Development of OxyCoal^{TM} Technology: Results from Testing Conducted at Doosan Babcock's CCTF and Application to Demonstration Projects

Session 4A- Towards Commercialisation of Oxyfuel Technology

2nd Oxyfuel Combustion Conference, Yeppoon, Australia

Doosan Power Systems

Outline

Demonstration Projects

Heat Transfer in Oxyfuel Fired Boilers

Engineering Models

Test Experience

Limitations of Test Facilities

Oxyfuel Plant Thermal Performance

Concluding Remarks

Demonstration Projects

To date, there are no large scale (100's of MWe) oxyfuel plant in operation

Large scale oxyfuel demonstrations planned:

Meredosia (USA)	200MWe PF	repowering	Ameren
Janschwalde (EU)	250MWe PF	new build	Vattenfall
Compostilla (EU)	323MWe CFB	new build	ENDESA

Other large scale oxyfuel demonstrations are proposed, but the projects are less advanced than those listed above.

Additionally there are a number of smaller scale and pilot scale oxyfuel demonstrations worldwide, including Callide, Schwarze Pumpe, etc.

Sources (accessed 30-Aug-2011):
http://sequestration.mit.edu/tools/projects/index.html
http://cdn.globalccsinstitute.com/sites/default/files/The-Status-of-CCS-Projects-Interim-Report-2010_1.pdf

Demonstration Projects

Reliable prediction of boiler thermal performance is essential for large scale demonstrations

From a boilermaker's perspective, the minimum requirement is to:

- Guarantee boiler thermal performance for air firing operation
- Provide credible thermal performance expectations for oxyfuel operation
- Supply a boiler that has sufficient flexibility to operate under either air or oxyfuel

In the absence of large plant experience of oxyfuel operation, it is necessary to use predictive models, backed by available experience at smaller scale

Heat Transfer in Oxyfuel Boilers

Radiant heat transfer is the dominant factor in pulverised coal fired furnaces. Key parameters include:

- Flame length / heat release profile
- Flame luminosity
- Gas extinction coefficient (gas composition, particle size distribution & concentration)
- Furnace geometry (beam length)

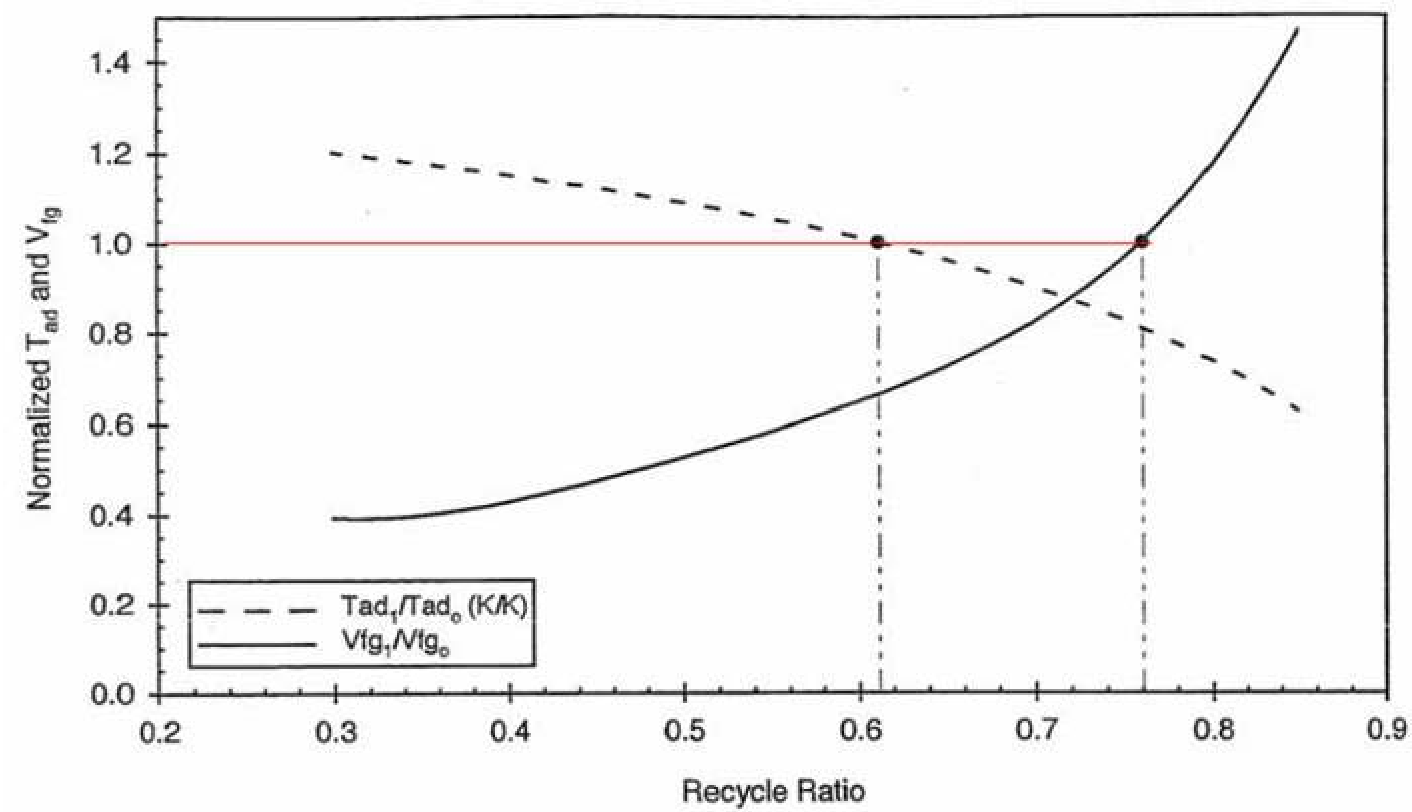
Convective heat transfer becomes progressively more important downstream of the furnace

Some, but not all, of these factors are predictable

- In the absence of operating oxyfuel plant data, test facility experience is essential to support the application of engineering models

Heat Transfer in Oxyfuel Boilers

Recycle flue gas flow rate can be used to vary radiant and convective heat transfer



Increased recycle flow leads to:

- Greater mass per unit heat input • lower adiabatic flame temperature and less radiant heat transfer
- Greater mass flow through boiler • higher gas velocity and more convective heat transfer

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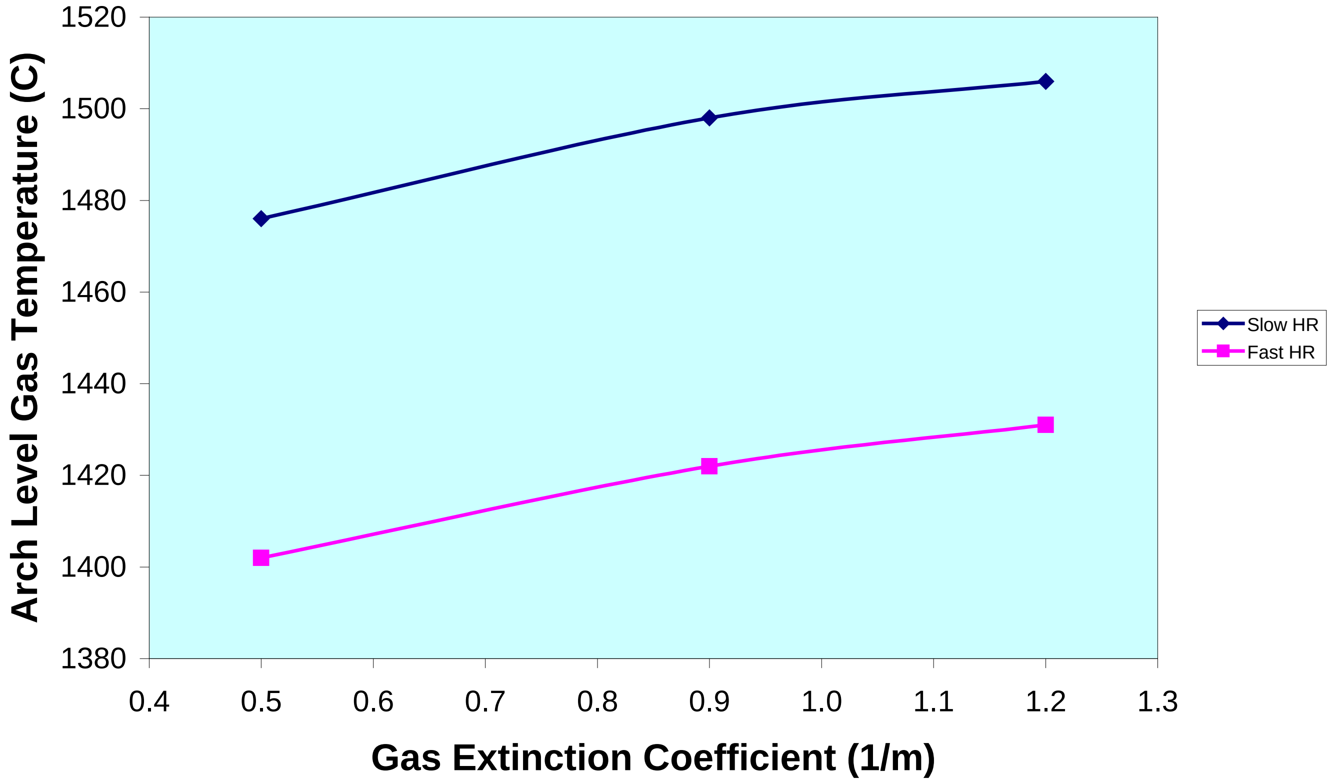
Source: IFRF Report F98/y/1

Heat Transfer in Oxyfuel Boilers

Increased gas extinction coefficient (increased optical thickness) and slower heat release (longer flames) leads to increased gas temperature at the furnace arch



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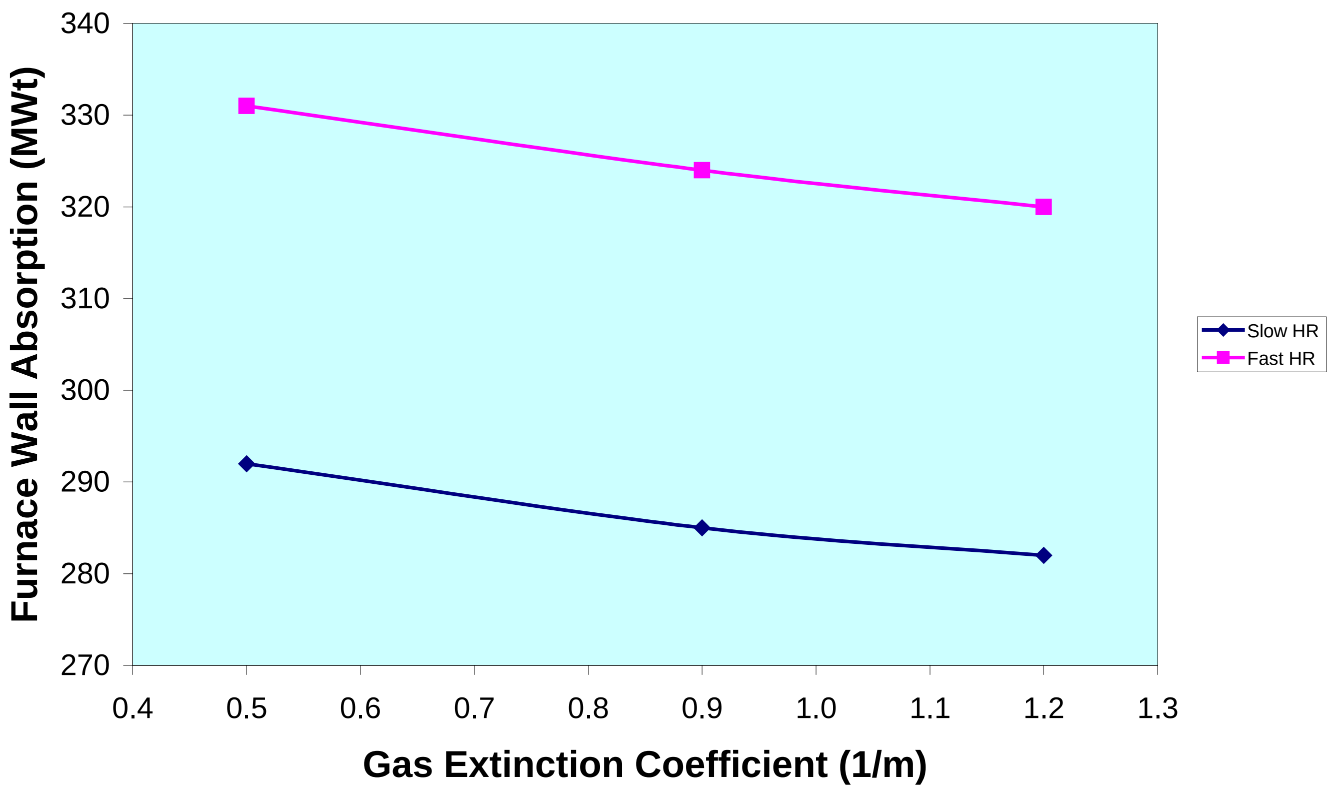
Heat Transfer in Oxyfuel Boilers

Increased gas extinction coefficient (increased optical thickness) and slower heat release (longer flames) leads to reduced heat absorption by the furnace walls



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Heat Transfer in Oxyfuel Boilers

Moving from air firing to oxyfuel firing has the potential to appreciably impact furnace thermal performance

– Consequential impact on convective pass thermal performance (in addition to that from changes to the convective htc)

Models can predict the impacts, but require reliable inputs

– It is challenging for models to predict soot formation in flames (impact on flame luminosity, gas extinction coefficient) and flame shape/length (heat release profile)

– Full-scale burner testing provides information to support the use of engineering models to predict furnace performance

Engineering Models

Simple semi-empirical models (e.g. stirred furnace models)

- Robust, easy to use, fast
- Require empirically derived factors
- Unreliable when extrapolated beyond validated experience

Zone models (e.g. Doosan’s “HotGen” model)

- Robust, easy to use, fast, based on sound theoretical principles, optimised for furnace design
- Some inputs (e.g. dirt factors) empirically derived by “calibrating” model to plant
- Can be used beyond validated experience (with care)

Computational Fluid Dynamics

- Can be difficult to converge (less robust), difficult to use (need experts), slower
- Some inputs (e.g. dirt factors) empirically derived by “calibrating” model to plant
- Can be used beyond validated experience (with care)

Engineering Models

HotGen - Thermal performance prediction of fossil fuel fired furnaces

- Overall furnace performance
  - FEGT
  - Heat to walls and pendant surfaces (platens, superheaters, reheaters, screens, etc.)
- Local furnace performance
  - Gas and surface temperatures
  - Incident and absorbed heat fluxes
- Sound theoretical basis
  - Implicitly handles thermal radiation issues (furnace size, impact of flyash, etc.)
  - All inputs have physical significance (no fiddle factors!)
  - Can accommodate oxyfuel firing
- Unique
  - HotGen is the only zone model worldwide that is capable of simulating pendant surfaces
- Robust
  - Can simulate all the main technologies (wall firing, downshot firing, tangential firing)
  - No convergence problems

Engineering Models

HotGen uses Hottel's Zone Method

Furnace volume divided into discrete blocks – "zones"

- Temperature and physical properties are implicitly assumed to be uniform within each zone
- Smaller zones better justify this assumption

Energy balance solved for enthalpy for each zone

- Radiation, convection, heat release in zone
- Gas extinction coefficient defines fraction of radiant heat absorbed within zone vs. fraction passing through

Monte Carlo approach used to calculate matrix of "Direct Exchange Areas" to define radiant heat transfer between zones

- Discrete packages of energy from each zone (of random strength and direction) are tracked through furnace volume
- Large number to give statistically valid solution
- Can handle complex geometries

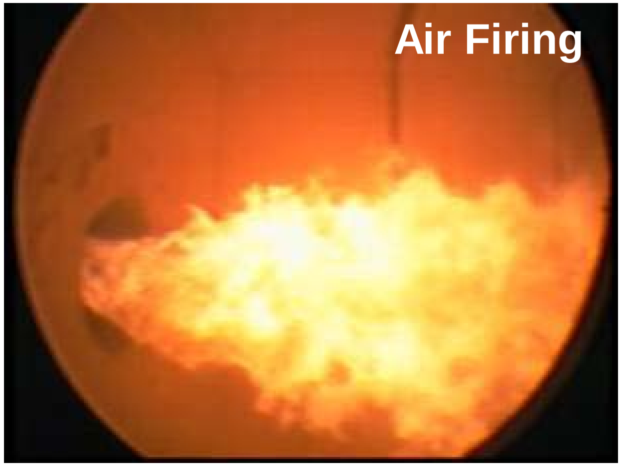
Test Experience

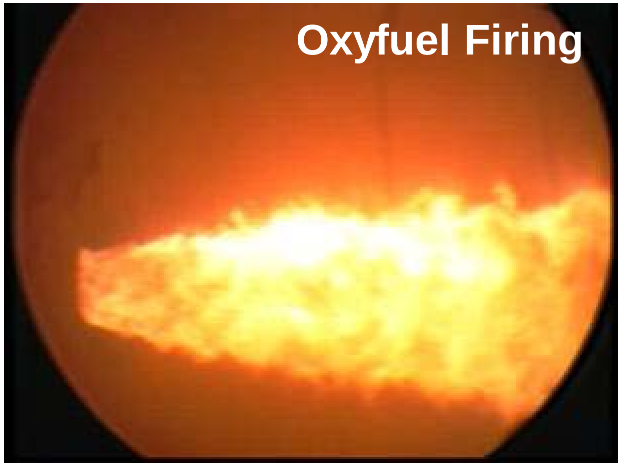
Session 3A “Doosan Power Systems OxyCoal™ Technology” presents the outcomes from testing a full-scale 40MWt burner operating under air and oxyfuel combustion conditions

Test Experience

The results from successful testing demonstrate Doosan Power Systems' pioneering expertise in the carbon capture field and mark a major step towards making full-scale carbon capture a reality

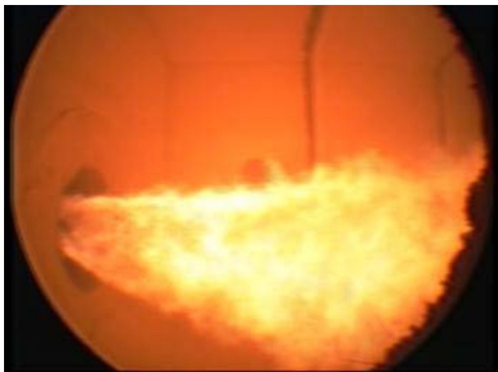
- A full scale 40MW$_t$ OxyCoal™ burner was successfully demonstrated on air and oxyfuel firing, achieving safe and stable operation across a wide operational envelope
- Oxyfuel flame stability and flame shape was comparable to air firing experience
- Safe and smooth transitions between air and oxyfuel operation were demonstrated
- Realistic CO_2 levels were achieved (in excess of 75% v/v dry, and up to 85% v/v dry)
- 40MW$_t$ OxyCoal™ burner turndown proven from 100% load to 40% load – a comparable turndown to Doosan Power Systems' commercially available air firing low NO_X axial swirl burners
- NOx and SO_2 is significantly lower under oxyfuel firing compared to air firing
- Combustion efficiency under air and oxyfuel conditions, as expressed by CIA and CO, is comparable

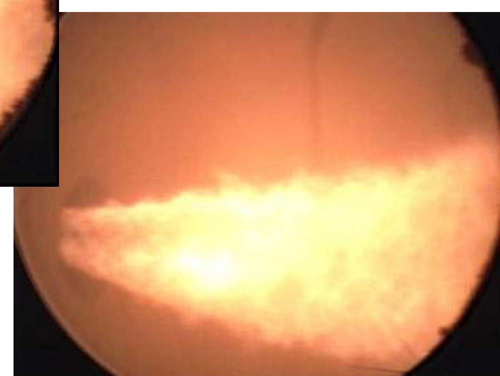


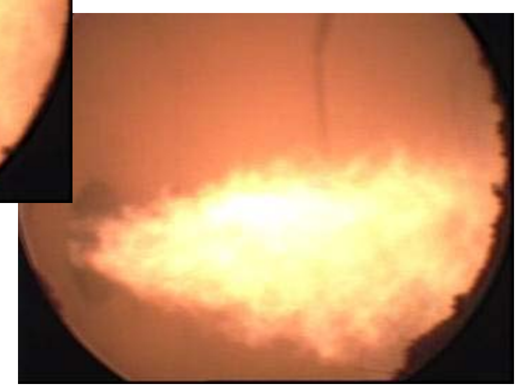


Test Experience

Test experience with the DPS 40MWt OxyCoal™ burner shows that flame shape, length, and luminosity are broadly similar for air and oxyfuel firing; FGR rate has some impact

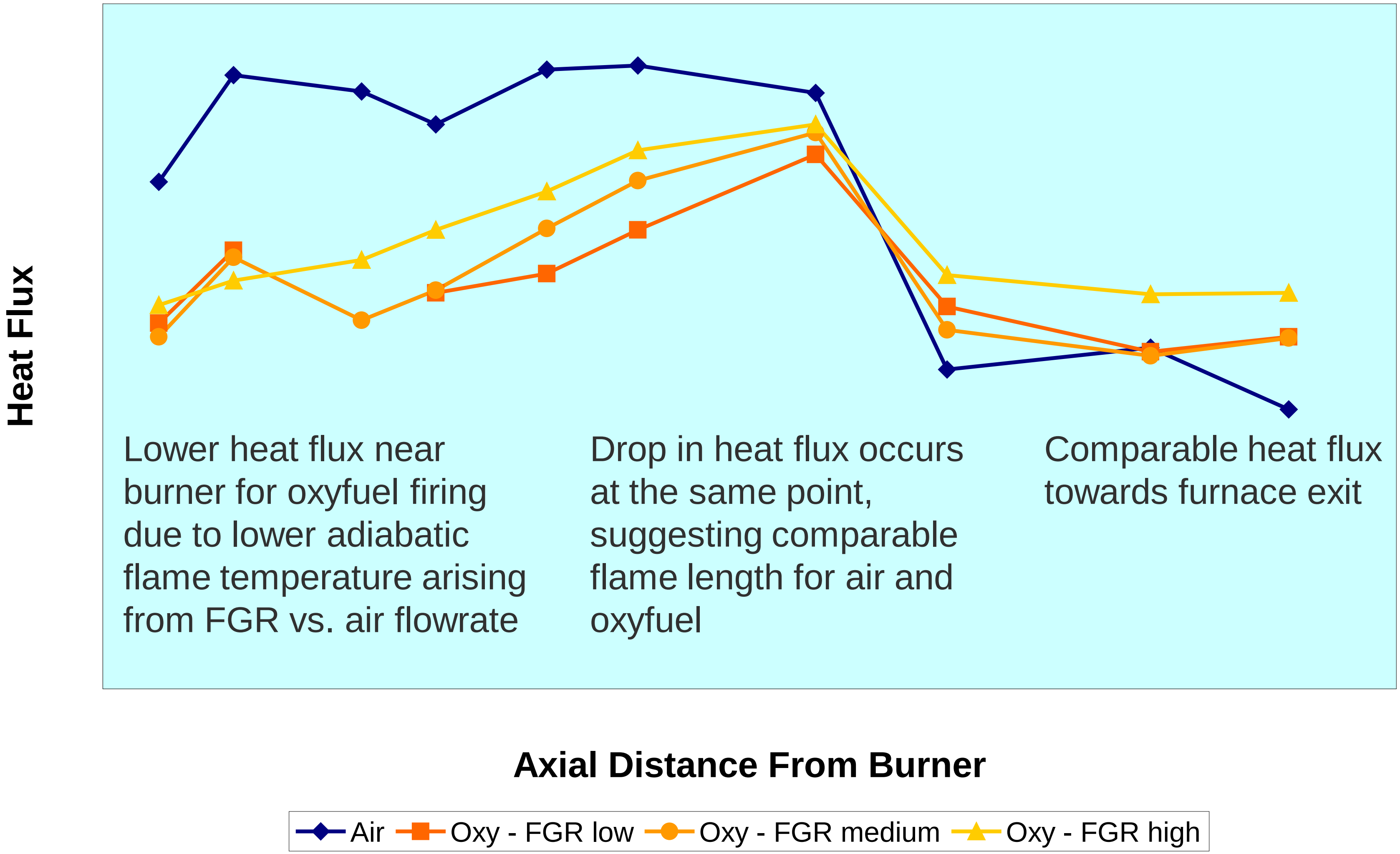






Air → Oxyfuel (increasing FGR)

Test Experience

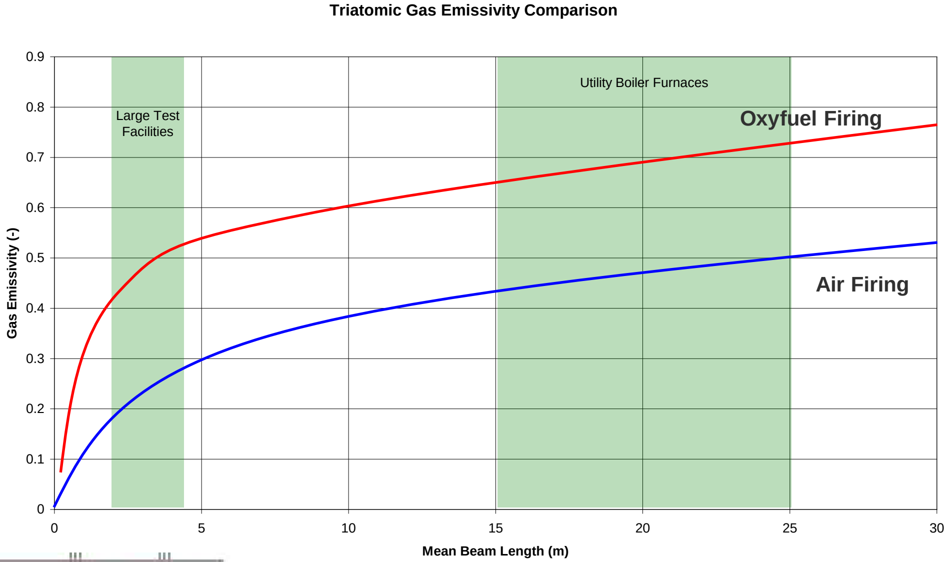


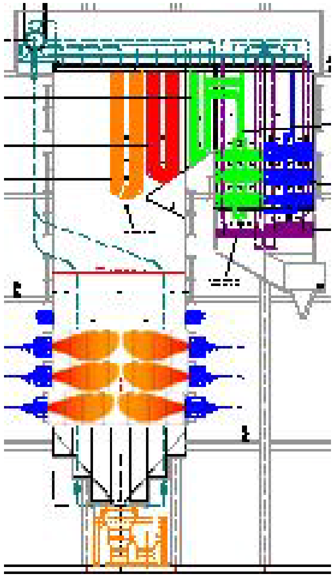
Limitations of Test Facilities

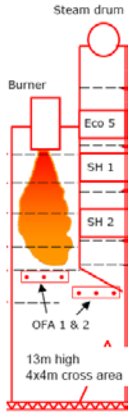
Plant scale demonstration is needed to verify thermal performance on oxyfuel fired boilers

Small-scale test furnaces cannot adequately replicate the radiation processes in utility plant

- Specific issues include
  - Realistic mean beam lengths
  - Estimation of extinction coefficient
  - Pendant (radiant) superheaters
  - Volumetric utilisation of the furnace







Illustrations: DPS, Vattenfall, T Wall

Oxyfuel Plant Thermal Performance

Basis

- 600MWe supercritical coal fired boiler
- Opposed wall fired
- Overfire air

Assumptions (HotGen model)

- Same flow distribution between burners and overfire air ports
- Same heat release profile (based on test experience)
- Gas extinction coefficients calculated from gas composition and particle concentration & size distribution (similar soot content in flame based on observed flame luminosity during burner tests)
- Same deposition in furnace and convective pass (surface emissivity, thermal resistance)

Oxyfuel Plant Thermal Performance

Modelling shows a modest impact on thermal performance arising from oxyfuel at the operating conditions simulated

Compared to air firing, the oxyfuel fired plant has:-

- Higher arch level gas temperature
- Higher heat absorption to the furnace walls
- Higher heat absorption to the platen superheater
- Similar furnace exit gas temperature, FEGT
- Lower gas temperatures and heat absorption further downstream in the gas pass
- Higher local gas temperatures throughout the lower furnace, with less variability in the burner belt
- Higher incident heat fluxes to the furnace walls

The predicted impacts on thermal performance arise from the increased gas extinction coefficients and the lower flue gas mass flow rate through the boiler under oxyfuel firing conditions

The predicted impacts are small compared to day-to-day variability due to ash deposition

A boiler designed for air firing can operate in oxyfuel firing mode without change to the boiler

- Demonstration at plant scale required to verify this conclusion

Concluding Remarks

The time is right for the full scale demonstration of oxyfuel

Oxyfuel burners have been successfully demonstrated at full utility scale (40MWt)

- Burner technology is ready and available for plant application
- No issues relating to the flame's impact on boiler thermal performance are anticipated

Engineering models to predict oxyfuel boiler thermal performance have been developed

- Predictions are credible with respect to the input values specified
- The models can be applied to the design of oxyfuel demonstration plant

Thermal performance predicted for oxyfuel fired utility boilers is comparable to air firing

- Oxyfuel can be retrofitted to existing plant with minimal impact to the boiler
- Operating conditions must be optimised with regard to combustion, emissions and thermal performance
- Large scale demonstration is needed to verify boiler operation with oxyfuel

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Doosan Babcock is committed to delivering unique and advanced carbon capture solutions.

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