The Impact of Burner Staging on NO Reburning during Oxy-coal Combustion

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Oxy-coal Combustion: An Introduction

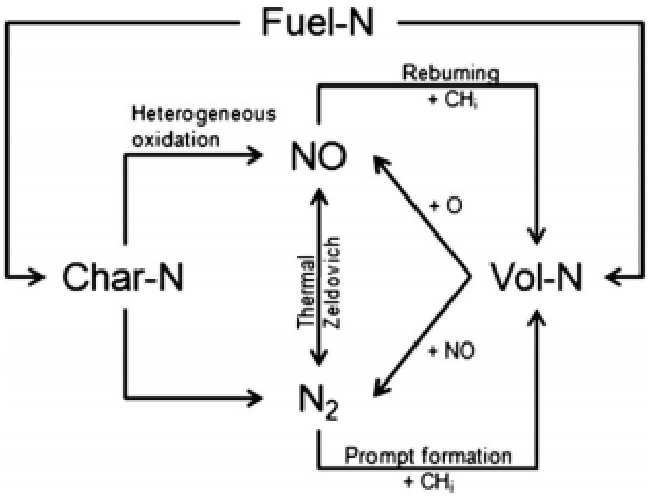
- Oxy-fuel combustion is a carbon capture technology
- An O_2/CO_2 oxidant is used instead of air in order to produce a flue gas with a far higher CO_2 content
- Greatly simplifying CO_2 capture
- The oxidant is formed by recirculating flue gas and combining with pure O_2
- Oxy-fuel combustion has been called the most techno-economically feasible CCS technology

Oxy-coal Combustion: Common Challenges

- Oxidant has some very different properties to air, including a higher heat capacity and density
- This impacts flame temperature and stability
- In order to match air’s flame temperature the oxygen concentration in the oxidant must be enriched
- The technology is associated with costly unit operations (ASU, SCR etc)

Oxy-coal Combustion: NO_x Processes

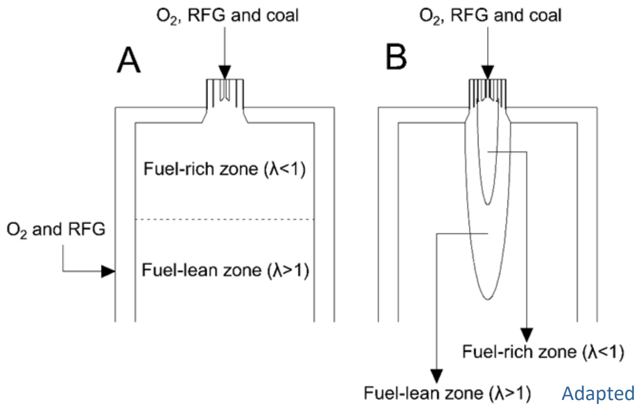
- NO concentration in flue gas tends to be higher than air
- Due to lack of nitrogen’s diluting effect
- Emission rate is lower though
- Higher O_2 concentration enabling increased conversion of fuel-N→NO
- Recycled NO reburning → reduction of NO through reaction with volatile-C, volatile-N and char (in presence of CO)



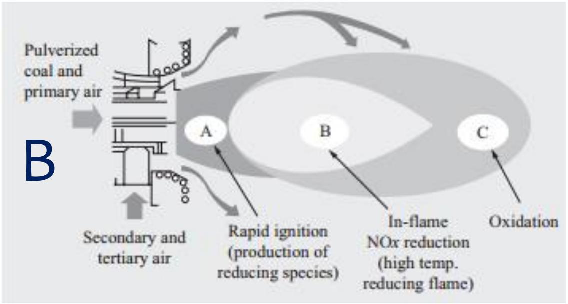
Toftegaard, M.B., Brix, J., Jensen, P.A., Glarborg, P., Jensen, A.D. (2010) Oxy-fuel combustion of solid fuels. *Progress in Energy and Combustion Science*, 36(5), 581-625.

Oxy-coal Combustion: Burner Staging

- Commonly, studies utilise furnace staging (A) in order to minimise NO formation
- However, the presence of NO in an over-fire stream could reduce overall rate of NO reburning
- Studying the impact of burner staging (B) on NO reburning is needed
- Increased in-flame NO reduction would reduce load on secondary NO_x technologies and help realise zero-NO_x oxy-coal combustion



Adapted from: Normann, F., Andersson, K., Leckner, B., Johnsson, F. (2009) Emission control of nitrogen oxides in the oxy-fuel process. Progress in Energy and Combustion Science, 35, 385-397.



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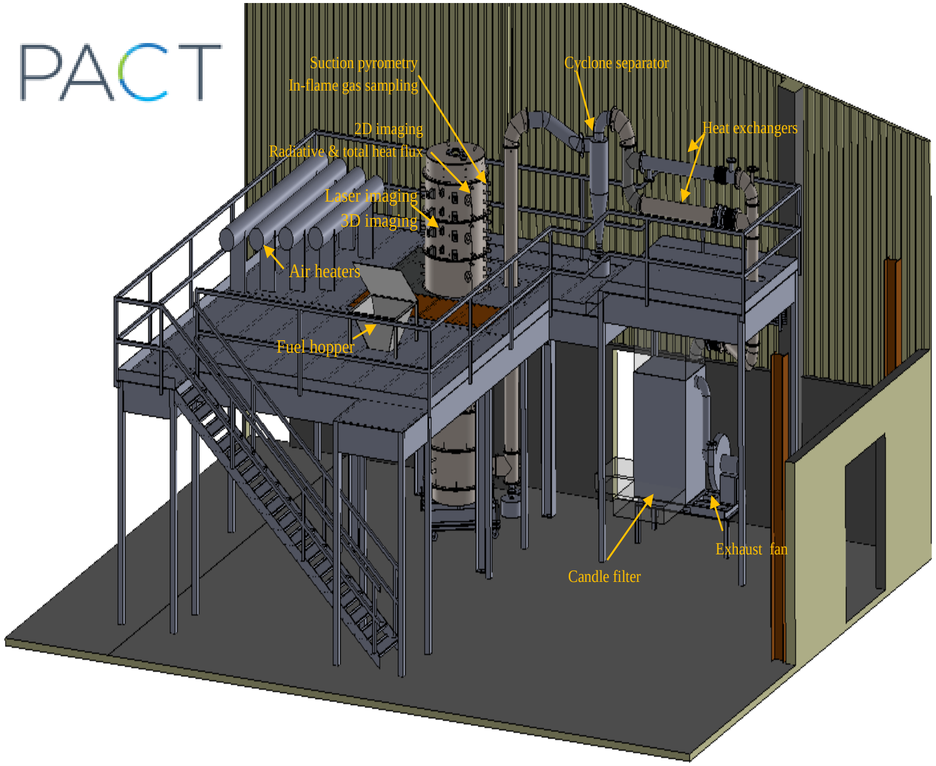
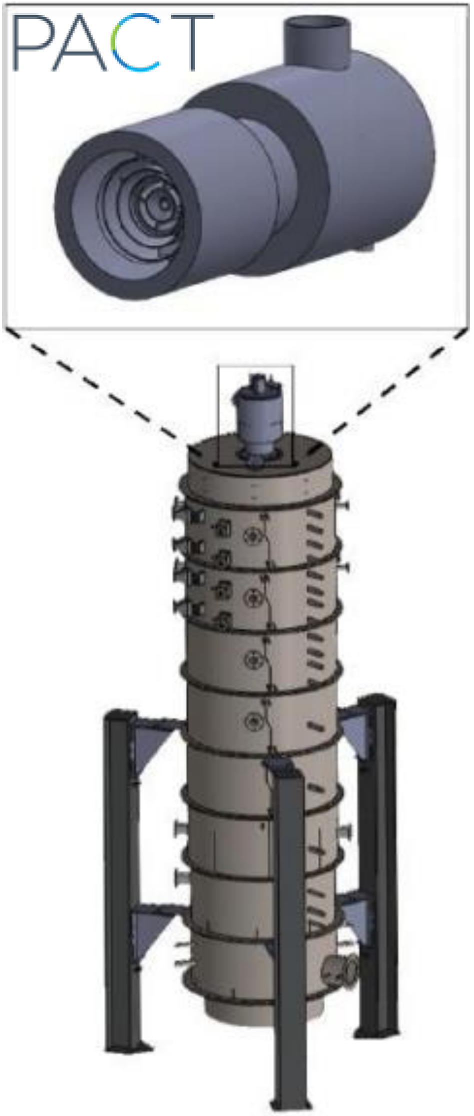
Experimental Setup

- 250 kW_{th} combustion test facility at PACT in Sheffield, UK
- Conditions: Air and OF 28 at 200 kW_{th} and OF 27 and OF 30 at 170 kW_{th}
- Measurements taken radially, axially and in the flue
- Oxidant with recycled flue gas is simulated using pure CO_2, O_2 and NO



Szuhanszki, J., Farias Moguel, O., Finney, K., Akram, M., Pourkashanian, M. (2017) Biomass combustion under oxy-fuel and post combustion capture conditions at the PACT 250 kW air/oxy-fuel CTF. Available: http://www.supergen-bioenergy.net/media/eps/supergen/presentations/assembly-2017/25.10.2017_SUPERGEN---Sheffield-Project-outputs_for-web.pdf

Operation of the Burner



- Initial (1°) oxidant and burnout (combined 2° and 3°) oxidant mass flows are controlled
- Sliding damper on the burner allows partitioning of the burnout oxidant into variable 2° and 3° flows, while 1° remains constant
- This enables variability of stoichiometry in the fuel-rich region and overall swirl of the flame
- The secondary oxidant proportion (S): ratio of mass flow of oxygen in the 1° and 2° oxidant to the mass flow of oxygen in the combined 2° and 3° oxidant

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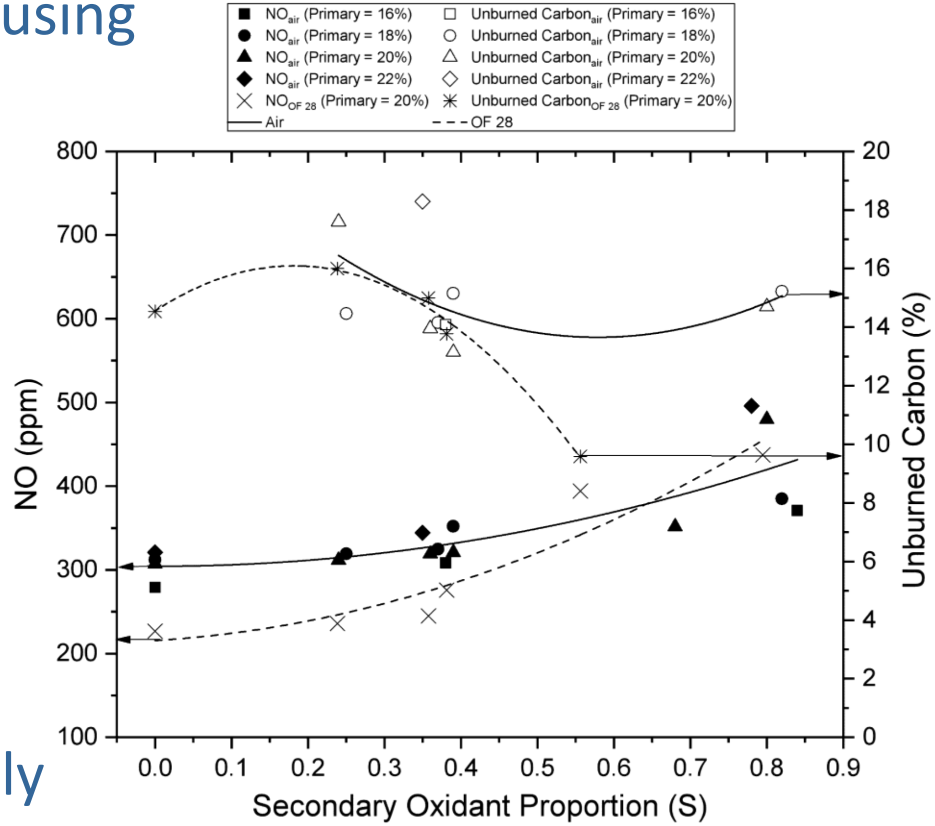
Air + OF 28 200 kW_{th}

Impact of the Primary Flow and Burner Staging on NO Formation

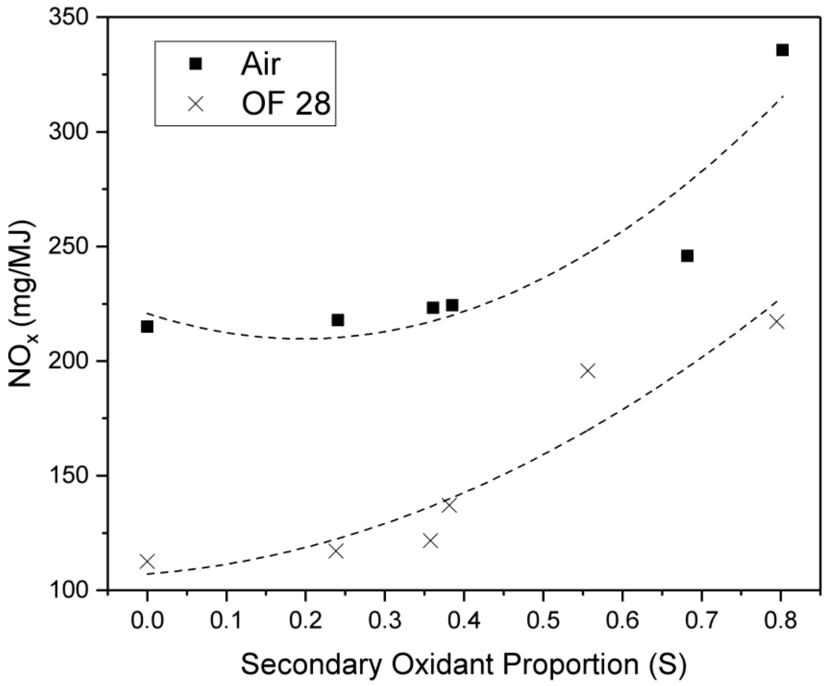
- Four 1° oxidant flowrates tested using air (16%, 18%, 20%, 22%)
- 20% most favourable setting across range of secondary oxidant proportions
- This is now used as a constant for all oxy-coal scenarios
- At OF 28, NO emissions are lower than air until S < 0.5, while unburned carbon only significantly improves when S > 0.5



Air + OF 28 200 kW_{th}

Comparison of NO_x Emission Rate without NO 'Recycling'

- Confirmation of far superior emission rate from a staged oxy-coal flame
- Reasons for lower NO_x formation:
  - Lack of thermal and prompt NO
  - The reverse Zeldovich mechanism
  - Likely temperature increase in the fuel-rich zone causing: reduced char-N→NO, increased fuel-N→volatile-N, increased volatile-N→N_2



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OF 27 + OF 30 170 kW$_{th}$

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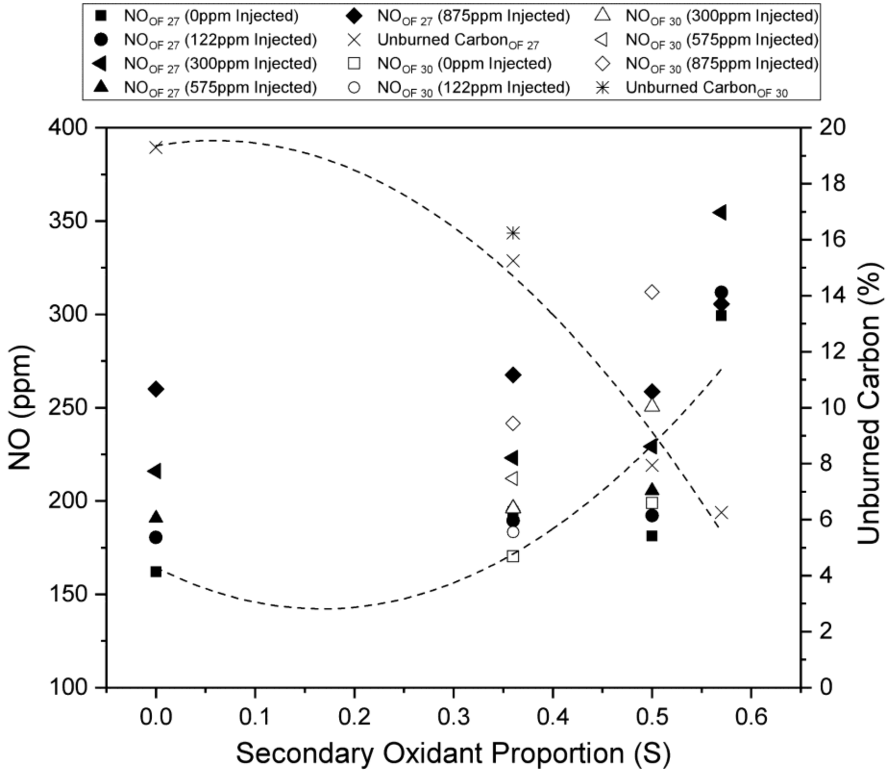
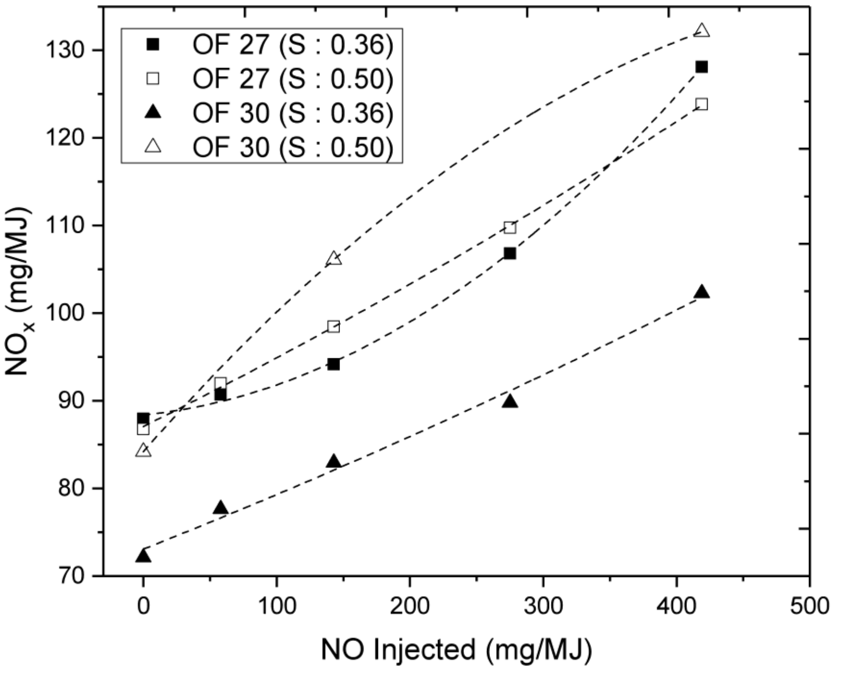
Impact of NO ‘recycling’ and Burner Staging on Combustion





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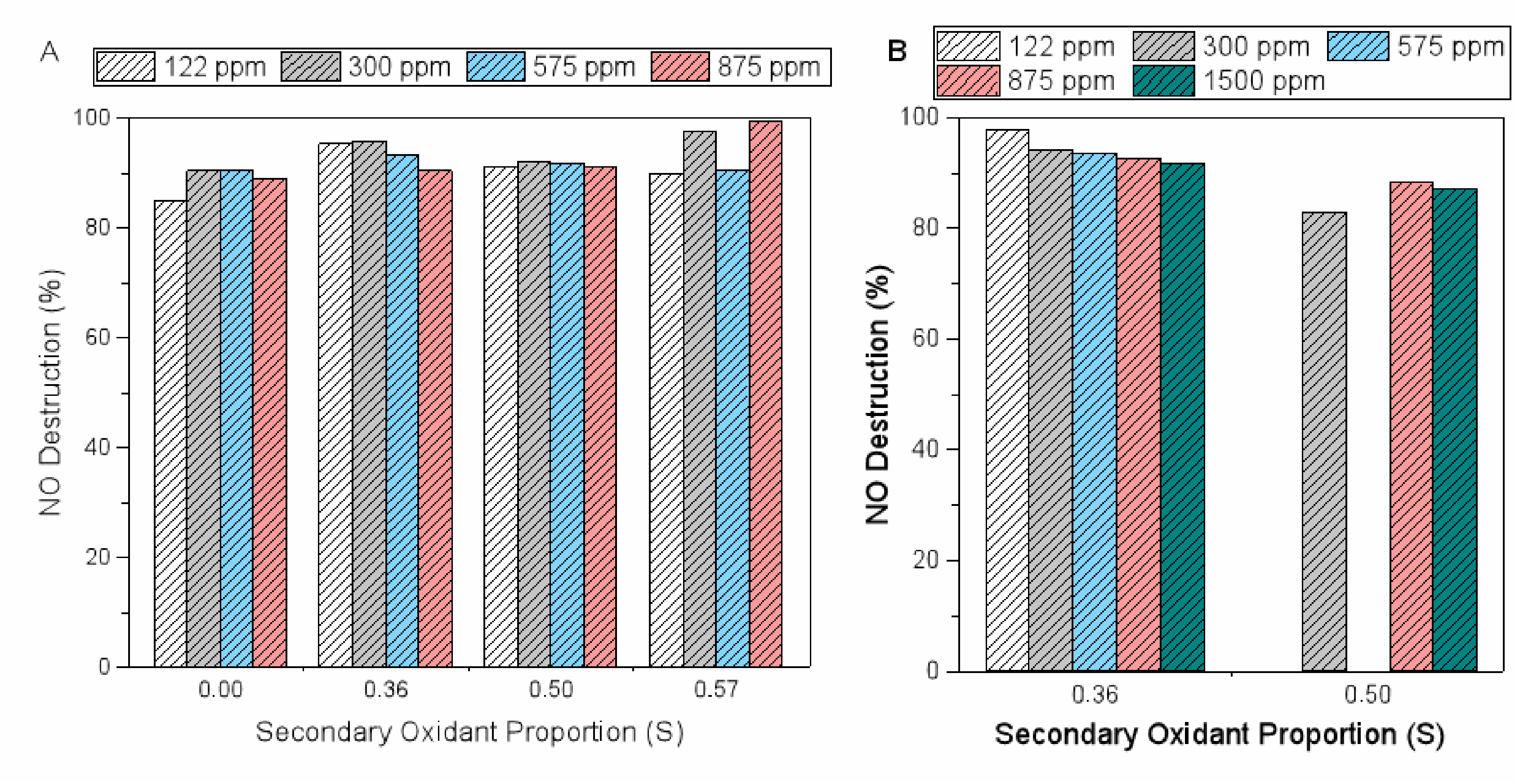
Impact of Near-Burner Stoichiometry on NO Reburning



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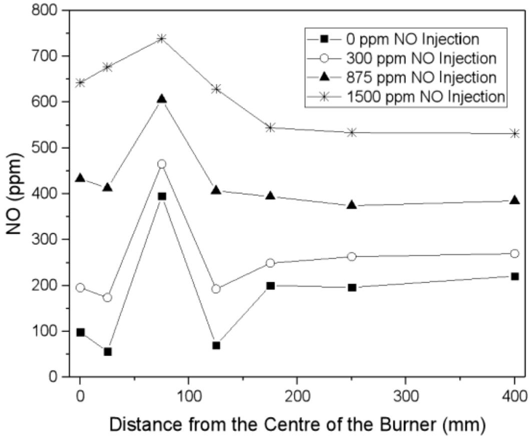
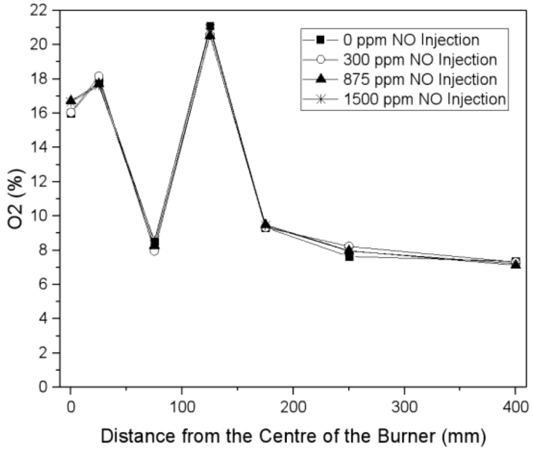
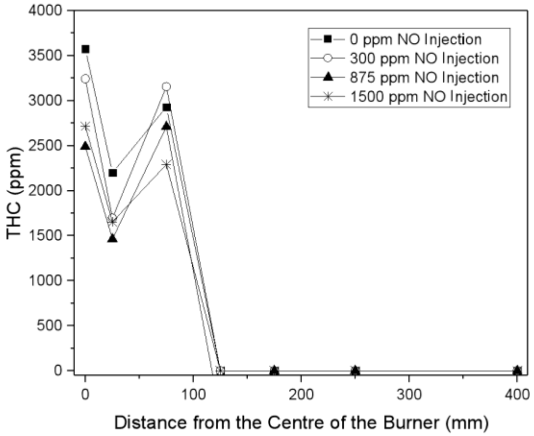
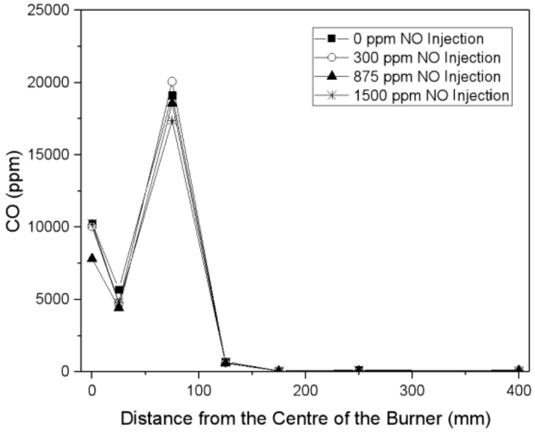
Impact of NO ‘Recycling’ on Radial Profile of Key Flame Constituents (S: 0.36)









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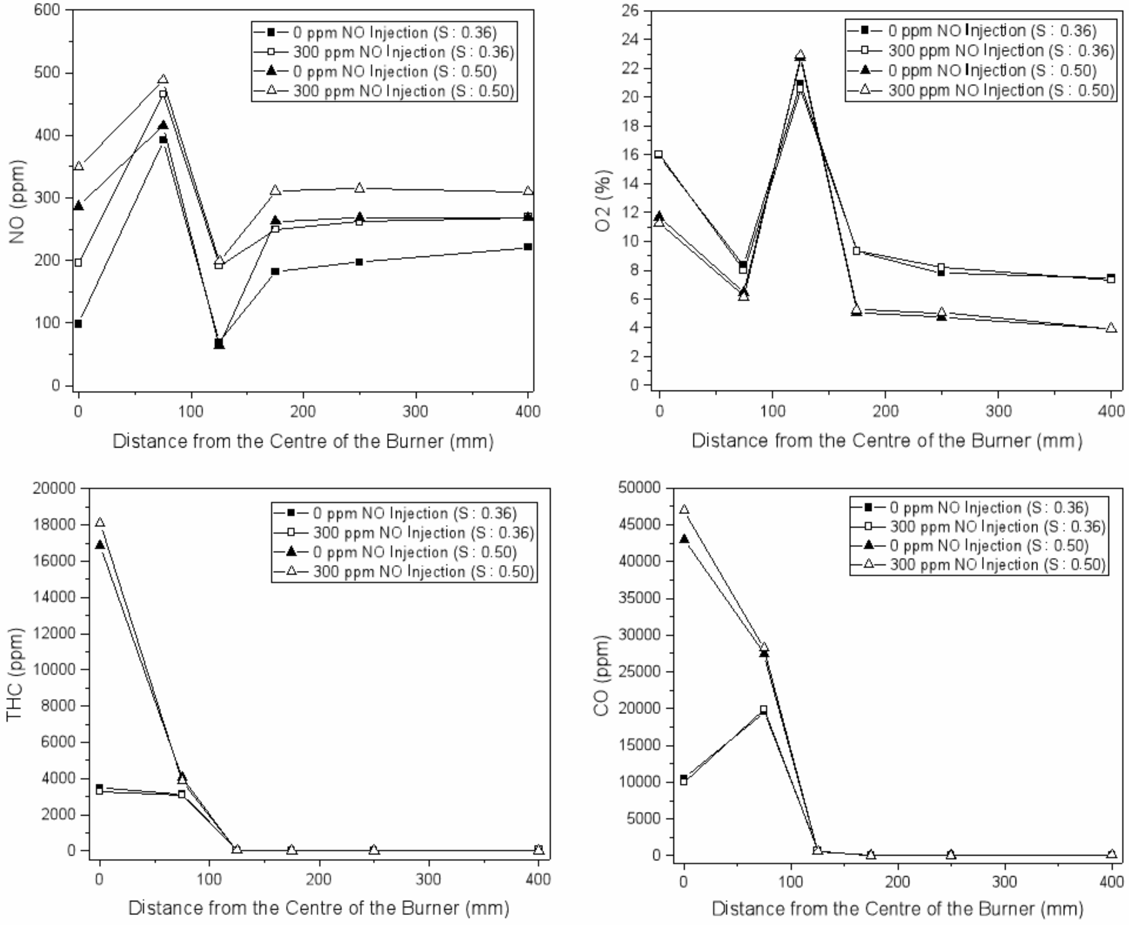
Impact of Varied Burner Staging Environments on Radial Profile of Key Flame Constituents



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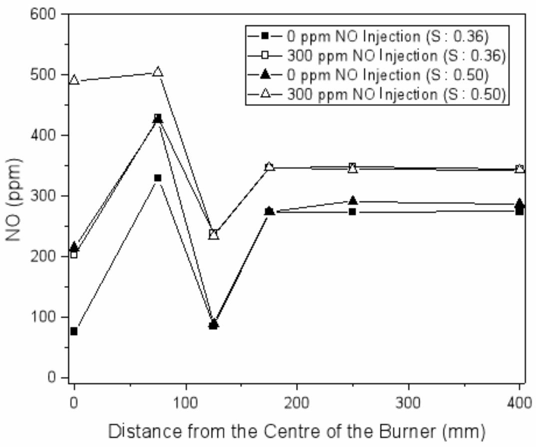
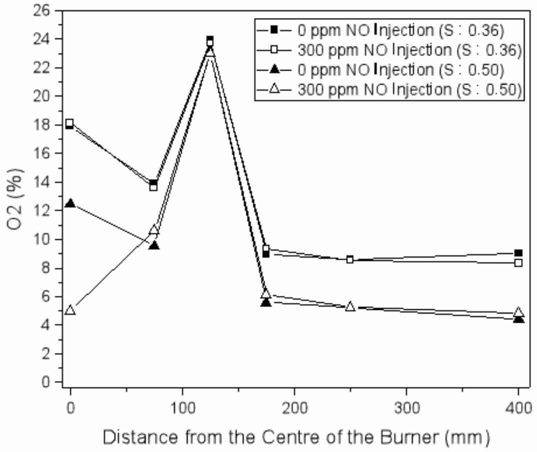
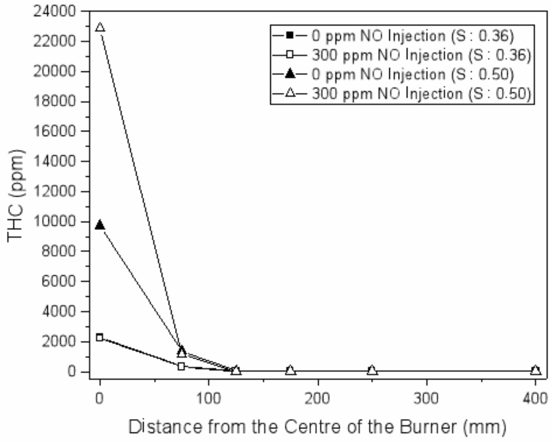
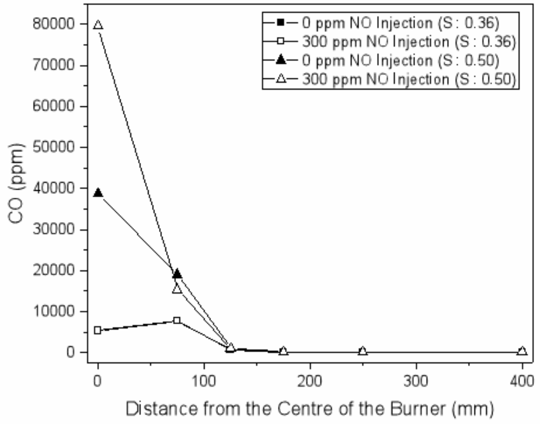
Impact of Varied Burner Staging Environments on Radial Profile of Key Flame Constituents



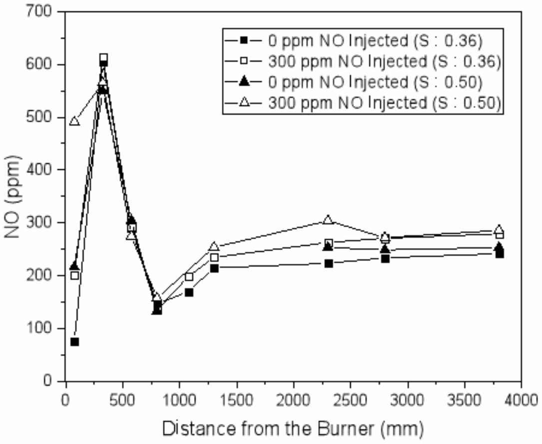


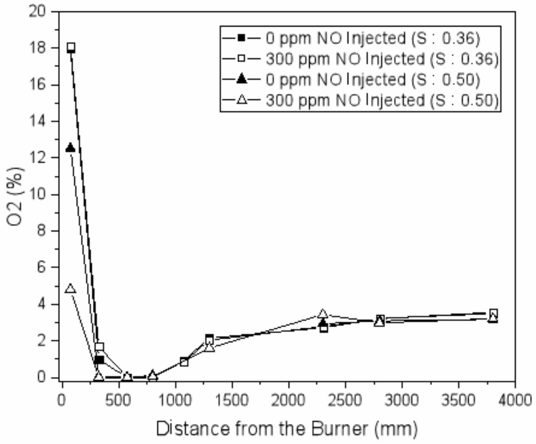


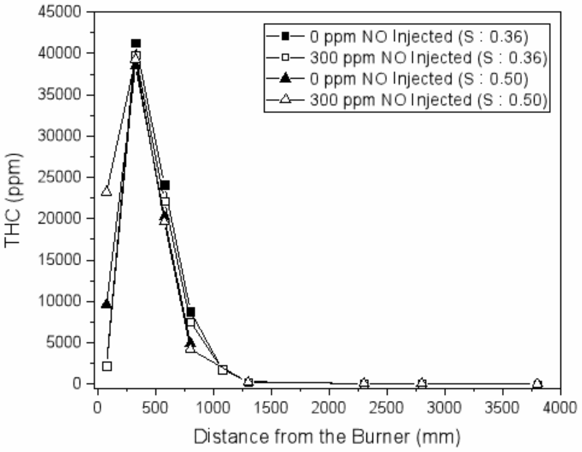


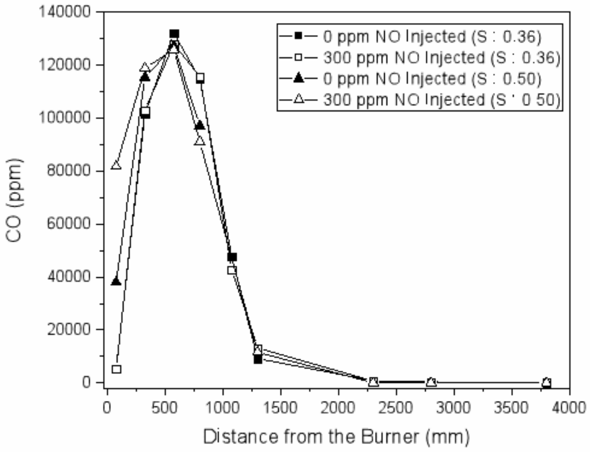
OF 30 170 kW$_{th}$

Impact of Varied Burner Staging Environments on Axial Profile of Key Flame Constituents









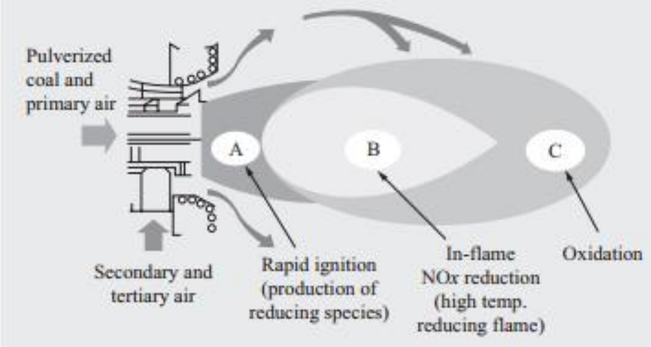
Conclusions

Comparison of burner staging impact on oxy flames and air flames:

- Prominently reduced NO_x formation
- Decreased sensitivity to burner staging

Comparison of burner staging impact on different oxy flames:

- Reduced NO_x formation at higher O_2 concentration
- Increased NO_x reduction at higher O_2 concentration
- Recycled NO is almost immediately destroyed (A), therefore control of by-products in the reducing zone (B) is very favourable



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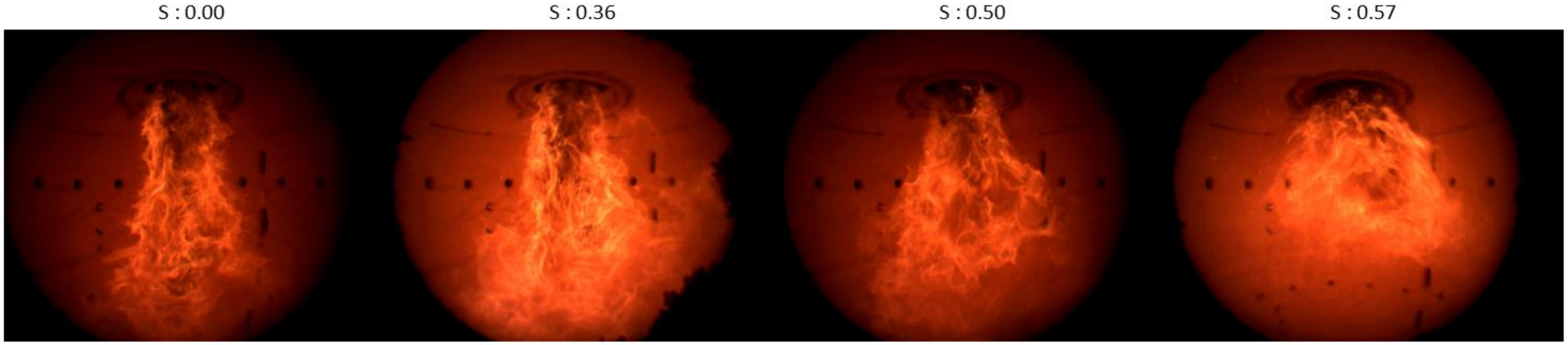
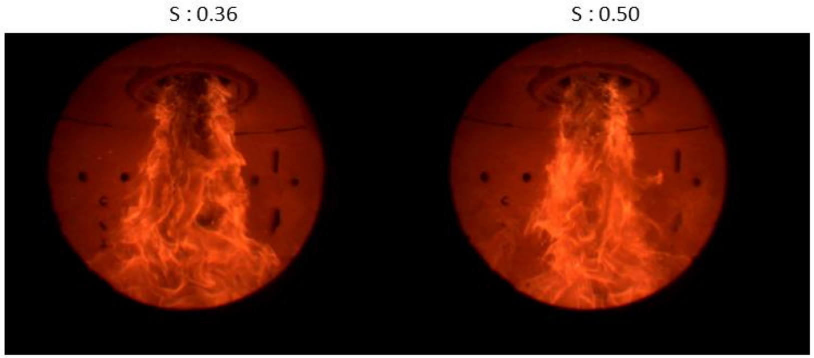
Thank you for listening, any questions?

OF 27





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