A BURNER MANUFACTURER'S APPROACH TO TACKLING CARBON IN FLY ASH

by

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SUMMARY

Although combustion staging is one of the most effective routes to lower NOx emissions when firing pulverised coal, it almost inevitably leads to an increase in carbon in fly ash. The challenge for the burner manufacturer is to design a system which will achieve all of the requirements of the client, that is NOx, steam temperatures, excess oxygen, CO, durability etc. without an unacceptable increase in carbon-in-ash, (CIA).

The increase in CIA when a low NOx burner, (LNB), system is fitted may be attributed to modification of the combustion process but there are a number of other factors such as boiler design, boiler operation and fuel properties which also play a part.

It is important to realise that the term LOI, (Loss on Ignition), is often wrongly used to mean CIA. Whilst it is true that in many cases the figures are quite similar, LOI also contains losses which are not carbon and so it is not a true indicator of the ability of a LNB system to burn coal efficiently. In most instances the LOI figure will be marginally higher than CIA depending upon the coal type and sample condition.

Firing configuration is known to affect burnout. Tangentially-fired boilers allow residence times which are longer than in other firing systems. These can be further adjusted by movement of the burner nozzle tilt mechanism. A LNB system installed on an opposed-fired unit may lead to flame-interactions which will reduce the effectiveness of staging, as also can closely-pitched burners.

Boiler operation also has an effect on CIA, for example, excess air, mill grouping, unit load and pulveriser performance will all influence unburnt carbon levels.

Fuel properties are particularly important if performance guarantees are to be met. The NOx reduction process relies on the ability of the burner to volatilise coal nitrogen in an oxygen-deficient zone. This then leads to the volatile nitrogen being rendered harmless as it is reduced to gaseous nitrogen. Any remaining nitrogen in the char may be oxidised in part during burnout to NOx. If, however, the overall yield of volatile matter can be maximised, the residual char particles will not only contain little nitrogen, thus limiting NOx formation, but will represent only a small proportion of the original coal. This will lead to minimal NOx evolution and is clearly one of the key objectives of the LNB designer.

ICL are aware that plant and operational issues can affect CIA and in a retrofit situation will address those areas of concern.

In summary these items are:-

* Fuel fineness
* Fuel distribution burner-to-burner
* Primary airflow must follow a defined ramp
* Primary air flow from each pulveriser should be measurable and controllable
* Secondary air flow should be measurable and proportional to the fuel supplied to the individual burners
* OFA should be measurable and controllable
* Coal flow to the pulverisers should be measurable and controllable
* PC line velocities must remain above minimum velocity at low load to avoid settling and pluggage
* Coal feed to the pulverisers must be constant with smooth changes during boiler load changes
* Combustion intensity

Important fuel properties which can affect CIA values are as follows-

* Ash content
* Coal rank
* Petrographic properties
* Swelling and plastic properties of the coal
* Porosity and structure of the char
* Reactivity of the char

To evaluate CIA tendency in coals, ICL makes use of a database which contains information on coals evaluated and fired in LNB systems previously. The database contains conventional analytical data together with information gathered from techniques such as thermogravimetric analysis, (TGA), and drop-tube furnace, (DTF) studies if appropriate. The latter are tools which are particularly appropriate in the study on low NOx burner systems, [1].

The significant effect of ash content on CIA can be easily demonstrated. If one considers a typical US utility coal having 10% ash and a calorific value of 12,500Btu/lb, at 99% combustible conversion efficiency, it would have a CIA value of 8.3%. For the same combustible conversion efficiency the CIA would rise to 16% if the ash were reduced to 5% and 28% if it were reduced to 2.5%. Whilst it is understood that the purchaser of fly ash needs a consistent product, for a limit to be applied to CIA which does not take account of coal ash variation imposes an unfair constraint on the burner. It is felt that it would be a much better indicator of the effectiveness of the low NOx burner if the CIA were expressed in lbs C/MMBtu as is the case for NOx and SOx. In both of the above cases, the figure would be the same, (0.72lbs/MMBtu), since the effect of ash variability would have been eliminated.

Coal rank is also one of the factors which determines how much CIA will be formed during combustion. The lower the rank, the better will be the burnout. The Fuel Ratio, effectively a measure of volatile matter content, is very often used as a simple indicator of CIA potential although the ash content, as stated previously, has an influence on the carbon content of the fly ash.

It is important to realise that the yield of volatile matter given by the proximate analysis test is much lower than in reality in a boiler and a better figure is obtained by using a drop tube furnace, (DTF). This subjects the coal particles to a more realistic heating rate and final temperature. The volatile yields using the DTF are often 50% higher than in the proximate volatile matter test. This method also produces a more realistic char from the coal and value of nitrogen volatility. Low rank coals produce little char and so retrofitting a unit which fires this type of coal may produce little or no increase in CIA. High rank coals produce more char hence they need a longer time to burn out. These coals, which sometimes have other unhelpful properties, are more likely to cause problems in units after LNB's have been fitted.

It is well known that the combustible fraction of coal is made up of many visually different components known as macerals which burn differently. Attempts have been made to relate the maceral composition of coals to combustion performance but it is difficult. Not only are the maceral components many and varied but geologically different coals appear to behave anomalously. Maceral analysis is also a specialised subject and has, until now, been rather slow and therefore expensive. A potentially useful technique has been developed, [2,3,4], at the University of Nottingham, England, (sponsored by EPRI), in which a reactivity index based on the proportion of coal below a certain grey scale reflectance has been related to unburnt carbon. This eliminates the need to perform detailed maceral analysis and is showing promise. ICL have made use of this technique in recent months and it has shown good agreement with actual combustion performance.

In addition to the amount of char formed, its physical properties will also influence the degree of burnout. The appearance of the char during low NOx combustion is related to the maceral composition described above. Some coals give rise to largely porous chars into which oxygen can penetrate and good burnout can be achieved. Others produce chars of lesser porosity and are clearly more difficult to burn out.

As part of an on-going UK collaborative project, [5], aimed at predicting CIA and NOx in wall-fired boilers, ICL produced chars from eight pulverised coals which were then subjected to scanning electron microscopy, [6]. The selected suite of coals included examples from the UK, USA, South Africa, South America and Indonesia and were all high volatile bituminous coals. It was found that all of the coals produced a variety of char types including solid particles and both thick and thin walled cenospheres. What was of interest was that the variations in burnout measured in the ICL DTF could be explained by reference to some of the observed properties of the coal and char. The best burnout was found in the lowest rank coal which also produced the smallest average sized char particle with the thinnest wall. There did not appear to be any correlation between the quantity of thin walled cenospheres and burnout. Cenosphere formation is known to be related to the vitrinite content of the coal and this was found to be the case with these results.

ICL also make use of mathematical modelling techniques using FLUENT and CFX codes to predict NOx and carbon burnout. The process enables flow characteristics, mixing patterns and temperatures to be modelled which can be used to estimate the extent to which NOx formation will occur and also carbon will burn out. The DTF and TGA are used to generate input parameters that are needed in the modelling experiments.

ICL have the capability to test fire full-sized burners on their Combustion Test Rig, (CTR), in Derby, England. This serves the dual purpose of enabling the development of burners to proceed without the uncertainties of scaling factors and also to test fire fully developed burners to ensure that the expected performance with regard to CIA and NOx is obtained.

To summarise the paper, ICL believe that they have developed an approach which recognises the areas in LNB systems which have an impact on CIA and how this is very closely coupled to NOx emission figures. There is the need to understand and optimise plant effects both in terms of design and operation where possible. The effects of fuel variation on CIA are also seen as important and although progress has been made and continues to be made on improving our understanding of the critical factors more still needs to be done and we are mindful of this.

Acknowledgements

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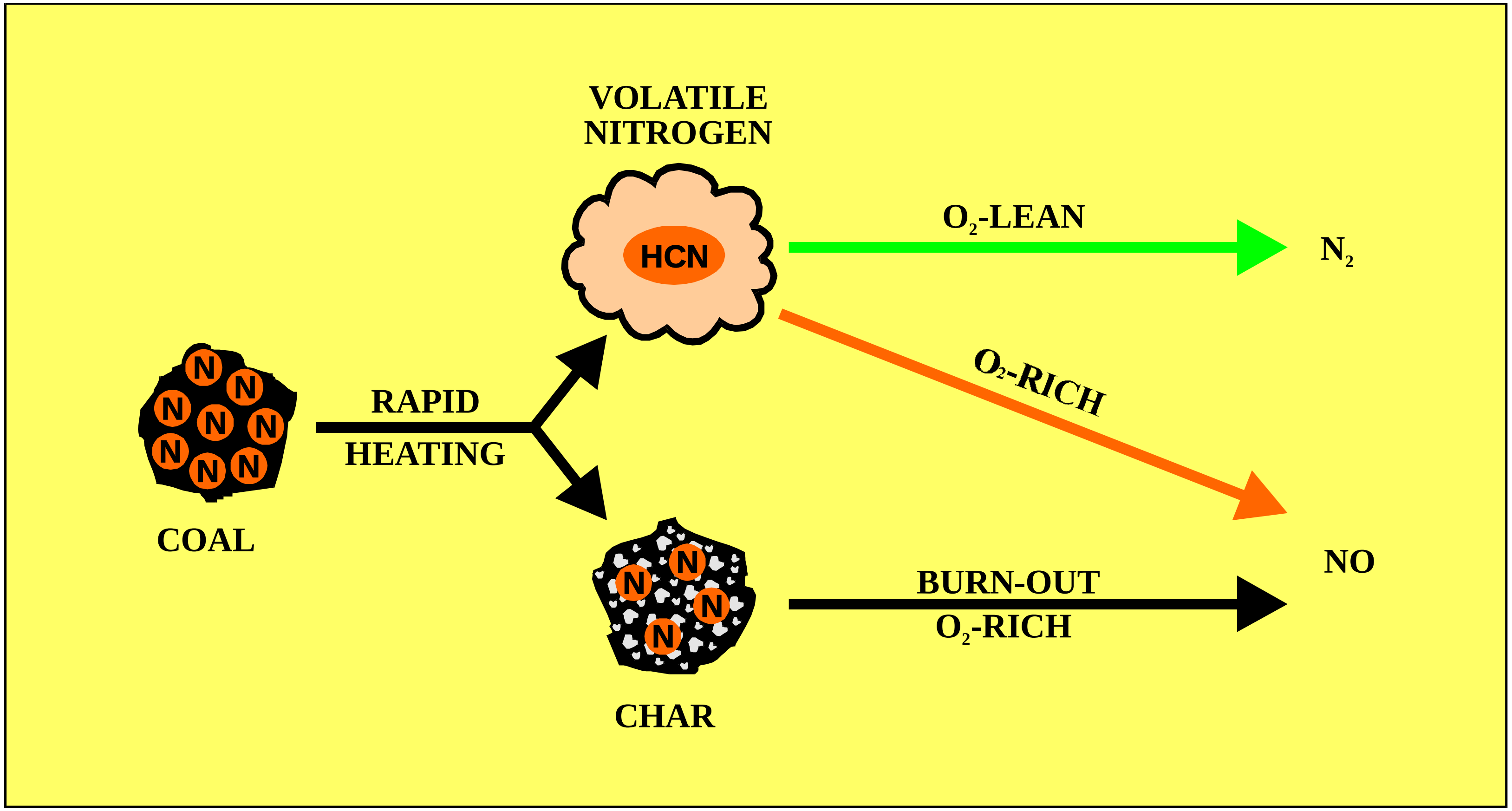
Fate of nitrogen during Low NOx combustion of coal



Plant & operational factors which affect carbon-in-ash

- Coal fineness
- Coal distribution (between burners)
- Primary airflow (from mill and ramp)
- Secondary & overfire air flows
- Coal flow to and from pulverisers
- PC line velocities
- Combustion intensity

Fuel properties which affect carbon-in-ash

- Ash content
- Rank
- Petrographic properties
- Swelling/plasticity
- Porosity/crystallinity of char

Illustration of effect of ash content on carbon-in-ash

Ash content, (dry)	GCV, (Btu/lb, dry)	Carbon in ash at 99% CCE, (%)	CCE, (expressed as lbs/MBtu)
10	12,500	8.3	0.72
5	13,195	16.0	0.72
2.5	13,540	28.0	0.72

The same coal is used with ash reduced to 5% and 2.5%
CCE is combustible conversion efficiency

Effect of coal rank on carbon burnout

Coal	Vitrinite reflectance, R_0	Fuel ratio	Rank	CCE, %
Powder River Basin	0.42	1.11	subB	99.7
North Colorado	0.61	1.38	hvCb	99.0
Marrowbone	0.84	1.49	hvAb	95.8
Shoal Creek	1.33	2.61	mvb	87.6
Jim Walter #3	1.59	3.88	lvb	72.7

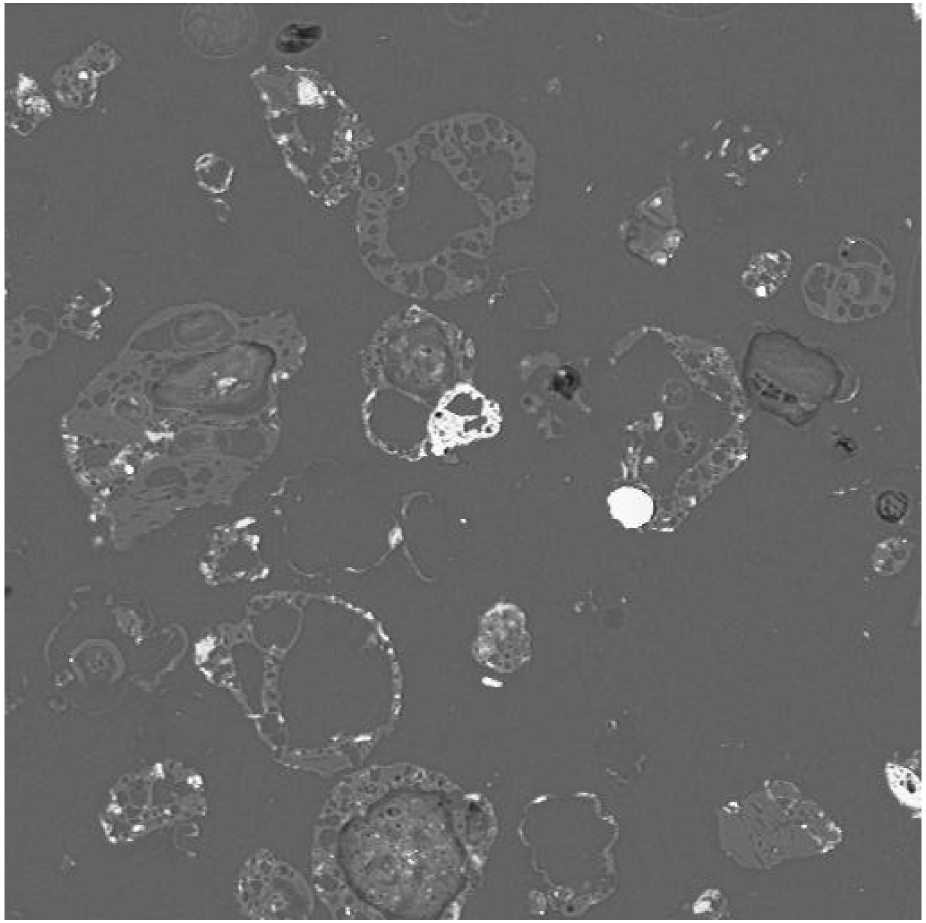
CCE = Combustible Conversion Efficiency

Plastic properties of coal

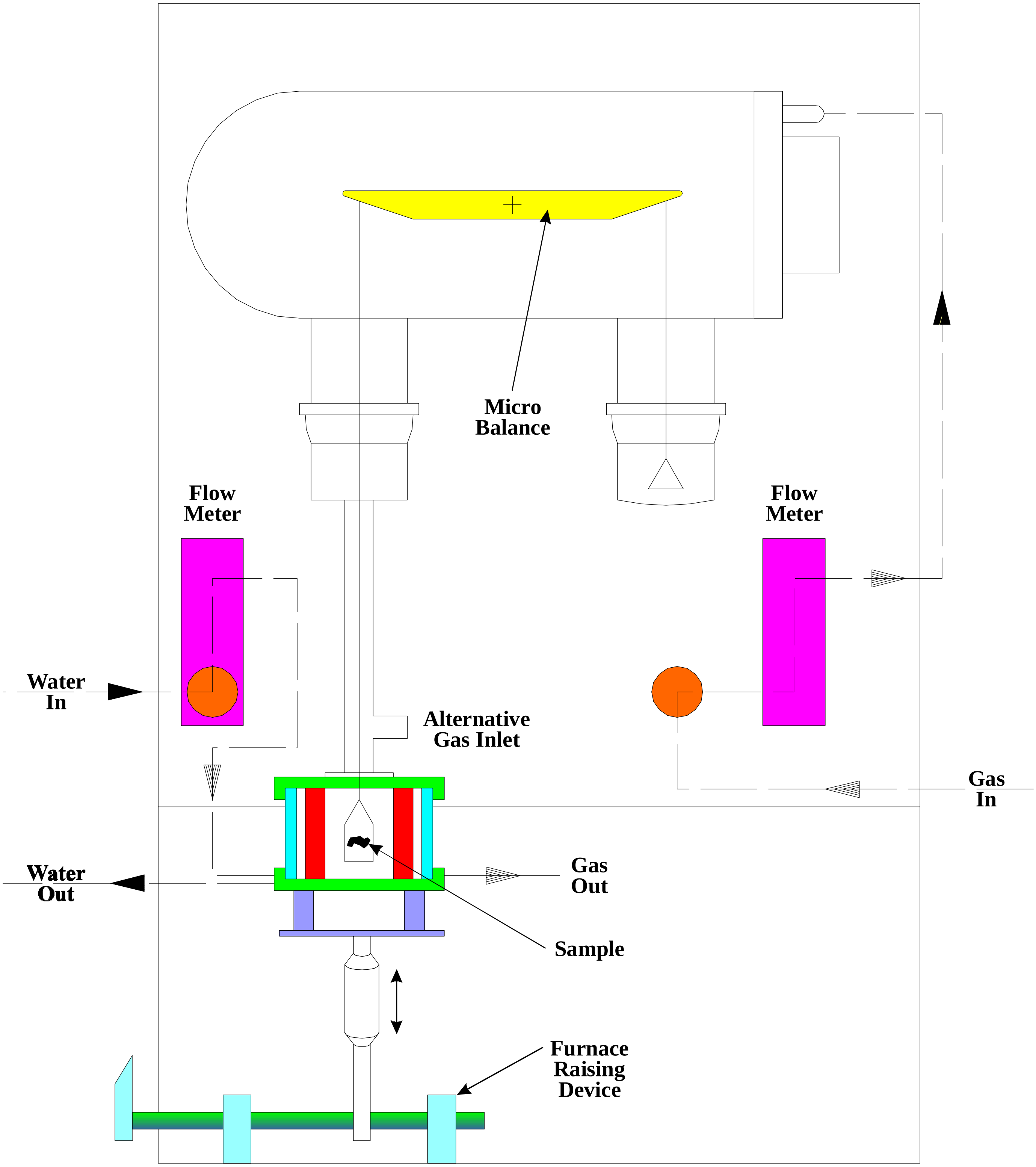
Plasticity refers to:

- **A coals ability to become soft when heated**
- **The characteristics the coal displays while in the softened state**
- **Unique to bituminous coals**
- **Coal can become soft enough to behave like a fluid**

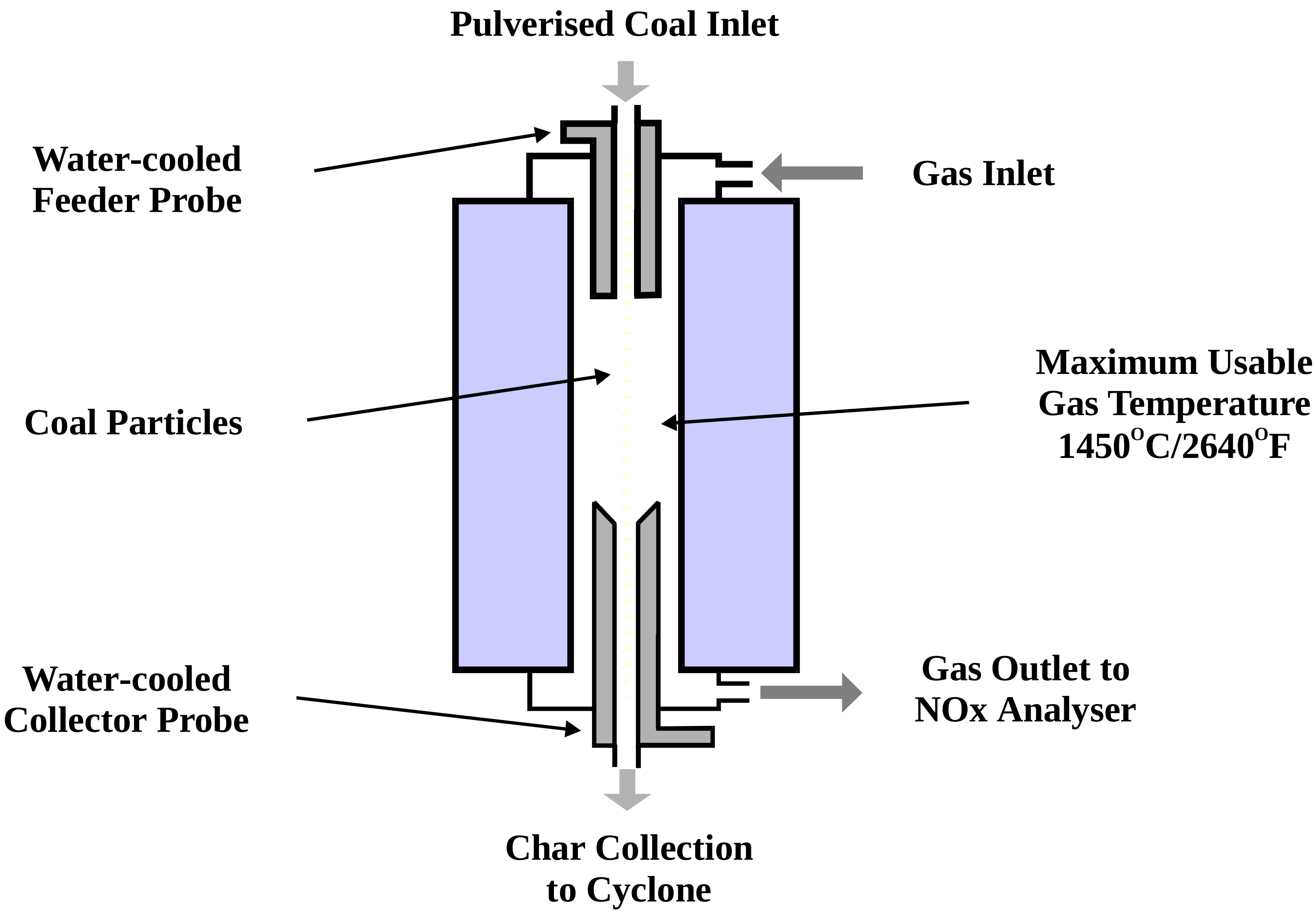
BEI of Betts Lane Char



Thermogravimetric analysis of fuels



Drop tube furnace



Summary

ICL's approach to carbon-in-ash prediction

- **Understand effects of plant design and operation and seek to address where possible**
- **Obtain feedback from converted boilers**
- **Evaluate fuels and compare with known data**
- **Use data generated from full size burner tests on combustion rig**
- **Apply physical and mathematical modelling techniques**