School of Chemical and Process Engineering

FACULTY OF ENGINEERING

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Modelling the emissions from a fuel flexible power plant and the impact on NOx emissions of coal with biomass ash in co-combustion

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EPSRC Pioneering research and skills

Comparison of standards for emissions from thermal power plants >50MW_{th}

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Pollutant	Power Plant Status	Emissions Standard, mg/Nm3		
		China	United States	Europe (BREF)
NOX	New	100	117	85
	Existing (built in the last 20 years)	100-200	117-160	150-175
SOX	New	100	160	75-320
	Existing	200-400	160	130-320
Dust	New & Existing	30	23	5-12

BREF-Best Available Technique Reference Document. Europe's Coal-Fired Power Plants: Rough Times Ahead Analysis of the Impact of a New Round of Pollution Controls. G. Wynn and P. Coghe. 2017
http://www.chinafaqs.org/files/chinainfo/China%20FAQs%20Emission%20Standards%20v1.4_0.pdf

NOX reduction strategies

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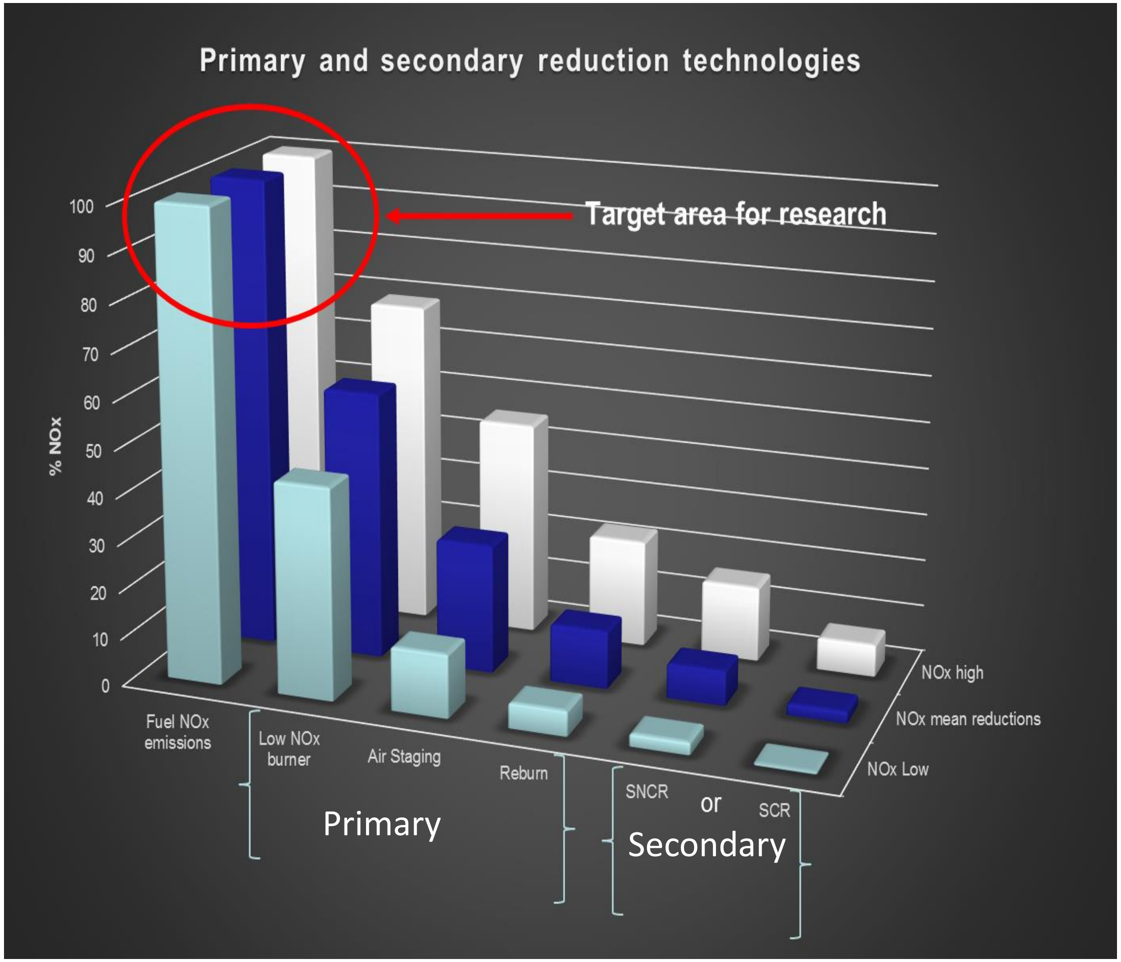

Reduction strategies	% NO_X saving
Low NOX burners	30-55%
Air staging	35-70%
Reburn	60%
SNCR	30-50%
SCR	90%

Technology	Load Factor, %	Emissions Rate, mg/Nm3	BREF Limit, mg/Nm3	Capital Cost, €/MW	Cost per Unit Power Generation, €/MWh
SCR	30%	<100	150-175	€ 138,000	€ 3.30
	70%	<100	150-175	€ 138,000	€ 1.91
SCR Upgrade	30%	100-200	150-175	€ 27,600	€ 0.90
	70%	100-200	150-175	€ 27,600	€ 0.63
SNCR/ SCR Hybrids	30%	<100 – 150	150-175	€ 120,000	€ 3.97
	70%	<100 – 150	150-175	€ 120,000	€ 2.76

NOX in pulverised coal combustion. Stuart C Mitchell April 1998 CCC/05
Europe's Coal-Fired Power Plants: Rough Times Ahead Analysis of the Impact of a New Round of Pollution Controls. May 2017 G Wynn, P Coghe.

Aim and objectives

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- Use additives to change the combustion characteristics of coals used for power production
- A particular focus is placed on the reduction of NO_X emissions through changing the N-partitioning during early stages of combustion
- Construct a model for the prediction of devolatilisation of coal in a drop tube furnace
- Build an operational model for calculating the emissions from a large scale furnace

Experimental measurements

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Experimental measurements have been taken for validation and calibration of the model

The experimental procedure and results can be found in:

Birley RI, Jones JM, Darvell LI, Williams A, Waldron DJ, Levendis YA, Rokni E, Panahi A. (2018). *Fuel flexible power stations: Utilisation of ash co-products as additives for NOx emissions control. Fuel 251, pp 800-807.*

Birley et al, 2018 https://doi.org/10.1016/j.fuel.2019.04.002

https://www.sciencedirect.com/science/article/pii/S0016236119305496?via%3Dihub

Fuels and additives

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Fuel/additive	Nitrogen % (db)	Carbon % (db)	Fuel ratio
Coals (4)	0.9-1.7	64-78	1.2-10.8
Biomass bottom ash (FBA)	0.12	40	3.28
Biomass fly ash (PFA)	0.03	4	0.63

$$\text{Fuel ratio}=\frac{Fixed\ carbon}{Volatiles}$$

Catalytic effect of alkali/alkaline earth metals on devolatilisation

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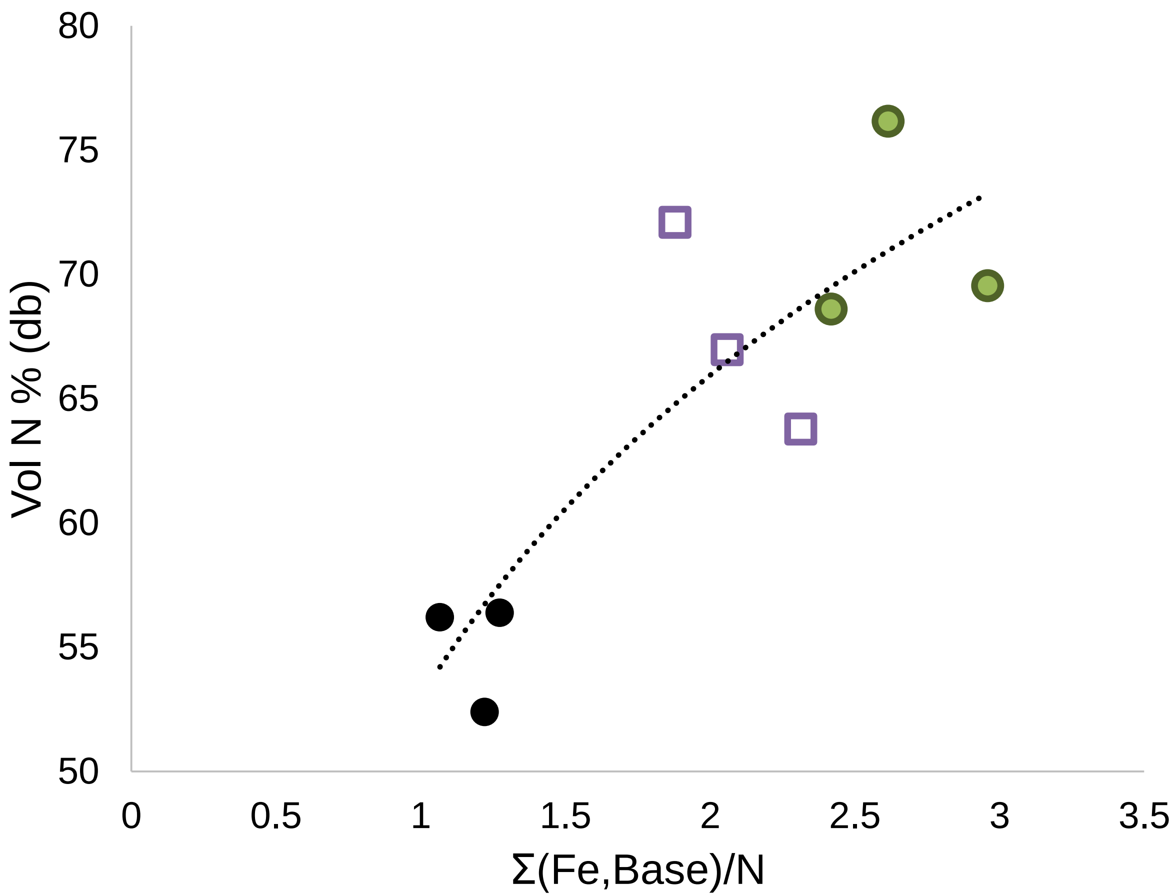

Volatile N release (DTF) as a function of mass ratio of alkali and alkaline earth metals to N-content of the feed, Σ(basic components in the feed)/N. Symbols: ● Coals, ● Coals+PFA, □ Coals+FBA, ◆ Olive cake, ◊ olive cake+coal PFA. Birley et al 2018.

Experimental work showed an increase in volatile N release with an increase in reactive components Fe, Na, Mg, K, Ca

All coals and biomass under test showed an increase in volatile N as percentage of additives increased.

The trend line relationship indicates the catalysis is initially highly effective, then become less so with increased additives. This may be due to nano-particle saturation of the catalytic surfaces

Carbon conversion as a function of reactive components in the additives

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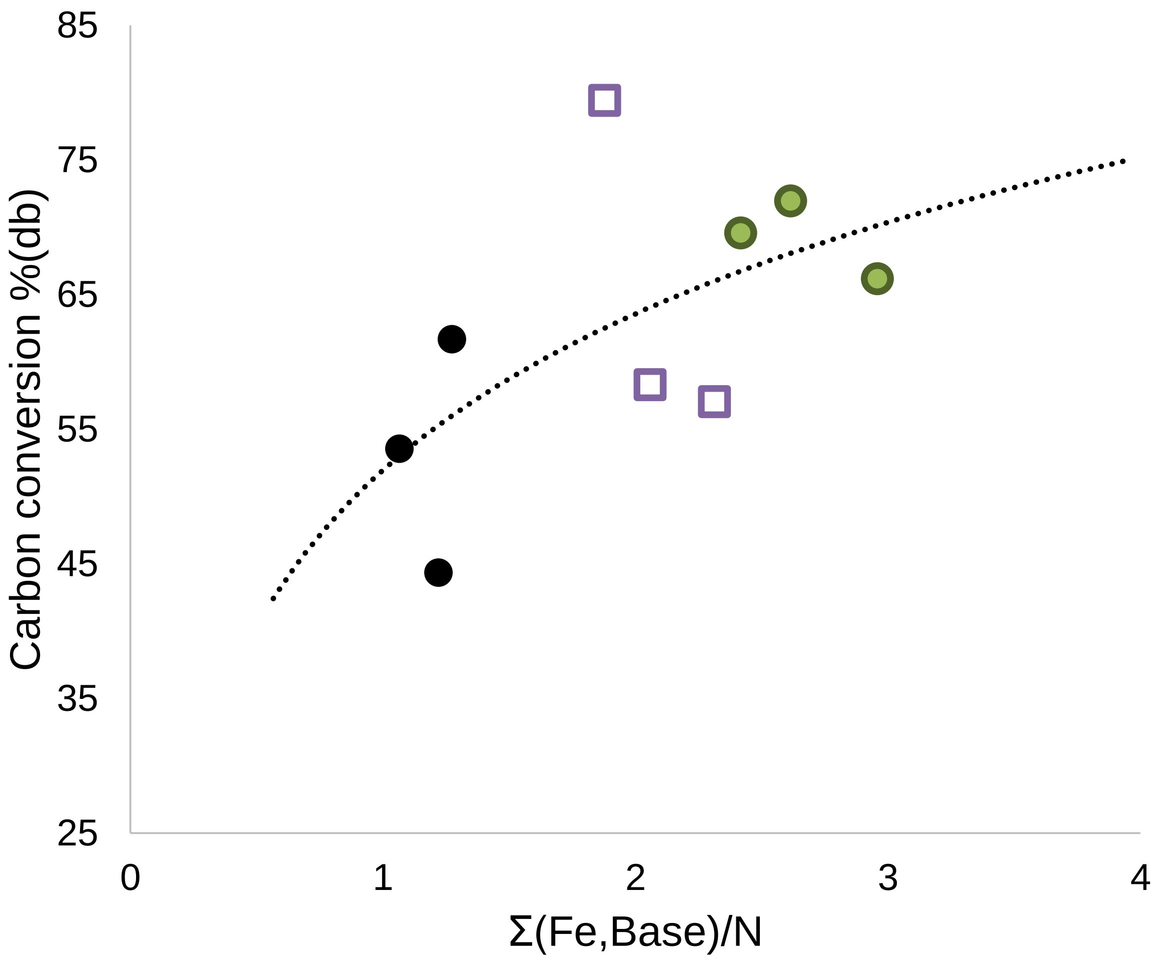

The carbon conversion shows a similar trend to the volatile N release across all of the fuels, with increases in carbon conversion as the reactive components increased.

The carbon conversion becomes less effective with larger amounts of additive, indicating a saturation of the catalyst surfaces.

Carbon conversion (DTF) as a function of mass ratio of alkali and alkaline earth metals to N-content of the feed, Σ(basic components in the feed)/N. Symbols: ● Coals, ● Coals+PFA, □ Coals+FBA, ◆ Olive cake, ◊ olive cake+coal PFA. Birley et al 2018.

Concepts of the model

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Different coal ranks and coal types devolatilise at different rates:

- Rates of devolatilisation of functional groups within coals are independent of the coal type
- The chemical composition of the tars is based on the composition of the virgin coal

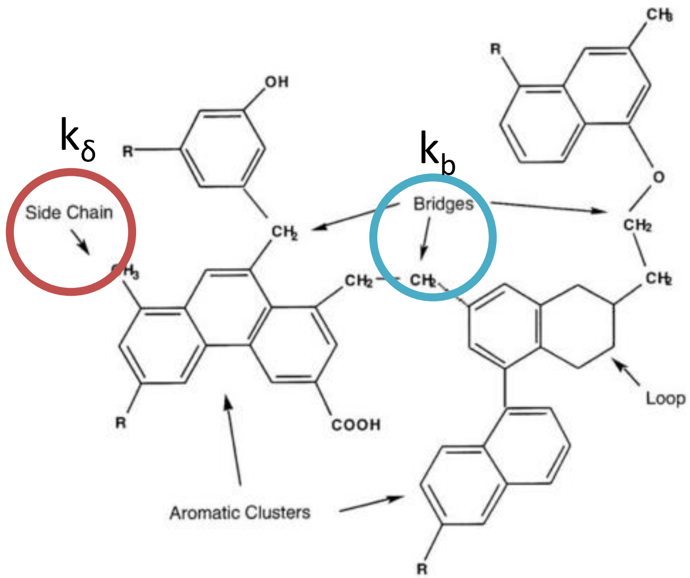
NO_X emissions are governed by:

- Fuel NO_X (primary area of interest as it accounts for >75% of NO_X)
- Thermal NO_X
- Prompt NO_X

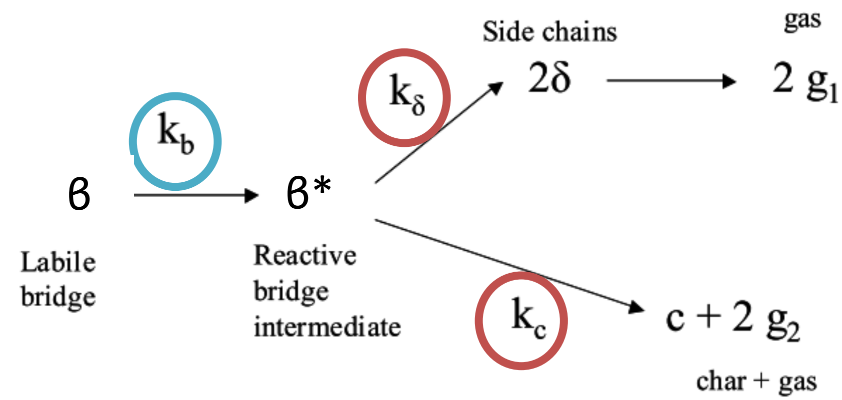
The output of each model is dependent on a series of sub-routines. The outputs are derived from:

- Chemical percolation and devolatilisation (CPD model)
- Carbon burnout kinetics (CBK8-Waldron 2005)
- NO_X model
- Slice model

Thermal decomposition of coal

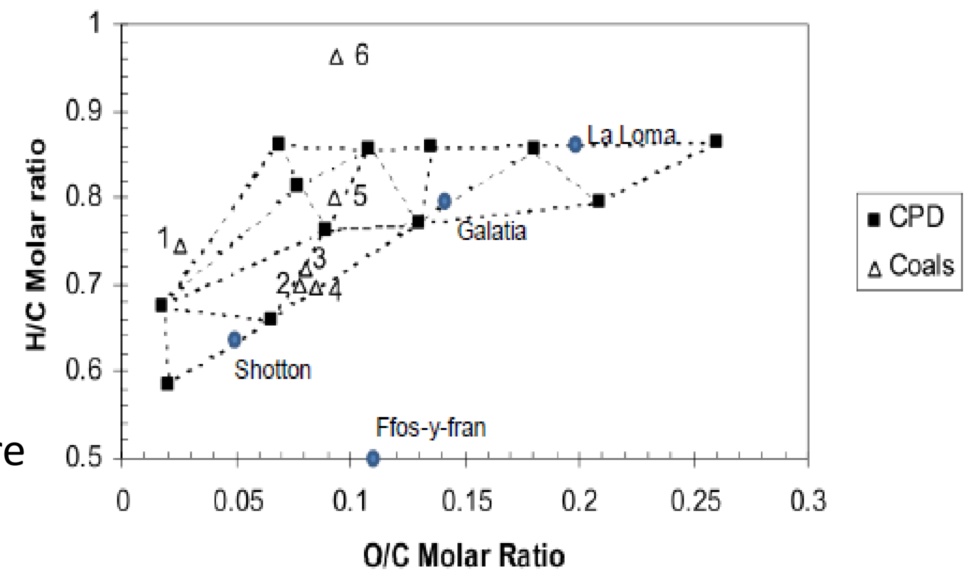


Representation of a coal structure (fletcher 1992)



Representation of reaction pathways

- Initial bonds broken are:
  - Labile bridge k_b
  - Side chains k_δ
- K_δ/k_c can be used to determine the catalytic effect of the additives on the fuel for the release of high temperature volatile yield (HTVY)
- Compared against CPD library coals



Van Krevelen representation of the CPD library

Comparison of model prediction to experimental data HTVY (additives at 15% w/w)

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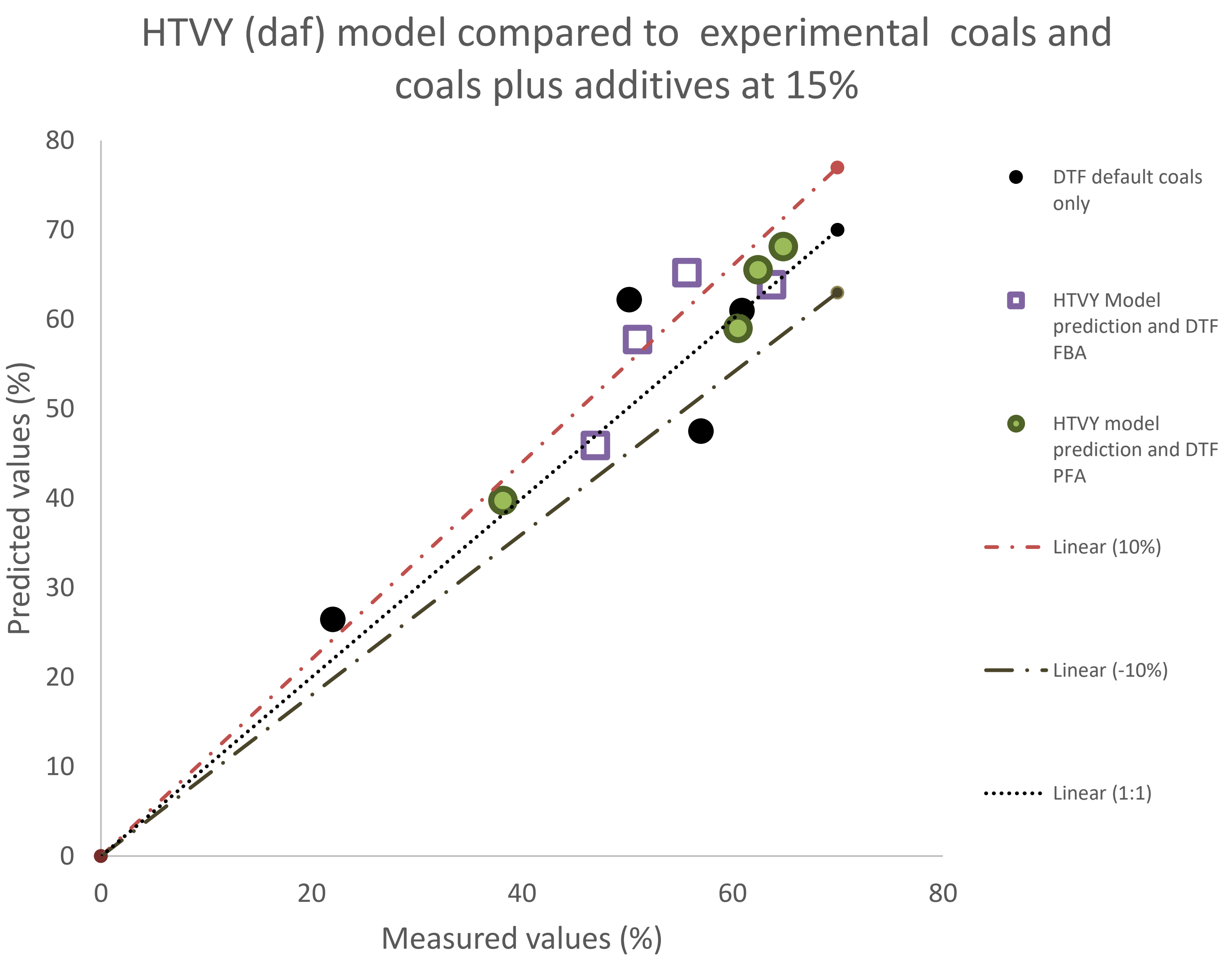
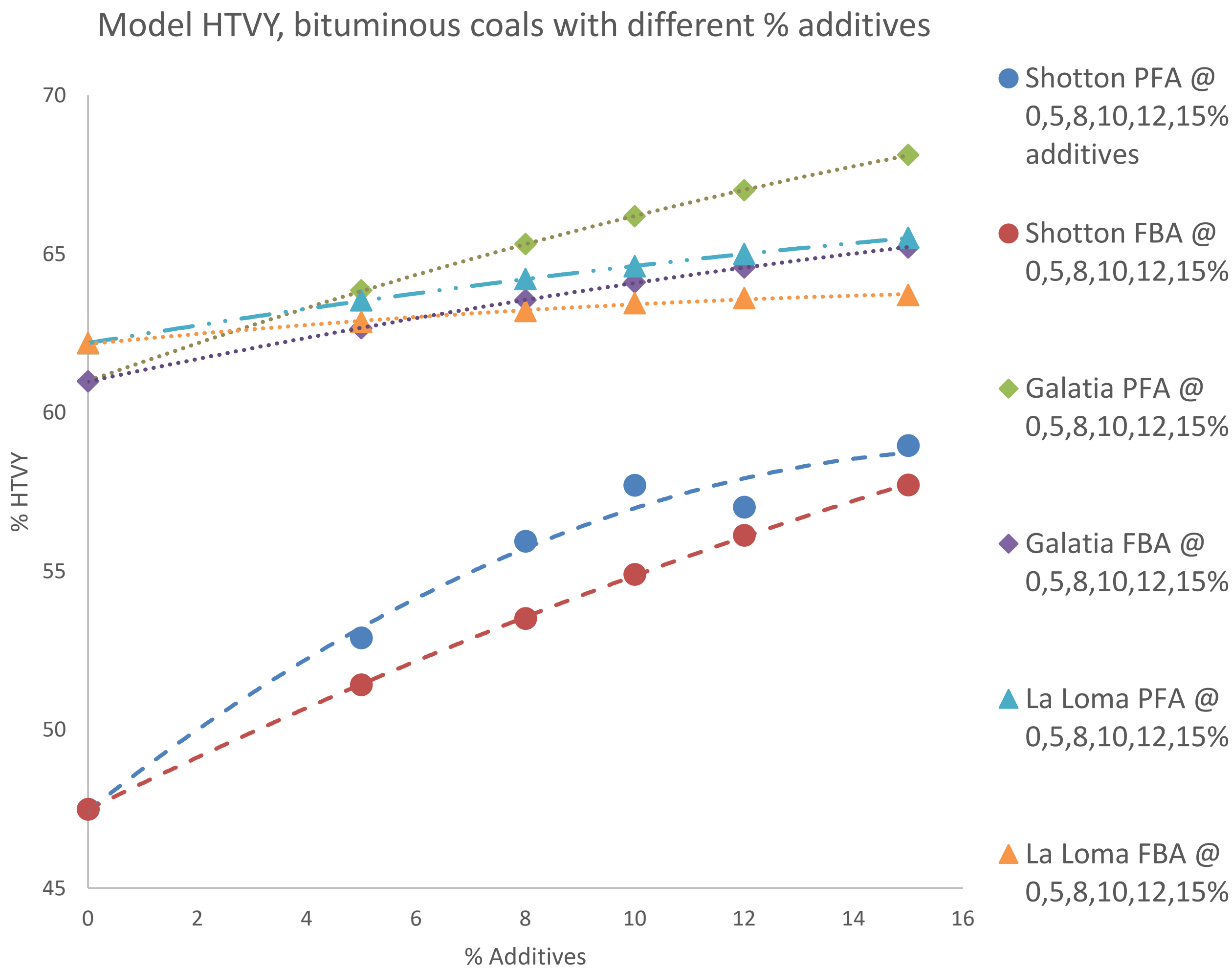


Despite the coals being spread across a range of characteristics, when the model is optimised, predictions of HTVY, compare well to experimental data

Calibration of HTVY model prediction



As the % of additives increases so the % HTVY increases

The calibration line is different for each coal type and additive (as expected)

Calibration of the CPD model enables interpolation beyond measured data.

Nitrogen release from coals

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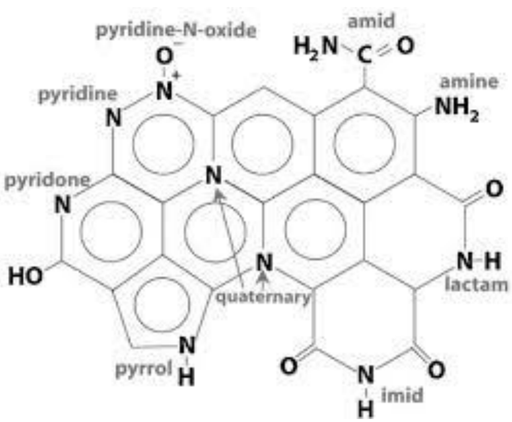
Nitrogen is released from the fuel as:

- Volatile
- Tar nitrogen
- Char nitrogen

$$k = Ae^{\frac{-Ea}{RT}}$$

Using the equation above (Arrhenius), we can make adjustments to the activation energy Ea and the pre-exponential factor *A* to calibrate the volatile N release values within the model.

Adjusting *A* (s^{-1}) , changes the slow light gas at high temperature, the factor controlling the nitrogen release as the char forms. This is optimised against experimental data.



Tar-N (loss of N from tar clusters)

Young char-N

Char-N → Slow light gas (loss of HCN at high T)

- Overall release rate of N is the sum of these routes.
- Predicted from the coal structural data in the model.

Comparison of predicted volatile N to experimental data (additives at 15% w/w)

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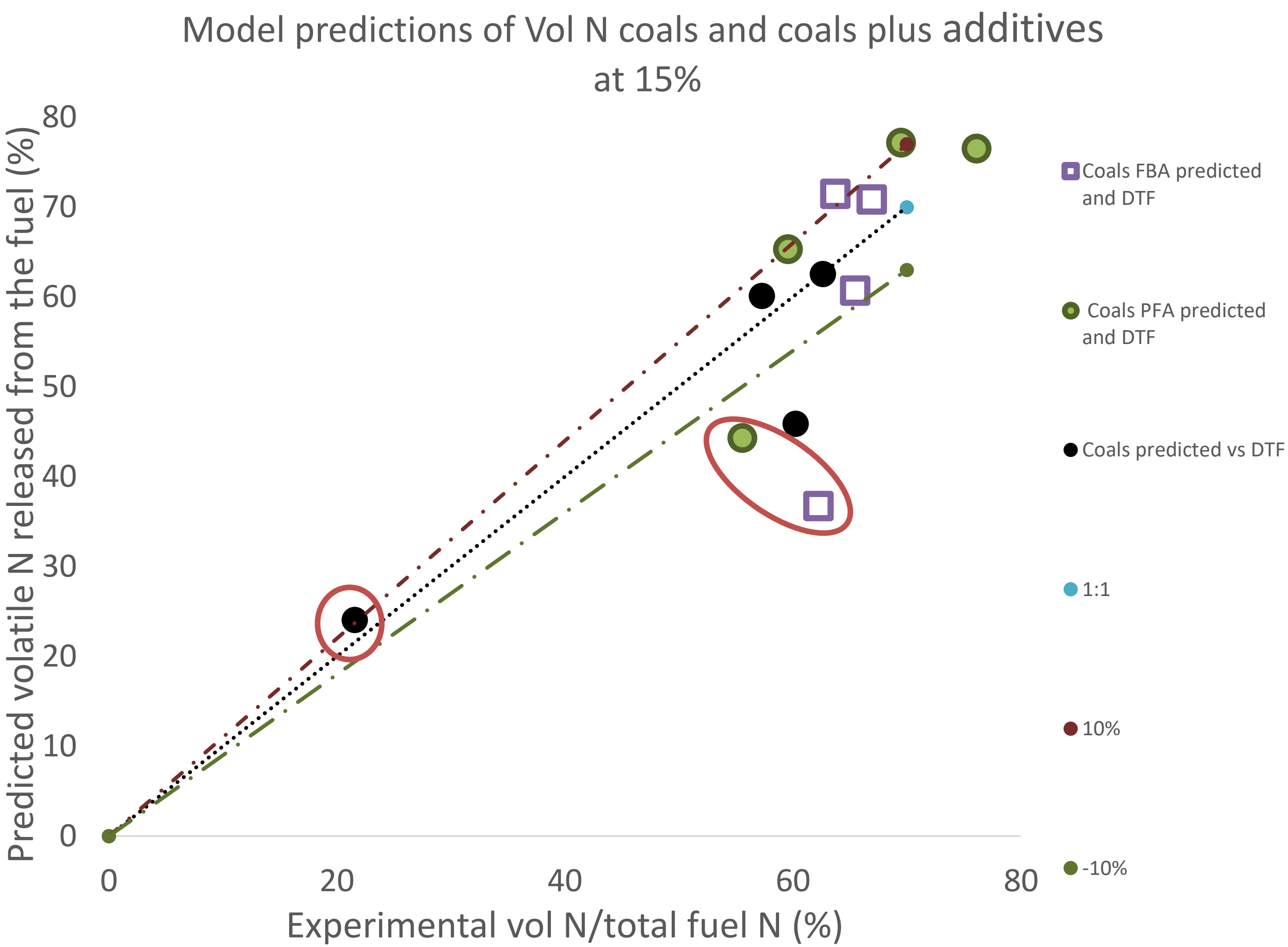
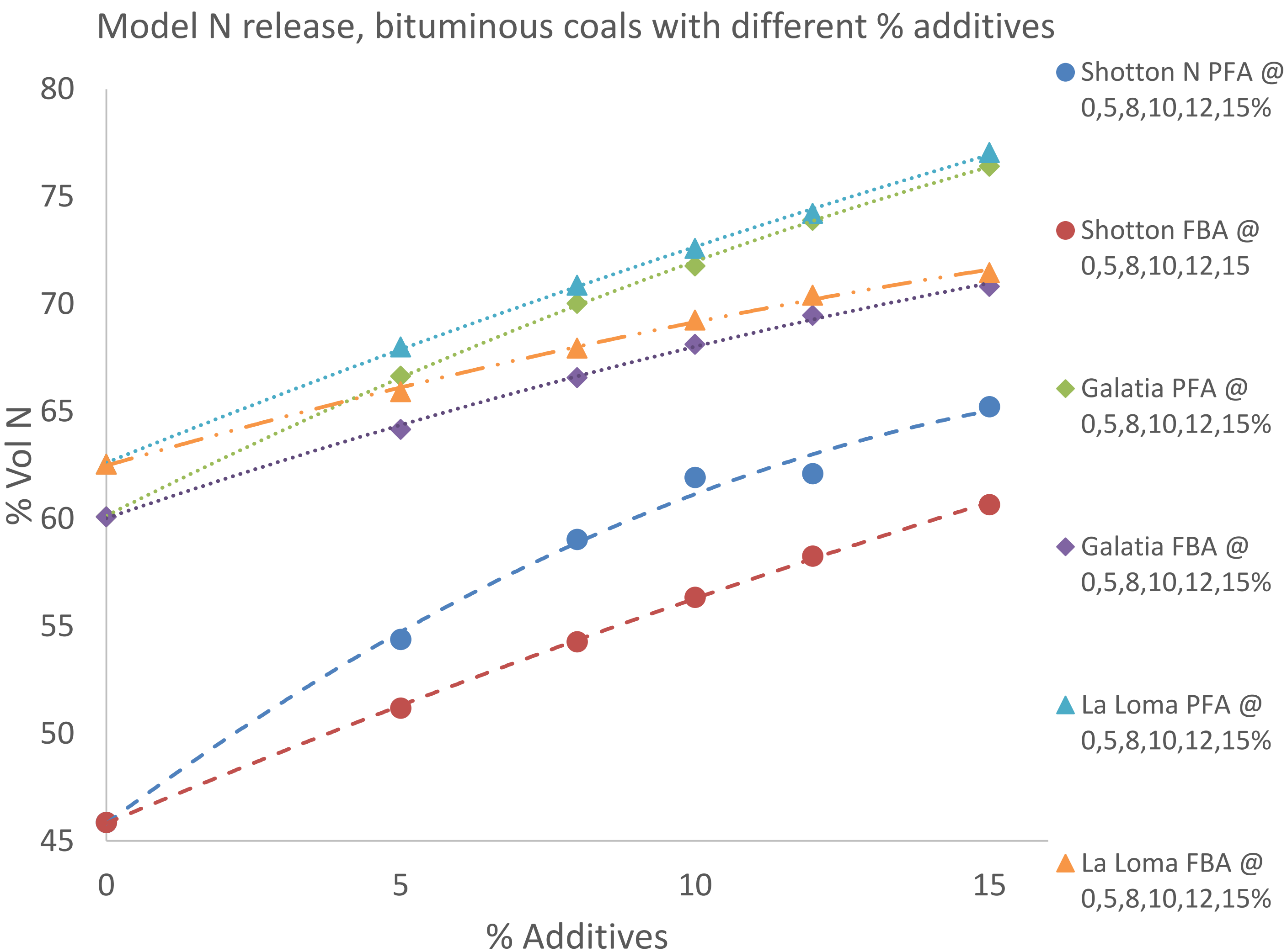


The model predicts vol N accurately for the bituminous coals with both additives.

The low reactivity coal, showed the greatest change in volatile N release (experimentally), this coal type was more difficult to model using the same values for all of the coals

Calibration of volatile N predictions



As the % of additives increases, so the % of volatile N increases.

The calibration +CPD model enables interpolation beyond measured data

The calibration of each coal and additive has a different volatile N % output

Conclusion

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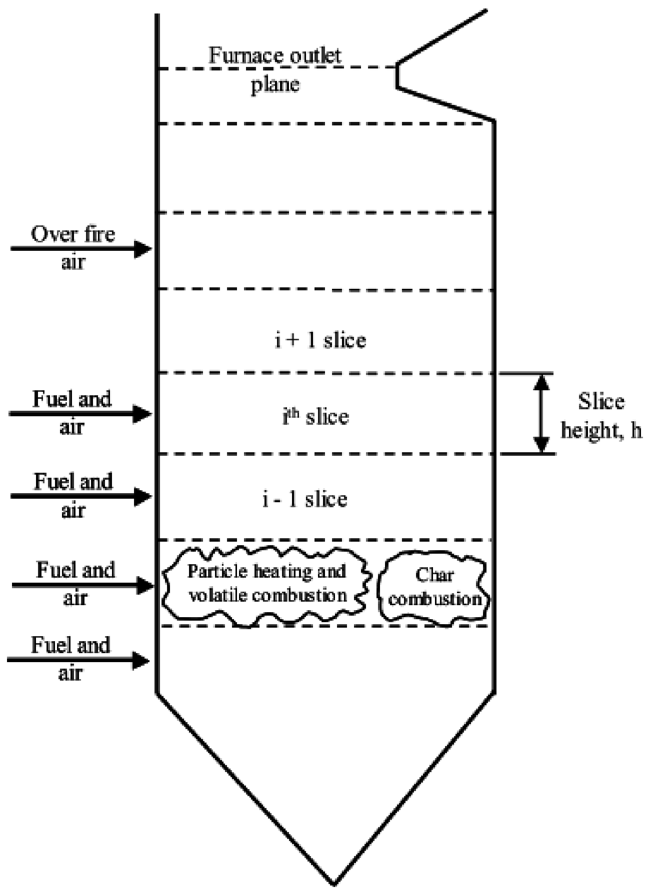
Experimental work has shown the additives:
- Change the HTVY from solid fuels (coals and biomass)
- Enhanced volatile N release
- Enhanced carbon conversion in solid fuels

The drop tube furnace model has been adapted to successfully predict:
- HTVY
- Volatile N release

Future work:
A slice model can be applied to a large scale furnace to predict the emissions characteristics from bituminous and sub-bituminous fuels

Future work-Slice model



Representation of the slice model

A furnace is divided into separate slices.

Each slice is calculated based on:

- Volatile combustion
- Char burnout

Σ(outputs of each slice) is used to predict the final output across the furnace outlet plane

This does not account for any reduction in emissions due to technologies after the furnace outlet plan

Acknowledgement

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