Oxyfuel Research at RWE npower plc.

The CRF 2012 Annual Meeting and Combustion Divisional Seminar,
25th April 2012.

Gerry Riley and John Smart

Presented by Mark Flower

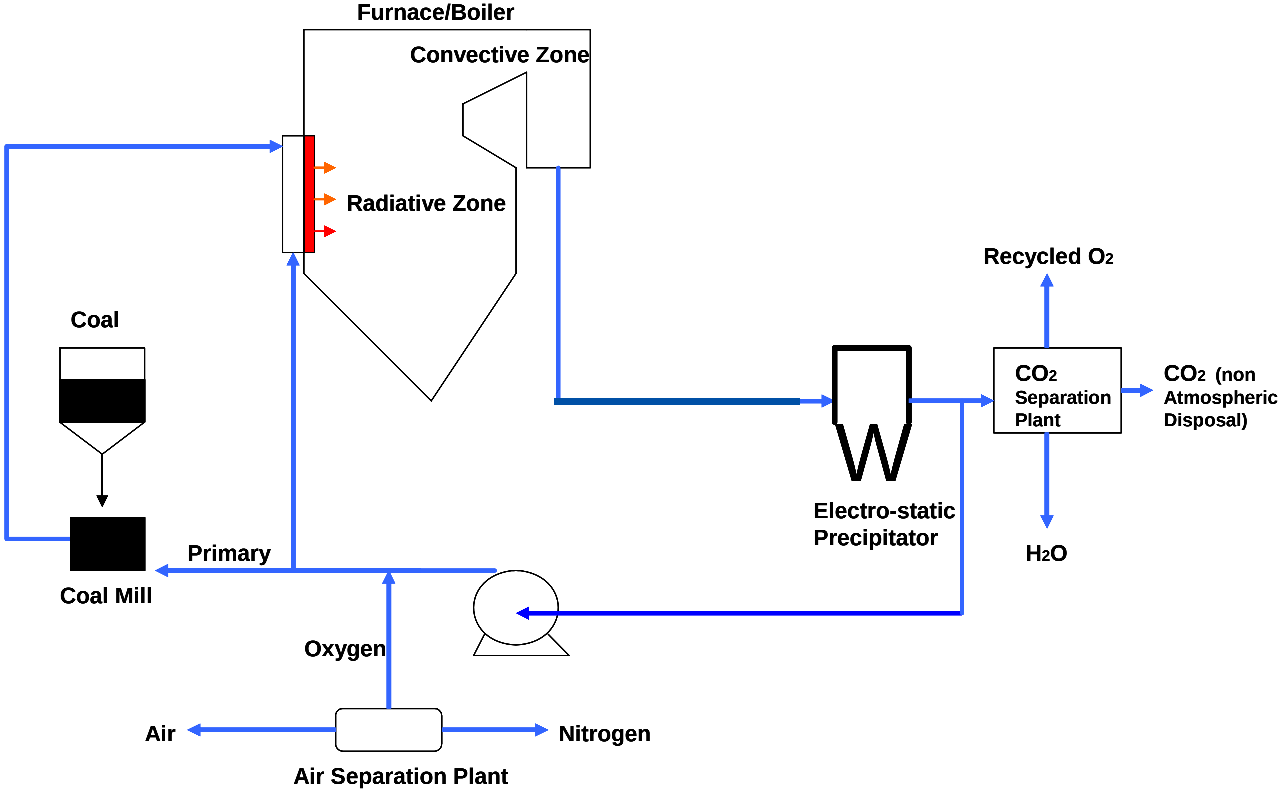
Presentation overview

- Background
- Highlights from Test Programmes
  - Oxyfuel UK DTI Project
  - BOM-COM RFCS
  - EcoScrub RFCS project
  - Fuel project (RWE npower project)
  - Oxygen injection project with BOC
- Summary

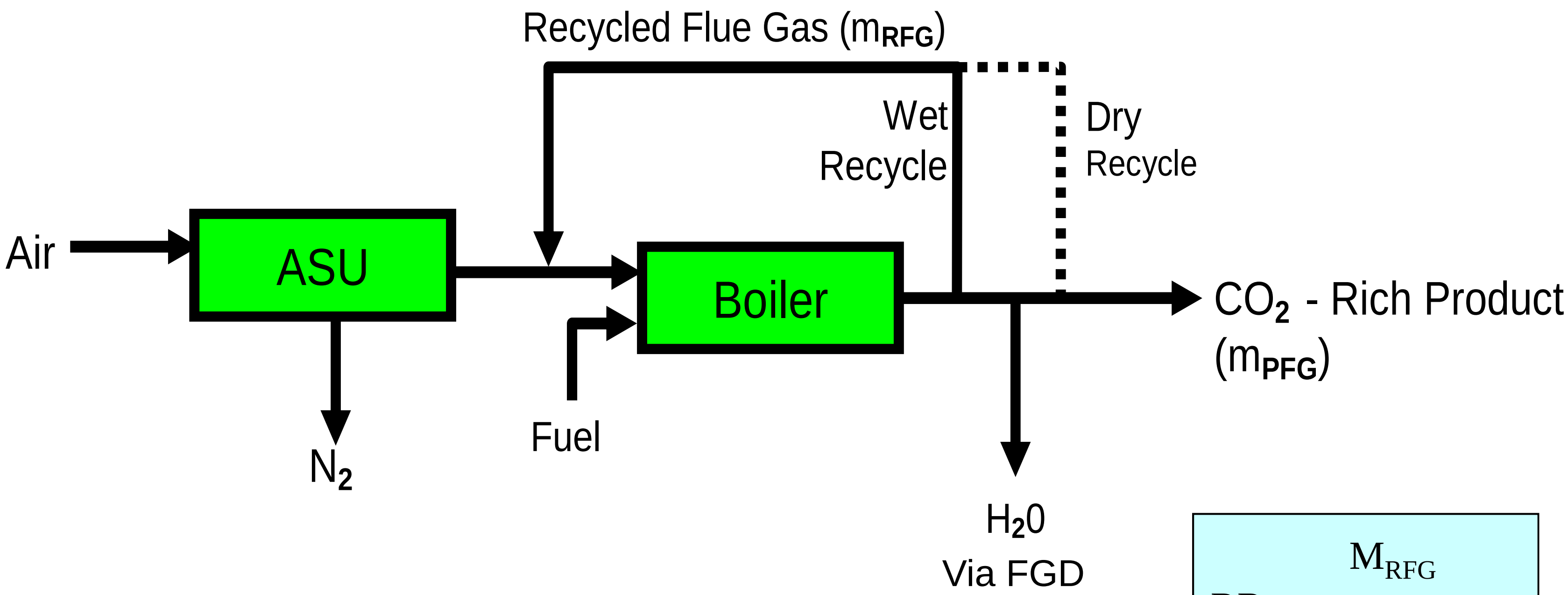
Background: What is oxyfuel?

> Flue gas is recycled and air is replaced by oxygen

> The gas inside the boiler becomes almost nitrogen-free and CO_2 is then removed.



Background – Recycle Ratio



$$RR = \frac{M_{RFG}}{M_{RFG} + M_{PFG}}$$

Overview of CTF programme

CTF Studies

Safety

Fuel Issues

Optimisation

Process Development

Desktop Studies

Overview of CTF programme

- Safety handling and storage of oxygen and CO_2
- Flame detection issues (higher moisture and CO_2 may affect UV and IR absorption)
- Safety of mixing oxygen/CO_2
- Flame stability
- Safe switch-over the oxyfuel combustion
- Safety of staff with CO_2 /flue gas leaks etc.
- Purging for safety

- Air leakage
- Optimum recycle ratio
- Air heater design
- Optimisation of mixing strategy (where to add O_2 - PA/SA/TA etc.)
- Gas recirculation
- Oil burner operation on oxyfuel
- Flexibility - start-up/shutdown limited by air separation unit so cold-start on air

- Selection of coals (optimise purchasing)
- Use of biomass
- Furnace slagging
- Furnace Corrosion
- Fouling
- NO_X (chemistry not well understood)
- Heavy metal recycling and ash composition

- Burner design
- Carbon burnout
- Heat transfer (radiative/convective properties)

- Regulation issue - LCPD limits for oxyfuel
- Pre-investment issues (upfront parameters)
- Required footprint for retrofit (e.g. air separation unit)

CTF oxyfuel conversion

> Two-stage conversion of the CTF

– Phase 1: Stored CO_2 injection

– Phase 2: Flue gas recirculation

> Why a two-phase strategy?

– Rapid start-up with less (though significant) engineering – air ingress

– Flexibility

– Identify show stoppers or new issues at an early stage

– Second stage to quantify full impact of issues such as NO_X, slagging, corrosion and trace elements that cannot be fully studied by CO_2 injection alone

CTF oxyfuel conversion

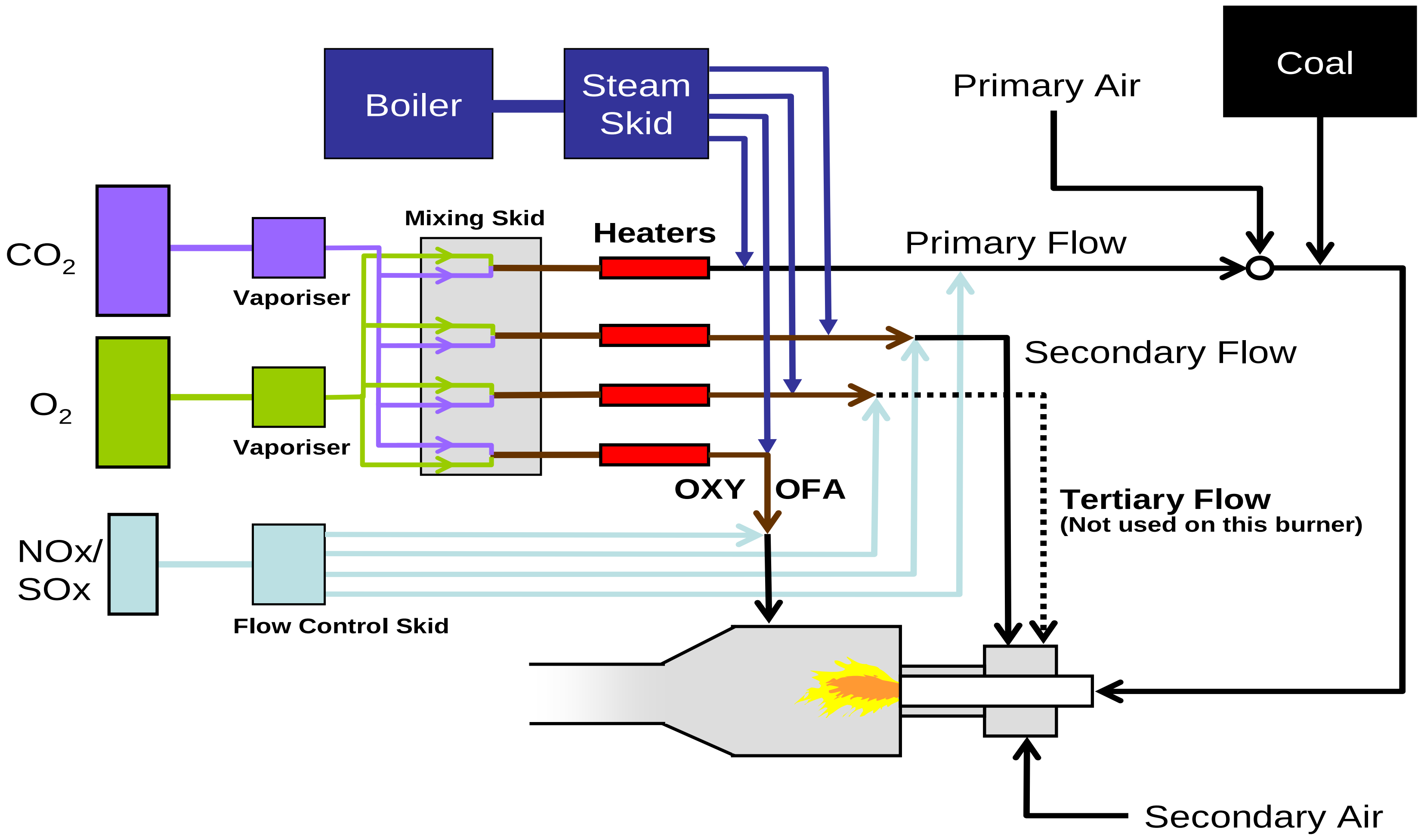
- > Two-stage conversion of the CTF
  - – Phase 1: Stored CO_2 injection
  - –
    – Cancelled following strategic review
- > Why a two-phase strategy?
  - – Rapid start-up with less (though significant) engineering – air ingress
  - – Flexibility
  - – Identify show stoppers or new issues at an early stage
  - –
    – Cancelled following strategic review

Rig modifications

> CO_2 injection

- Storage tanks for O_2 and CO_2 with mixing and safety systems
- Modified system of blowers and SA/TA heaters
- Steam boiler
- Doping gasses (SO_x, NO_x)
- Controls and logic interface with existing CTF system

Schematic of Once Through Oxy-Fuel System



RWEnpower's OxyFuel facility

O_2, CO_2 and N_2 Storage Vessels

RWEnpower’s OxyFuel facility

Evaporators

RWEnpower’s OxyFuel facility

Gas mixers

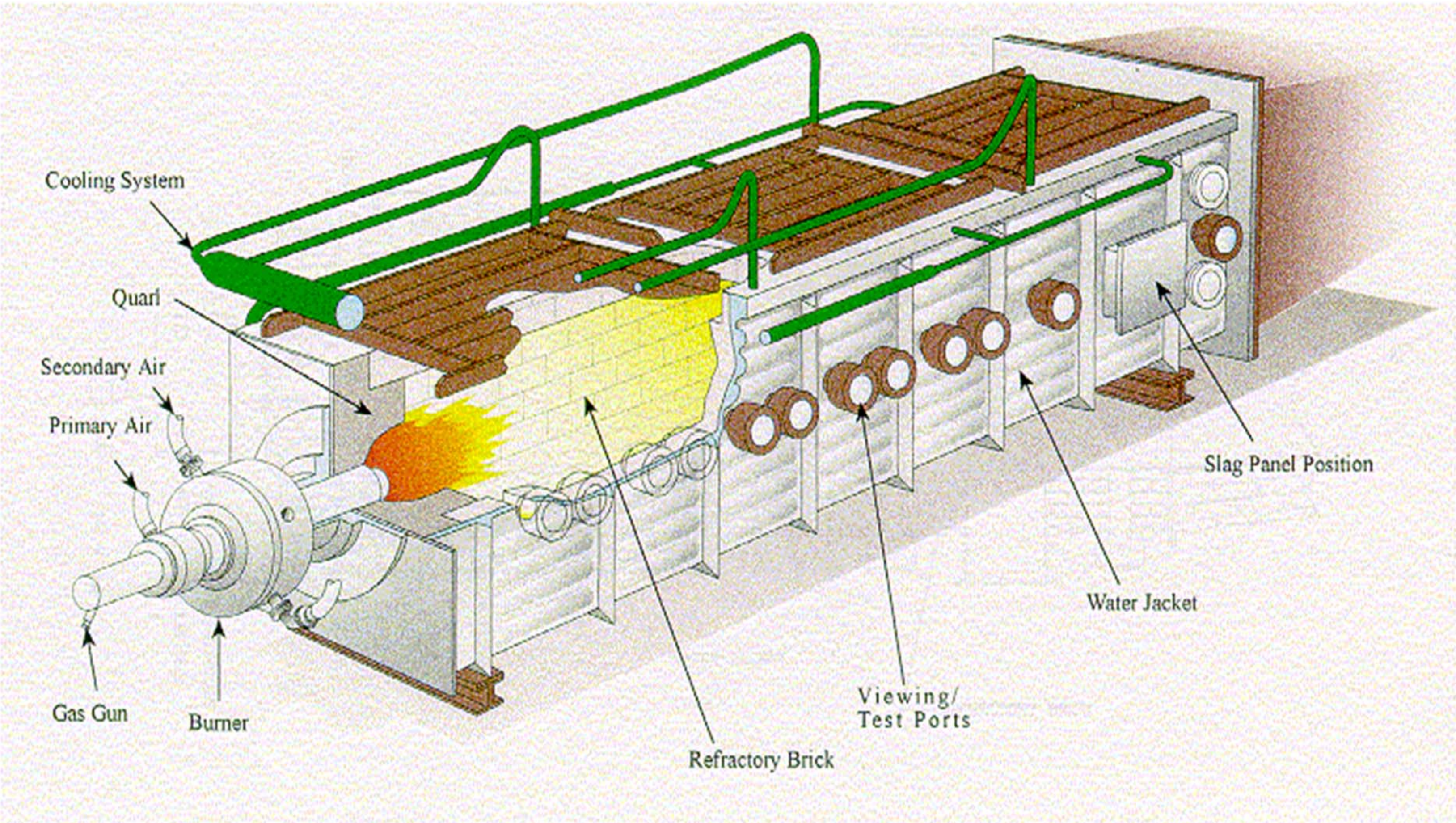
RWEnpower's OxyFuel facility

Gas Heaters

RWEnpower's OxyFuel facility

Burner

Schematic of CTF Test Furnace



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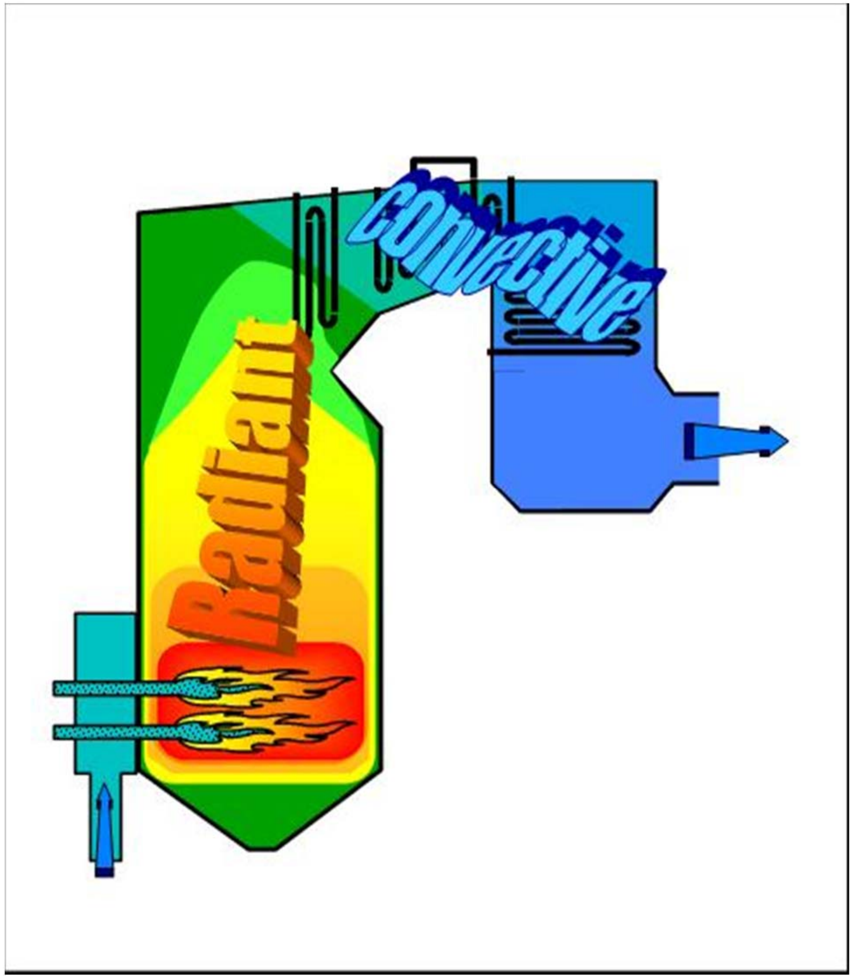
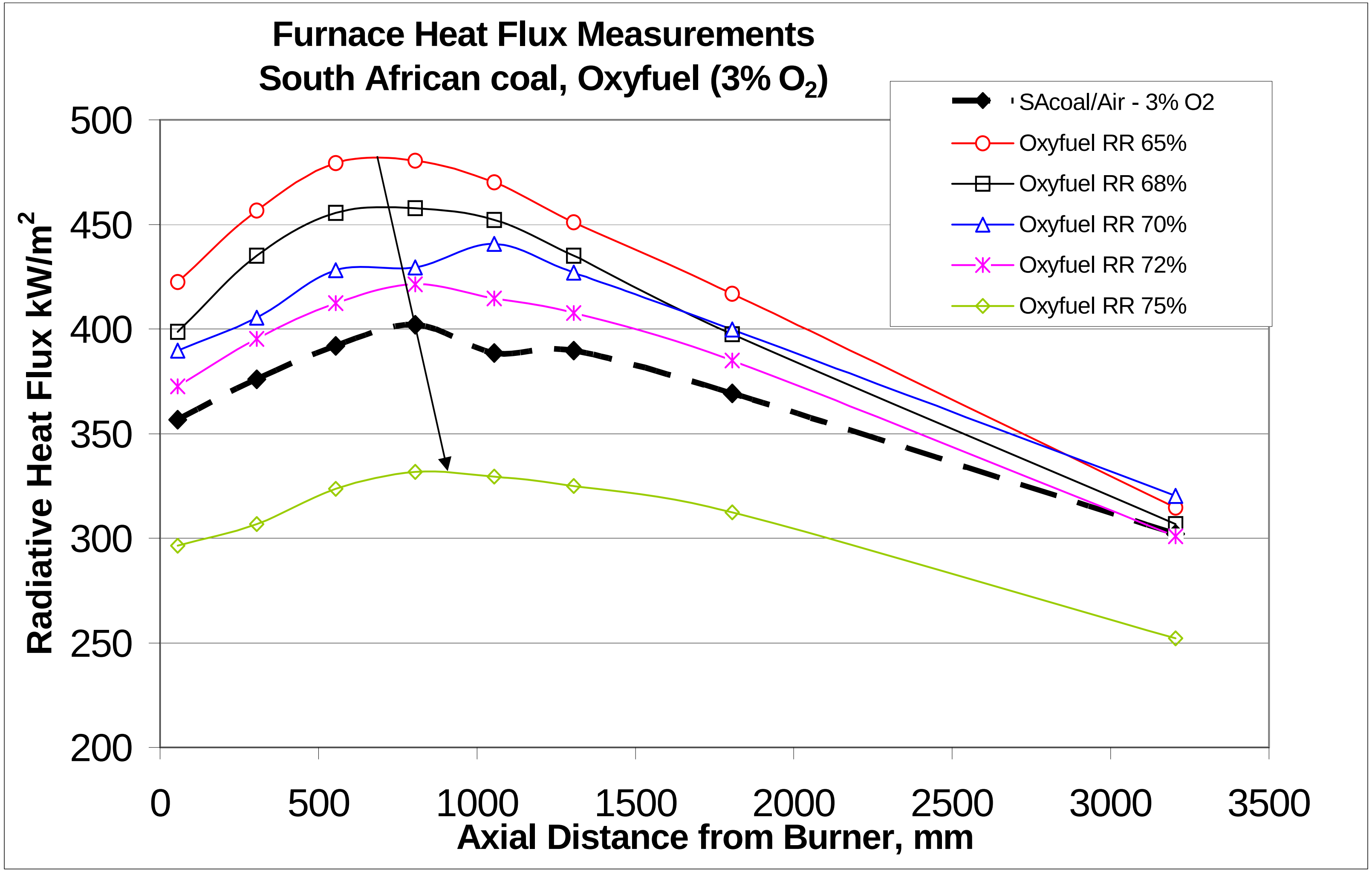
Heat Transfer under OxyFuel Firing Conditions

Driver for Studying Heat Transfer Distributions – Radiative and Convective

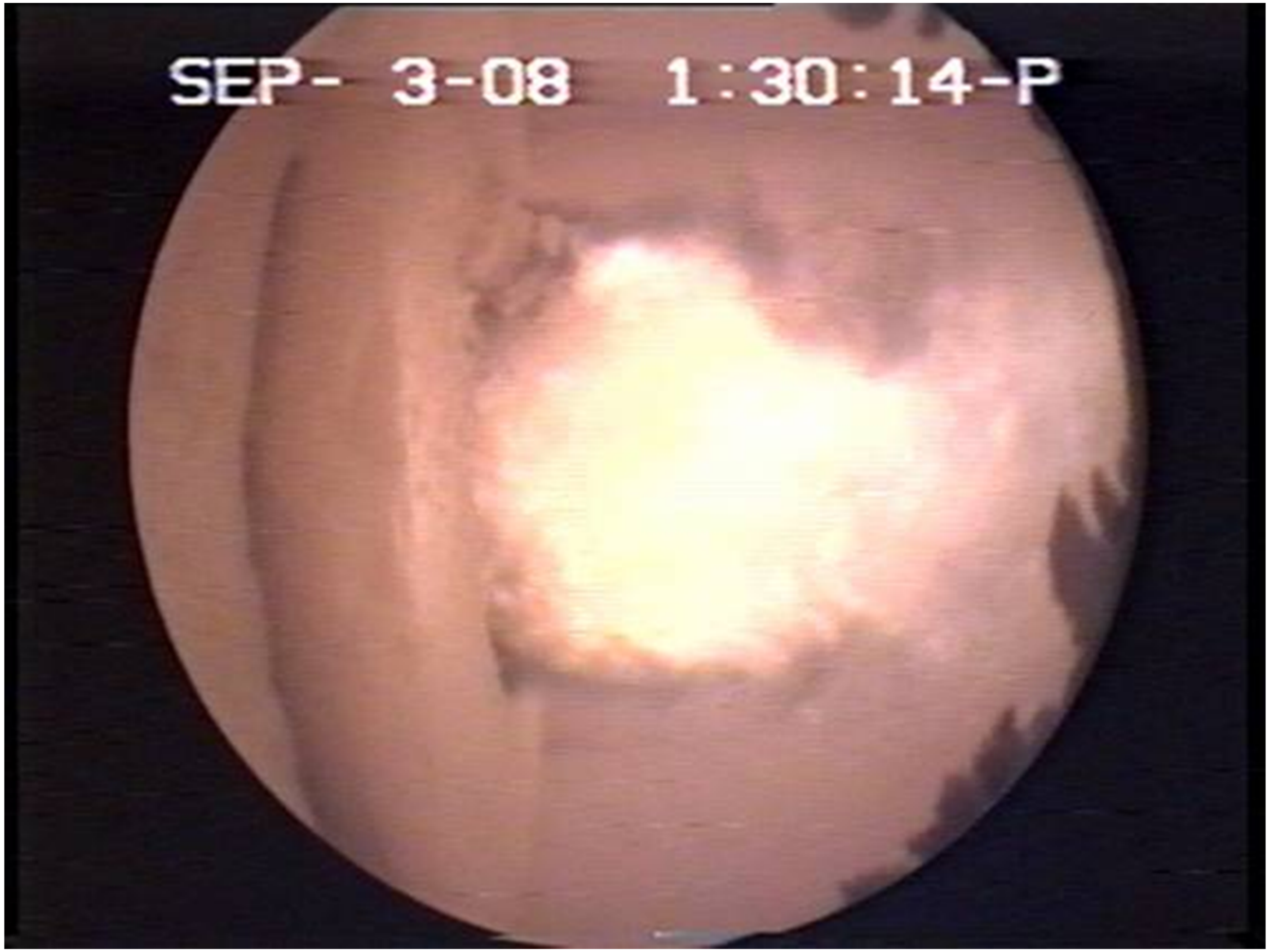


- Radiation heat transfer is driven by gas temperature (T^4) while convective heat transfer by gas temperature and velocity.
- To operate as "air equivalent" the balance between radiative and convective heat transfer has to be found
- The recycled flue gas can be either wet or dry dependent on where the recycled flue gas taken from in the system.
- The recycled flue gas could be take wet from the outlet of the ESP (where the moisture content would be circa 18% by volume) or after an FGD system (where the moisture content would be circa 8% by volume).

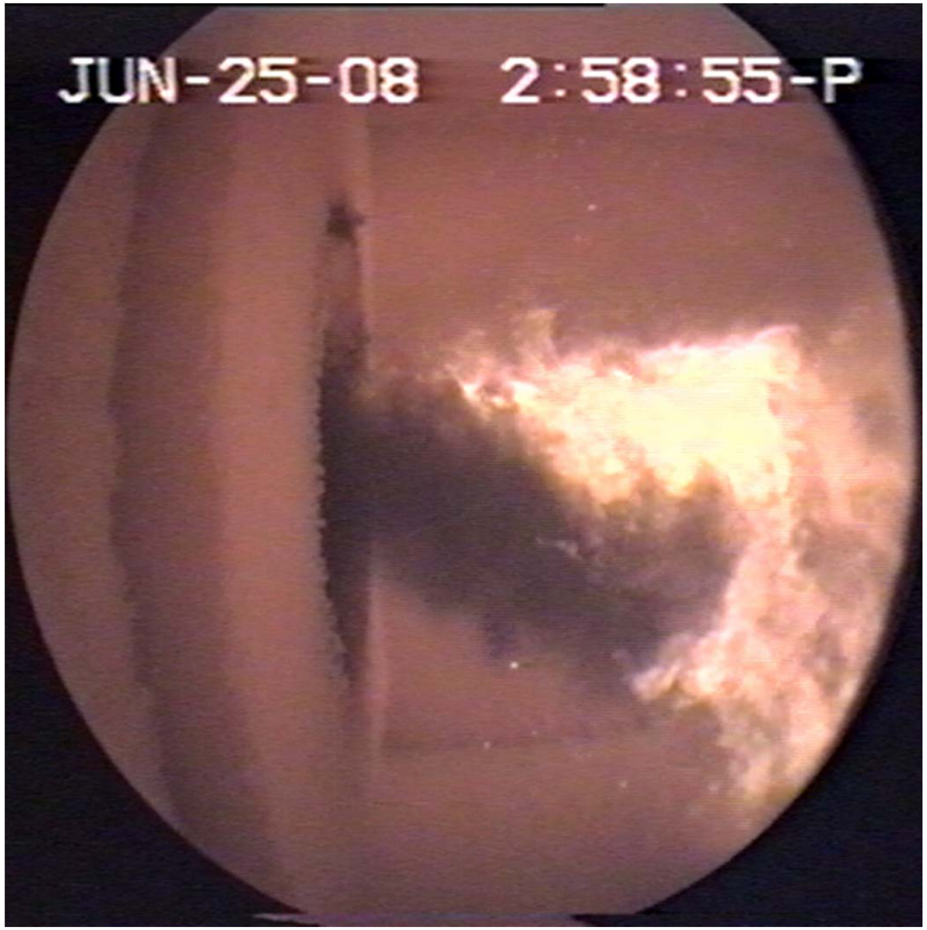
Radiative HT - South African coal – Dry Recycle

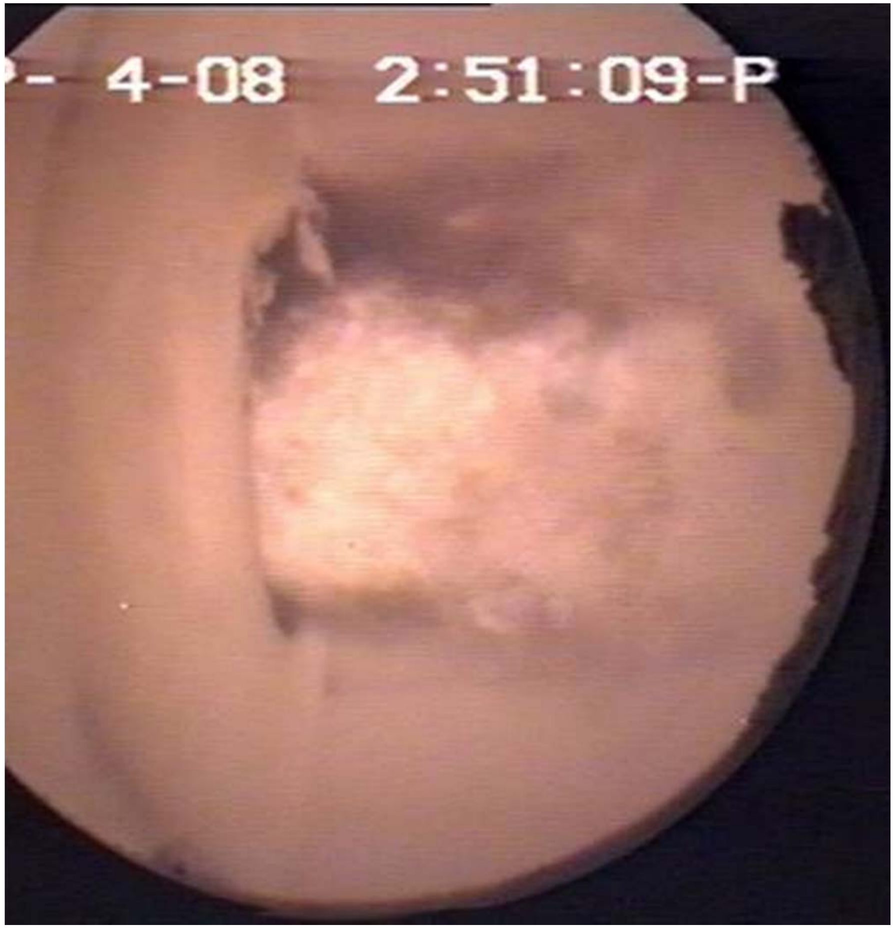


IFRF Burner - RR 66%, 38% Inlet O_2
Hot intense flame

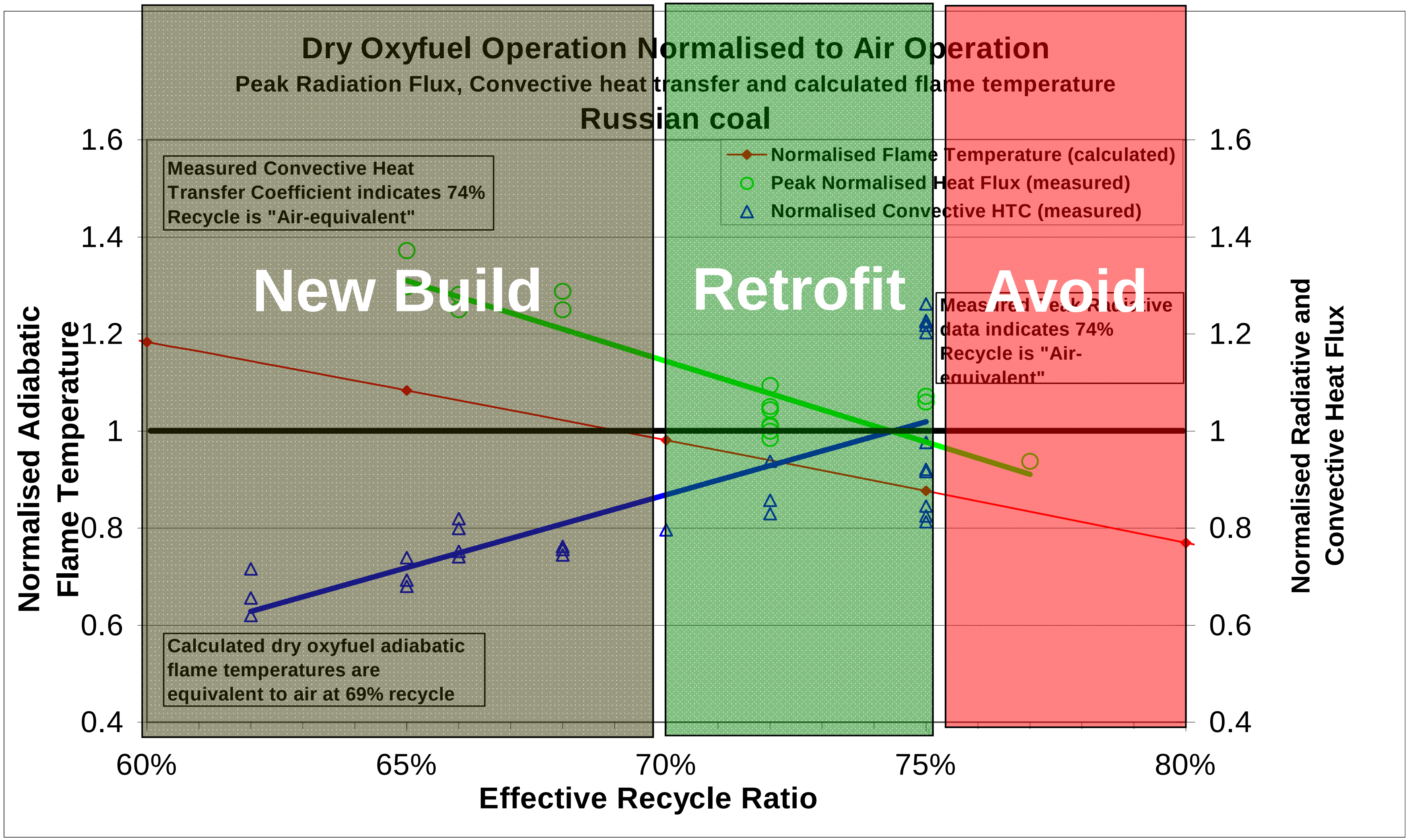


IFRF Burner – RR 77%; 28% Inlet O_2 Cool Flame





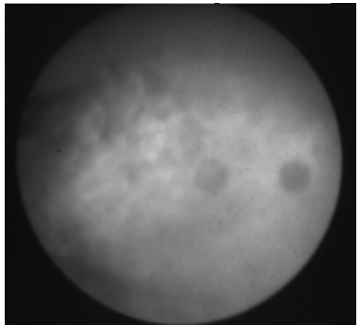
Normalised Convective & Radiative Heat Flux
Russian Coal - Dry Recycle



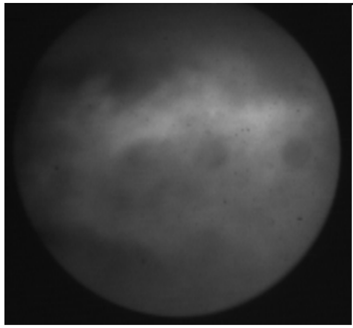
Oxycoal - Flame Stability

Flame Animations (South African Coal)

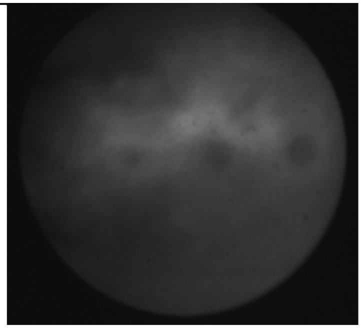
- **Images for different simulated recycle rates under low O_2 settings**



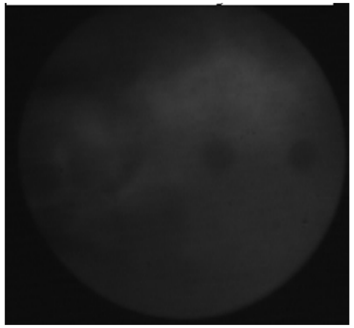
65% rr, Total flow 554.74kg/h
Sec 400kg/h@35.8% O_2
(time: 14:19)



68% rr, Total flow 615.71kg/h
Sec 457kg/h@31.6%
(time: 13:44)

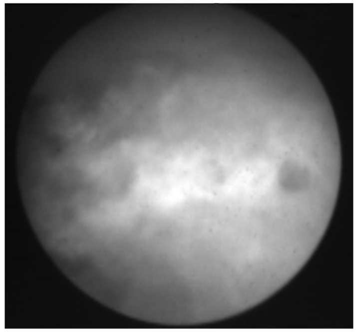


70% rr, Total flow 656.99kg/h
Sec 501kg/h@29.0% O_2
(time: 13:14)

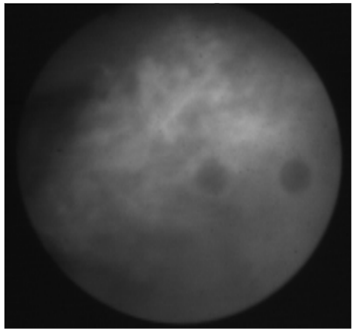


72% rr, Total flow 709.04kg/h
Sec 552kg/h@26.5%O_2
(time: 12:41)

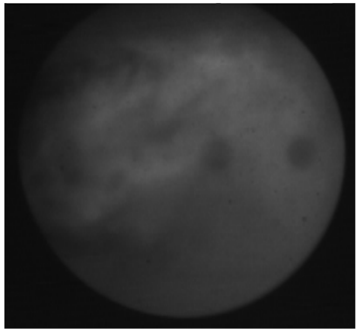
- **Images for different simulated recycle rates under high O_2 settings**



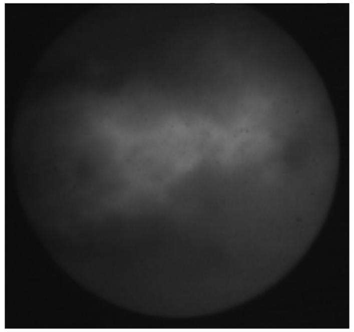
65% rr, Total flow 567.69kg/h
Sec 412kg/h@38.0% O_2
(time: 14:36)



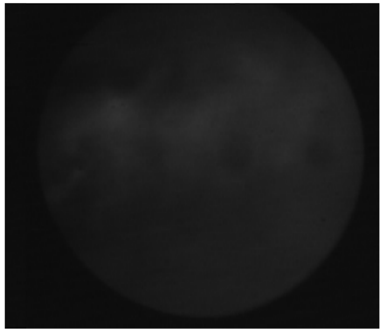
68% rr, Total flow 624.70kg/h
Sec 470kg/h@33.9%O_2
(time: 14:04)



70% rr, Total flow 670.91kg/h Sec
516kg/h@31.3%O_2
(time: 13:27)



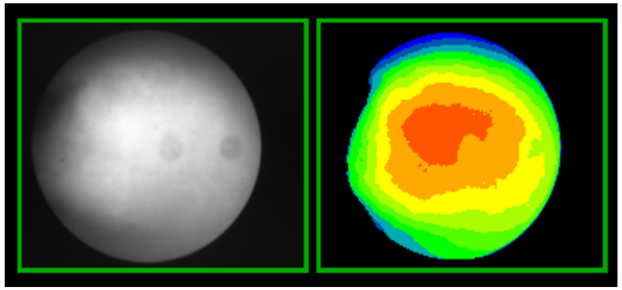
72% rr, Total flow 722.64kg/h
Sec 567kg/h@28.9%O_2
(time: 12:54)



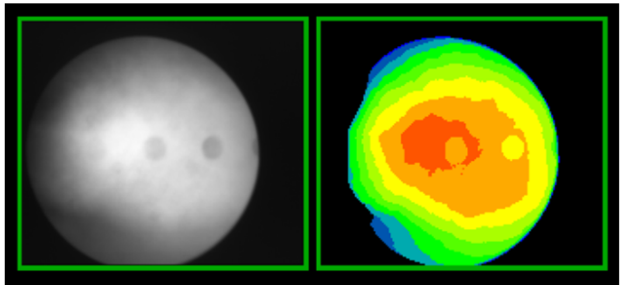
75% rr, Total flow 806.57kg/h
Sec 650kg/h@25.4% O_2
(time: 12:29)

Flame Images

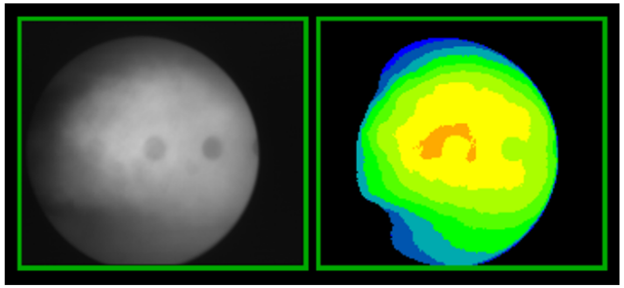
- **Temperature profiles for different simulated recycle rates under lower O_2 settings**



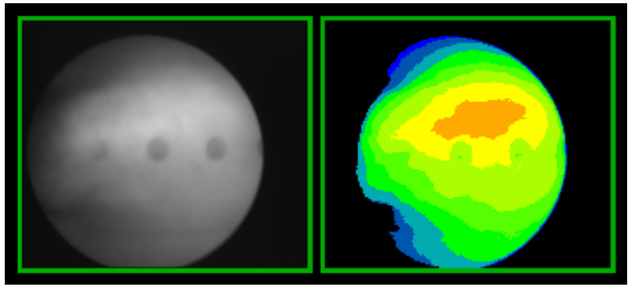
62% RR: Sec.f 322kg/h@39.4% (time: 12:32, 30-10)



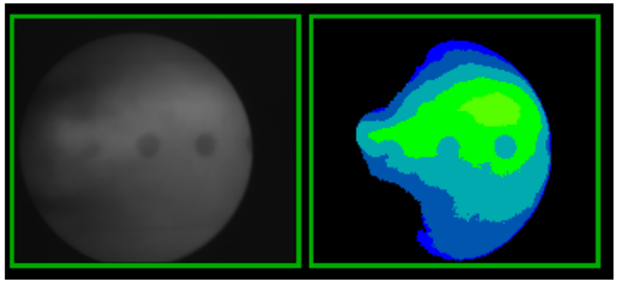
65% RR: Sec.f 368kg/h@34.8% (time: 15:18, 29-10)



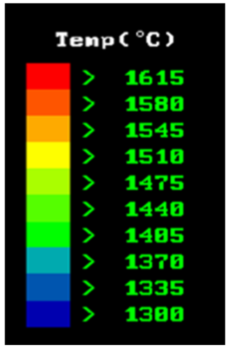
68%RR: Sec.f 422kg/h@30.5% (time: 15:05, 29-10)



72% RR: Sec.f 513kg/h@25.5% (time: 14:18, 29-10)



75% RR: Sec.f 600kg/h@22.1% (time: 13:41, 29-10)



Note: Images and temperature profiles shown here are averaged for 10 instantaneous readings over about 2 minutes.

Conclusions (Dry recycle data)

> Air operation radiative heat flux found to be equivalent to 72 – 75% recycle ratio (due to different radiative properties of carbon dioxide compared to nitrogen)

> Radiative heat flux peak shifts downstream as recycle rate increases

> Convective Heat Transfer equivalent to air at 74% recycle ratio (main factors here are temperature and mass flow)

> Working range exists (there is a recycle ratio for which both radiative and convective transfer can be reasonable matched between air and oxyfuel operation. It is therefore possible to design a boiler for efficient operation in both oxyfuel and air conditions).

> Flame stability decreases with increasing recycle ratio

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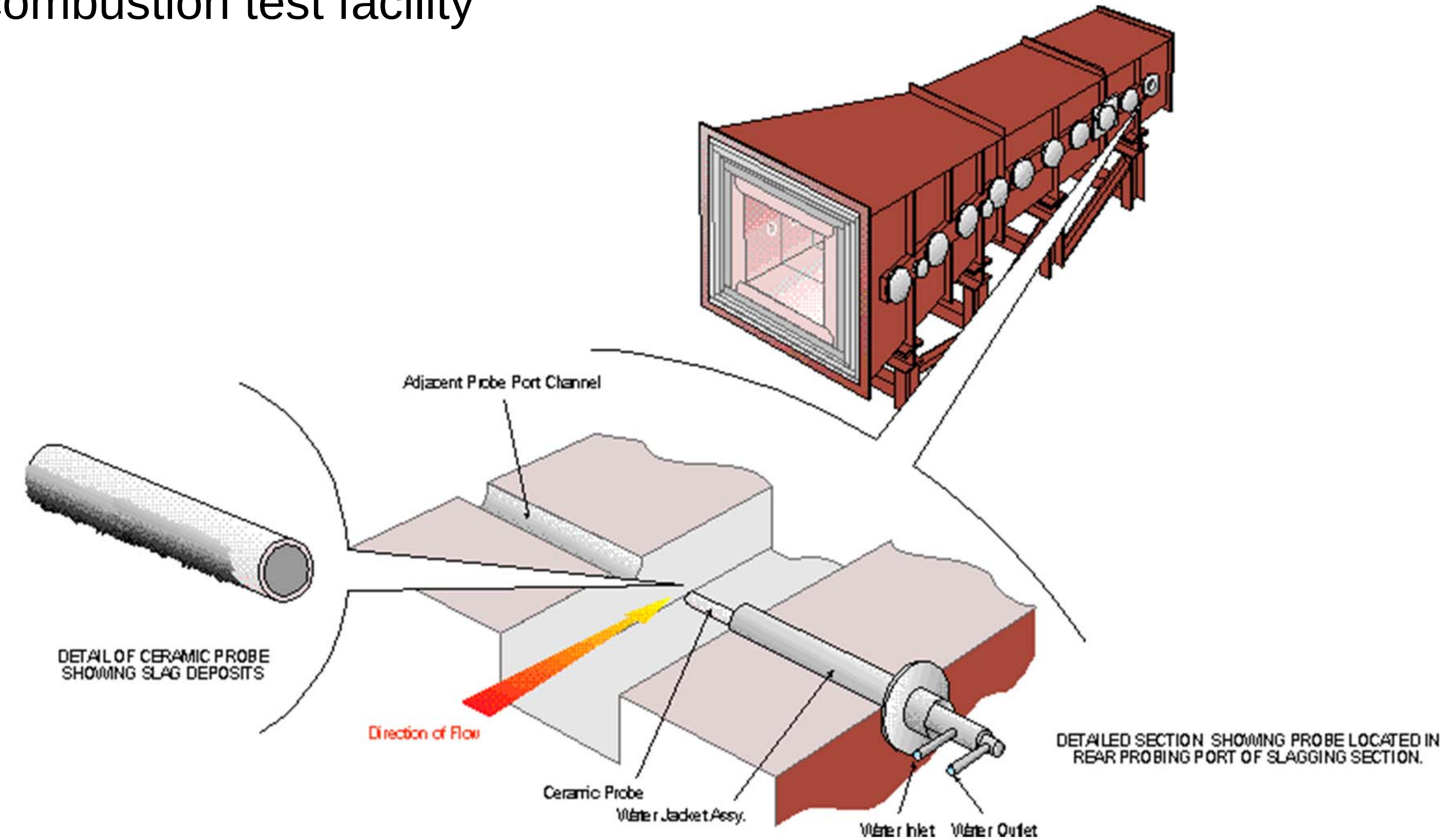
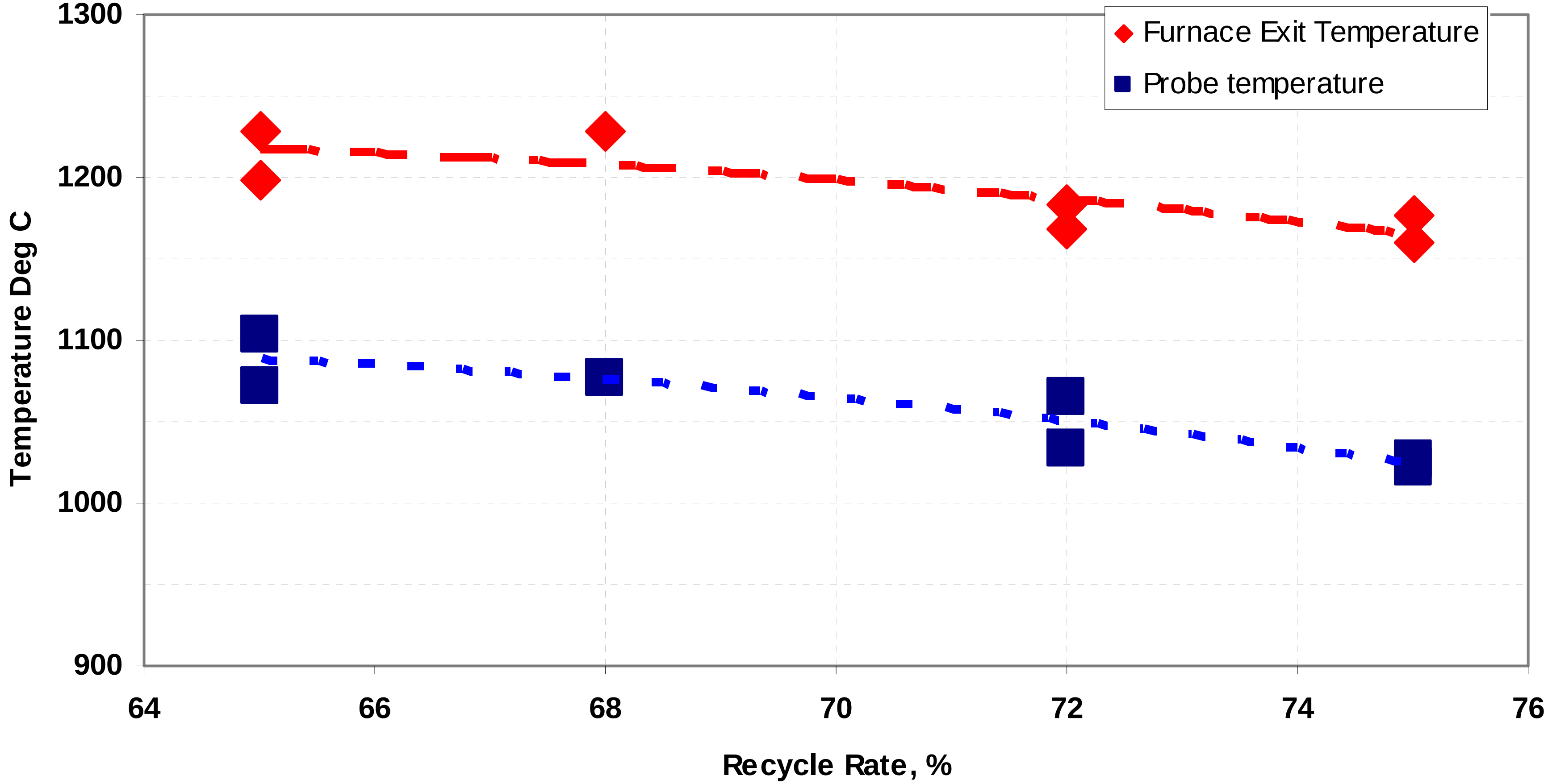
Deposition Studies under OxyFuel Firing Conditions

Combustion Test Facility

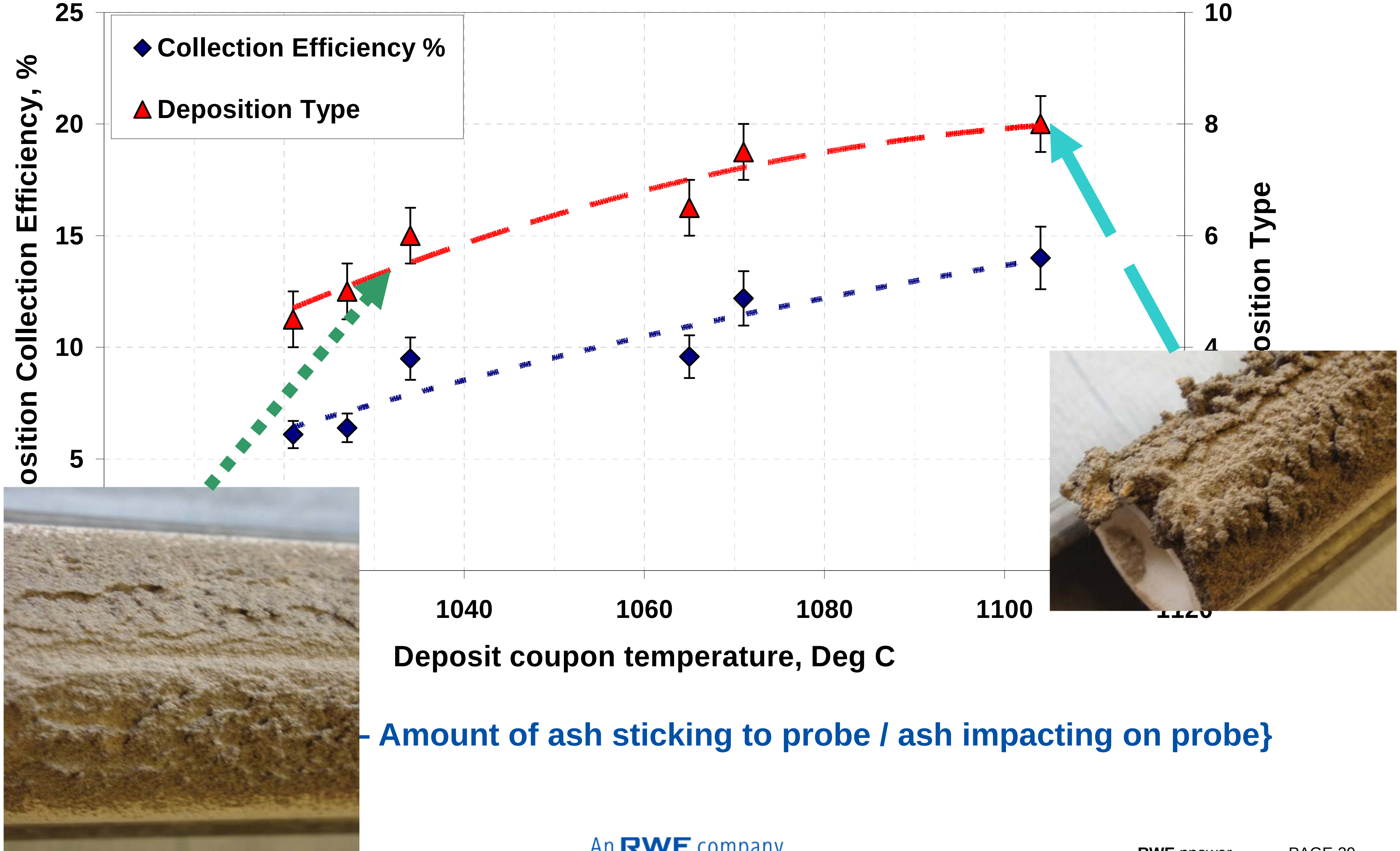
RWE have carried out a series of deposition runs on their pilot scale combustion test facility



Bofcom Deposition Data – Russian Coal 2

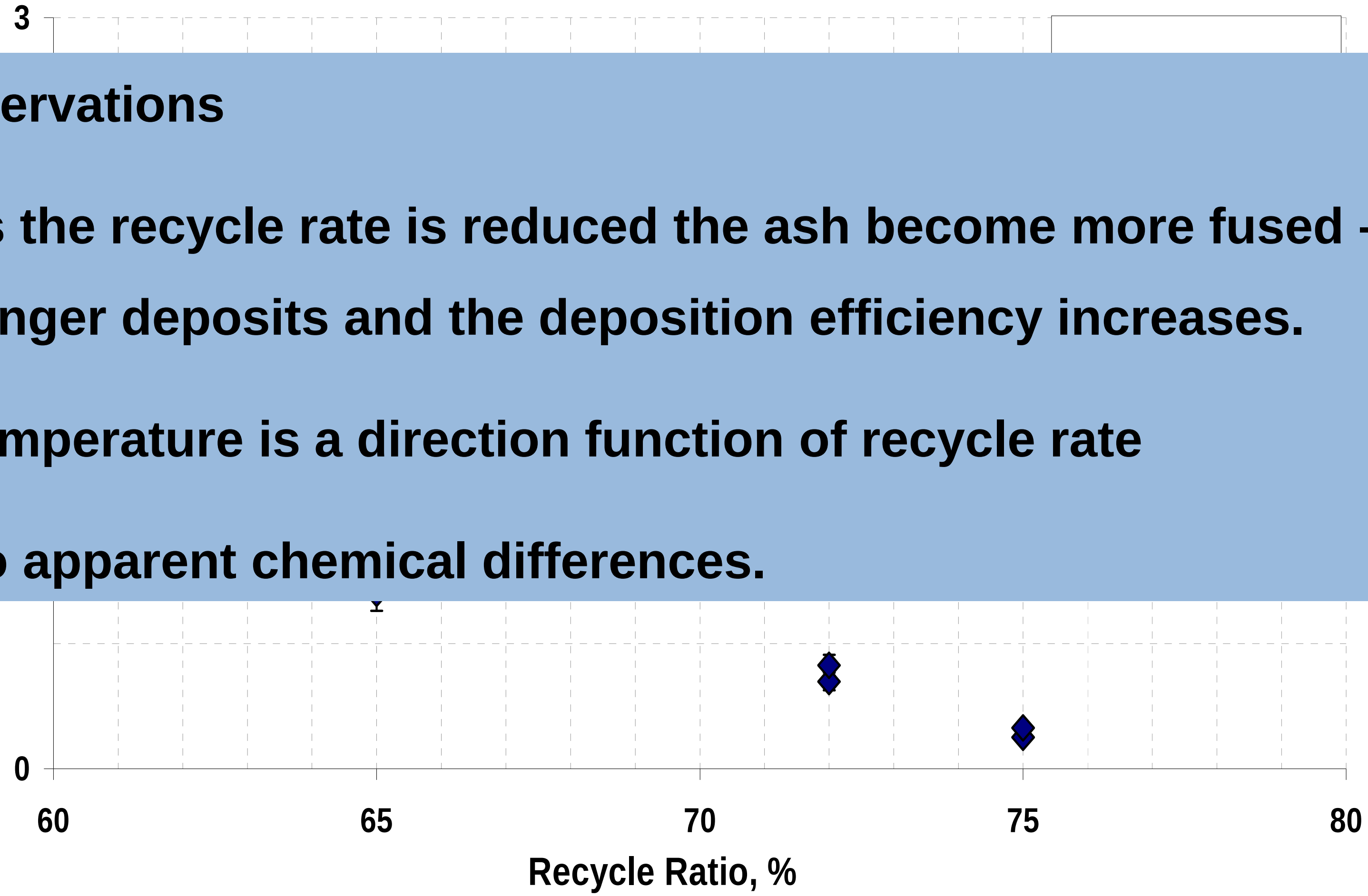


Deposition efficiency and Deposit Type



– Amount of ash sticking to probe / ash impacting on probe}

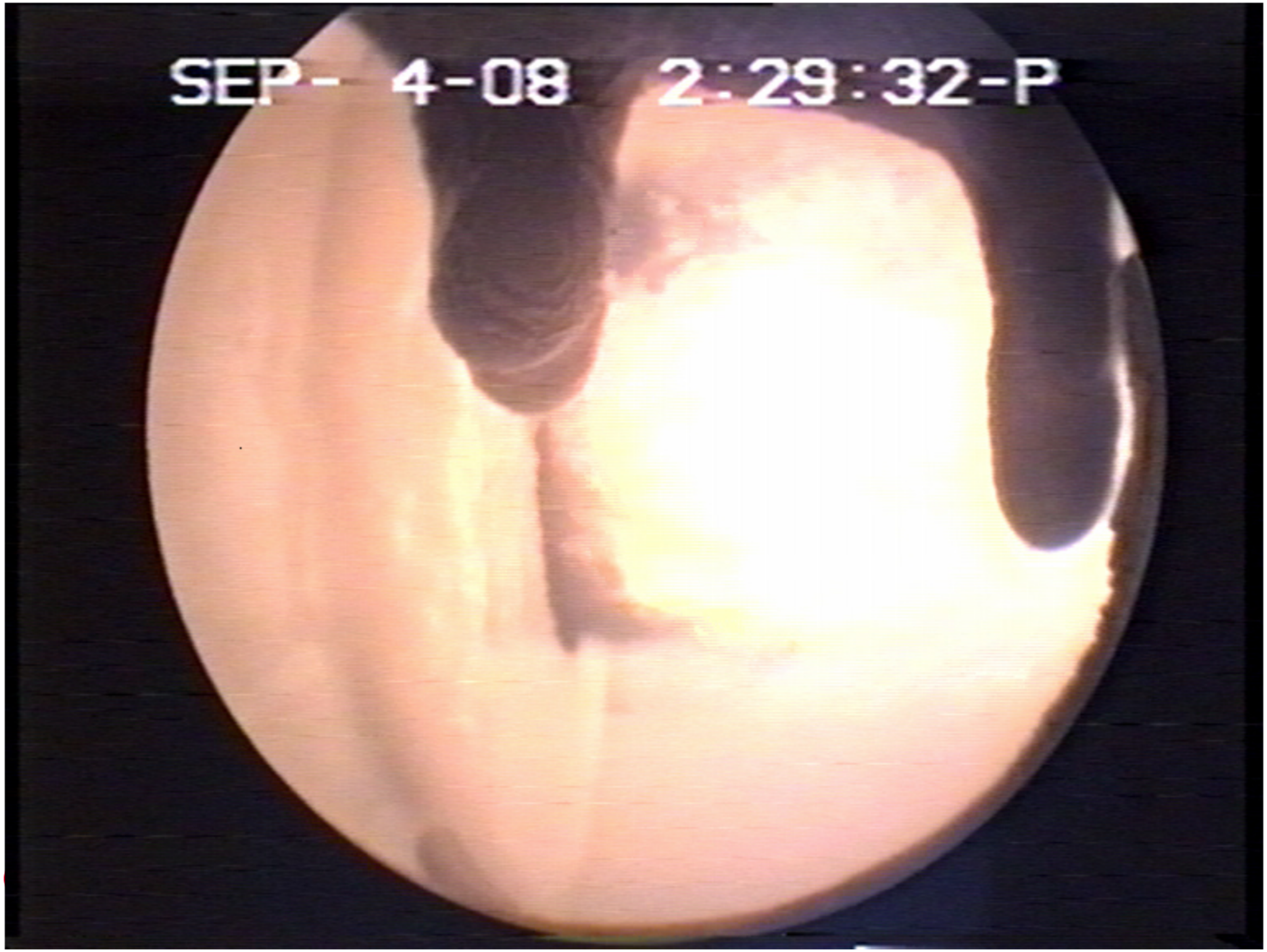
Impact = *f* (deposition rate and Deposit type)



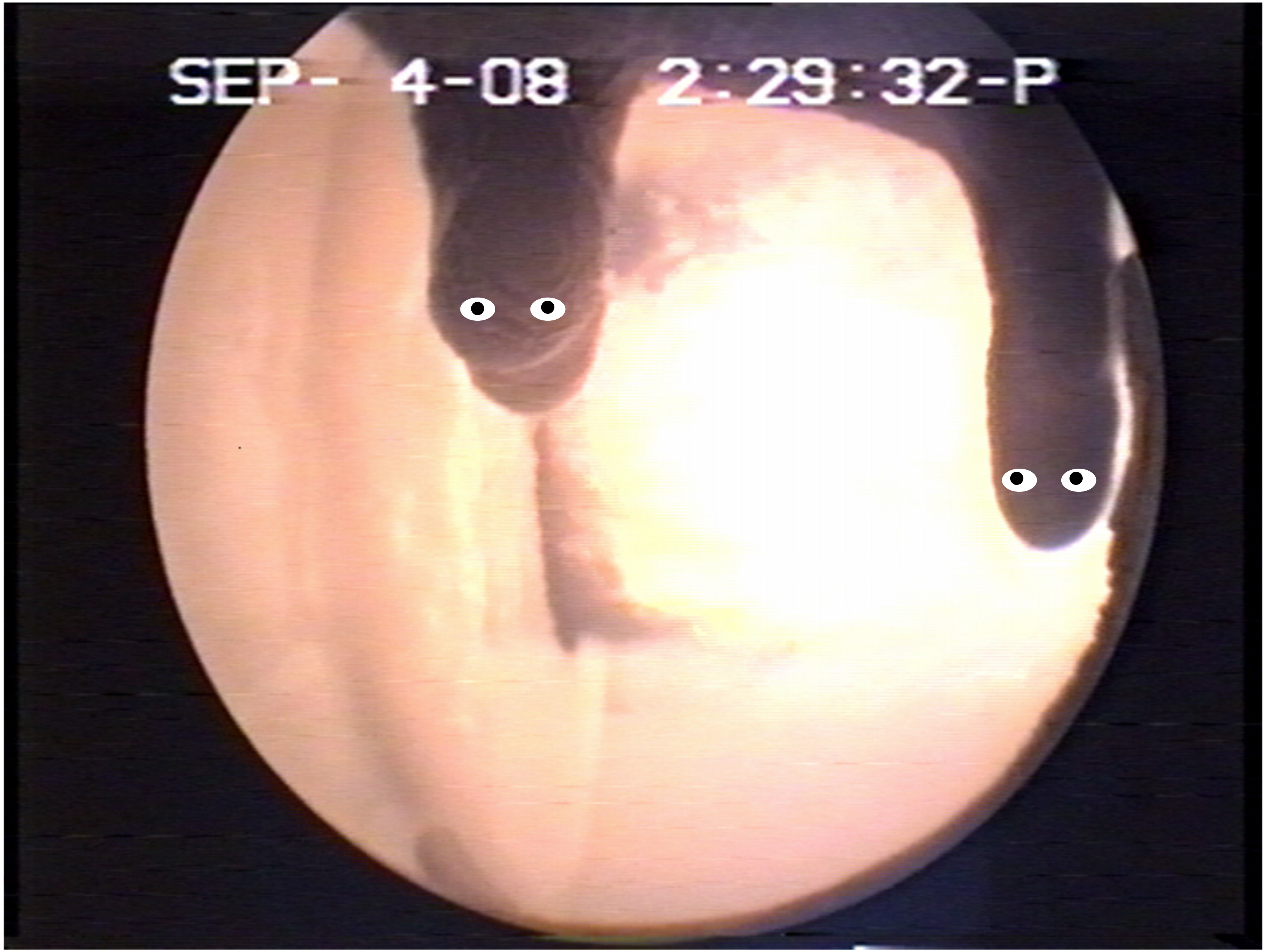
Observations

- **As the recycle rate is reduced the ash become more fused – stronger deposits and the deposition efficiency increases.**
- **Temperature is a direction function of recycle rate**
- **No apparent chemical differences.**

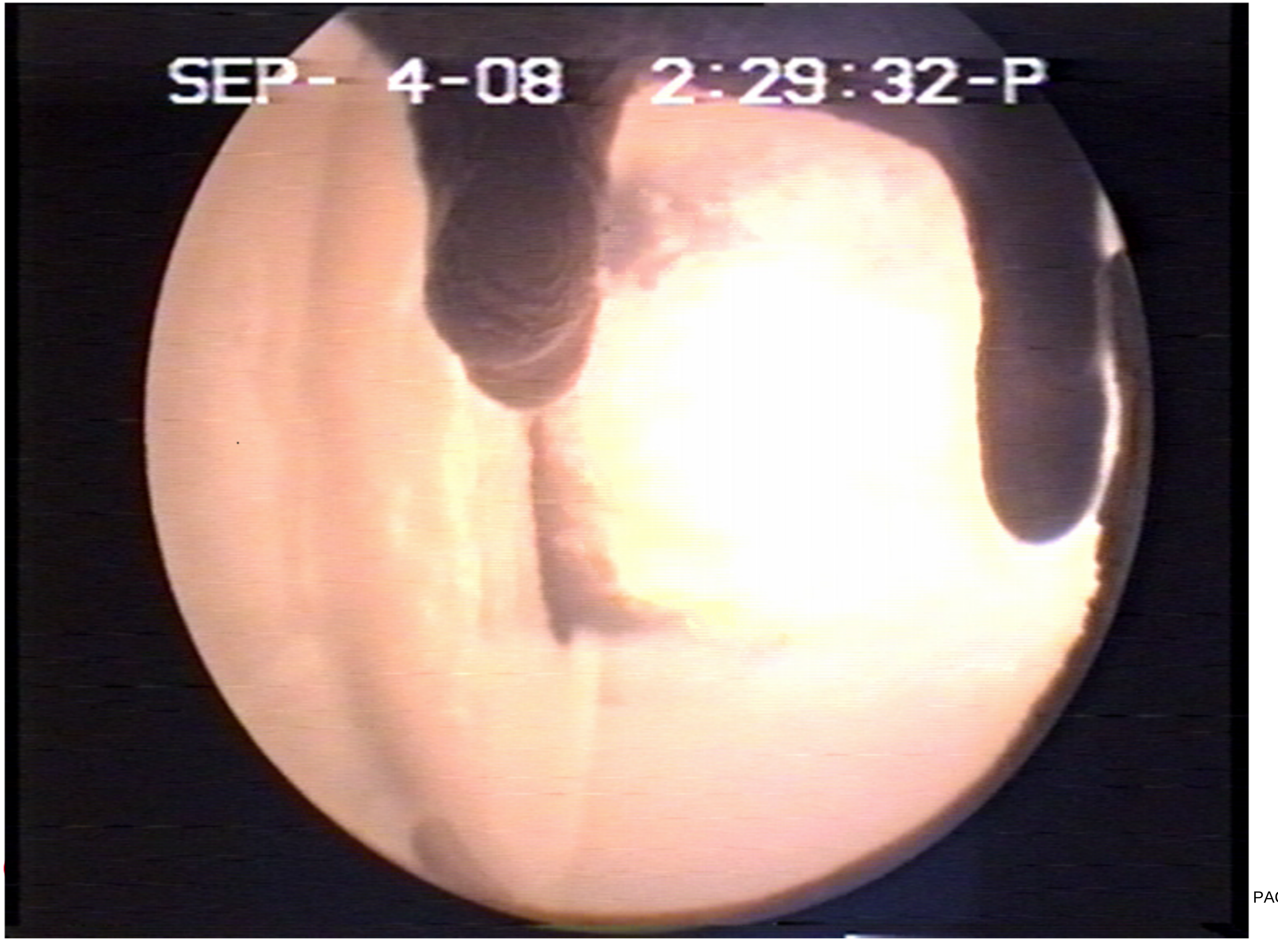
Caption competition!



Caption competition!



Caption competition!



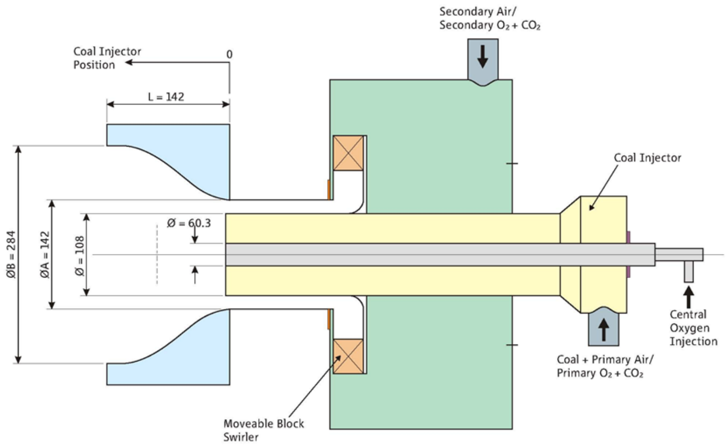
BOC / RWE
Oxygen injection

Oxyfuel with Centre Lance Oxygen injection

> Injection of pure oxygen centrally through the burner's core air tube instead of through the secondary air register.

> Strong impact on the flame

> Potential reduction in NO_x

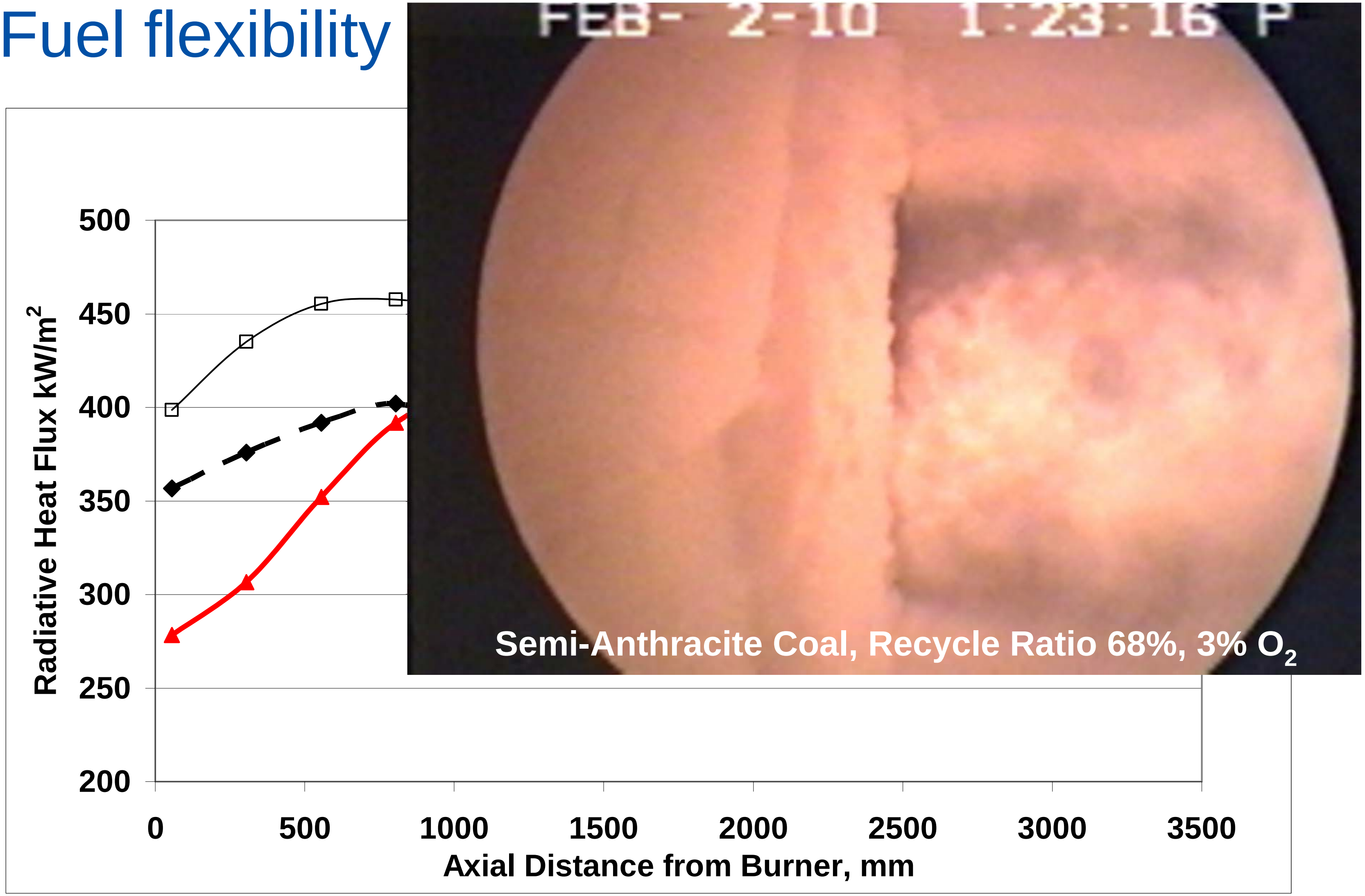


O2 injection: 39kg/h

O2 injection: 52kg/h

RWE
Fuel Flexibility

Fuel flexibility



npower

An RWE company

Fuel Flexibility

> What has been demonstrated is that:

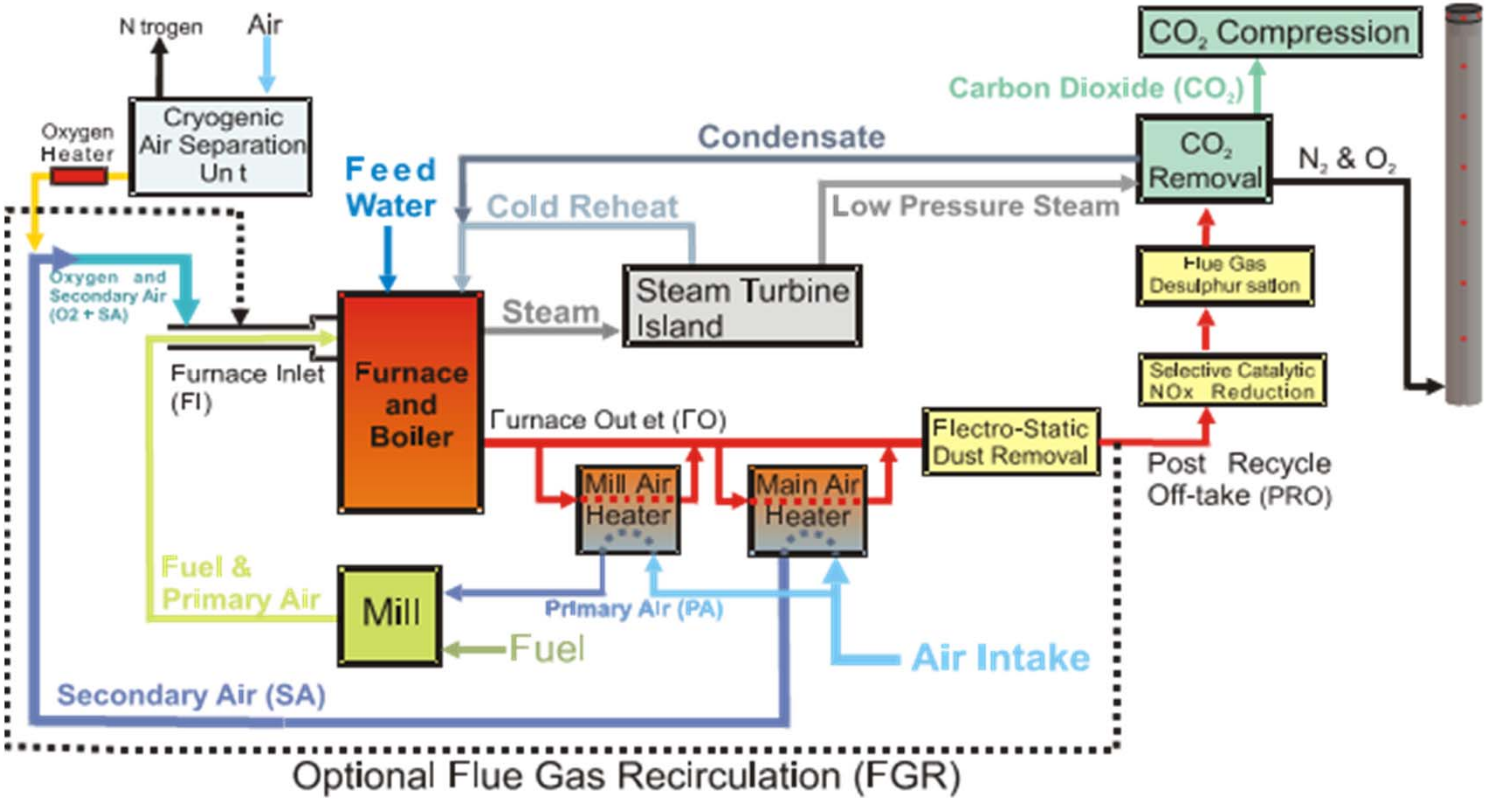
  – Using oxy-fuel combustion technology, a wider range of coals can be fired in a swirl burner configuration for application in wall fired boilers than is conventional with standard air firing.

  – This offers potential for greater fuel type flexibility, wider options in fuel diet and consequential fuels costs than would be normal in a conventional only air fired wall fired boiler.

> This scoping study has demonstrated that flame ignition, stability and luminosity for low volatile fuel can be improved under oxy-fuel firing conditions compared to air and deserves a more systematic study.

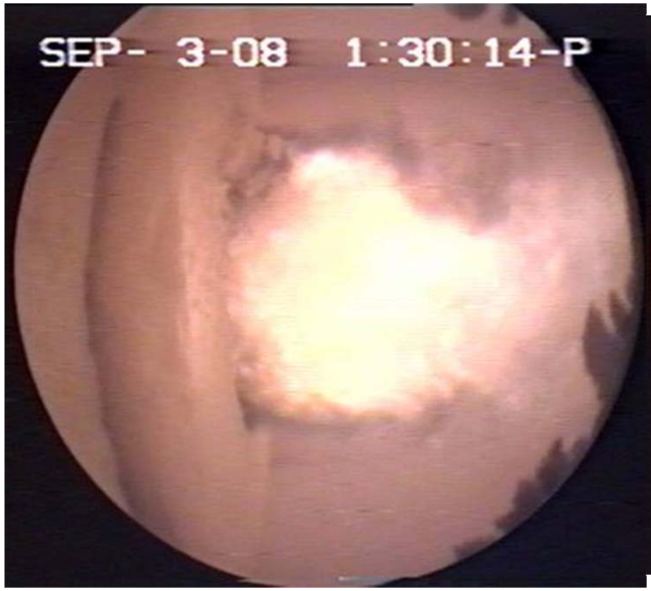
EcoScrub
OxyFuel / Post Combustion Capture Hybrid

Ecoscrub

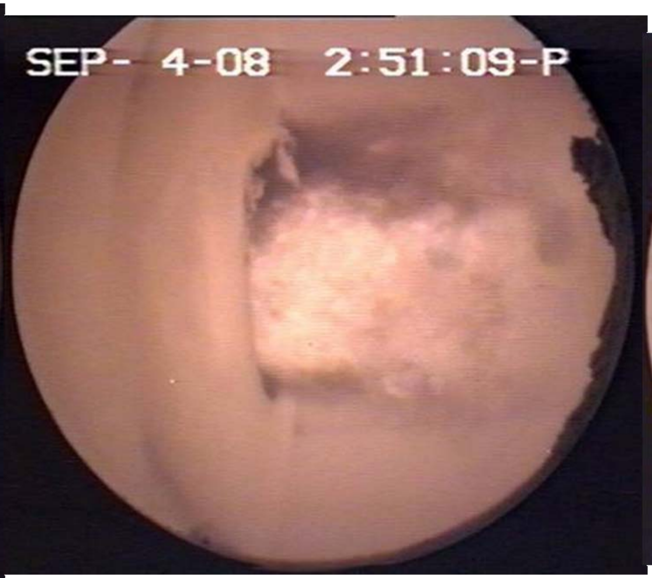


N trogen
Air
Cryogenic Air Separation Un t
Oxygen Heater
Feed Water
Condensate
Cold Reheat
Low Pressure Steam
Carbon Dioxide (CO_2)
CO_2 Compression
CO_2 Removal
N_2 & O_2
Oxygen and Secondary Air (O2 + SA)
Steam
Steam Turbine Island
Furnace and Boiler
Furnace Inlet (FI)
Furnace Out et (FO)
Flue Gas Desulphur sation
Selective Catalytic NOx Reduction
Electro-Static Dust Removal
Post Recycle Off-take (PRO)
Mill Air Heater
Main Air Heater
Fuel & Primary Air
Mill
Primary Air (PA)
Fuel
Air Intake
Secondary Air (SA)
Optional Flue Gas Recirculation (FGR)

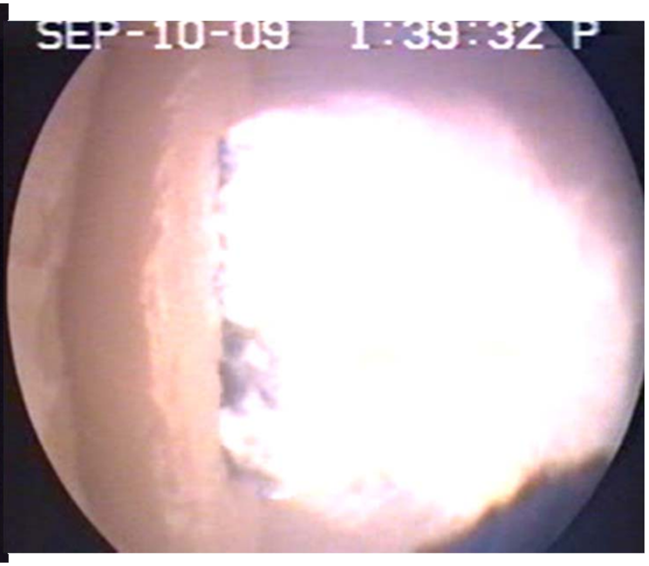
Flames



IFRF Burner - RR 66%, 38% Inlet O2



IFRF Burner – RR 77%; 28% Inlet O2



IFRF Burner – ECO Scrub Case 3B
Air as Primary gas!
Reduced heat capacity of N_2 vs CO_2

Some Thoughts

- Development of a low cost option for carbon capture on existing modern coal-fired power plant using a novel combination of techniques employed for CO_2 capture, such as O_2 enrichment and post-combustion solvent scrubbing, together with measures to increase efficiency, reduce steam consumption and generate power requirements.
- Definitely an interesting idea and not crazy but lots of questions to answer
- Demonstrate the ideas
- Commercial – Fuel flexibility; Key pluses over pure OxyF/Amine
- Air ingress

Further work

- Further cost analysis but needs to be site specific
- Future developments in Amines targeted at 28% CO_2 concentration
- Lower cost oxygen production
- Membrane development.

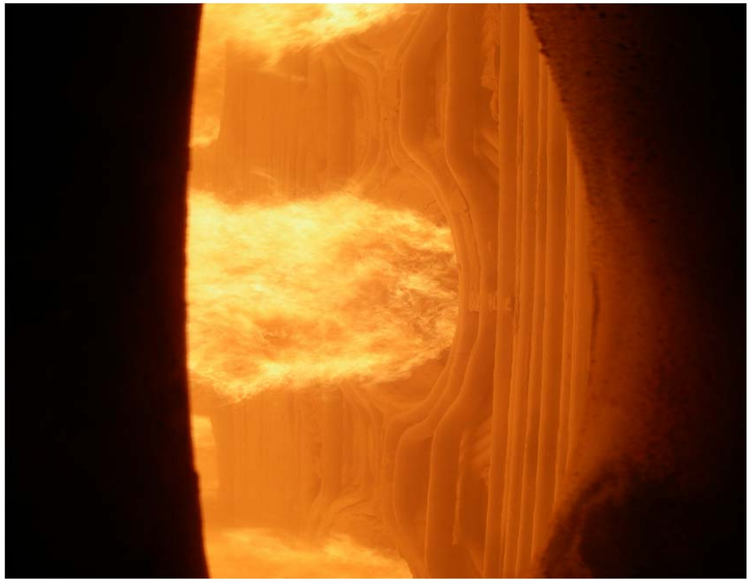
Acknowledgements

- The combustion test facility conversion to OxyFuel was financed by RWE npower
- The experimental programmes are co-funded by RWE npower and:
- The European Commission Research Fund for Coal and Steel - BOFCom
  - Heat Transfer, Wet and Dry recycle, Biomass, OFA, Deposition studies
- The UK Technology Strategy Board - Oxycoal-UK

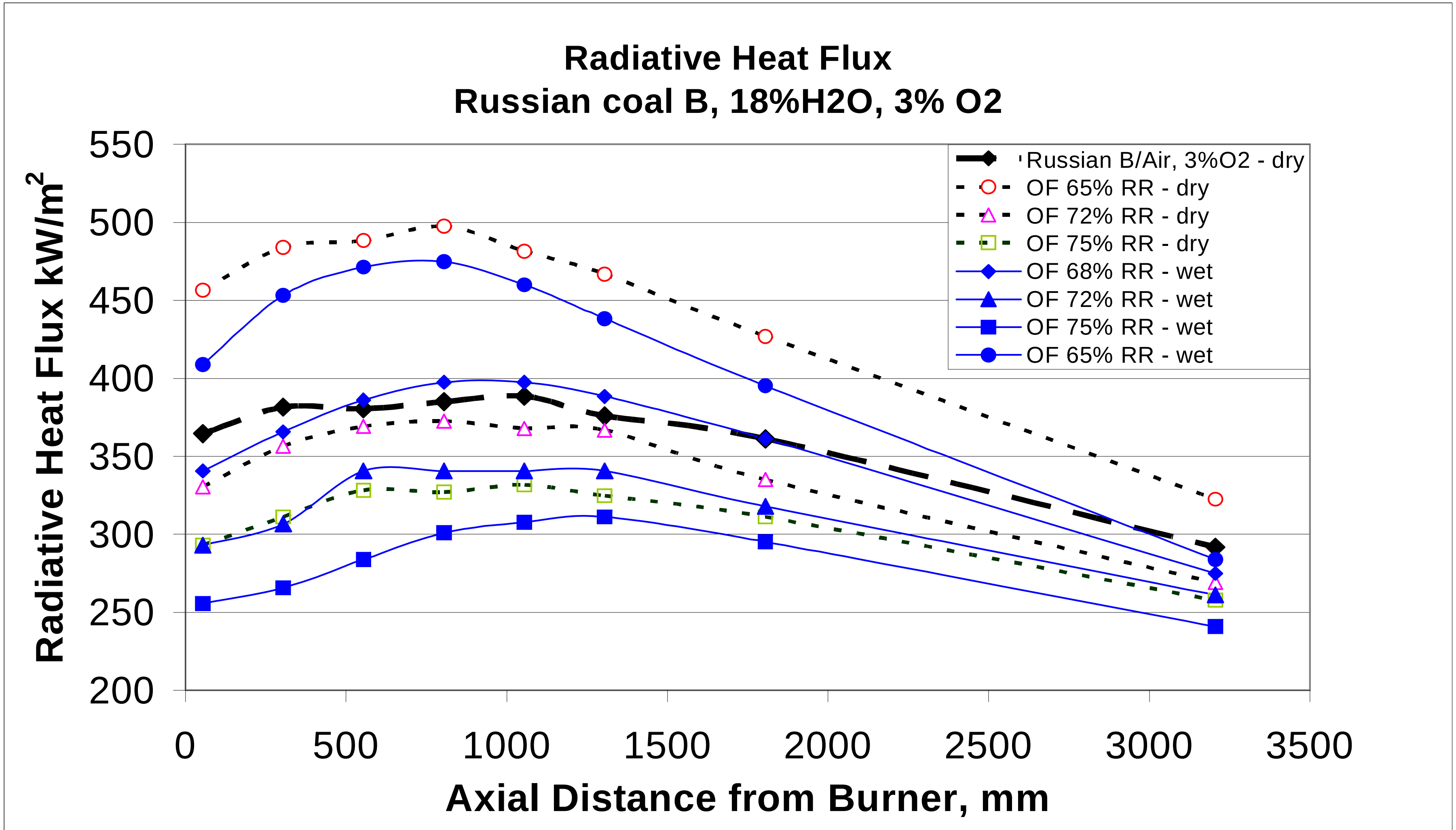
Conclusion
(Biased and do not represent RWE's views!!)

- Oxyfuel is a better option than post combustion capture
  - Suitable for retrofit
  - Flexibility on fuel
  - It is more flexible than Post Combustion Capture
    - Where the oxygen is injected
    - Recycle rate
    - OFA port options.

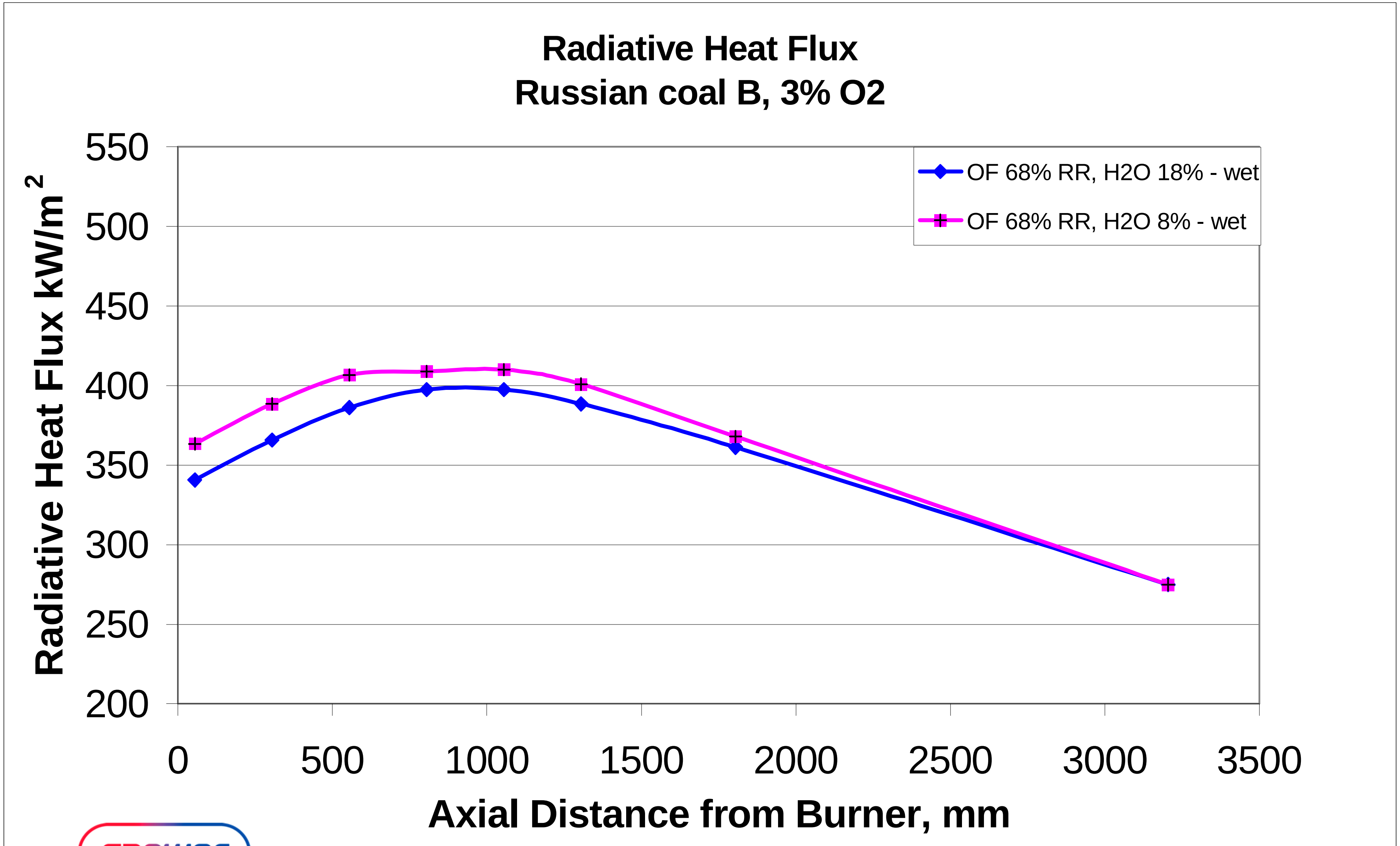
Thank you for your attention.



Latest results – Wet / Dry comparison



Latest results – Wet (8%) / Wet (18%) comparison



Wet (18%) and Dry Recycle Normalised Peak Radiative and Convective Heat Flux