ERRI/CFD Centre
Faculty of Engineering
UNIVERSITY OF LEEDS

Co-Firing Coal/Biomass And The Estimation Of Burnout And NOx Formation

A Williams, J. M. Jones, M. Pourkashanian and L. Ma

BCURA Contract B79 June 2008

Co-firing is widely used in UK power stations.

The biomass does not mill as well as coal and can lead to larger particles.

There are uncertainties about the mechanism of the formation of NO when biomass is present.

Test Coal and Co-firing Blends Studied.

UNIVERSITY OF LEEDS

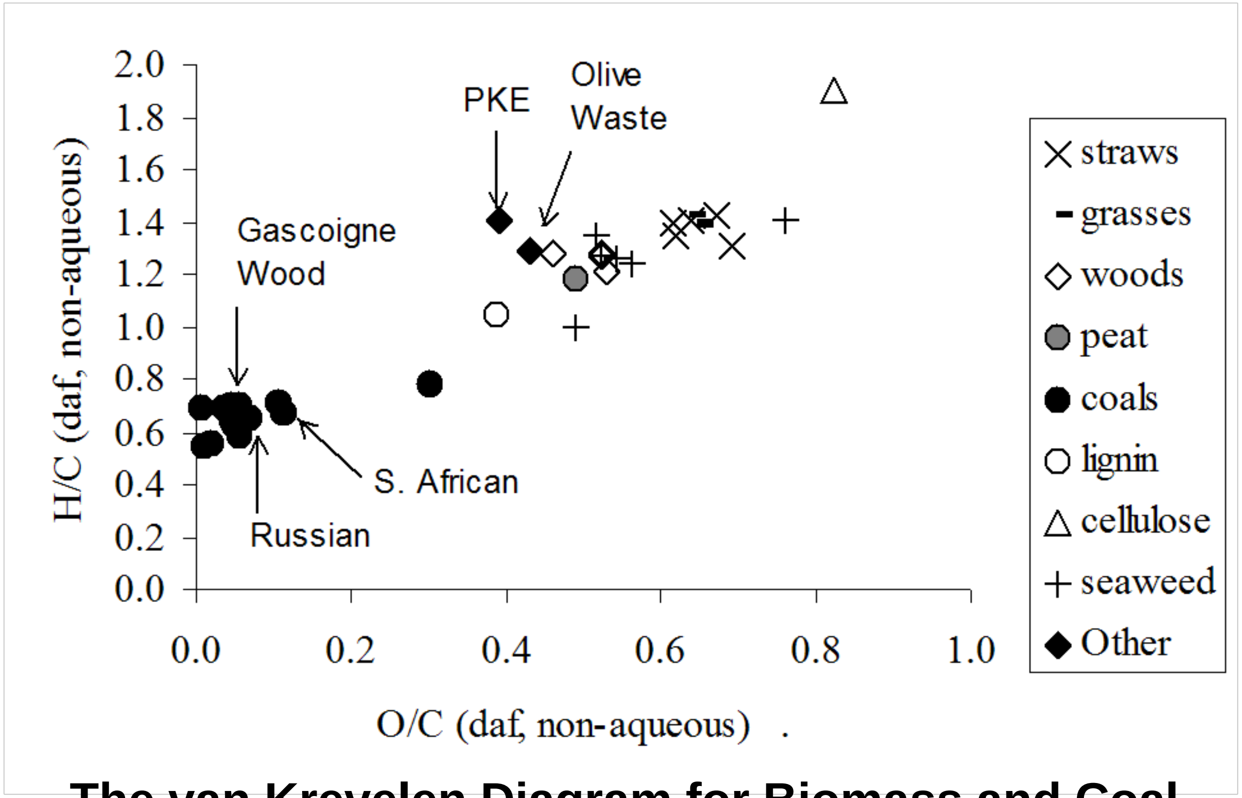
1. Gascoigne Wood (GW) coal- used as a test coal for the CFD model
2. Russian coal
3. Russian/PKE
4. S. African coal
5. S. African coal/milled wood(20% thermal)
6. S. African/Miscanthus Giganteus (20% thermal)
7. S. African/ Olive waste (15% thermal)
8. S. African/Torrefied wood (20% thermal)

Experimental data: exit NO, T and C-in-ash, and data on radiation and flame properties for GW coal

Centre for Computational Fluid Dynamics University of Leeds

Properties of Biomass and Coals.

UNIVERSITY OF LEEDS



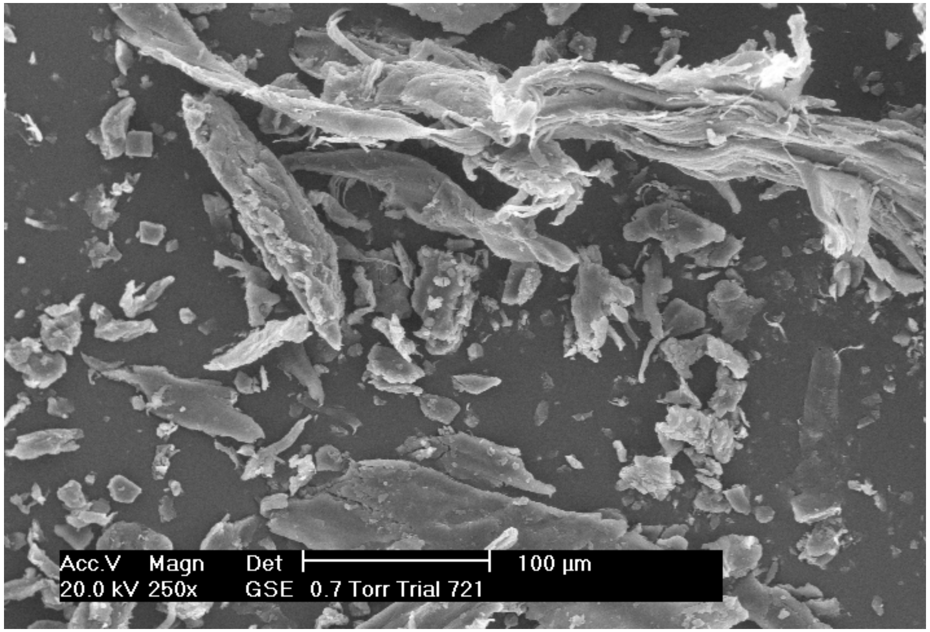
The van Krevelen Diagram for Biomass and Coal.

*Coals and most biomass have conventional properties-
PKE and Olive waste are different*

Computational Fluid Dynamics

Milled Wood.

UNIVERSITY OF LEEDS



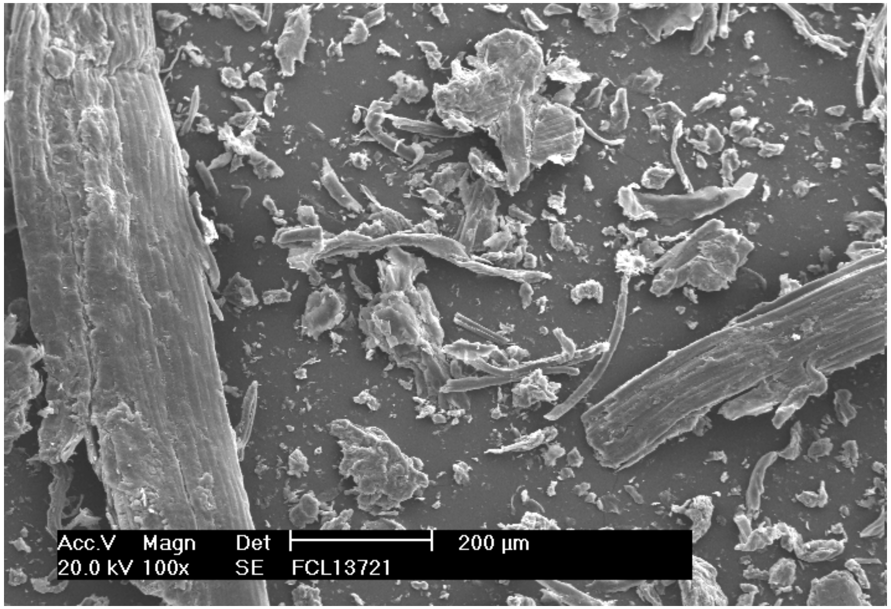
Milled Wood

Centre for Computational Fluid Dynamics University of Leeds

ERRI

Miscanthus.

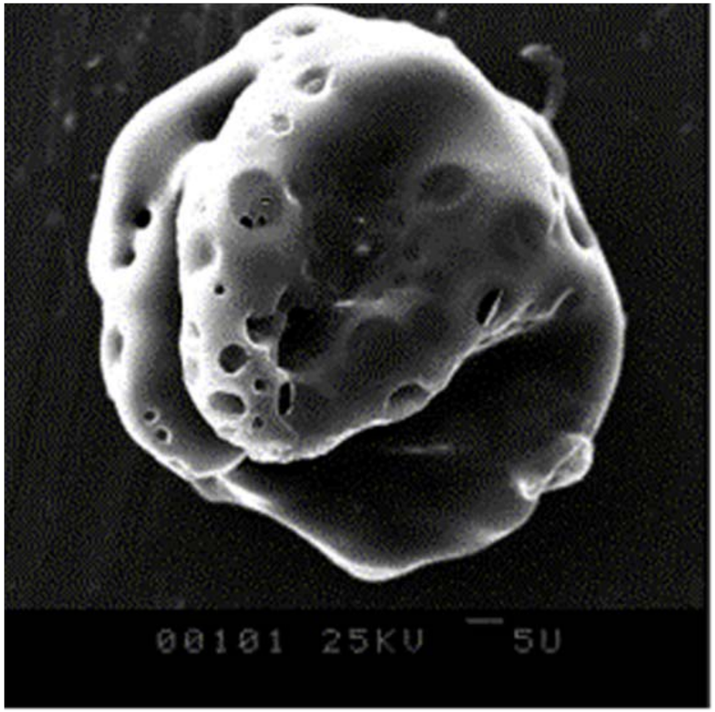
UNIVERSITY OF LEEDS



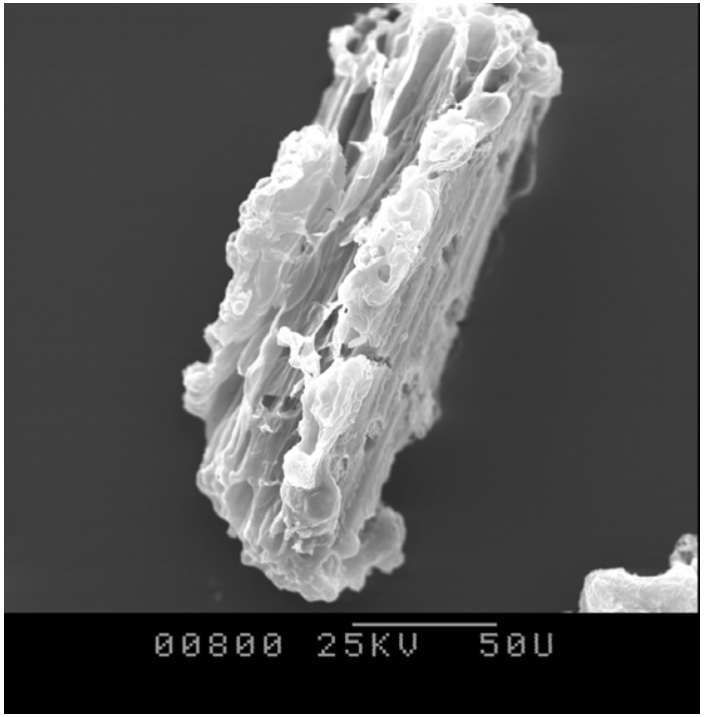
Miscanthus

Biomass combustion: particle shape is complex.

Coal



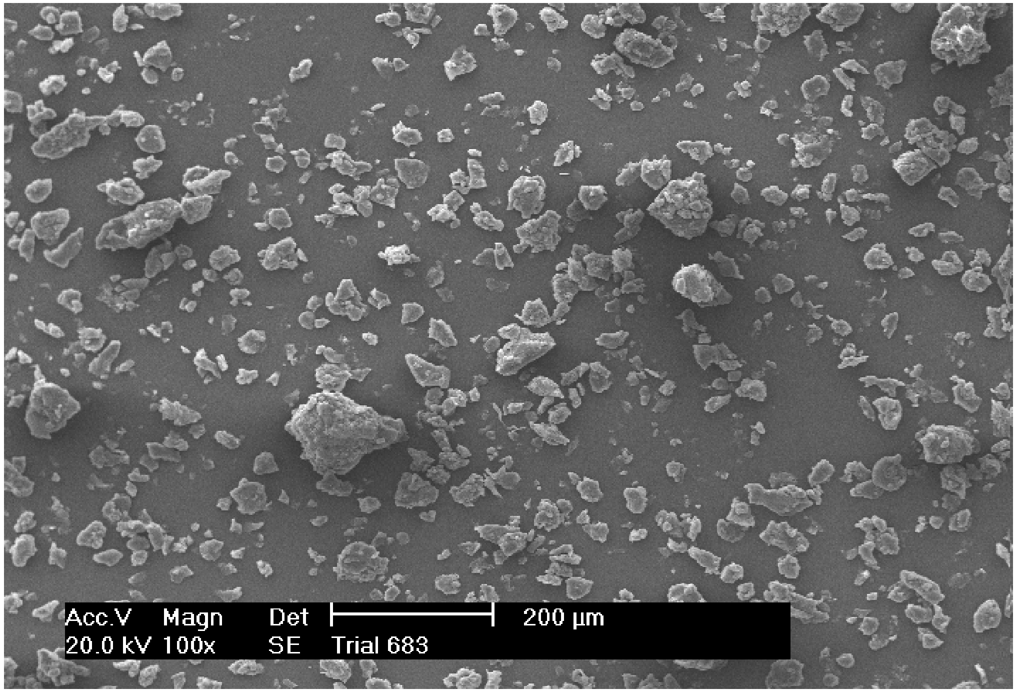
Wood



Complex drag coefficients. Shape factor given by:
f = {surface area equivalent sphere}/{actual surface area}

Palm Kernel Extractor.

UNIVERSITY OF LEEDS

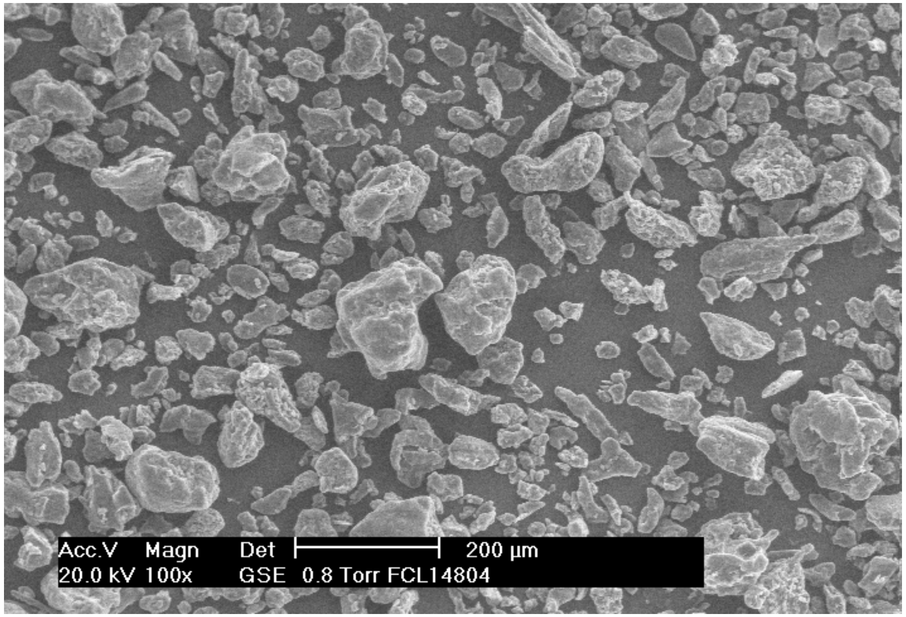


PKE

Computational Fluid Dynamics

Olive Waste.

UNIVERSITY OF LEEDS



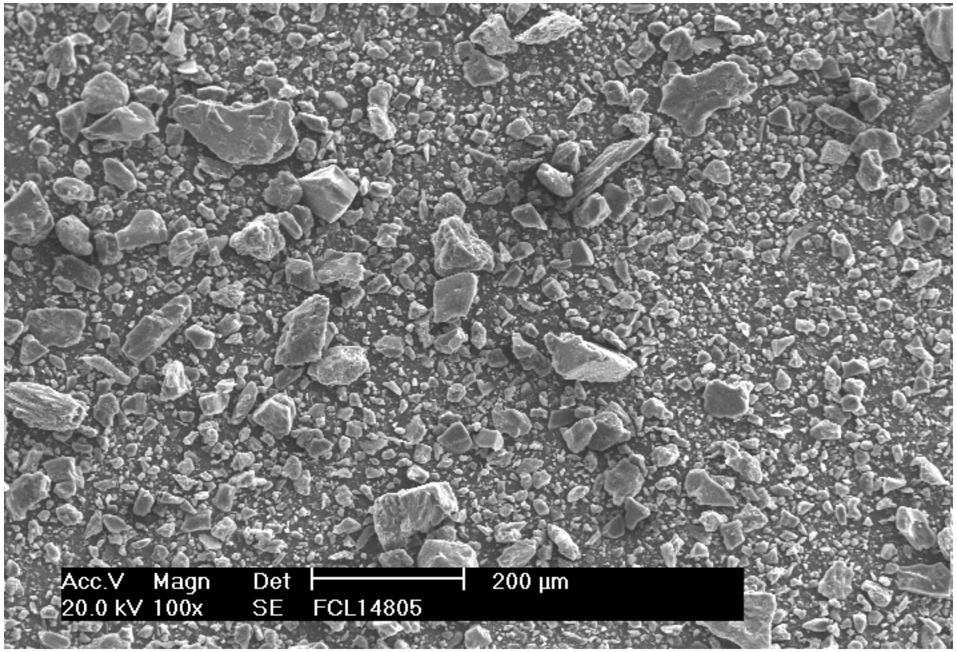
Olive Waste

Centre for Computational Fluid Dynamics University of Leeds

ERRI

South African Coal/Olive Waste.

UNIVERSITY OF LEEDS



Blend of South African coal and 15% Olive waste

Computational Fluid Dynamics

ERRI

Coal Reaction Mechanism.

UNIVERSITY OF LEEDS

Coal = char + gases + tar   R 1

volatiles + O_2 = CO + H_2O R 2

CO+ 0.5 O_2 = CO_2 R 3

C (char) + O_2 = CO   R 4

CO + O_2 =CO_2 R 5

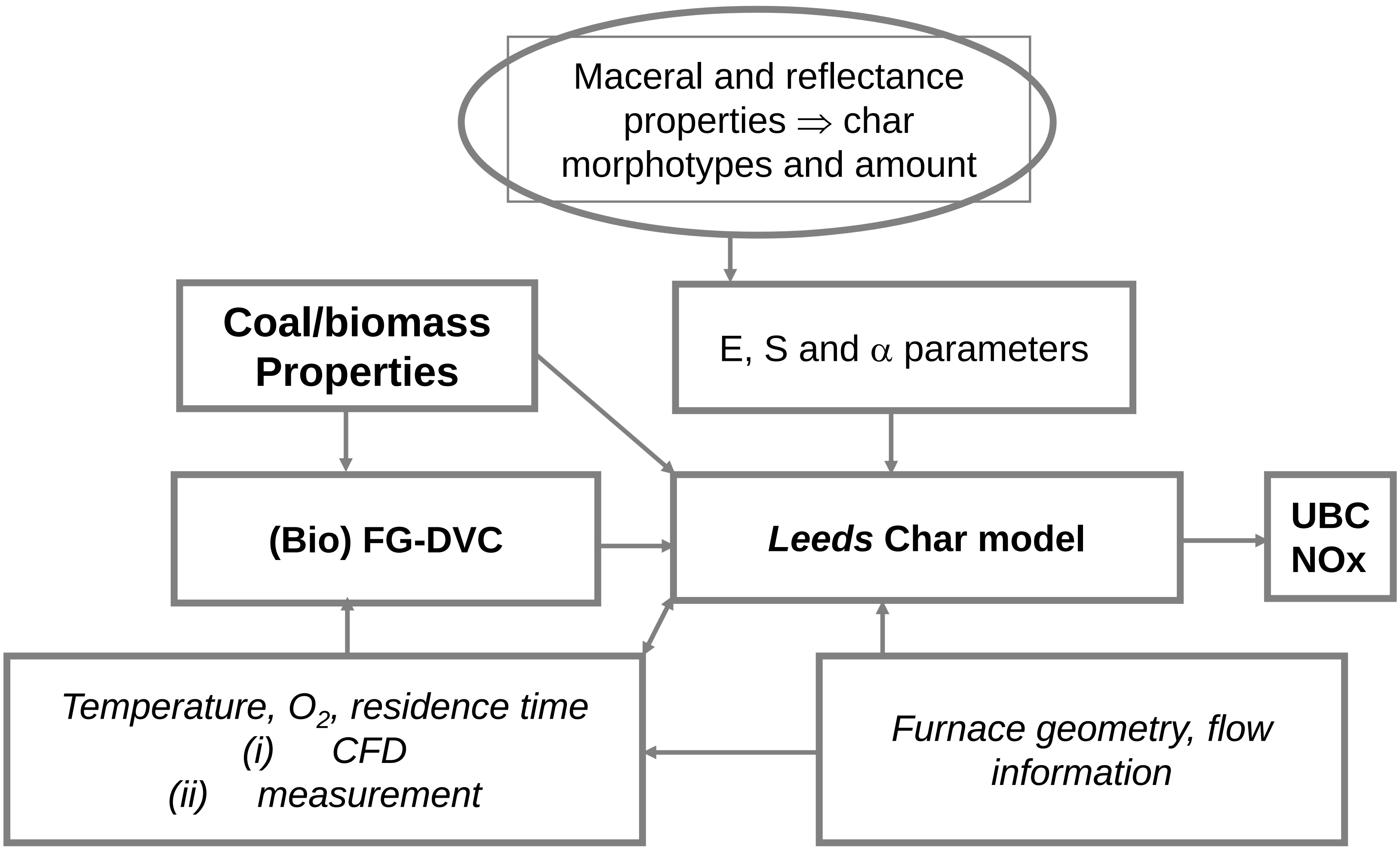
and soot formation and burnout.

A potassium release mechanism can be added if required.

Centre for Computational Fluid Dynamics University of Leeds

ERRI

Coal/biomass BURNOUT MODEL



Devolatilisation Rates of Coal.

UNIVERSITY OF LEEDS

Coal (Origin)	Devolatilisation Rates – FG-DVC computed					
	Activation Energy, E_d (J/kmol)			Pre-Exponential factor, A_d (s^{-1})		
	Tar	Gas	Total	Tar	Gas	Total
Thoresby	3.3×10^8	2.4×10^8	2.4×10^8	3.8×10^{14}	4.6×10^{13}	5.2×10^{14}
Asfordby	2.0×10^8	2.1×10^8	2.3×10^8	3.7×10^{14}	4.2×10^{13}	4.8×10^{14}
Betts Lane	2.5×10^8	2.3×10^8	2.4×10^8	2.1×10^{14}	3.2×10^{12}	3.3×10^{14}
Pittsburgh#8	2.3×10^8	2.2×10^8	2.3×10^8	3.7×10^{14}	4.8×10^{12}	3.8×10^{14}
Ensham	2.4×10^8	2.7×10^8	2.4×10^8	4.1×10^{14}	3.2×10^{14}	4.3×10^{14}
Prodeco	2.3×10^8	2.4×10^8	2.4×10^8	3.0×10^{14}	4.6×10^{13}	5.2×10^{14}

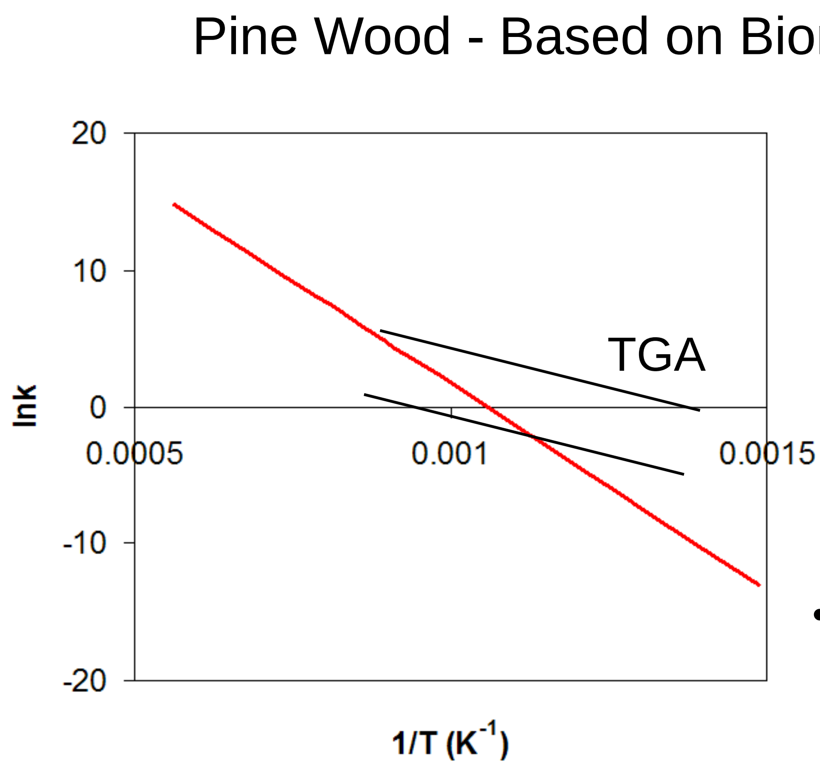
We used an averaged value for all coals.

A similarly high value was used for biomass

Centre for Computational Fluid Dynamics University of Leeds

ERRI

Biomass Devolatilisation Kinetics.



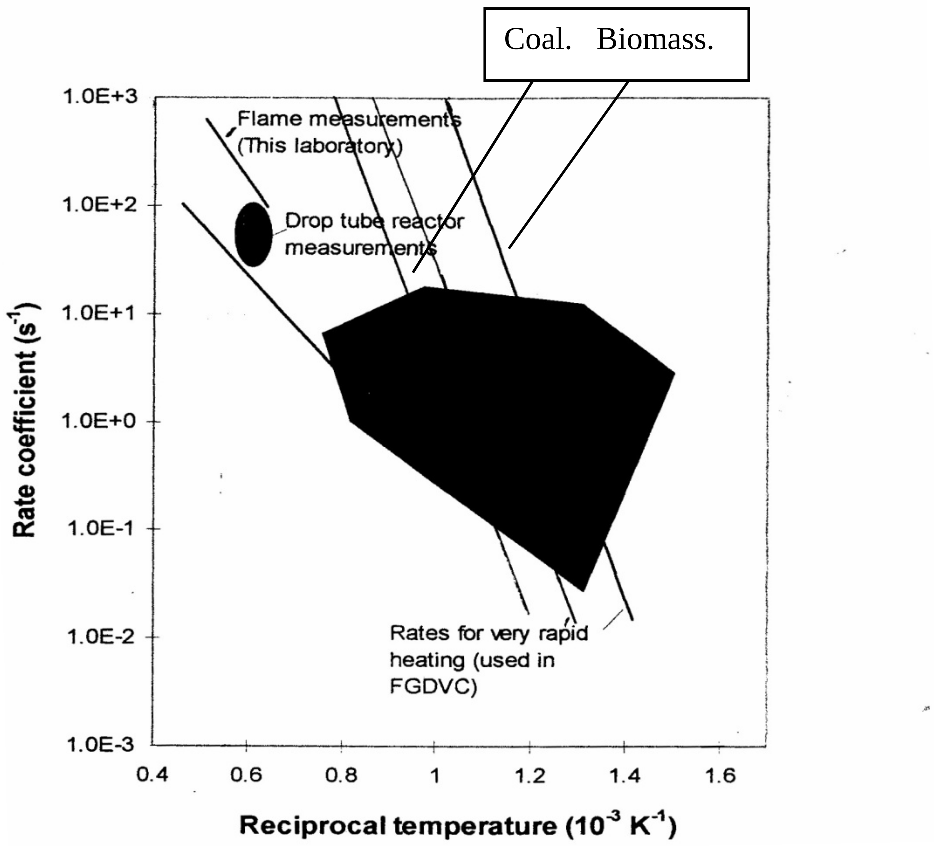
$k = A\ e^{(-E/RT)}$

A = 6.0 e13
E = 2.5 e8

Lack of high T data
- Metals effect rate

Kinetic Data.

UNIVERSITY OF LEEDS



Summary of Kinetic Analysis

The use of rapid rates implies that the controlling step is the heating-up process, T, Cp important.

Volatile Yields of the Coals Studied.

UNIVERSITY OF LEEDS

Volatile Yields (%wt, daf)

Coal	VM (daf)	Calculated, FG-DVC	Values from RWE npower	Experimental values: CRE, 1350^o C
Gascoigne Wood coal	35.11	55.1	55.5%	48.7
Russian coal	43.43	58.1	57.5 - 69.5*	58.3
South African	37.64	54.75	48.9 - 60.2*	49.92

•*From Man et al., Fuel, 2005*

Centre for Computational Fluid Dynamics University of Leeds

ERRI

Volatile Yields of the Biomass Fuels.

UNIVERSITY OF LEEDS

Volatile Yields (daf)

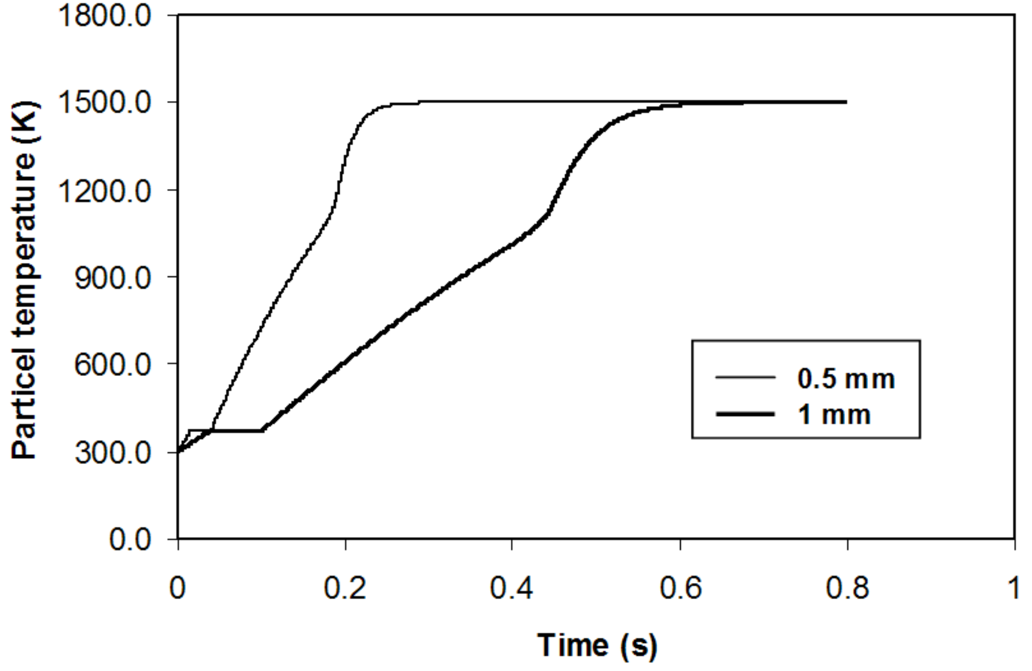
Biomass	VM (daf)	Calculated by Bio-FG	Value given by RWE npower
Milled wood	86.58.7	90.91	76.34
PKE	93.13	97.79	85.54
Olive	75.71	79.50	
Miscanthus	80.8	84.8	
Torrefied wood	75	80	

CENTRE FOR Computational Fluid Dynamics UNIVERSITY OF LEEDS

ERRI

Heating-up Curves for Large Biomass Particles.

UNIVERSITY OF LEEDS



Heating-up Curves for Biomass Particles, (0.5 and 1 mm diam, 5%water content).

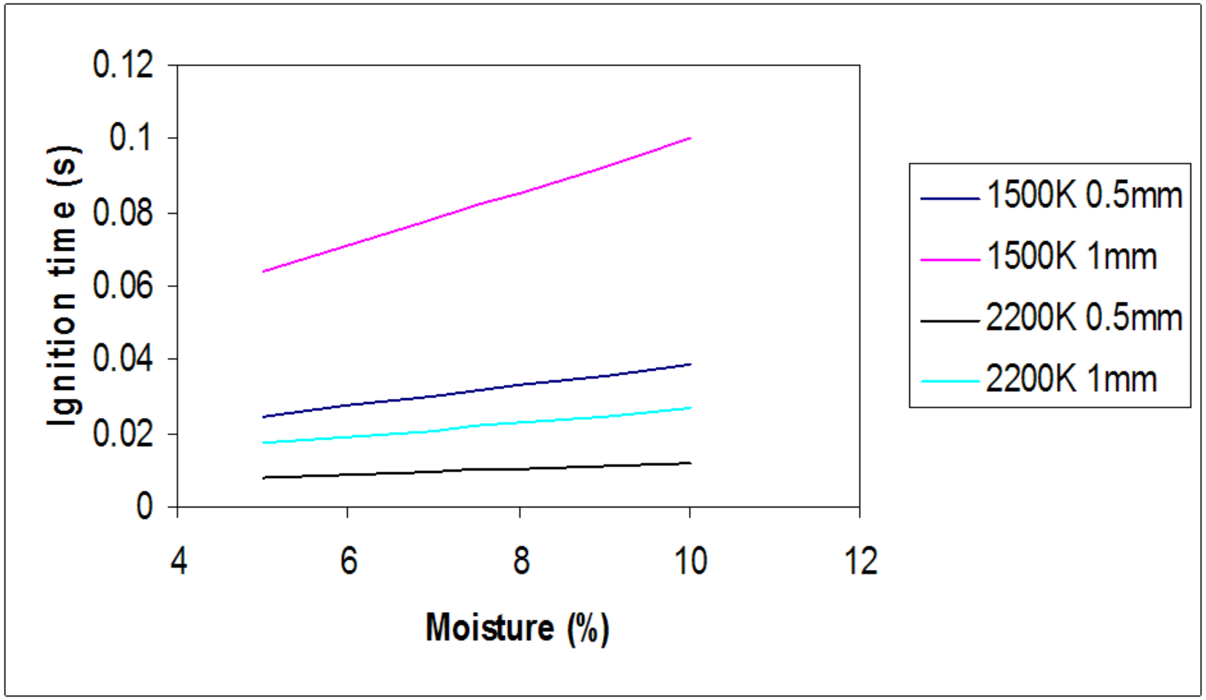
Cp and the water content are important

Centre for Computational Fluid Dynamics University of Leeds

ERRI

Effect of Moisture Content on Biomass Ignition.

UNIVERSITY OF LEEDS

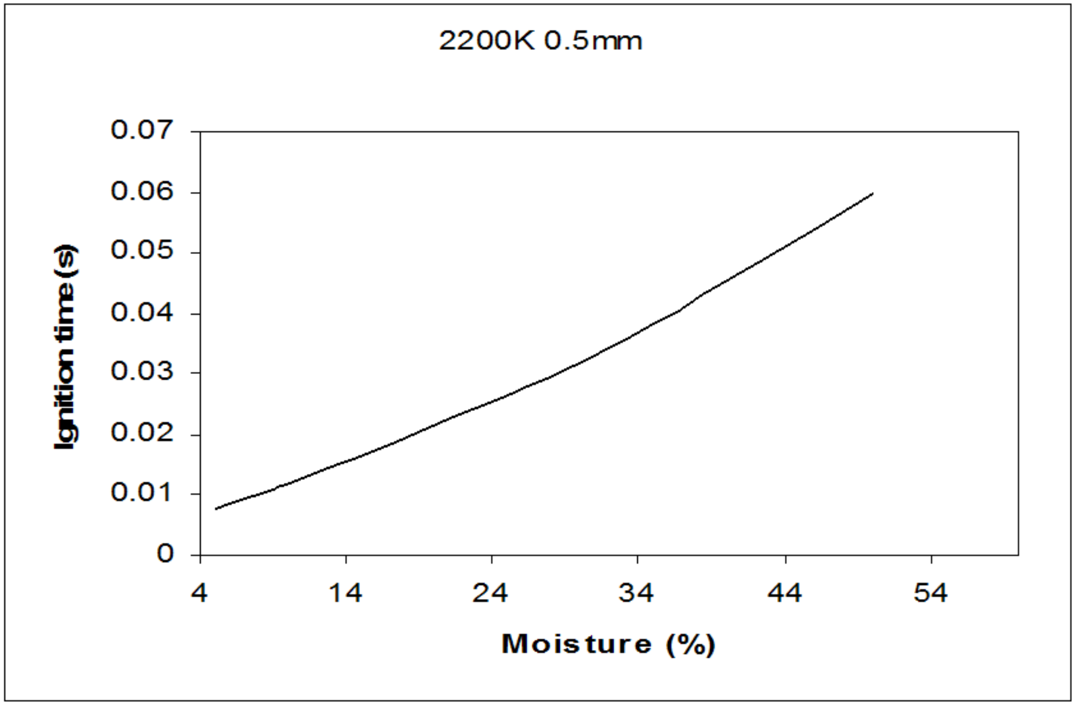


Time to Ignition (taken as the end of water evaporation) as a function of moisture content for different sized particles and temperature.

Computational Fluid Dynamics

Effect of High Moisture Content.

UNIVERSITY OF LEEDS



Ignition times for high moisture levels, 0.5 mm and 2200K.

Soot Formation.

UNIVERSITY OF LEEDS

The formation of soot was estimated by the equation below-

$$\mathcal{R}_{\text{soot,form}} = C_s p_{\text{fuel}} \phi^r e^{-E/RT}$$

The combustion of the soot particles was governed by the Magnussen equation.

Centre for Computational Fluid Dynamics University of Leeds

ERRI

RWE npower CTF

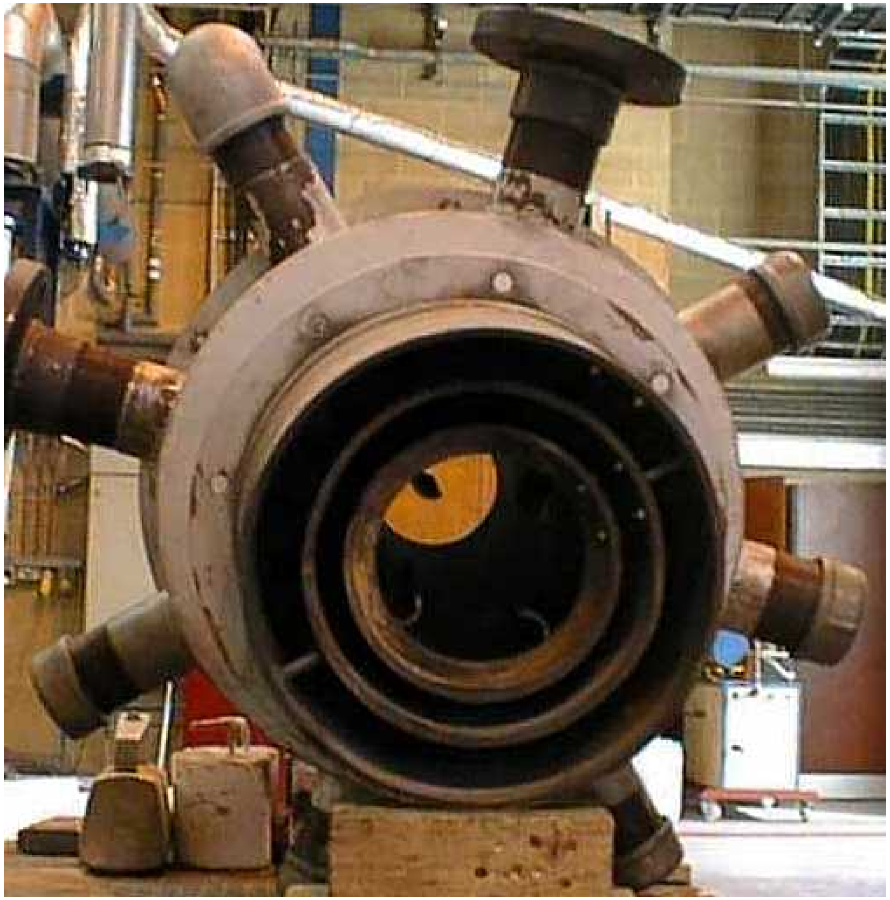
Modelling the RWE npower CTF.

UNIVERSITY OF LEEDS

Furnace Geometry

CENTRE FOR Computational Fluid Dynamics UNIVERSITY OF LEEDS

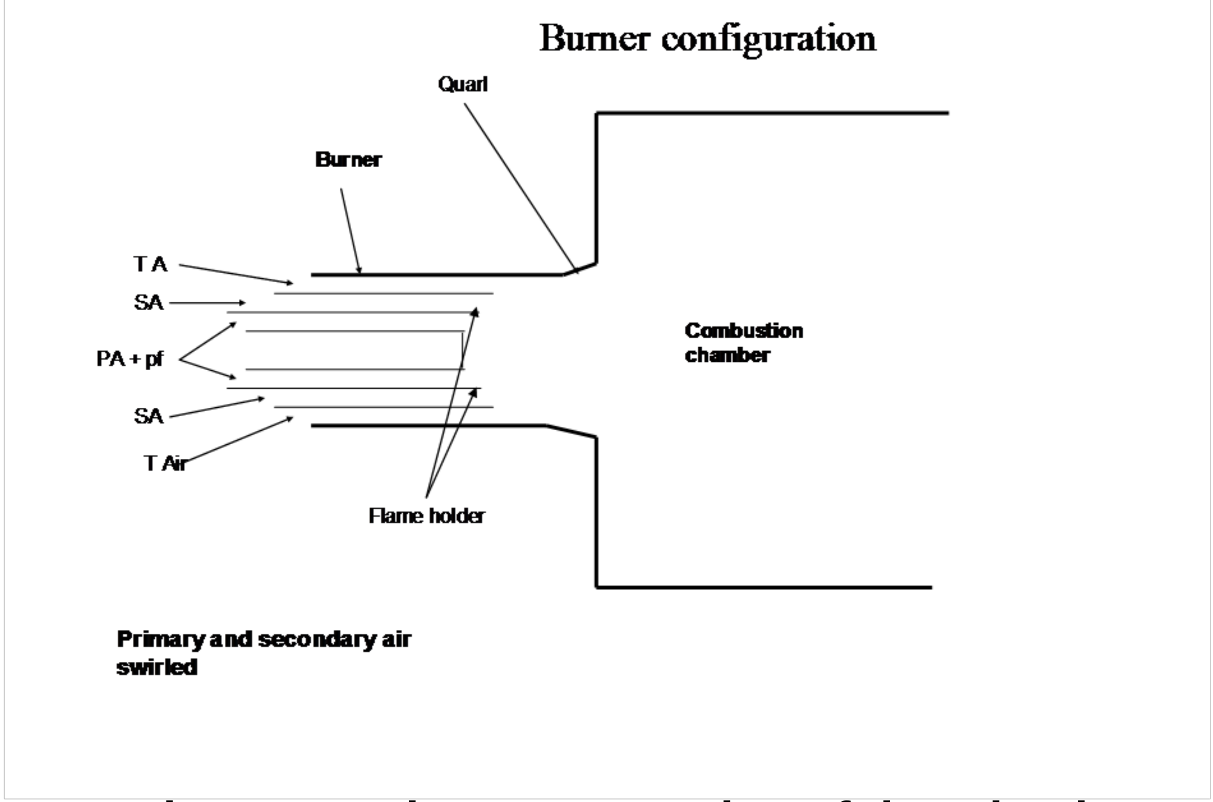
Mitsui Babcock Burner.



Burner Face Details.

Burner Details.

UNIVERSITY OF LEEDS

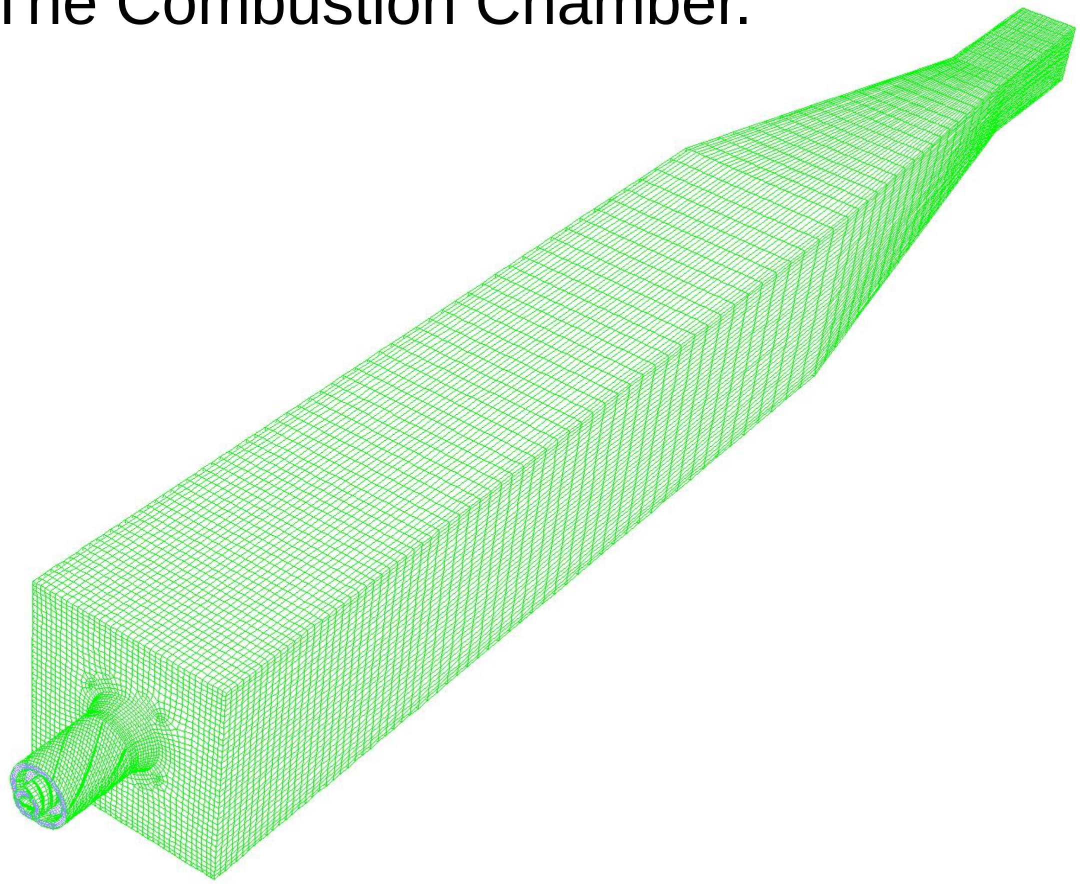


Diagrammatic representation of the Mitsui Babcock Mark III Burner.

Centre for Computational Fluid Dynamics University of Leeds

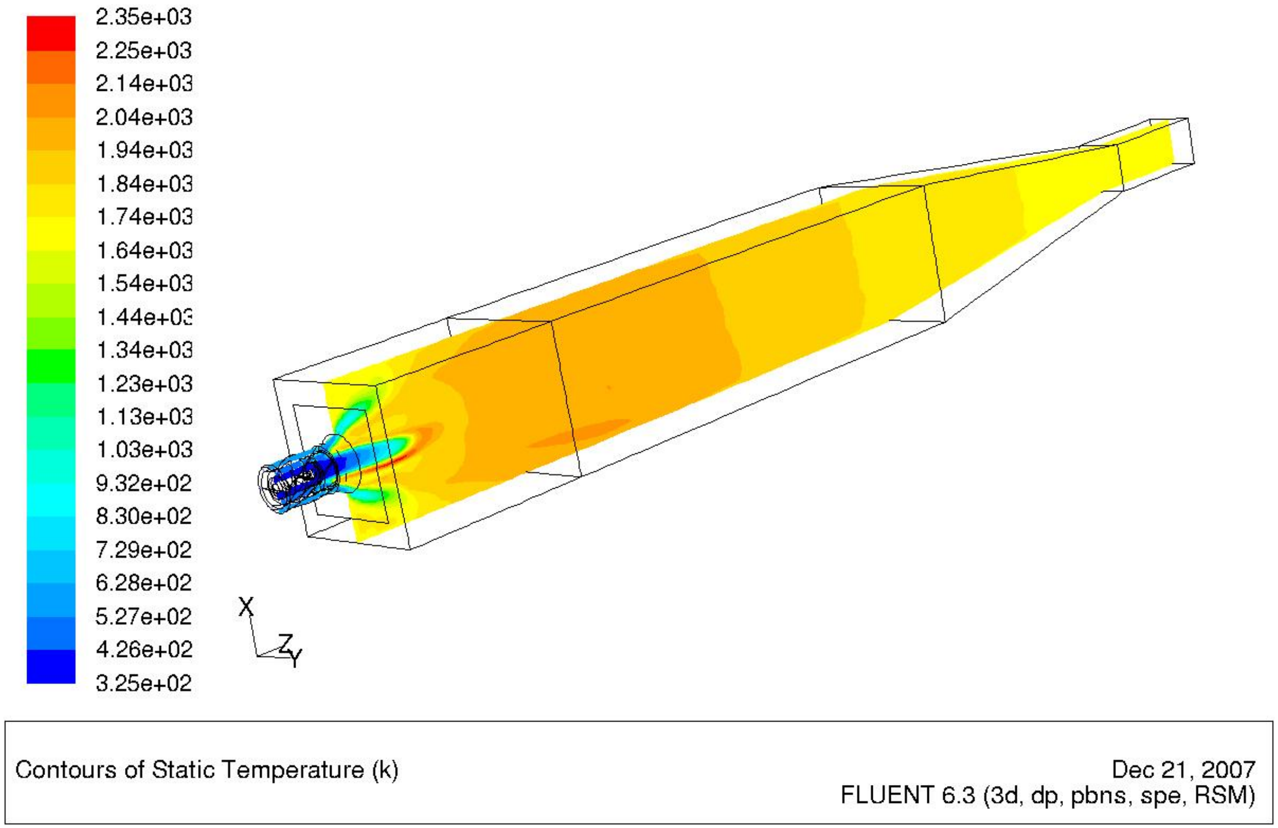
ERRI

The Combustion Chamber.



Typical Computed Temperatures.

UNIVERSITY OF LEEDS

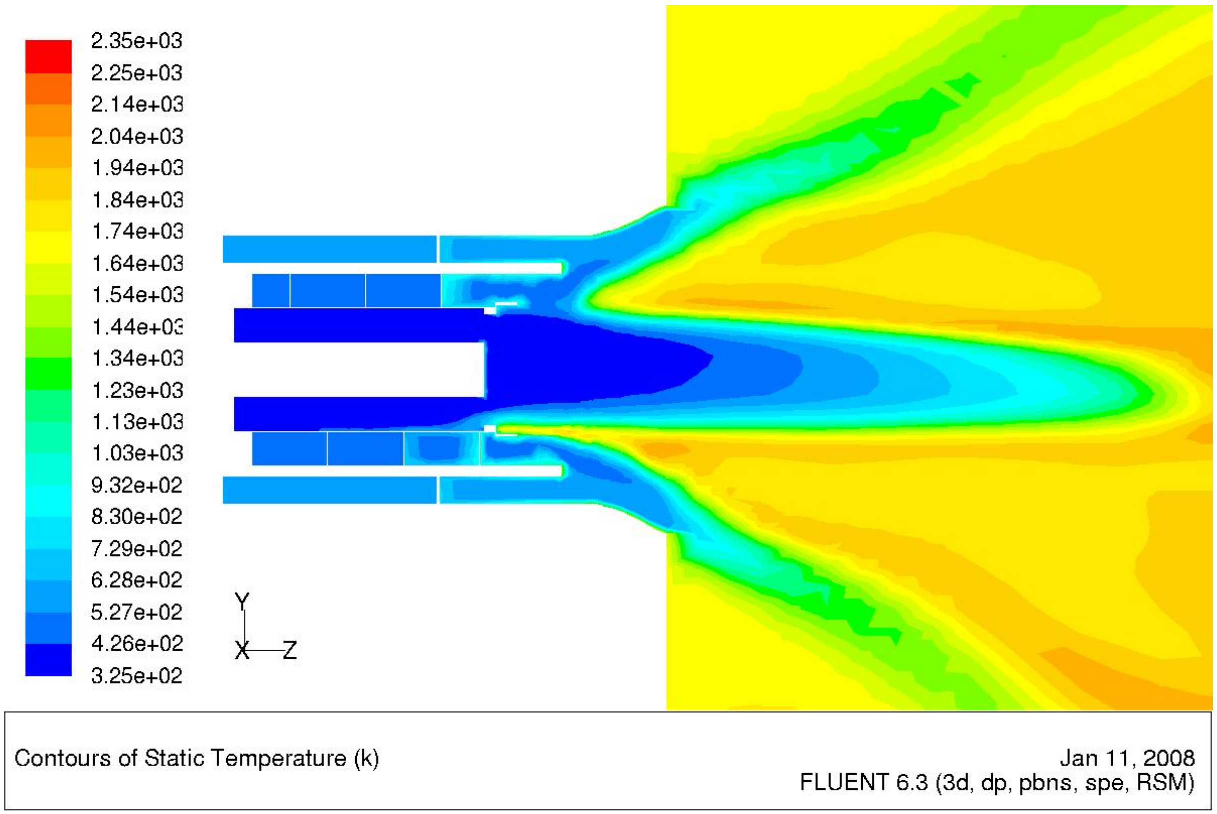


Centre for Computational Fluid Dynamics, University of Leeds

ERRI

Computation of the Near Burner Region.

UNIVERSITY OF LEEDS



Centre for Computational Fluid Dynamics University of Leeds

ERRI

Photograph of the Flame.

UNIVERSITY OF LEEDS

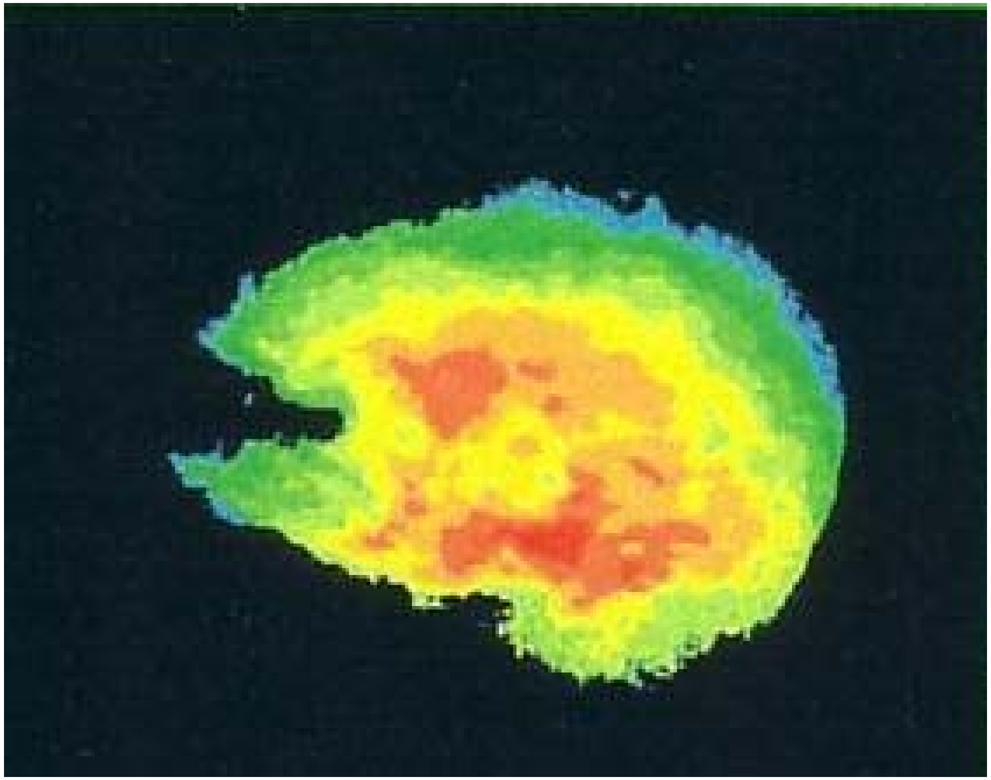
Photograph of the Flame

CENTRE FOR Computational Fluid Dynamics UNIVERSITY OF LEEDS

ERRI

Measured Temperature Field.

UNIVERSITY OF LEEDS

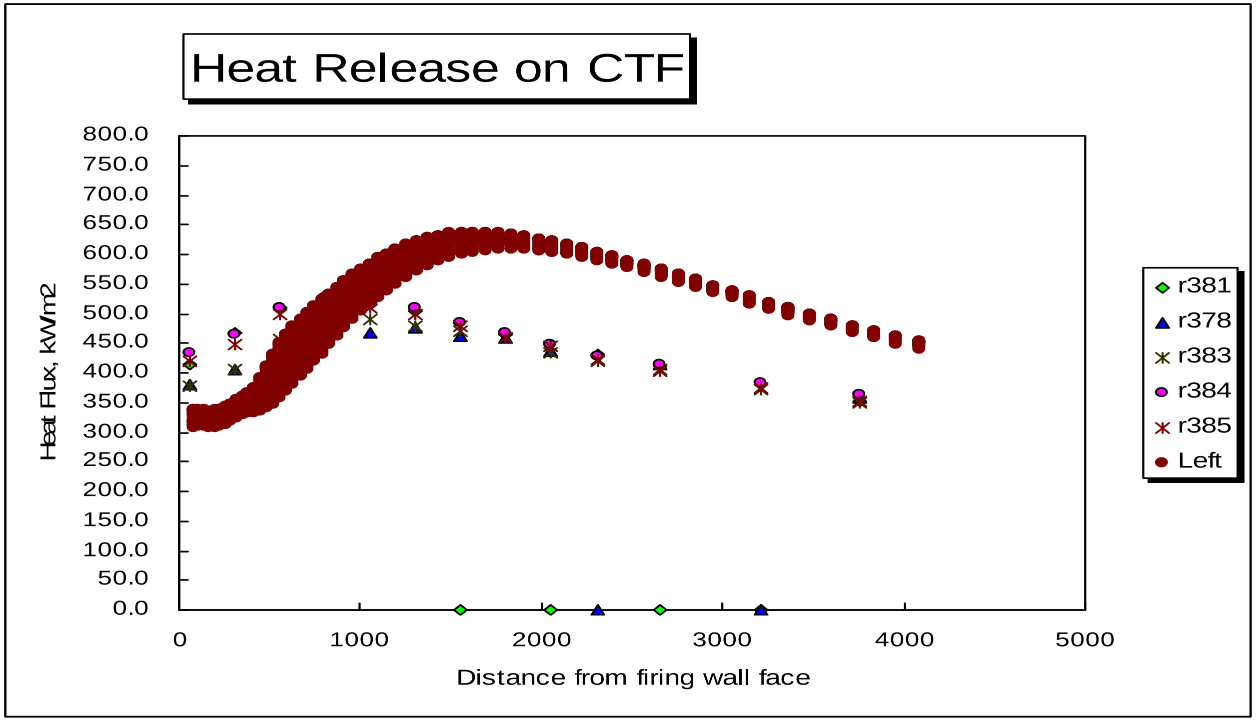


Measured Temperature Field (Professor Yan): red 1650°C; yellow,1580°C; blue/green,1450°C.

Centre for Computational Fluid Dynamics University of Leeds

Measured and Computed Incident Radiation.

UNIVERSITY OF LEEDS



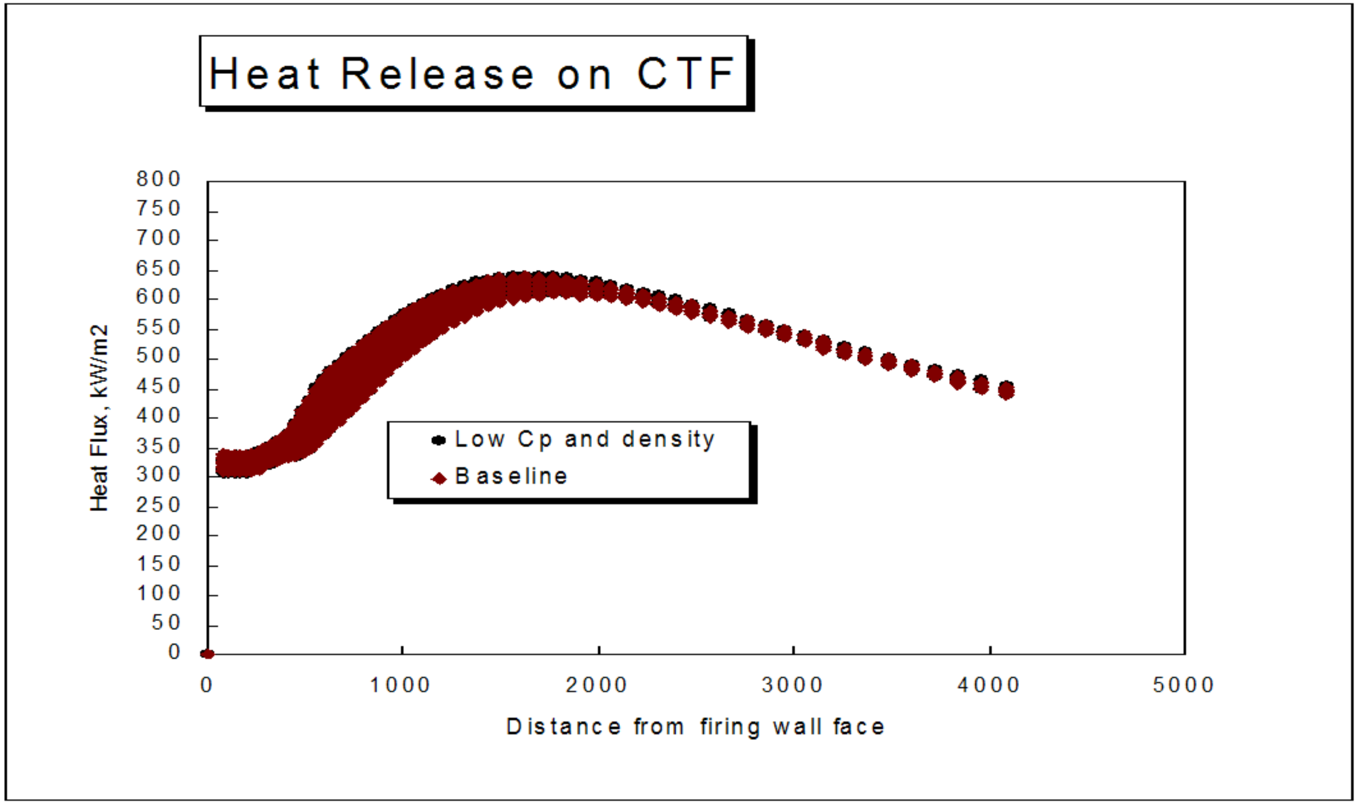
Surface Incident Radiation Measurements and Computed Values for Gascoigne Wood Coal.

Centre for Computational Fluid Dynamics University of Leeds

ERRI

Measured and Computed Incident Radiation-Effect of Cp and Density.

UNIVERSITY OF LEEDS

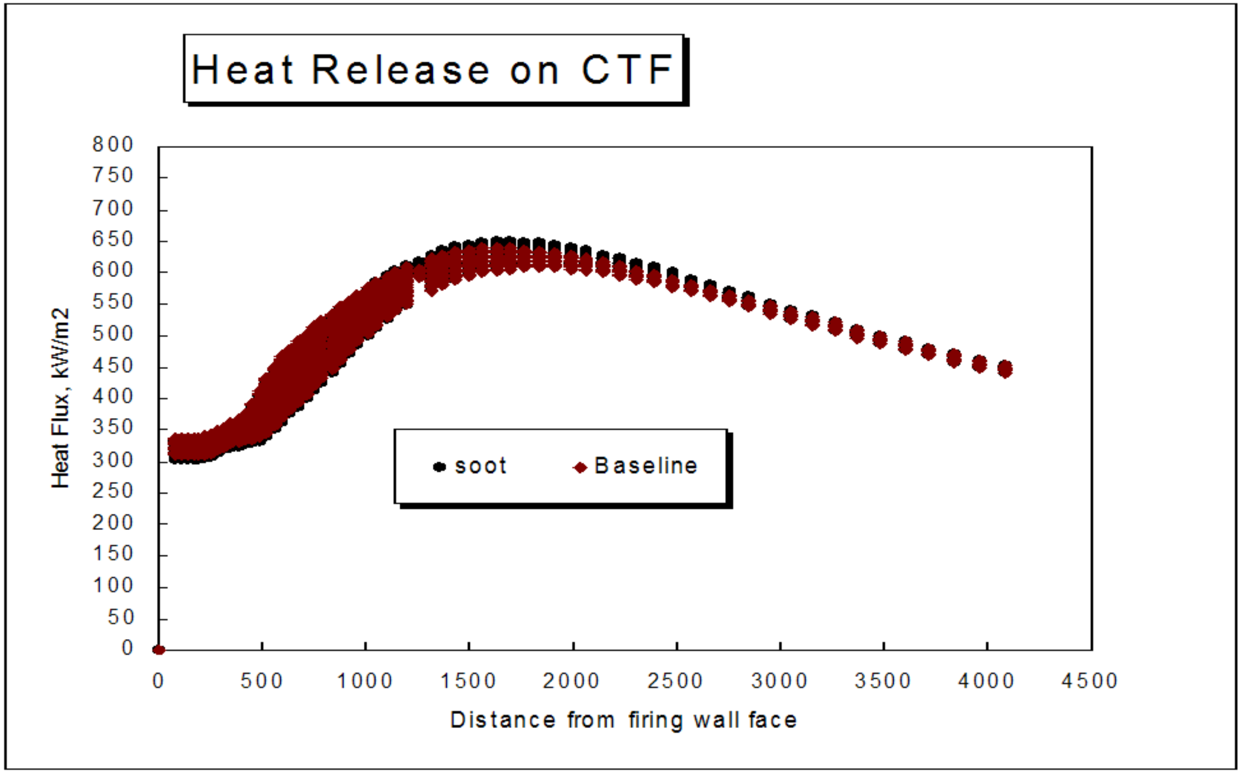


Surface Incident Radiation. Effect of Lowering Cp and Density of Fuel Particles (Gascoigne Wood) (both lowered about 10%).

Centre for Computational Fluid Dynamics, University of Leeds

Effect of Changing Rate of Soot Formation.

UNIVERSITY OF LEEDS



Surface Incident Radiation. Effect of Soot Formation is small (Gascoigne Wood).

Co-firing - Irregular Shaped Biomass Particles.

UNIVERSITY OF LEEDS

Aerodynamic Factors

The drag coefficients, C_D, were calculated as below and shape factors, f, were used to account for the irregular biomass particles shapes.

$$C_D = (24/Re)(1 + b_1 Re^{b_2}) + [b_3 Re/(b_4 + Re)]$$

$b_1 = 2.3288 - 6.4581f + 2.4486f^2$

$b_2 = 0.0964 + 0.5565f$

$b_3 = 4.9050 - 13.8944f + 18.4222f^2 - 10.2599f^3$

$b_4 = 1.4681 + 12.258f - 20.7322f^2 + 15.8855f^3$

Centre for Computational Fluid Dynamics, University of Leeds

ERRI

Examination of Combustion of Single Particles of Biomass.

UNIVERSITY OF LEEDS

Examination of the Combustion of a Single Particle of Wood

There is little disruptive burning. A major issue is the use of equivalent spheres in the combustion model

Centre for Computational Fluid Dynamics University of Leeds

ERRI

NO Formation.

UNIVERSITY OF LEEDS

The NO model used in Fluent permits the N-component in the fuel to be converted to HCN or NH_3 which is then oxidised to NO and N_2 depending on the reaction conditions.

In coal it is known that the fuel-N converts to HCN.
In biomass the fuel–N is in the form of proteins or amino acids and is converted to a mixture of NH_3 + HCN.

For the biomass used here we have allowed it to be converted to 90% NH_3/ 10% HCN which then reacts to form NO.

Centre for Computational Fluid Dynamics University of Leeds

ERRI

Co-firing Biomass and Coal.

UNIVERSITY OF LEEDS

Experimental Furnace Flame Shape.
The flame divergence is greater with biomass

Centre for Computational Fluid Dynamics University of Leeds

Experimental and Computed Results for Single Coals and Co-firing Blends ..

UNIVERSITY OF LEEDS

Fuel	Calc NO ppm (dry)	Measured NO ppm (dry)	Calc C in Ash, Mass %	Measured C in Ash, Mass %	Calculated exit T, K	Experimental Exit T, K
Gascoigne Wood coal	300	325	1.32	3.0	1605	1597
Russian coal	296	325	1.24	3.4	1617	1407
Russian/PKE	316	321	3.5	4.8	1487	1488
S. African coal	292	312	5.87	6.7	1668	1424
S. African coal/ wood	288	319	5.6	5.9	1583	1527
S. African/ Miscanthus (20%)	250	242	8.9	1.94	1664	1470
S. African/ Olive waste (15%)	276	230	0.62	0.98	1646	1539
S. African/Torrefied Wood* (20% thermal)	264	Not available	0.3	Not available	1724	Not available

Comparison of Experimental and Computed Data.

Centre for Computational Fluid Dynamics University of Leeds

ERRI

Conclusions

•A coal combustion model has been tested using Gascoigne Wood coal with the RWE npower Combustion Test Facility. Reasonable agreement has been obtained for exit temperatures, NO, unburned carbon-in-ash. However agreement with the radiation measurements is not good. The influence of heating-up of the particles, and the devolatilisation and soot models have been examined, but the key factor seems to be the correct aerodynamic modelling of the burner.

•In the case of biomass the behaviour of water content has been examined and the effect on the release of volatiles from large biomass particles examined.

•Co-firing of wood, miscanthus, PKE and olive wastes with a number of coals has been modelled with reasonable success..