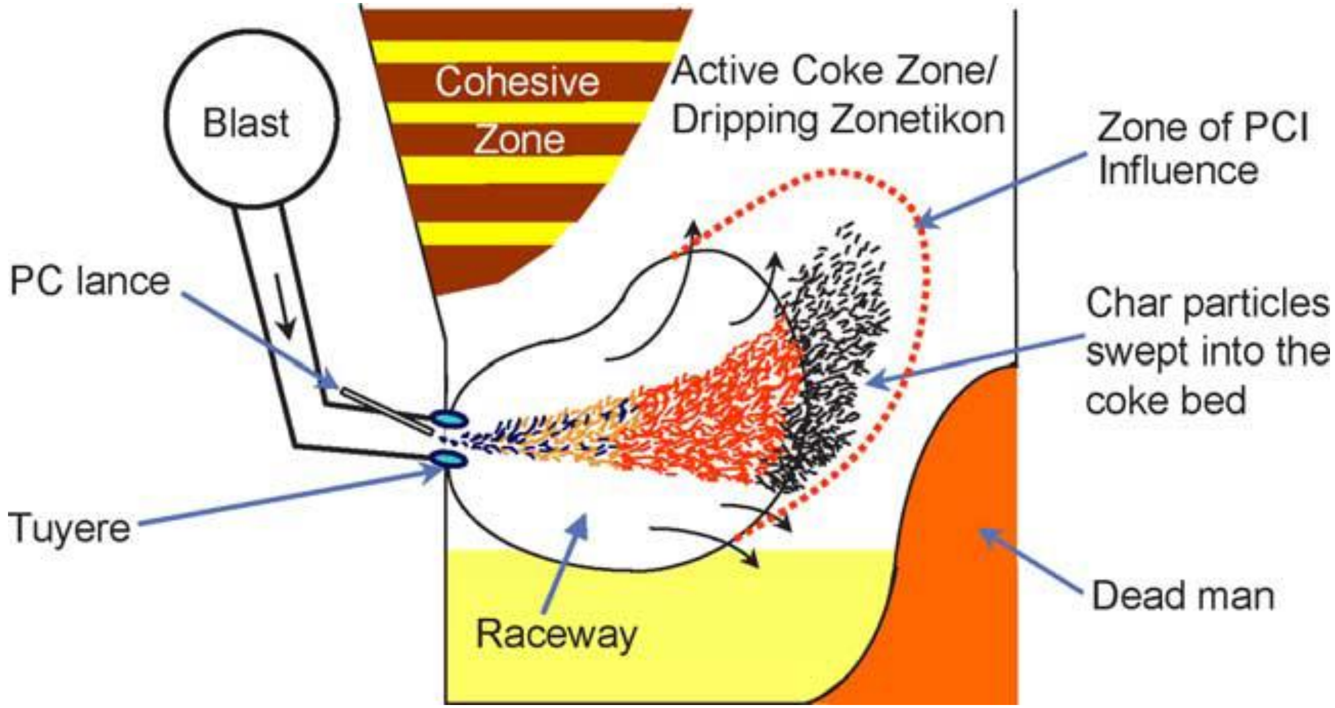
Supervisors: Richard Marsh, Julian Steer

Cardiff School of Engineering

Sponsored by Tata Steel IJmuiden

Industrial Supervisor: Stefan Born

Introduction



Raceway. Figure taken from (Mathieson et al. 2005)

- Coal is injected with hot oxygen enriched air at the bottom of the blast furnace via the **tuyeres**.
- This creates a void known as the **raceway**.
- The coal contains **mineral matter** which is made up of numerous elements.
- These elements have different properties in the blast furnace.
- They have effects within the raceway, the blast furnace as a whole, and for the slag chemistry.

Research Summary

- To use a Drop-Tube Furnace (DTF) to prepare chars and ashes under a range of conditions.
- To analyse the ash mineralogy and chemistry using a range of techniques.
- To investigate physical and chemical properties of the ash with respect to the injection, combustion, burden interaction and slag chemistry.

<u>Hard, high melting point minerals</u>
May cause wear in the coal injection zone.

<u>Ash fusion temperature</u>
Could determine whether ash is caught in the bird's nest or travels up the furnace as a dust.

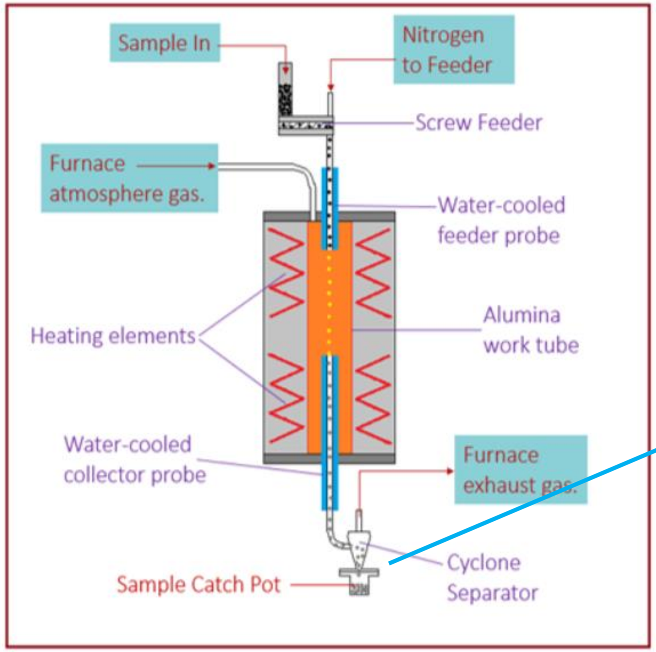
Better understanding of the ash changes can allow us to determine which minerals may:

- Volatilise
- Stick in the back of the raceway.
- Go up the stack
- Cycle through the furnace
- End up in the slag

Experimental Procedure

Low Volatile injection coal
- Pulverised particle size.
- 100% <300 µm 50% <75 µm.
- Volatiles: 8.5%. Ash: 10.4%

Drop Tube Furnace (DTF)
- High heating rates 10^4-10^5 K/s
- Temperature up to 1300°C
- Choice of feed gases: air, nitrogen, CO_2
- Sample feed 30 g/hr
- Residence times ranging from 35-700 ms



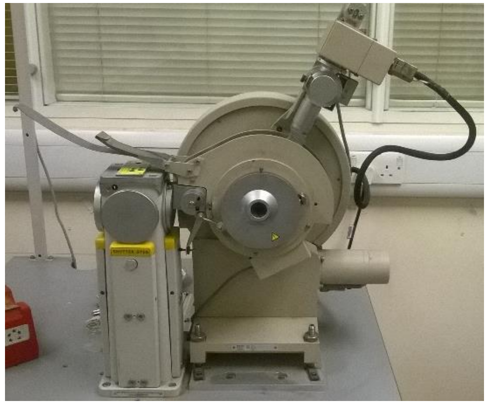
Char from DTF

Furnace Ashing at 815°C
BS ISO 1171:2010
Determination of Ash

Ash

X-ray Fluorescence
Elemental Analysis

X-ray Diffraction (XRD)
Mineral Analysis



Ash Fusion Testing
To determine ash melting temperature.

Testing Conditions

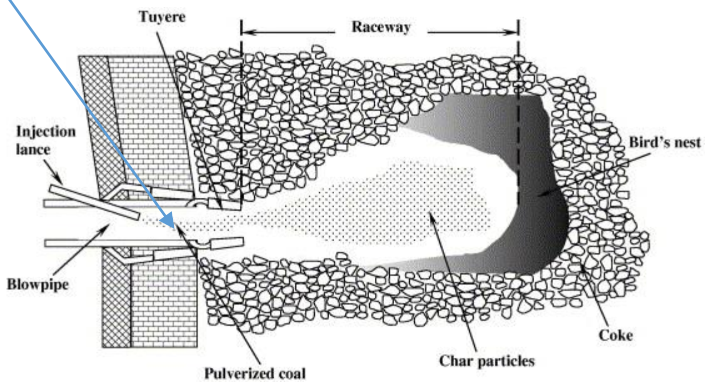
- The DTF reaction conditions are shown in the table below.
- Aiming to investigate the effect of temperature, residence time and gas environment.

Temperature	Residence Time	Gas Environment
1100°C	100ms	Air
1100°C	350ms	Air
1300°C	100ms	Air
1300°C	350ms	Air
1100°C	100ms	Nitrogen
1100°C	350ms	Nitrogen
1300°C	100ms	Nitrogen
1300°C	350ms	Nitrogen
1100°C	100ms	CO2
1100°C	350ms	CO2
1300°C	100ms	CO2
1300°C	350ms	CO2

Combustion occurs in the raceway in the presence of O_2 enriched air. High particle temperatures reached.

A nitrogen atmosphere will be cooler than in air, due to absence of combustion.

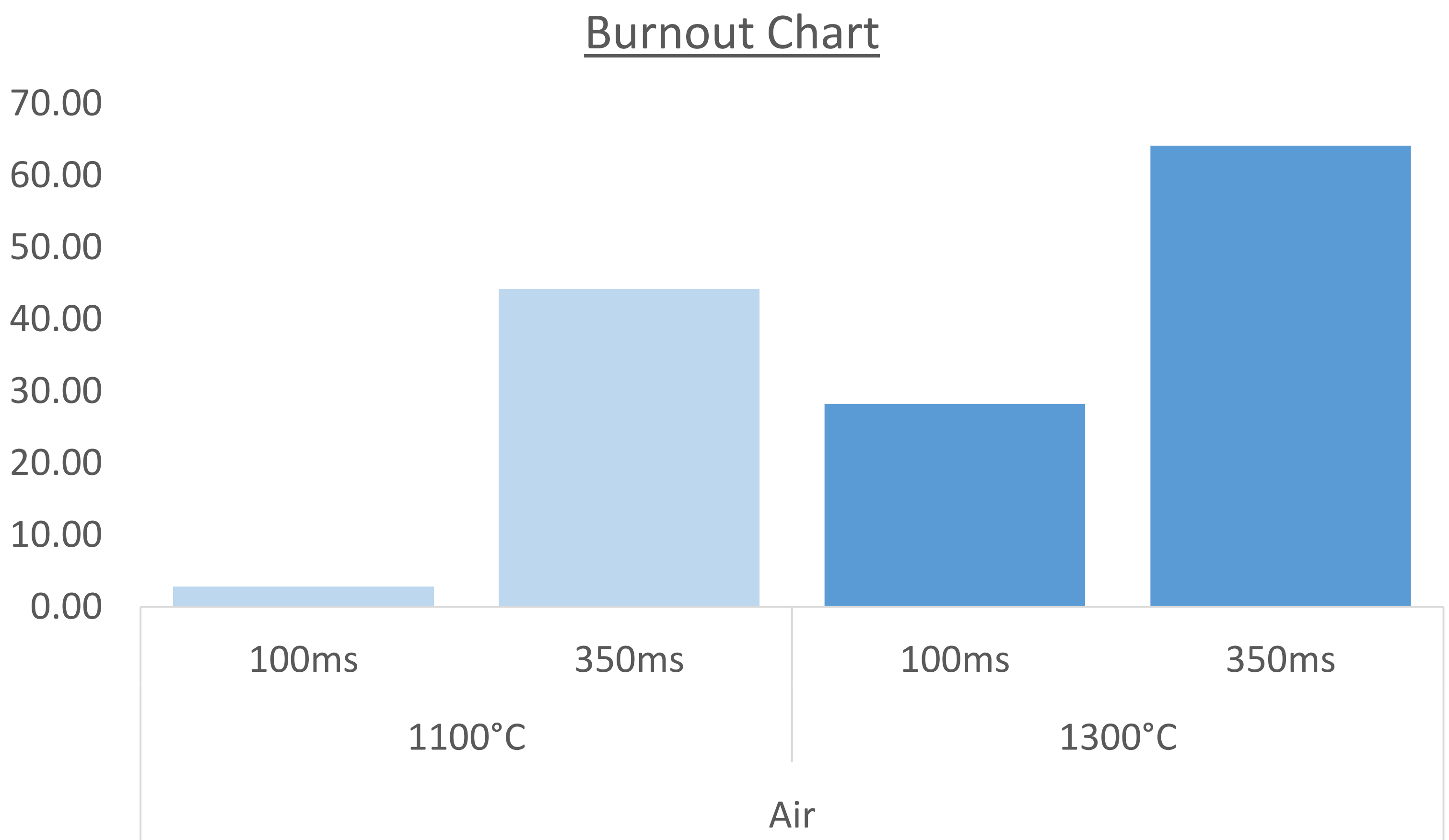
CO_2 is used to investigate what might happen in a reducing environment where $C + CO_2 \leftrightarrow 2\ CO$.



Raceway. Figure taken from (Chen et al. 2007)

- Minerals present in the ashes were semi-quantitatively analysed (using XRD diffractograms).
- Ash melting temperature was determined for each of the reaction conditions.

DTF Coal Combustion



- The sample in 1300°C Air burns out to a greater extent than the 1100°C sample.
- The samples in the non-oxidising gases do not combust.
- DTF allows us to compare injection coal reactivity.

Typical Coal Minerals

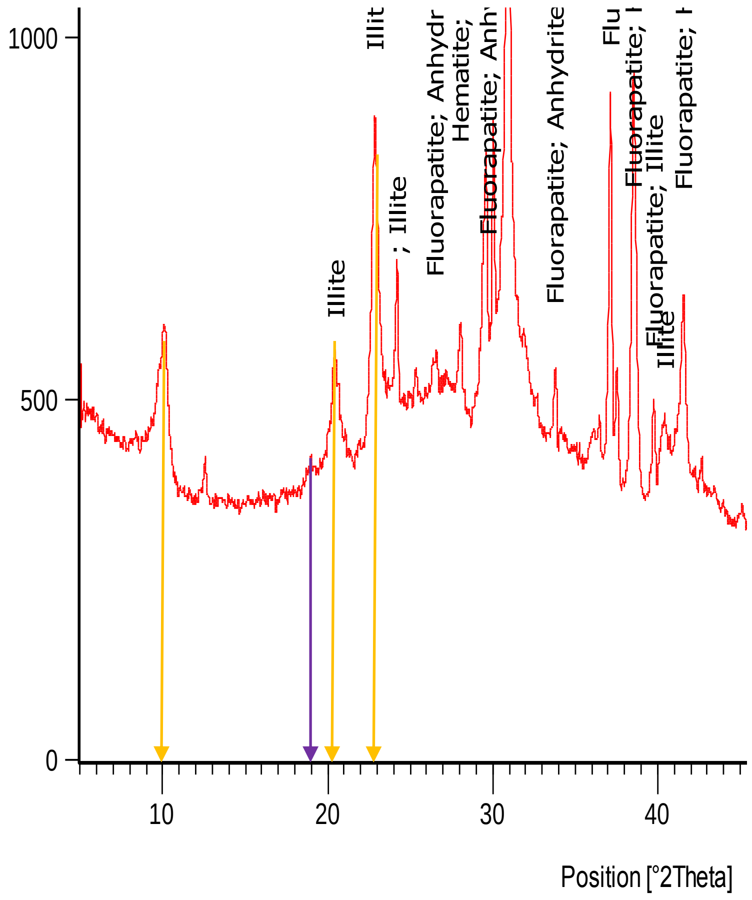
- Typical coal minerals are described on the left table.
- The resultant elements and potential effects are described on the right.

Mineral Type	Common Example
Silicate (Quartz)	SiO_2
Clays	$Al_2Si_2O_5(OH)_4$, $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})$, $KAl_2(AlSi_3O_{10})(F,OH)_2$
Carbonates	$CaCO_3$, $CaFe(CO_3)_2$
Sulphates	$CaSO_4$
Sulphides	FeS_2
Phosphates	$Ca_5(PO_4)_3F$
Metal oxides	Fe_2O_3, TiO_2

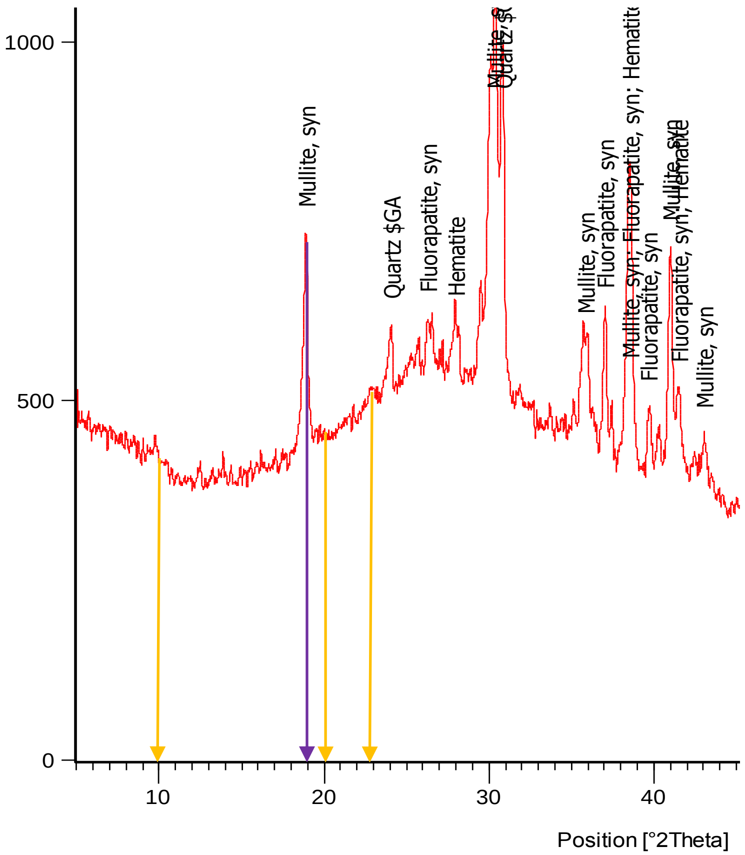
Element	Effect on Ash Melting Temperature	Effect in the raceway	Effect in the furnace
Silicon	Increase	Possible silica vaporisation	Enters slag.
Aluminium	Increase		Enters slag.
Iron	Decrease	Catalytic	
Magnesium	Decrease		Enters slag.
Calcium	Decrease	Catalytic	Enters slag.
Sodium	Decrease	Catalytic	Cycling and accumulation. Coke degradation
Potassium	Marginal Effect	Catalytic	Cycling and accumulation. Coke degradation
Sulphur	Decrease		Enters slag and hot metal
Titanium	Increase	None	Healing effect on refractory lining
Phosphorus			90-100% Enters hot metal.

XRD Diffractogram Analysis

1100°C 100ms Air



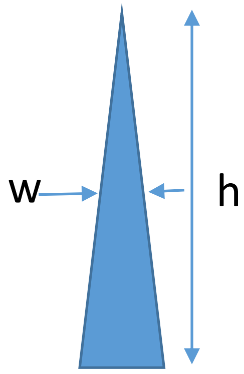
1100°C 350ms Air



With increasing residence time, the following occurs:

- The structure of the clays are destroyed.
- Mullite forms.
- There are other changes also.

We can semi-quantify the percentage of a mineral phase by measuring the **area** of its main peak. But we need to identify all of the minerals present.



Area = h x width at half maximum height (FWHM)

Therefore given sufficient temperature and time this hard mineral forms.

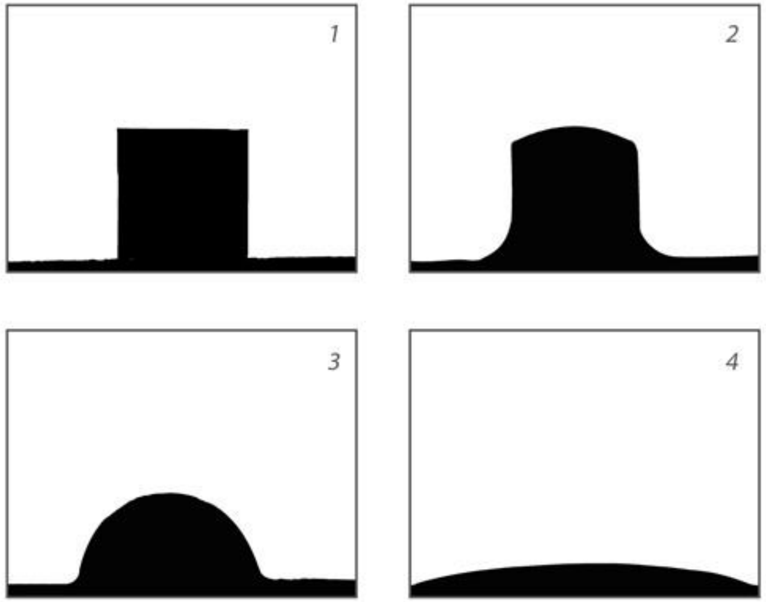
X-Ray Diffraction Mineral Identification and Quantification

Temperature	Residence Time	Gas Environment	% Quartz (SiO_2)	% Hematite (Fe_2O_3)	% Fluorapatite [$Ca_5(PO_4)_3F$]	% Clay $Al_2Si_2O_5(OH)_4$	% Anhydrite ($CaSO_4$)	% Mullite ($3Al_2O_3.2SiO_2$)
1100°C	100ms	Air	33.5	13.2	14.6	19.8	13.9	4.9
1100°C	350ms	Air	29.8	25.0	7.8	8.3	2.2	26.8
1300°C	100ms	Air	34.5	24.2	8.3	3.6	6.2	23.2
1300°C	350ms	Air	28.2	30.1	6.0	2.8	8.3	24.6
1100°C	100ms	Nitrogen	36.9	7.9	11.8	36.3	7.1	0.0
1100°C	350ms	Nitrogen	31.7	10.9	16.2	32.7	8.4	0.0
1300°C	100ms	Nitrogen	32.1	12.1	14.3	26.1	15.4	0.0
1300°C	350ms	Nitrogen	35.3	23.1	19.1	3.3	4.2	15.0
1100°C	100ms	CO2	34.5	11.5	13.8	31.8	8.4	0.0
1100°C	350ms	CO2	35.6	9.0	15.6	35.5	4.3	0.0
1300°C	100ms	CO2	39.6	14.3	16.7	23.9	5.5	0.0
1300°C	350ms	CO2	27.4	18.3	18.4	10.7	13.9	11.3

- As temperature and residence time increases, the proportion of clay decreases.
- Mullite forms in air but there is more at 1300°C than 1100°C
- Mullite only forms in N_2 and CO_2 at 1300°C 350ms.
- Therefore, the formation of mullite is temperature dependent.

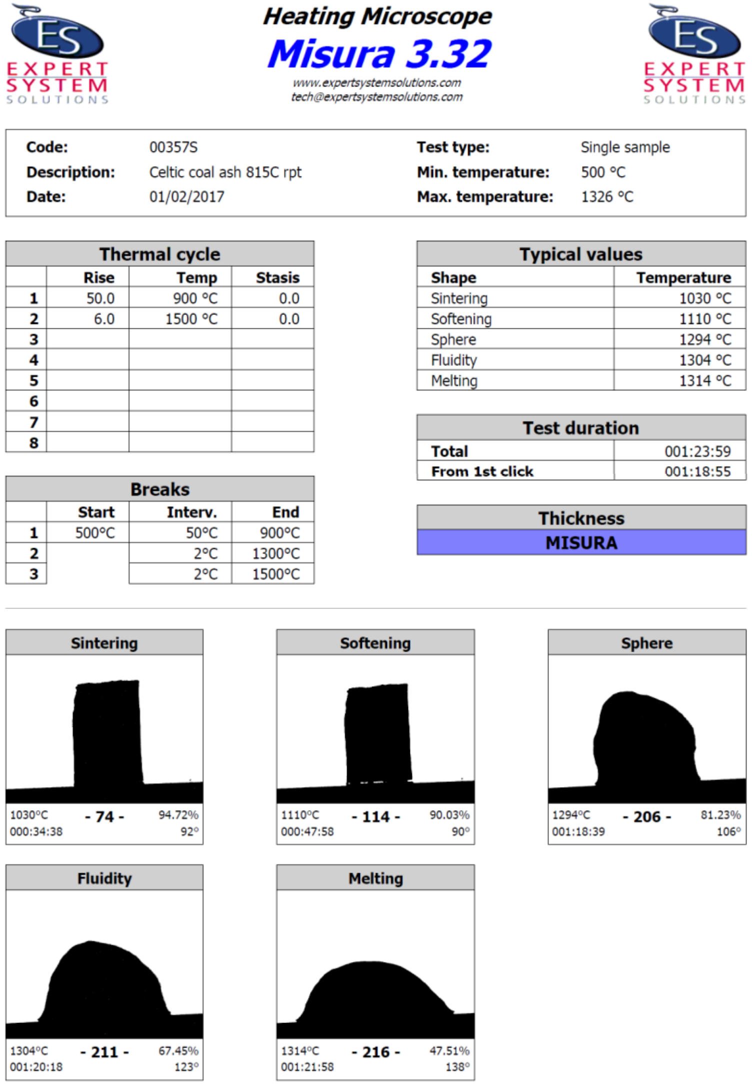
Ash Fusion Tests (AFT)

- Ash fusion tests (AFTs) were carried out on a Misura Heating Microscope at Materials Processing Institute (MPI).



1. Prepared Sample
2. Softening Temperature
3. Hemispherical Temperature
4. Flow Temperature

Ideal Ash Fusion Test



EXPERT SYSTEM SOLUTIONS

Heating Microscope
Misura 3.32
www.expertsystemsolutions.com
tech@expertsystemsolutions.com

EXPERT SYSTEM SOLUTIONS

Code:	00357S	**Test type:**	Single sample
Description:	Celtic coal ash 815C rpt	**Min. temperature:**	500 °C
Date:	01/02/2017	**Max. temperature:**	1326 °C

Thermal cycle

	Rise	Temp	Stasis
1	50.0	900 °C	0.0
2	6.0	1500 °C	0.0
3			
4			
5			
6			
7			
8			

Typical values

Shape	Temperature
Sintering	1030 °C
Softening	1110 °C
Sphere	1294 °C
Fluidity	1304 °C
Melting	1314 °C

Test duration

Total	001:23:59
From 1st click	001:18:55

Breaks

	Start	Interv.	End
1	500°C	50°C	900°C
2		2°C	1300°C
3		2°C	1500°C

Thickness
MISURA

Sintering
1030°C - 74 - 94.72%
000:34:38 92°

Softening
1110°C - 114 - 90.03%
000:47:58 90°

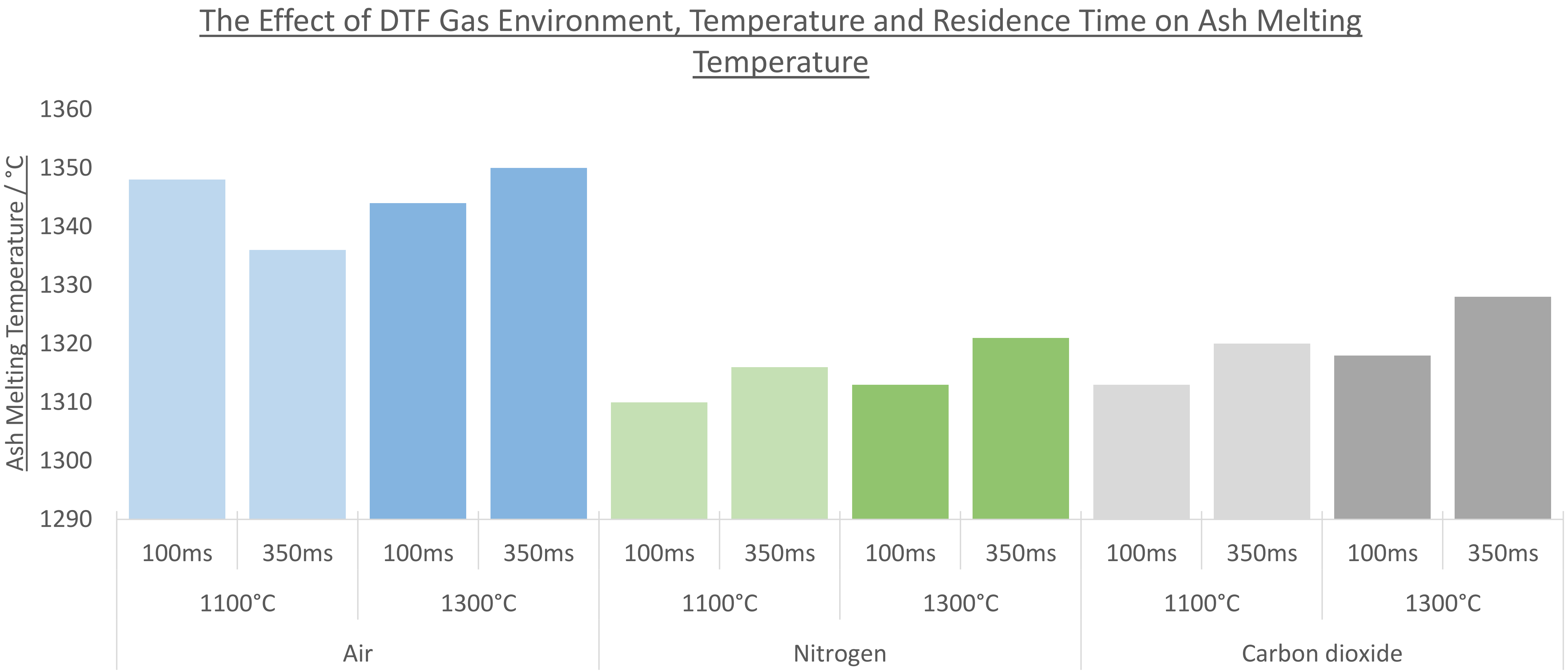
Sphere
1294°C - 206 - 81.23%
001:18:39 106°

Fluidity
1304°C - 211 - 67.45%
001:20:18 123°

Melting
1314°C - 216 - 47.51%
001:21:58 138°

Example of a real Ash Fusion Test

Ash Melting Temperature



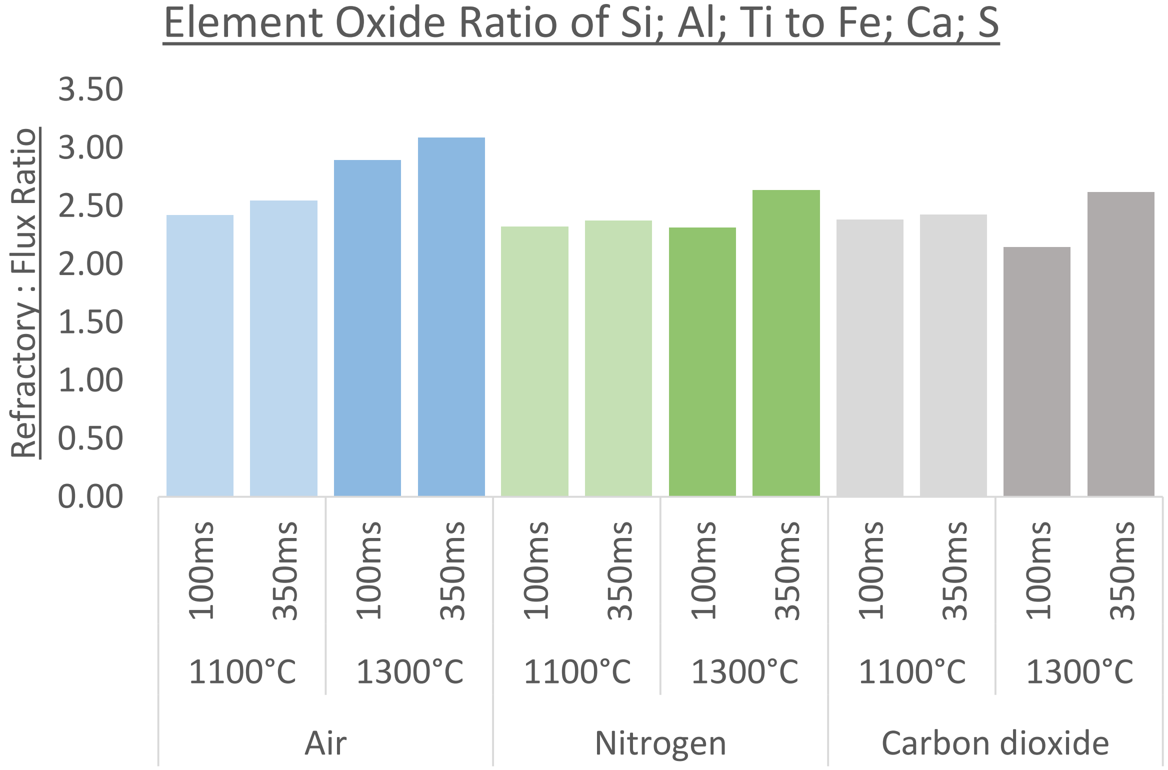
- In almost all cases, the melting temperatures increase with residence time.
- The highest ash melting temperatures are from the chars that reacted in the DTF in air.
- Therefore, ash melting temperature is dependent on the DTF reaction temperature.

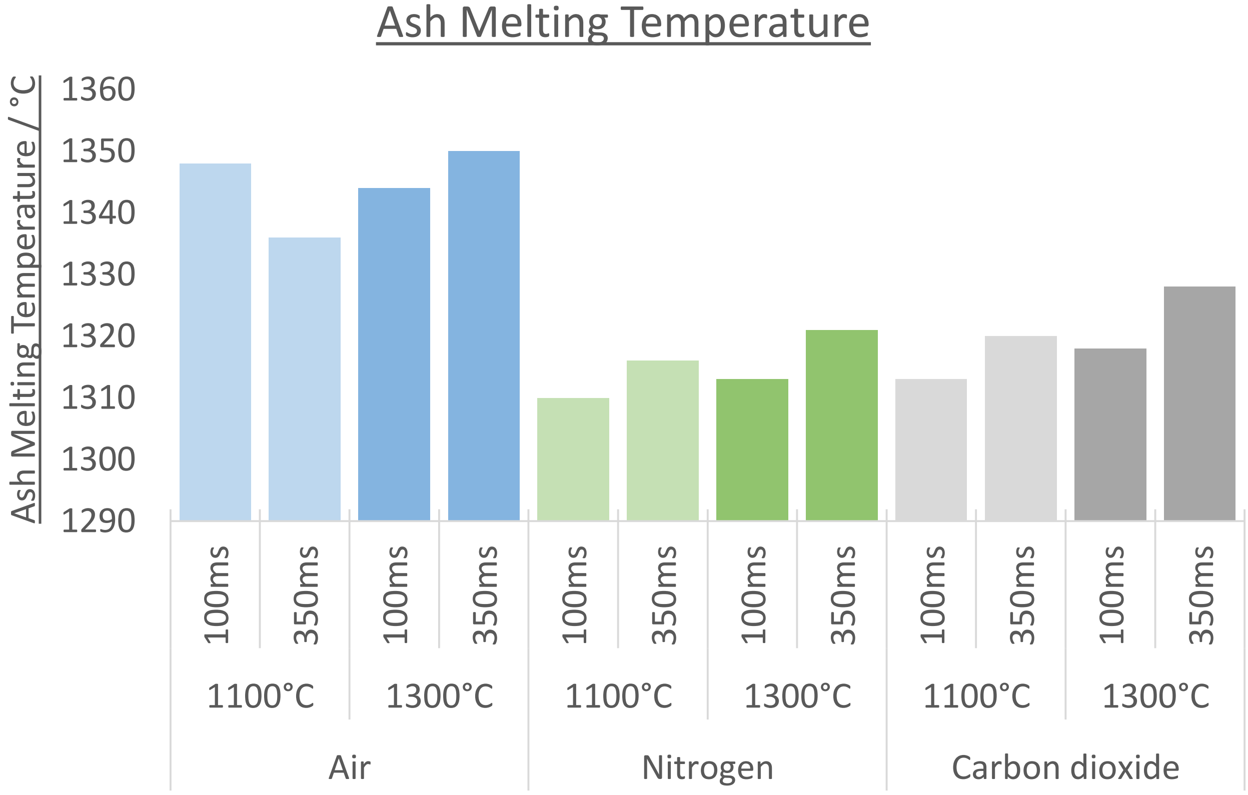
What is causing the increase in ash melting temperature?

- Mullite formation?

Temperature	Residence Time	Gas Environment	% Mullite	Ash Melting Temperature / °C
1100°C	Furnace Coal Ash	Air	29.3	1308
1100°C	100ms	Air	4.9	1348
1100°C	350ms	Air	26.8	1336

- Changes in the acidity, basicity, fluxing agents in the ash?





Key points

- Mullite may cause wear in the coal injection zone of the blast furnace.
- The softening behaviour could determine whether ash is caught in the bird's nest or travels up the furnace as a dust.
- Elemental analysis shows changes that affect the properties of the ash and thus could affect its behaviour in the furnace.
- Recirculating elements such as K and Na can be studied.

Future Work

- Investigate the abrasivity / hardness of different coal ashes.
- Investigate the effect of ashes on coal / coke gasification.
- Look at the sulphur related changes that occur in the ash.