Experimental Investigation into Burner Staging during Oxy-coal Combustion

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Objectives

- Briefly introduce the concepts of oxy-coal combustion, burner staging and NO reburning
- Present the findings of an investigation into the utilisation of burner staging during oxy-fuel combustion and the impact on NO reburning

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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 most techno-economically feasible CCS technology

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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)

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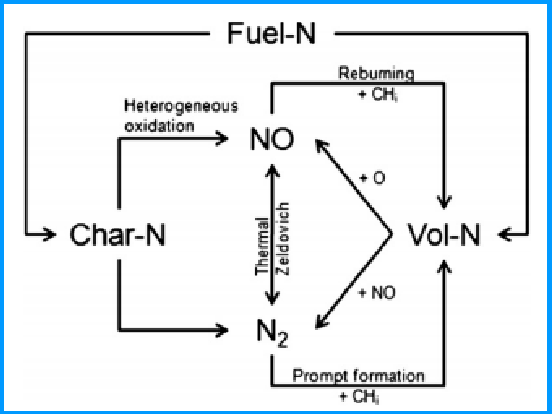
Oxy-coal Combustion: NO_x Processes

- 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.



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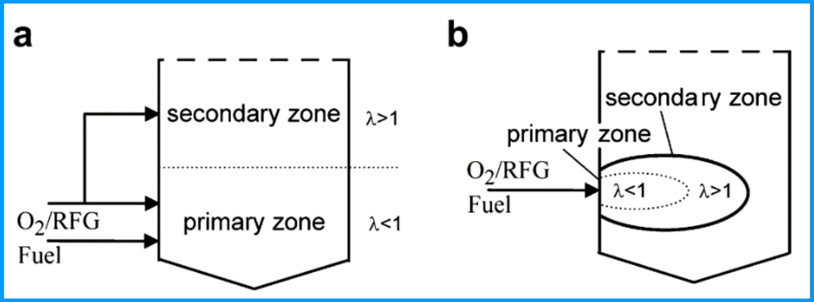
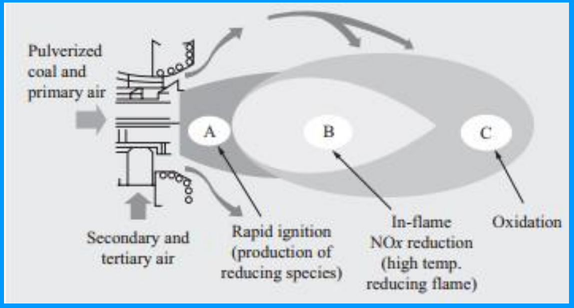
Oxy-coal Combustion: Burner Staging

- It is common for studies to utilise furnace staging for minimising NO formation
- The presence of NO in an over-fire stream would reduce overall rate of NO reburning
- Therefore, studying the impact of burner staging on NO reburning is essential
- Increased in-flame NO reduction would reduce load on secondary NO_x technologies and help realise zero-NO_x oxy-coal combustion





Adaptesd from: Ochi, K., Kiyama, K., Yoshizako, H., Okazaki, H., Taniguchi, M. (2009) Latest low-NOx combustion technology for pulverised-coal-fired boilers. Hitachi Review, 58(5), 187-193.

Adaptesd 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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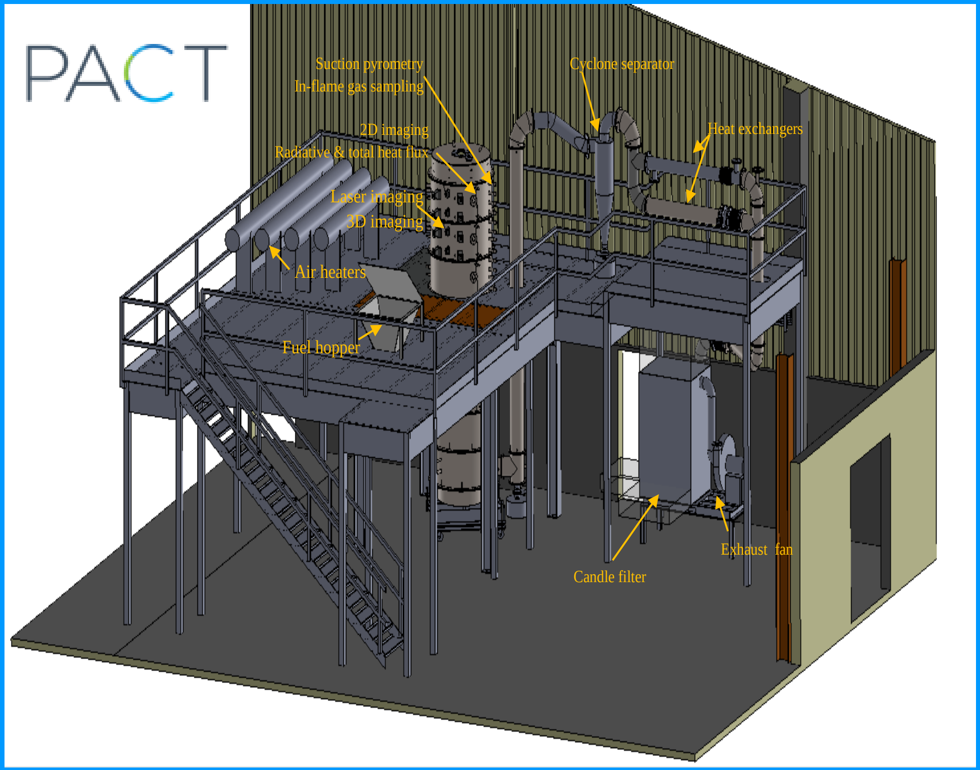
Experimental Setup

- 250 kW_{th} combustion test facility at PACT
- Conditions: Air and OF 28 at 200 kW_{th} and OF 27 and OF 30 at 170 kW_{th}
- Radial in-flame, axial and flue measurements
- 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

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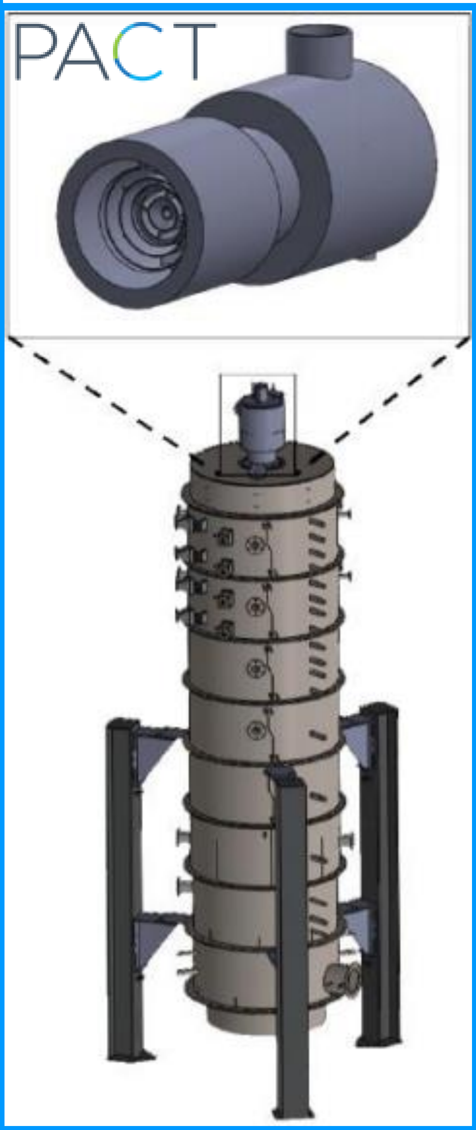
Burner Operation



- Initial (1°) oxidant and burnout (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 controlled variability of stoichiometry in the fuel-rich region
- The near-burner stoichiometry is a term used to represent the 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

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

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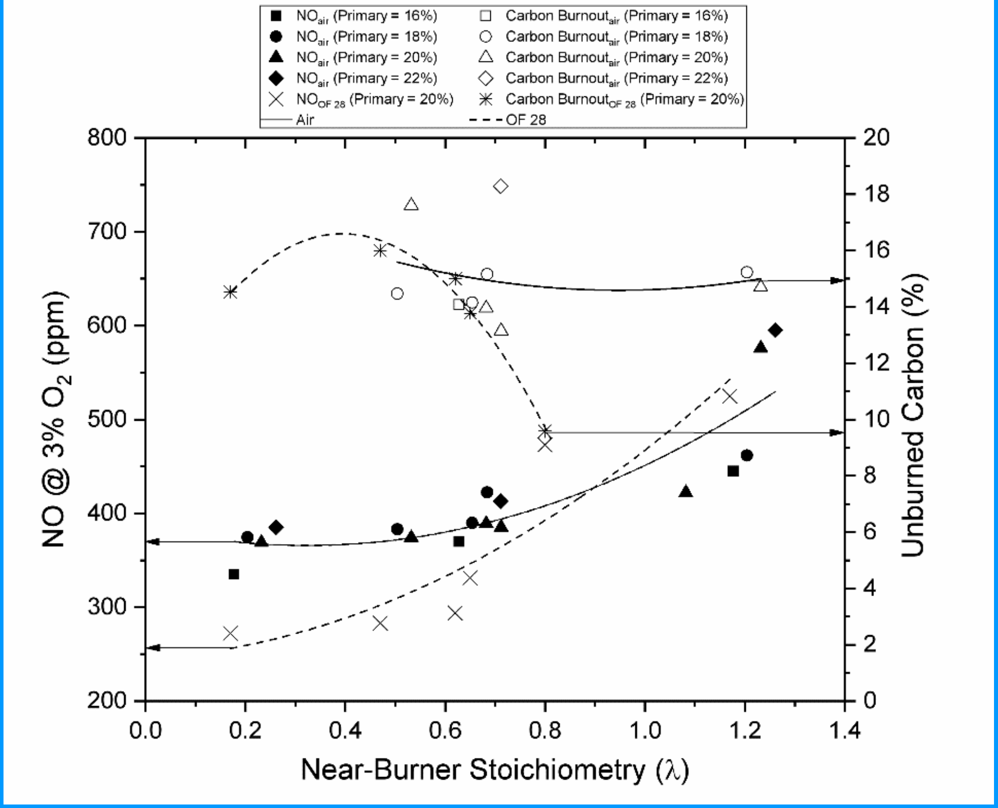
Air + OF 28 200 kW_{th}

Impact of the Primary Flow and Burner Staging on NO Formation

- Four primary flowrates (vol%) tested for air
- 20% decidedly most favourable across near-burner stoichiometry spectrum
- This now used as constant for all oxy-coal scenarios
- At OF 28, NO emissions are lower than air until λ < 0.7 and unburned carbon becomes lower past this point



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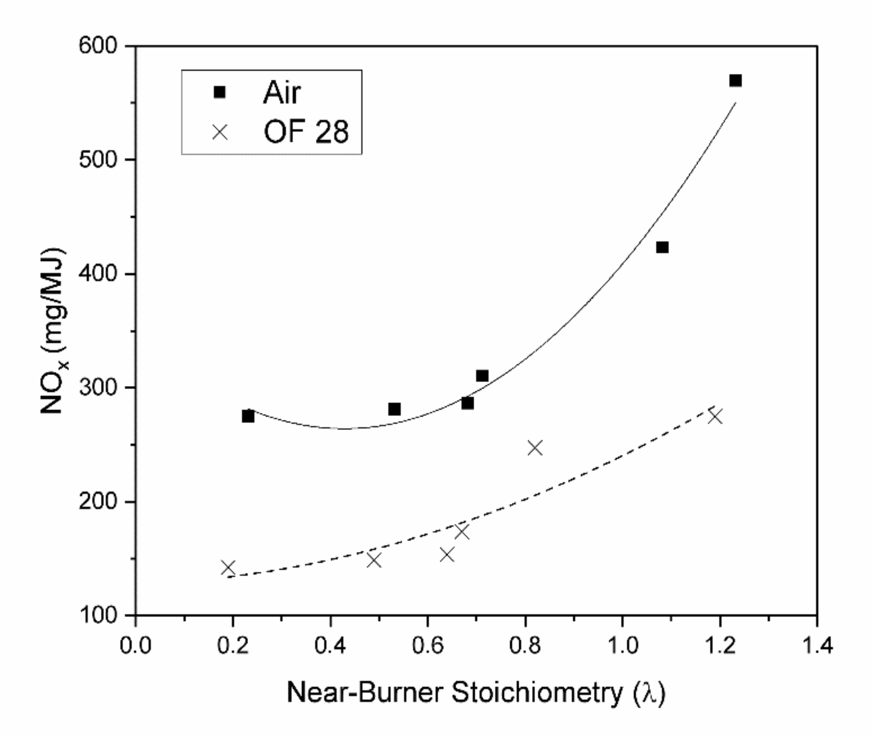
Air + OF 28 200 kW_{th}

Comparison of NO_x Emission Rate without NO 'Recycling'

- Confirmation of far superior emission rate from oxy-coal flame
- Reasons for lower NO_x formation:
  - The reverse Zeldovich mechanism
  - Lack of thermal and prompt NO
  - Likely temperature increase in fuel-rich zone causing: reduced NO formation from char-N, increased volatile-N formation and increased volatile-N to N2 conversion



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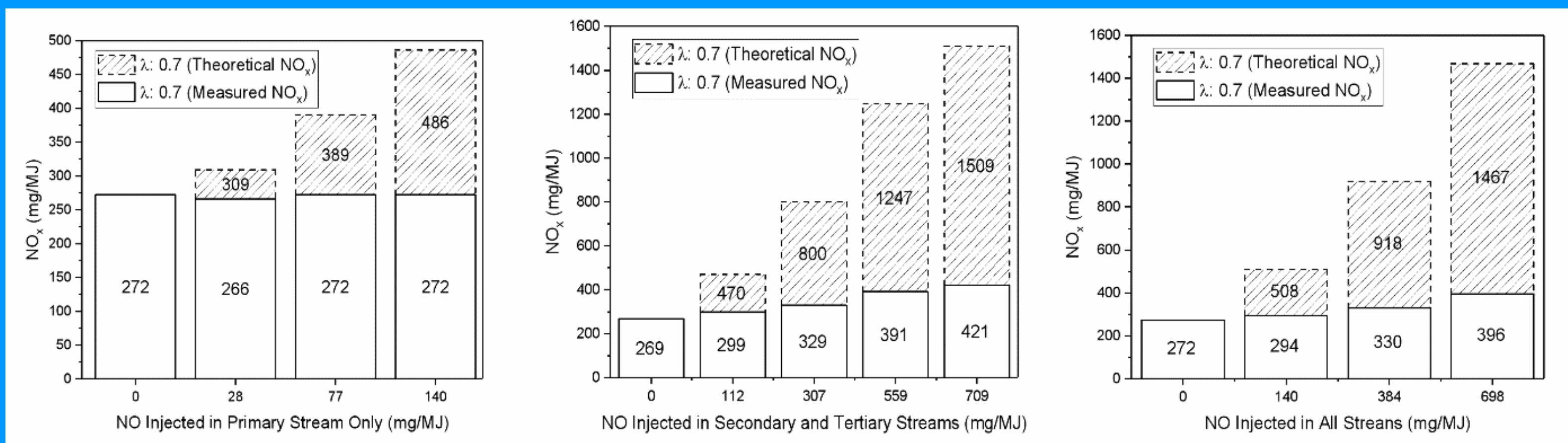
Air + OF 28 200 kW_{th}

Impact of Injecting NO into Each Stream on NO Reburning

Air



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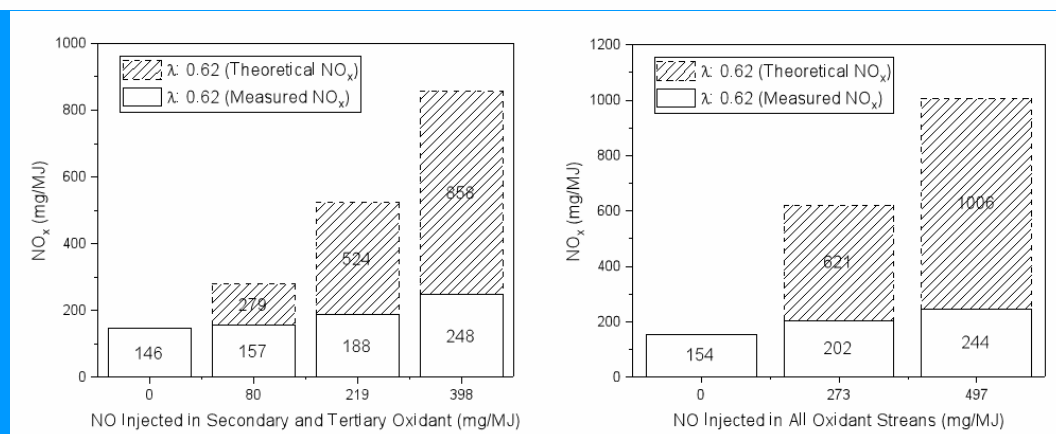

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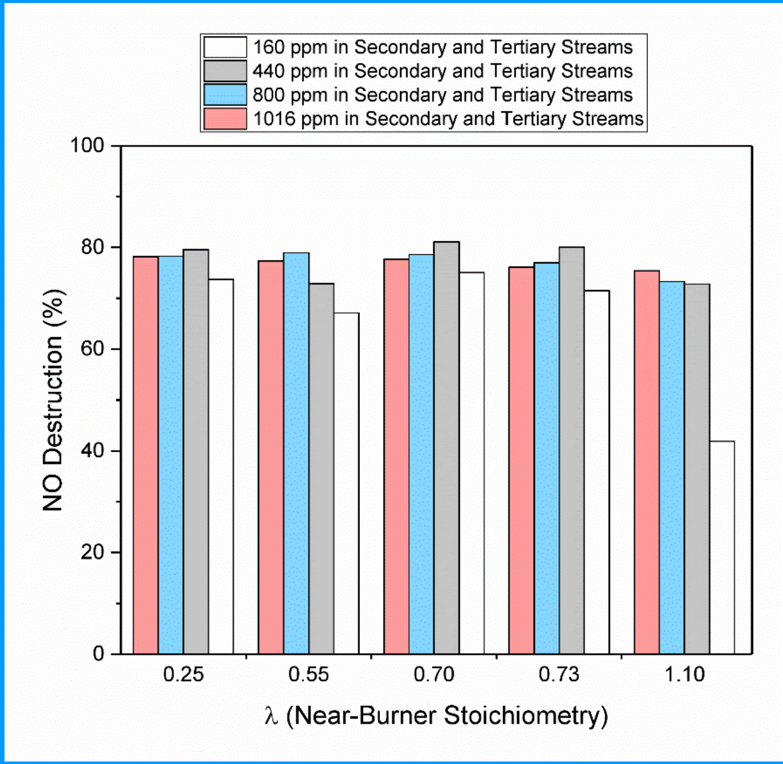
Air + OF 28 200 kW_{th}

Impact of Near-Burner Stoichiometry on NO Reburning

Air



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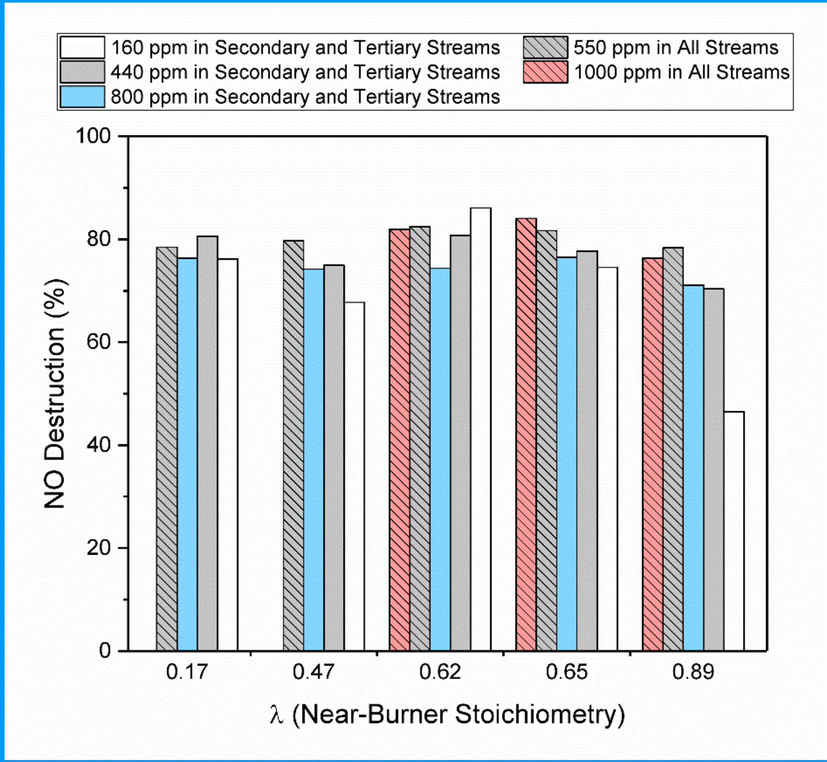

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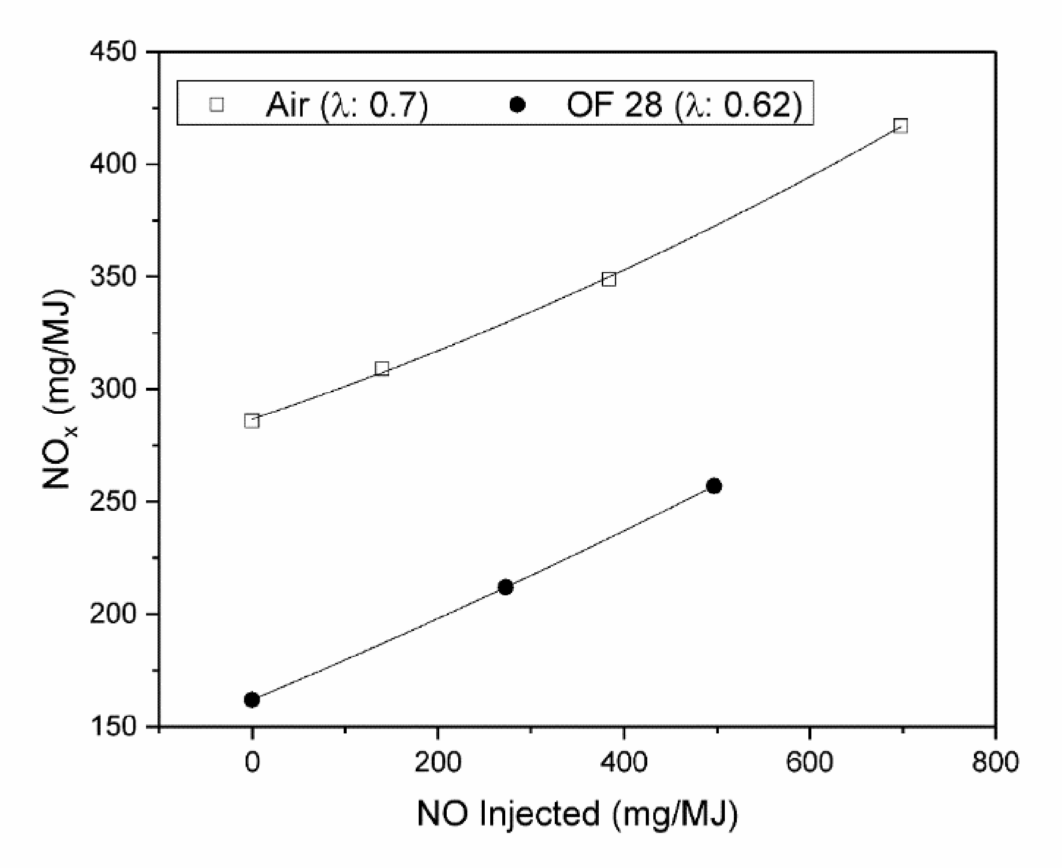
Air + OF 28 200 kW_{th}

Comparison of NO_x Emission Rate with NO 'Recycling'



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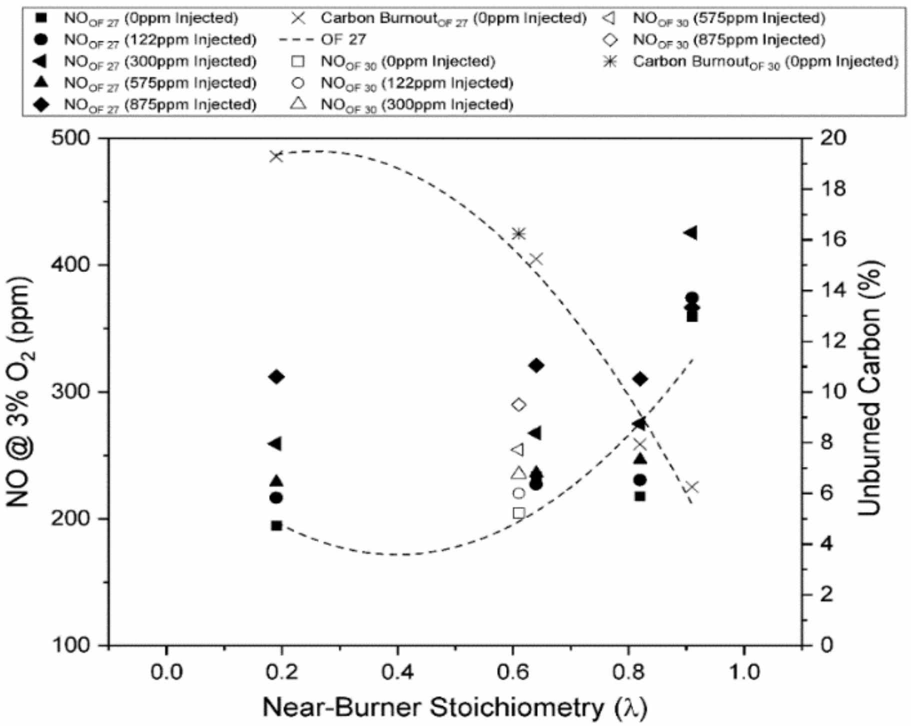
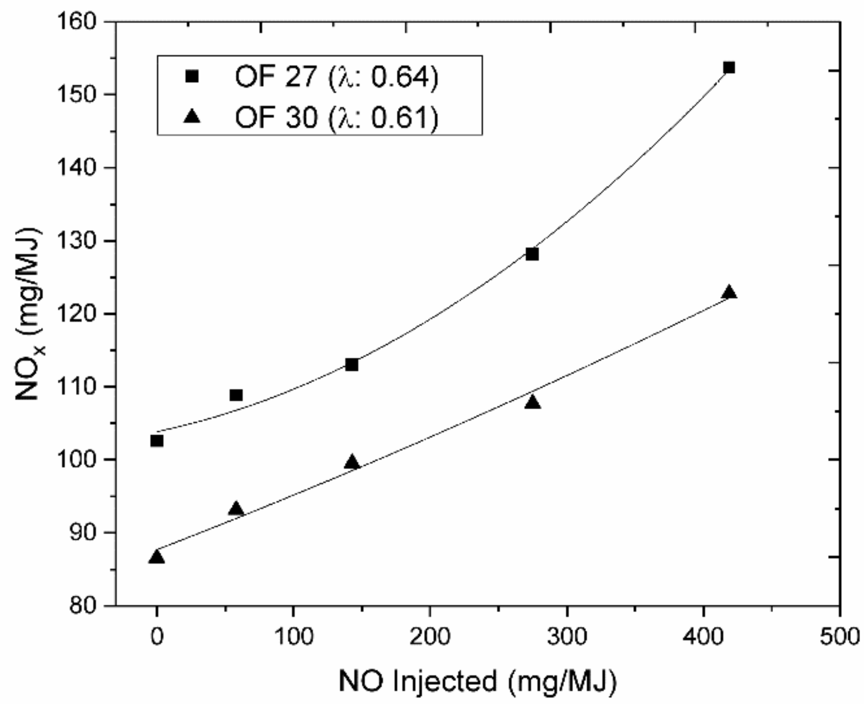
OF 27 + OF 30 170 kW_{th}

Impact of NO ‘recycling’ and Burner Staging on Combustion





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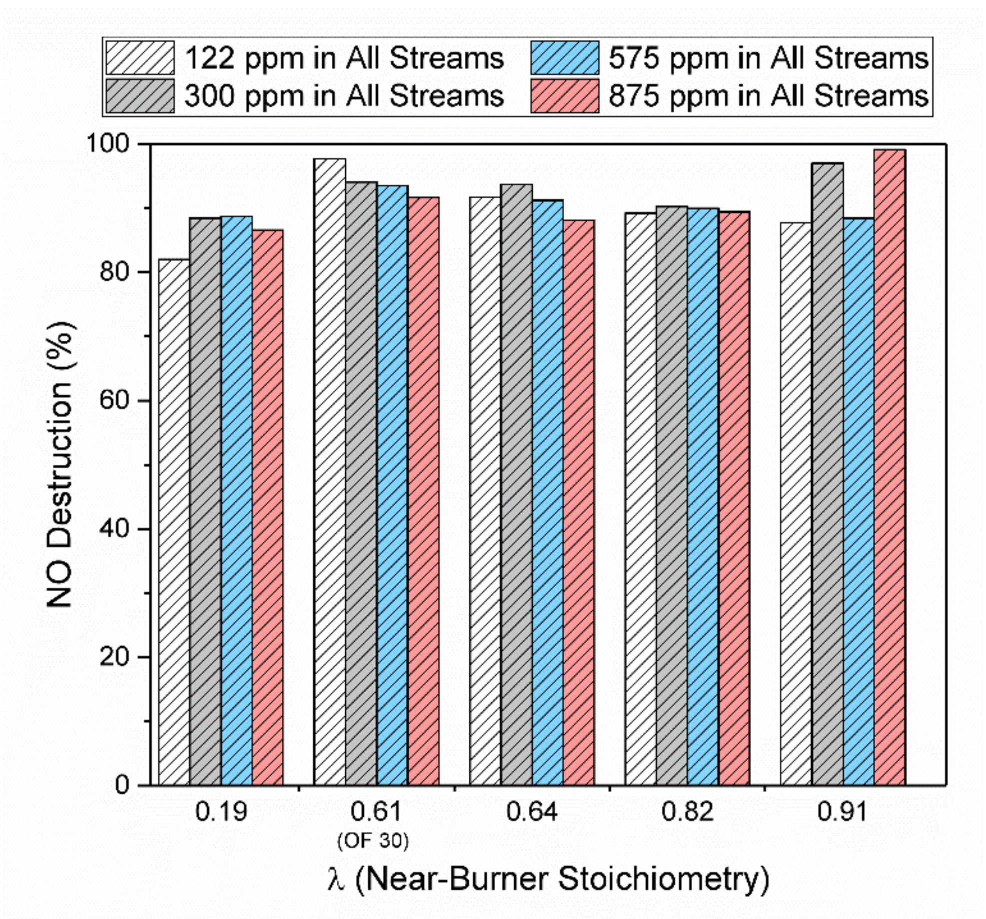
OF 27 + OF 30 170 kW_{th}

Impact of Near-Burner Stoichiometry on NO Reburning



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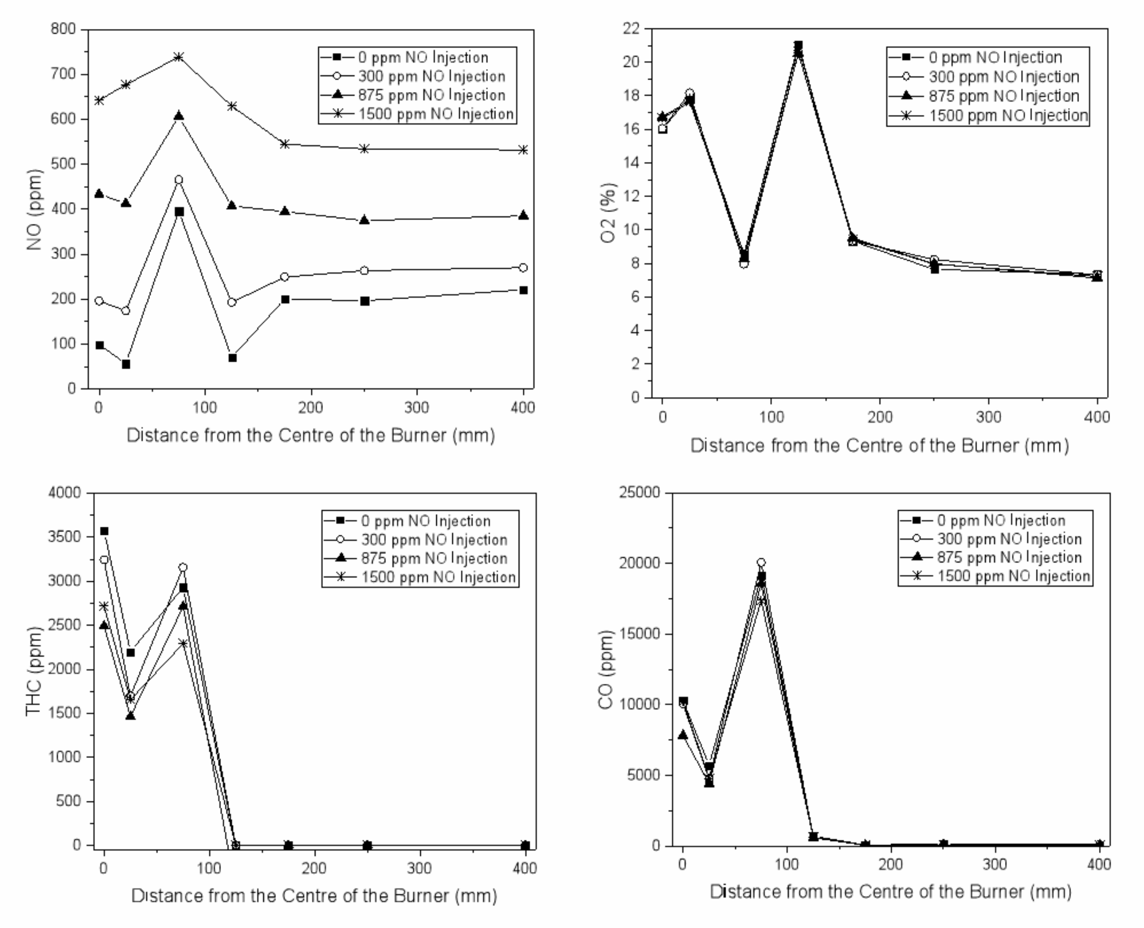
OF 27 170 kW_{th}

Impact of NO 'Recycling' on Radial Profile of Key Flame Constituents (λ: 0.64)



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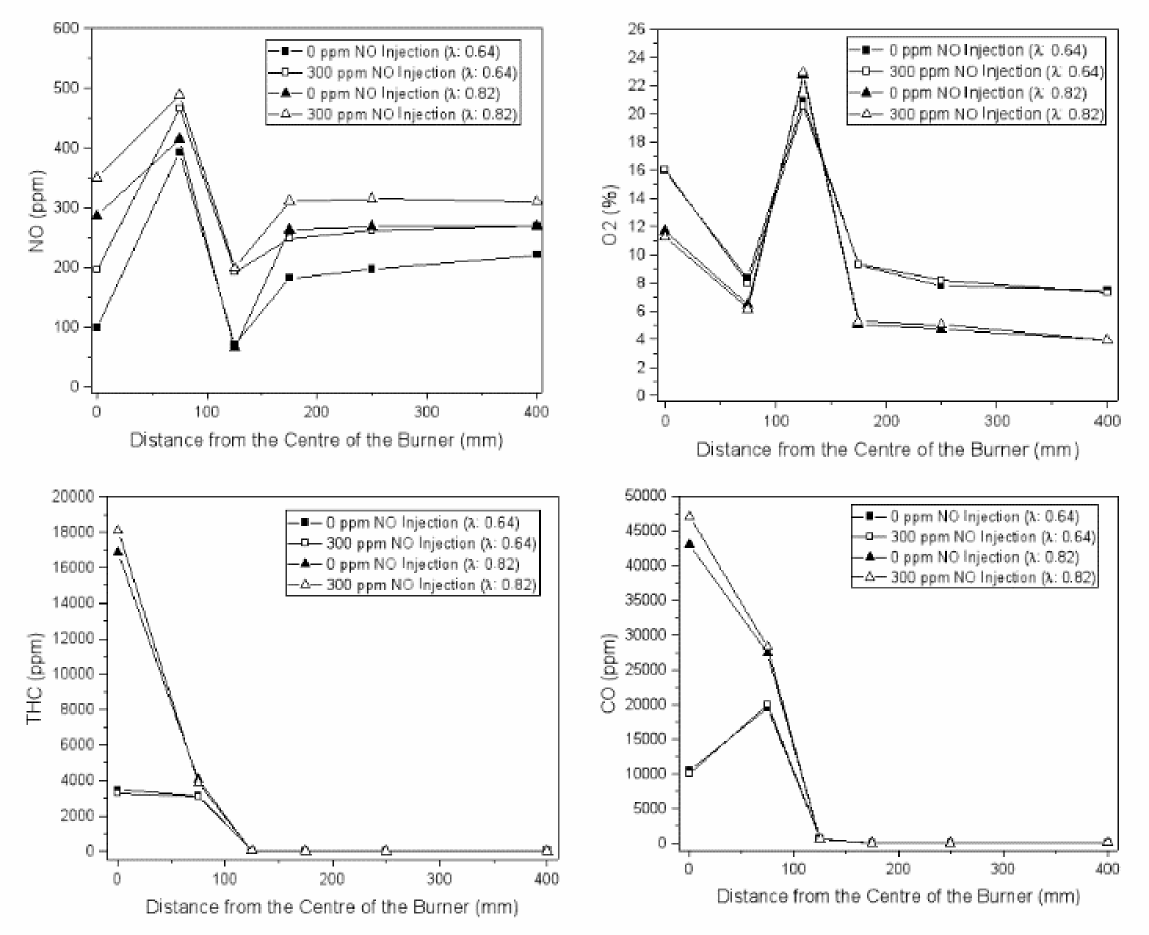
Impact of Varied Burner Staging Environments on Radial Profile of Key Flame Constituents



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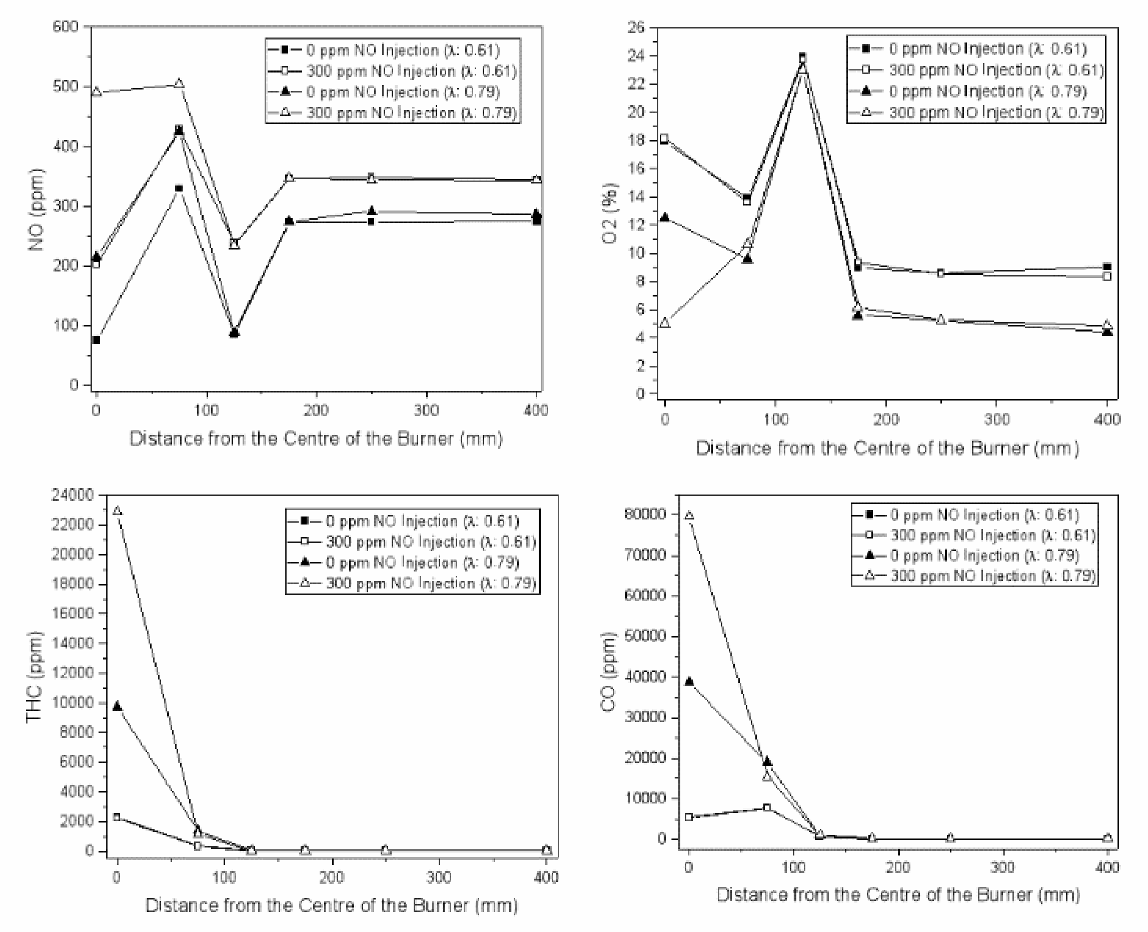
OF 30 170 kW_{th}

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



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OF 30 170 kW_{th}

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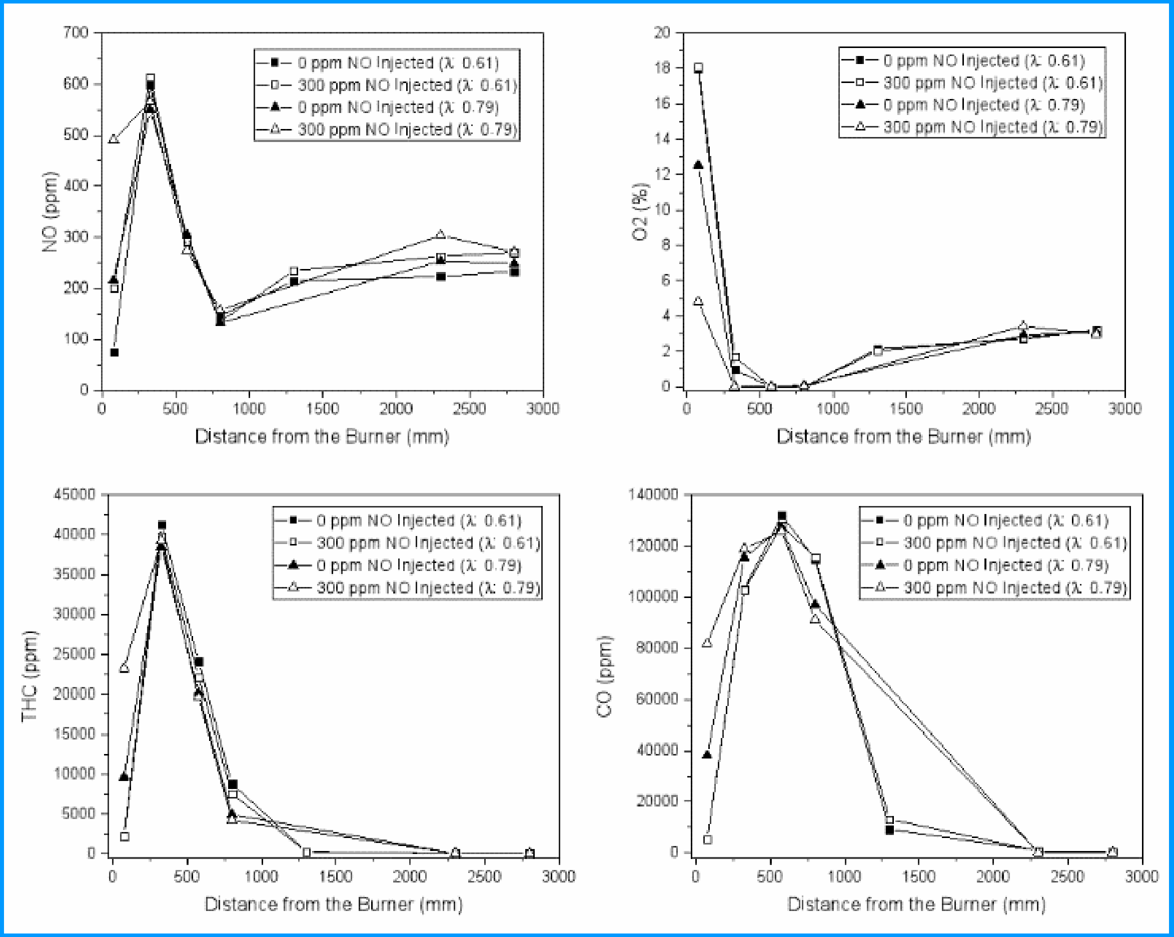
Impact of Varied Burner Staging Environments on Axial Profile of Key Flame Constituents



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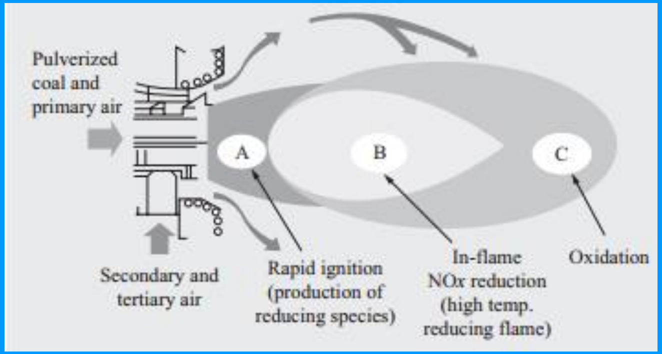
Conclusions

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

- Decreased sensitivity to burner staging
- Prominently reduced NOx formation
- Reduced unburned carbon in ash

Comparison of burner staging impact on different oxy flames:

- Reduced NOx formation at higher O2 concentration
- Increased NOx reduction at higher O2 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?

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