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Novel Oxy-steam Burner for Zero-emission Power Plants

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Clean Electric Power Generation (CEPG)

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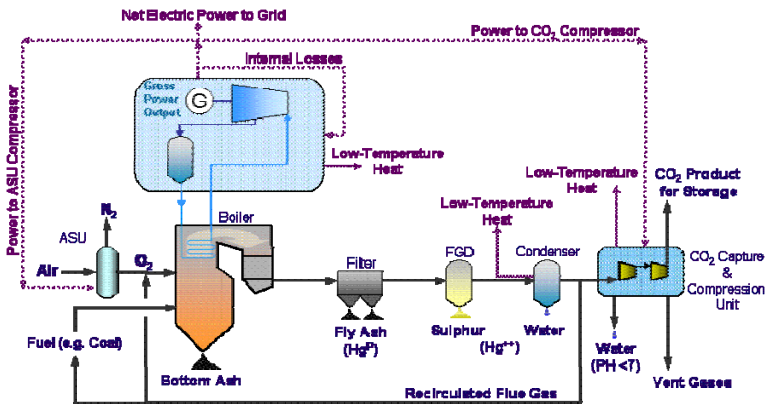
Outline

- Hydroxy-fuel combustion
  - Motivation and Overall Objectives
  - 3rd generation oxy-fuel systems
- Novel burner concept and design
  - Modes of operation
  - Design and optimization
  - Pilot-scale implementation
- Experimental validation

Need for New Concepts and Technologies

- **Design for plant life**
  - **Current and future needs (CO2 market, etc.)**
  - **Flexibility in design to adapt**
  - **Environmental regulations (near zero emissions for fossil fuels)**
  - **Low-value fuels and co-firing (bitumen, petcoke, biomass, etc)**
- **Advancements in technology, e.g.,**
  - **Ion transport membrane for O_2 production**
  - **High temperature materials (boiler tubes, etc)**
- **Moving away from Rankin cycle (lower efficiency)**
  - **3rd generation of oxy-fuel combustion systems**
  - **Advanced turbines and power cycles**
  - **Emerging technologies…**



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Hydroxy-Fuel Technology Development

Motivation:

- Develop the technology base necessary for the implementation of efficient zero-emission fossil fuel systems

Overall Objectives:

- Investigate the feasibility of hydroxy-fuel combustion for the 3rd generation of oxy-fuel systems
- Investigate the reduction in size and capital cost of equipment
- Use of water/steam, preferably with no FGR, to moderate the flame temperature
- Achieve high concentration of CO_2 (> 90% on dry basis) in the exit flue gas stream

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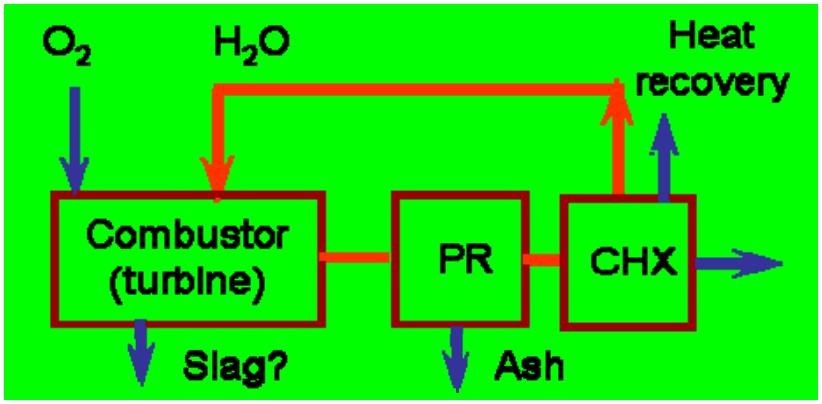
3rd Generation Oxy-fuel Systems

3rd Generation Oxy-fuel Combustion

Oxy-steam Combustion

- Low NOx & excess O_2,
- Higher radiative & convective heat transfer,
- Process model, CFD, new system and component design

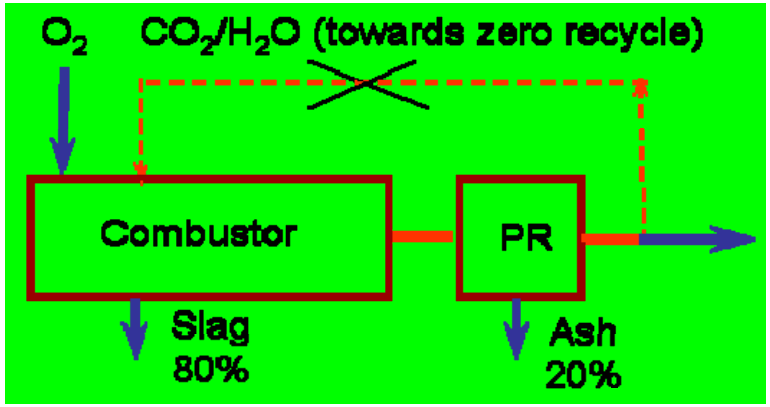
Up to 40% scale reduction in unit size



O_2 Combustion (no FGR)

- Minimize NOx & excess O_2,
- High radiative & convective heat transfer,
- New materials,
- Process model, CFD, new system and component design

Up to 80% scale reduction in unit size



Novel Burner Design

Modes of Operation:

- Firing Rate 0.3 MWth (1.0 X 106 Btu/h)
- Fuels: Natural gas, Oil, Emulsion, Pulverized coal, Petcoke, Coal Slurry, etc.
- Operational modes
  - ►O_2/steam
  - ►O_2/RFG & O_2/CO_2
  - ►Air & oxygen enriched air
  - ►O_2/steam/RFG
  - ►O_2/steam/CO_2
- Variable mass flow rates on secondary and tertiary streams
- Variable oxygen concentration on secondary and tertiary streams
- Independent swirl on secondary and tertiary stream

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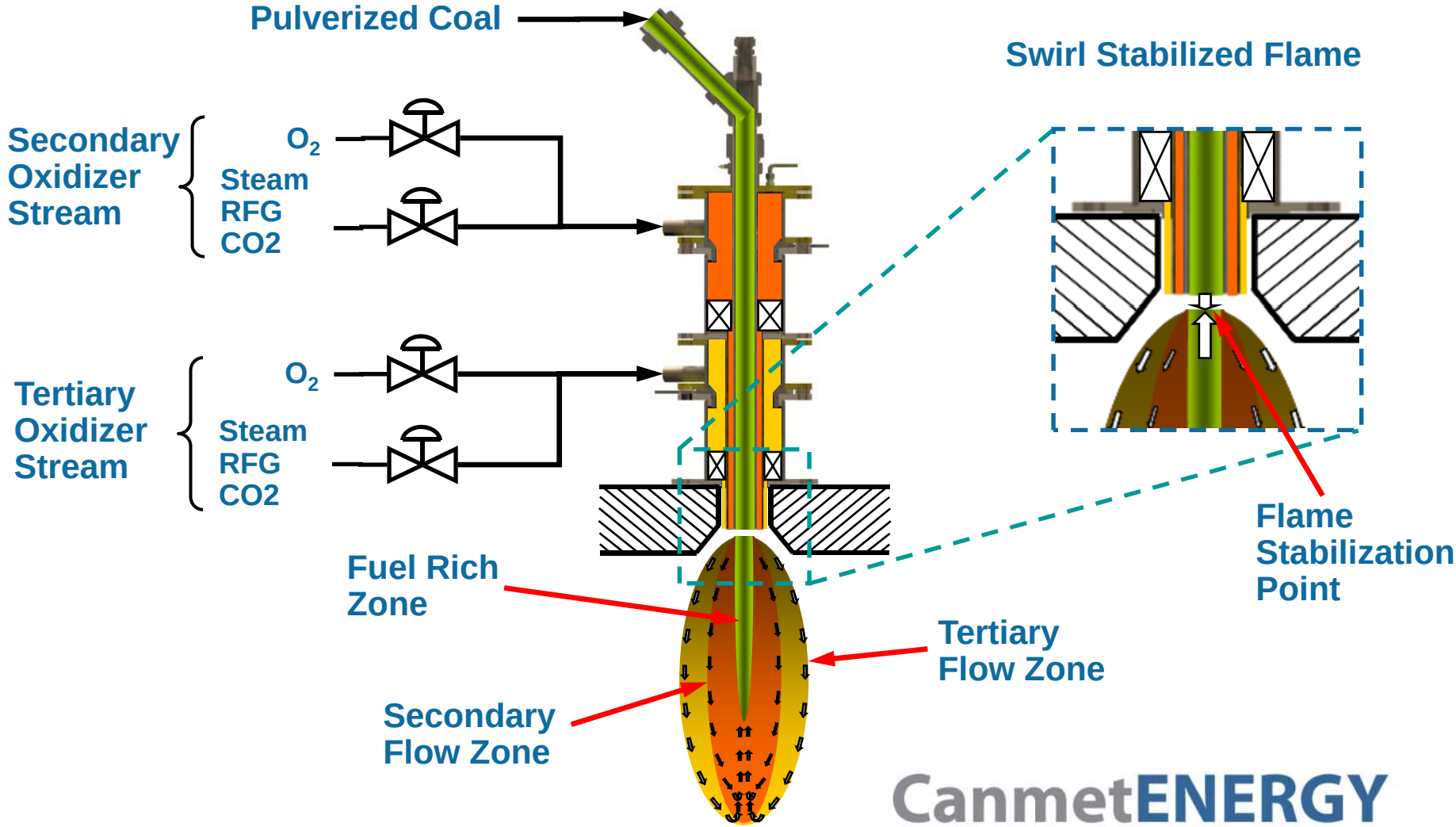
Burner Operational Principles



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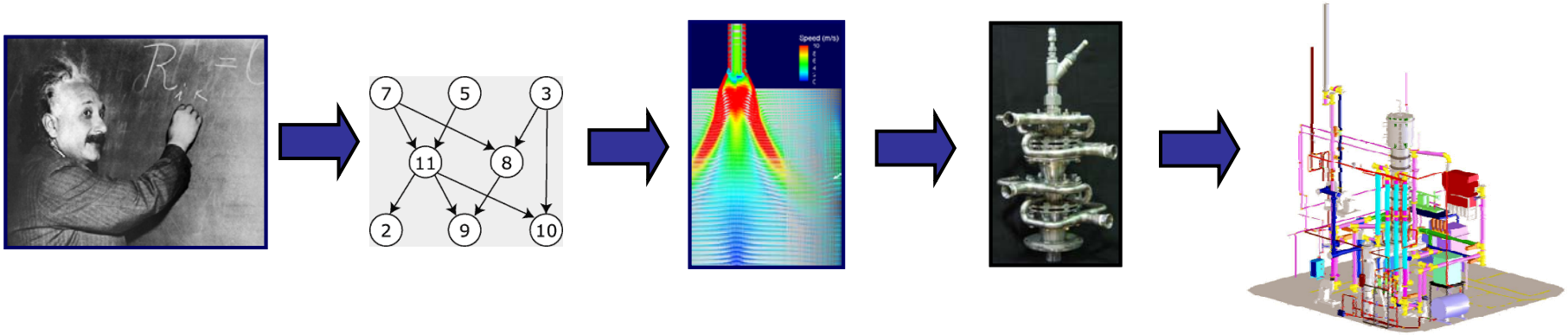
Design and Optimization



- Determined system requirements via HYSYS simulations
- Extended simulations to fix additional combustion parameters; i.e. O_2-steam composition, adiabatic flame temperature, etc.
- Based on swirl burner theory, established the desired burner exit parameters
- Based on HYSYS Simulations, swirl burner requirements, and the possible effect of the combustor geometry, created a short list of possible burner geometries

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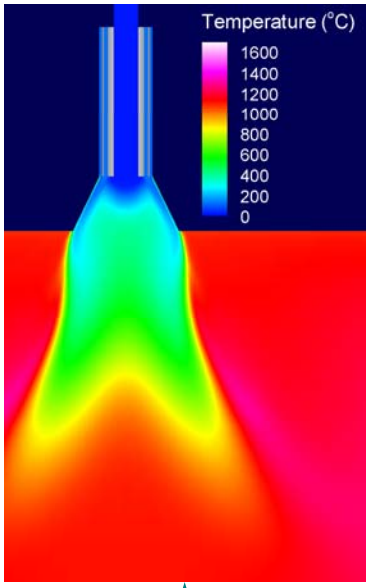
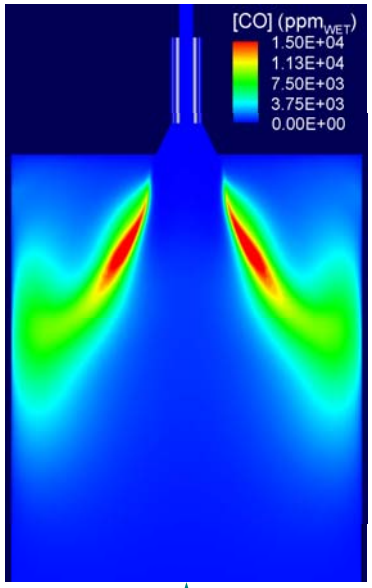
Design Validation

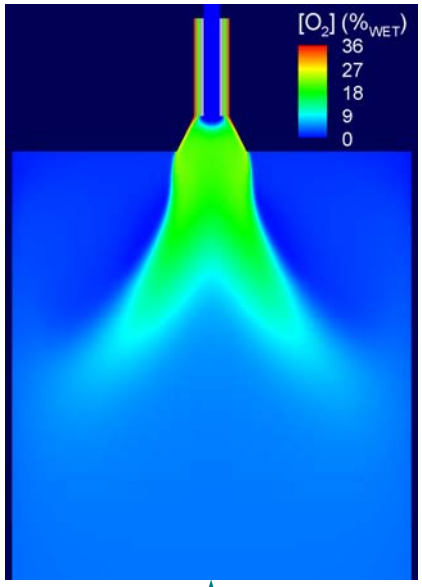
Temperature



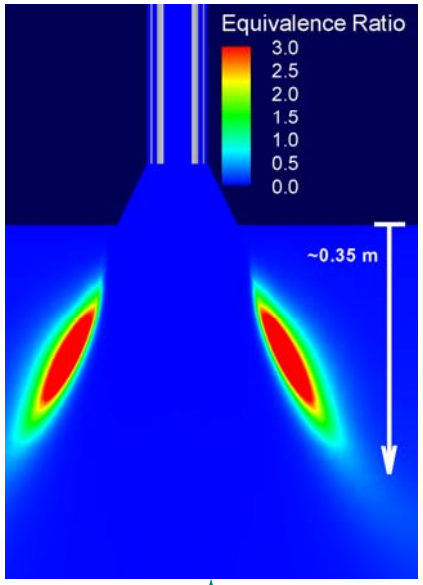
CO Distribution

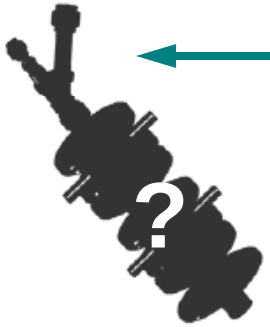


O2 Distribution



Equivalence Ratio





CFD Simulation done by CEPG CFD Group

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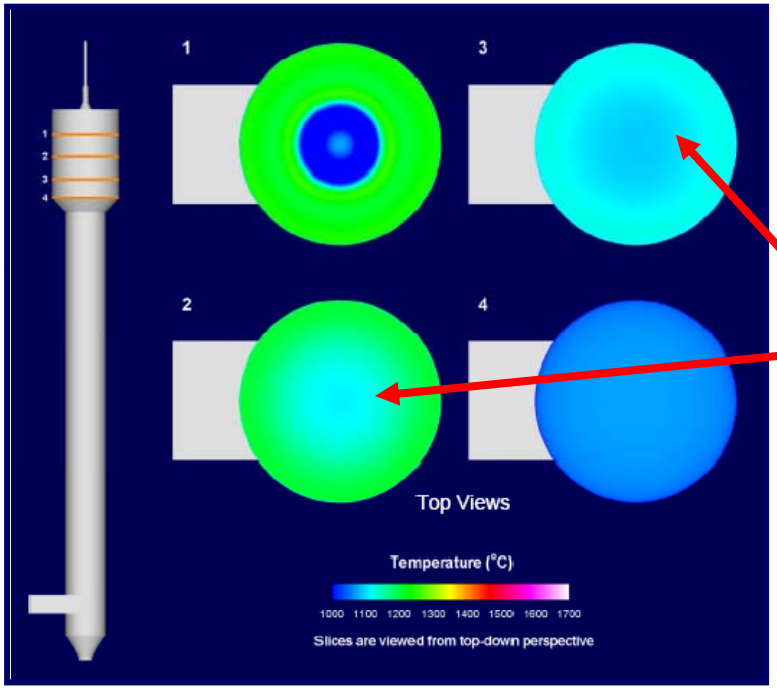
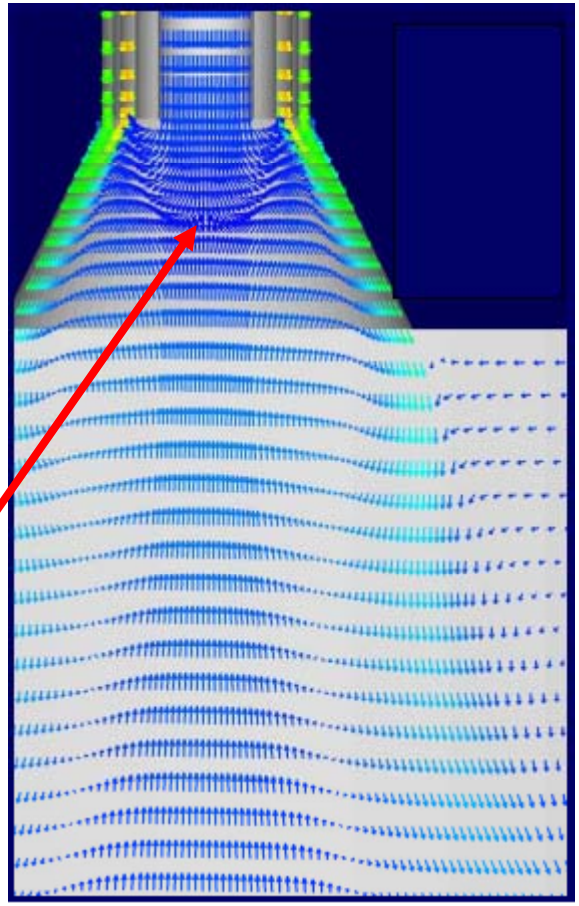
Design Validation *(cont'd)*

Temperature Profile



Uniform temperature distribution

Stagnation Point



Vector Plot of Speed

CFD Simulation done by CEPG CFD Group

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Burner Prototypes Development

1st Generation

2nd Generation

3rd Generation

4th Generation

- Fixed Swirl Generator
- Testing

- Variable Swirl Generator
- Testing

- Modified Variable Swirl Generator
- Testing

- 2nd Variable Swirl Generator
- Testing

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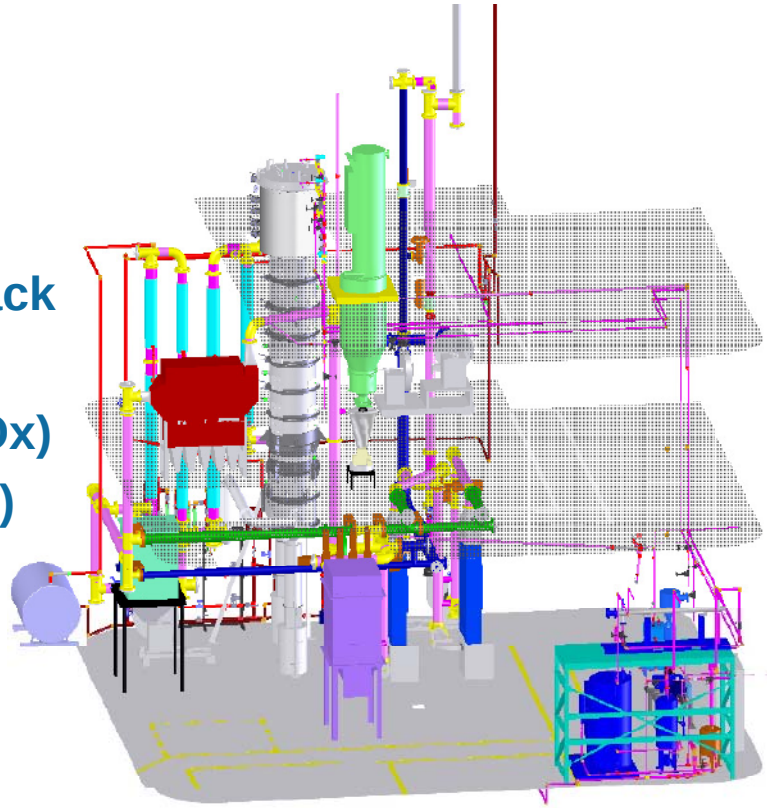
Pilot-Scale Implementation

- Firing rate for tests: 0.2 MWth (0.7 X 106 Btu/h)
- Combustion mode: O2/RFG or O2/Steam
- Fuel: Saskatchewan lignite coal
- Flow Paths:
  - O_2/Steam: ESP ⇨ CHX1 ⇨ Stack
  - O_2/RFG: ESP ⇨ CHX1 ⇨ Recycle ⇨ Stack
- Measurements
  - Gas composition (O_2, CO_2, CO, SO_2, NOx)
  - Mercury (Ontario Hydro Method & CEM)
  - Suction pyrometer
  - Radiation heat flux
  - Ash Samples

Oxy-fuel Vertical Combustor Research Facility (VCRF)



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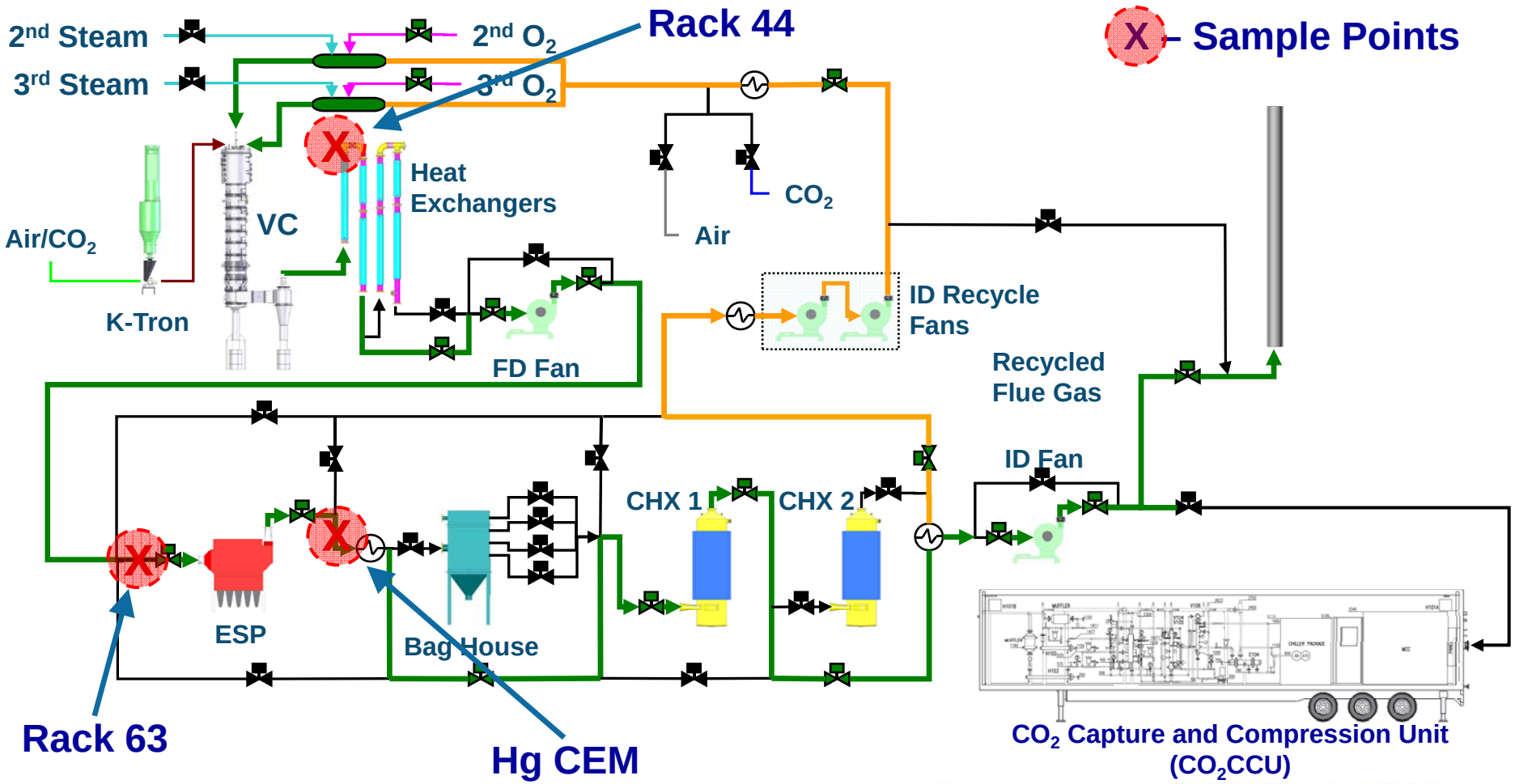
VCRF Flow Diagram



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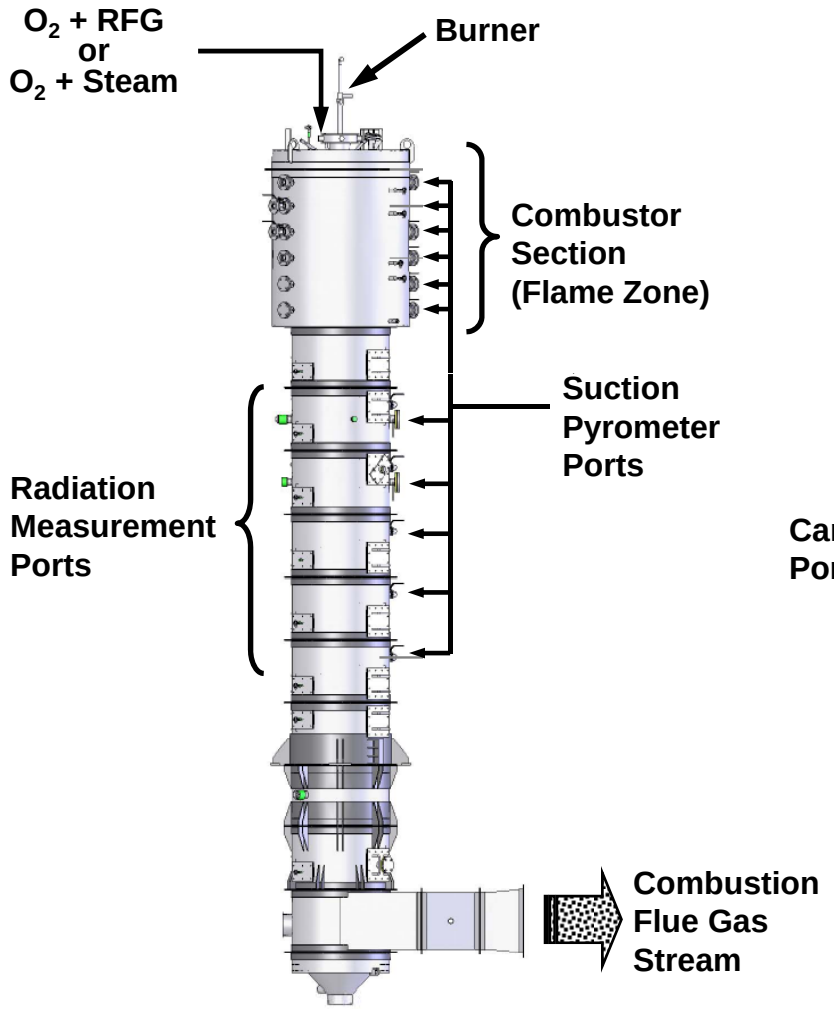
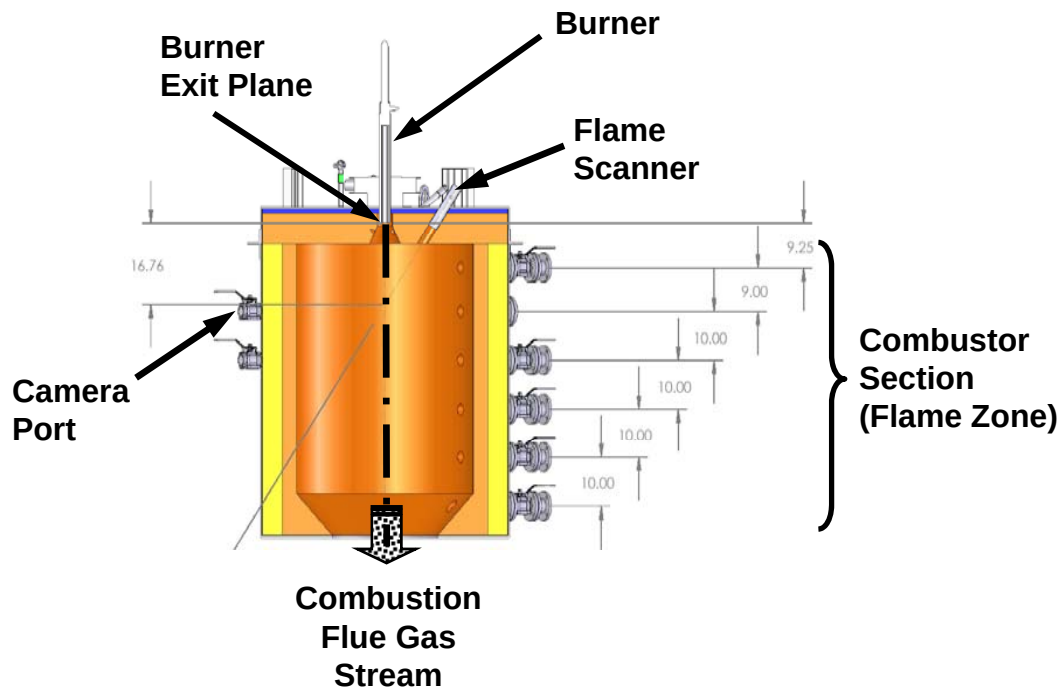
VC Furnace Measurement Ports





** All dimensions in inches*

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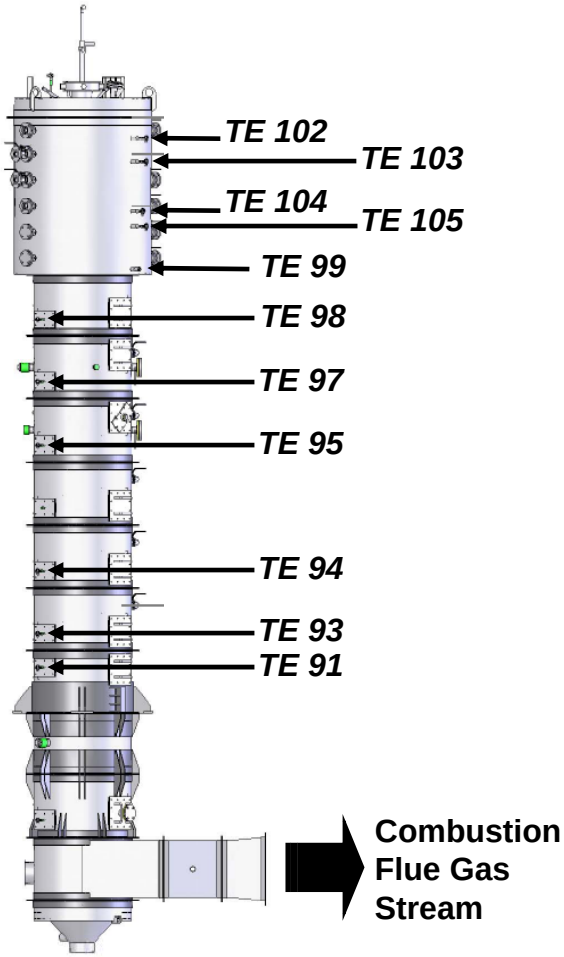
Results – Oxy-fuel Temperature Profile



Oxy-fuel Combustion
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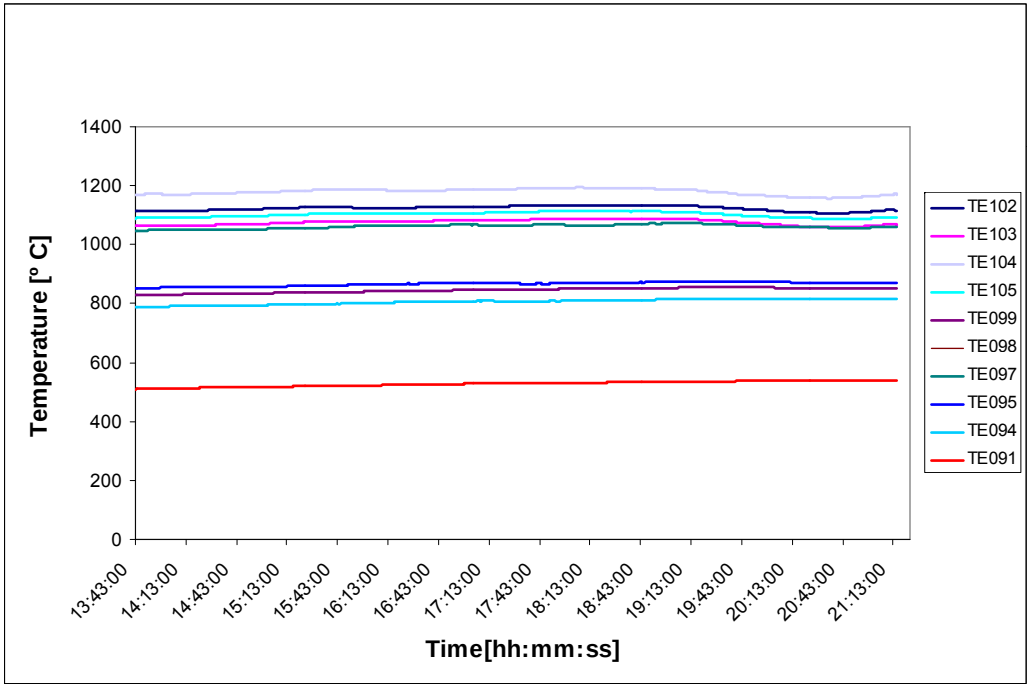

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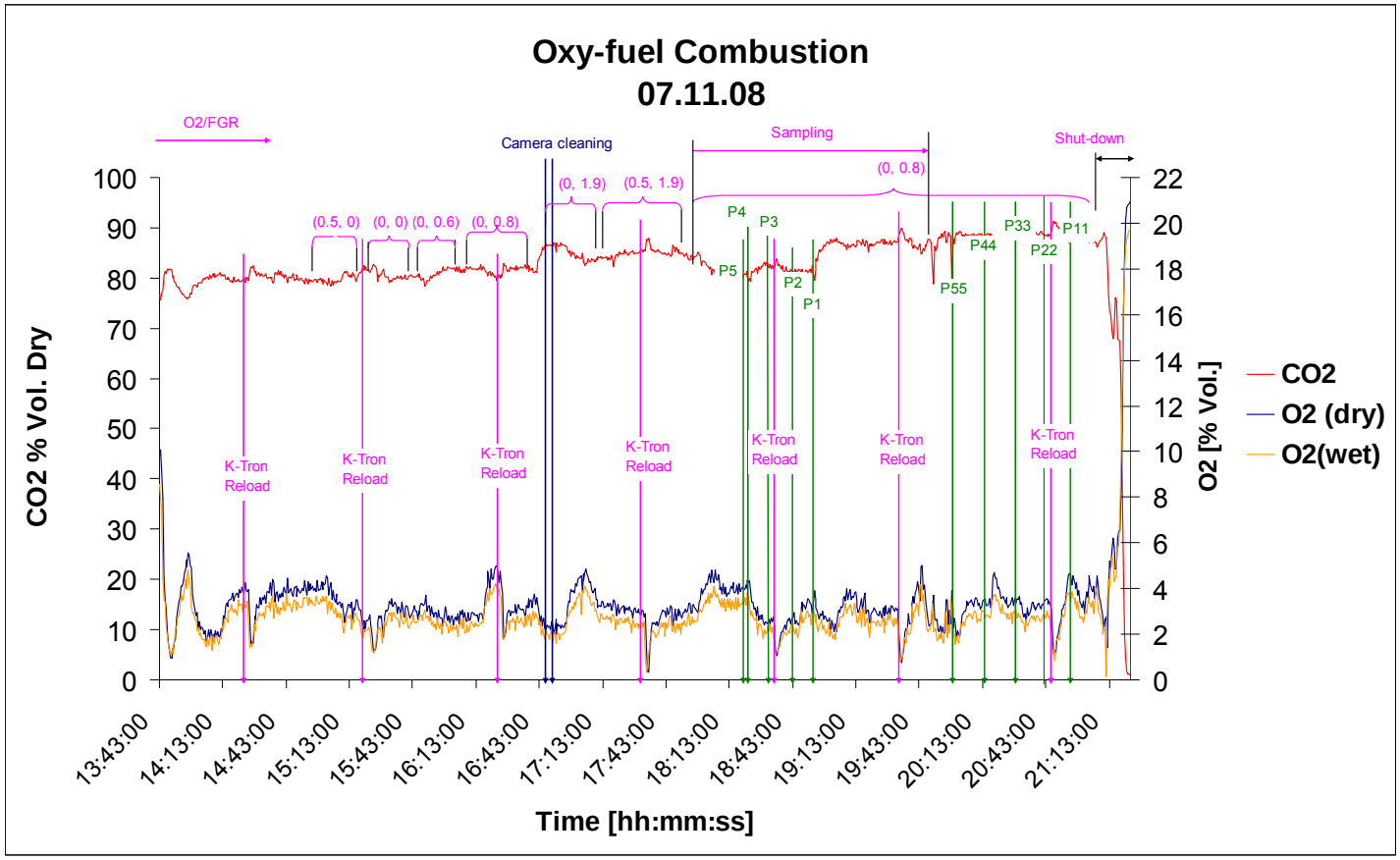
Results - Oxy-fuel Combustor Exit

Rack 44



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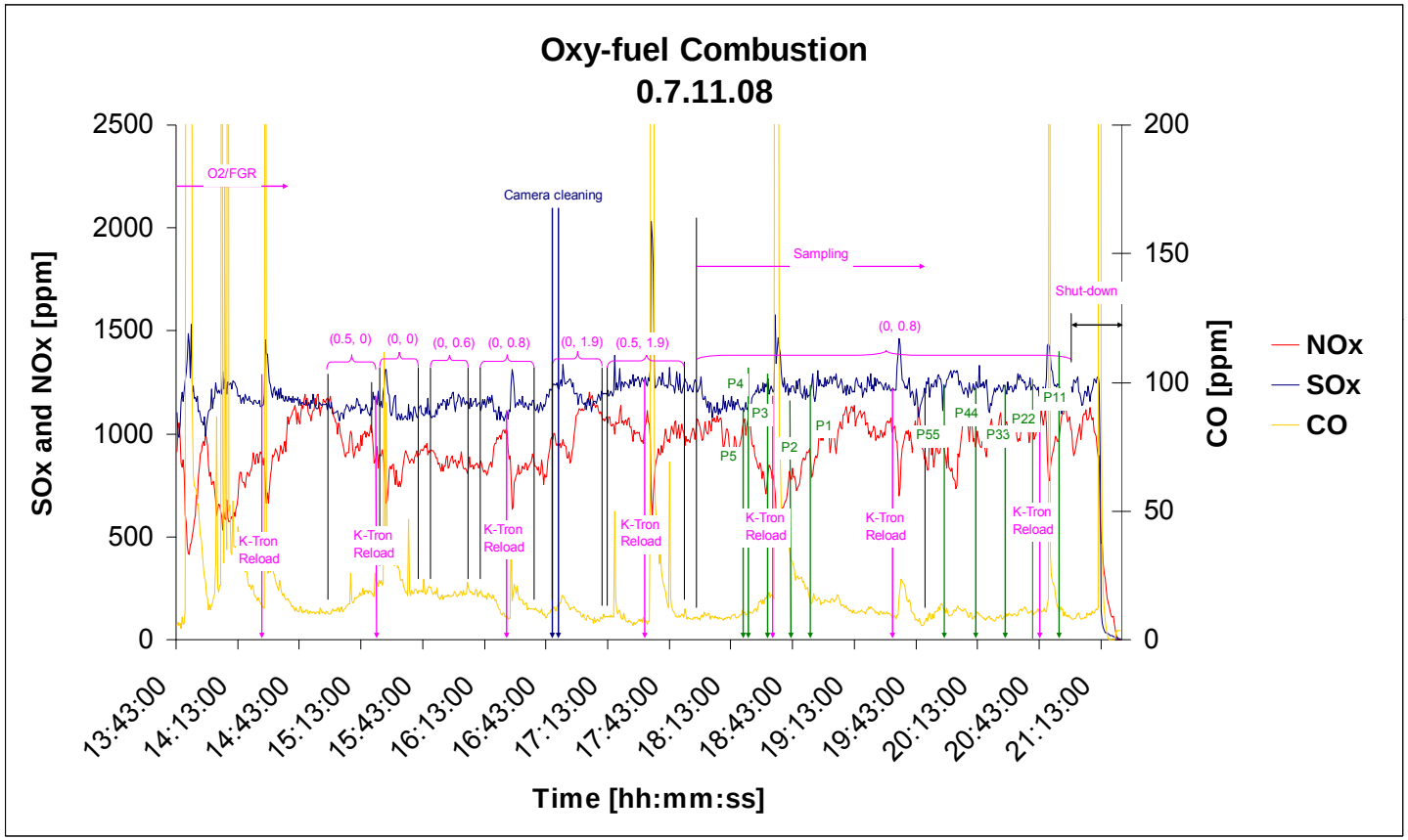
Results – Oxy-fuel Combustor Exit *(cont'd)*

Rack 44



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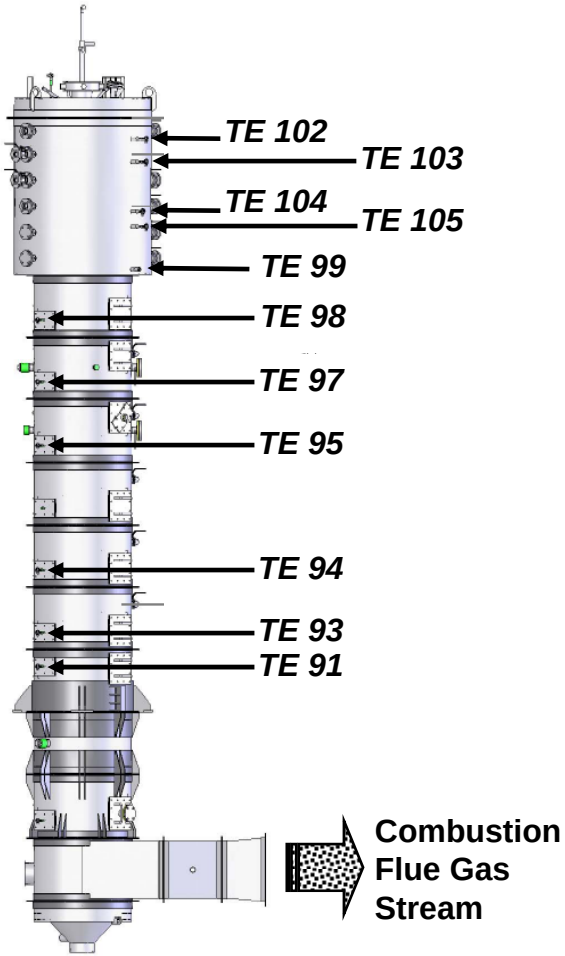
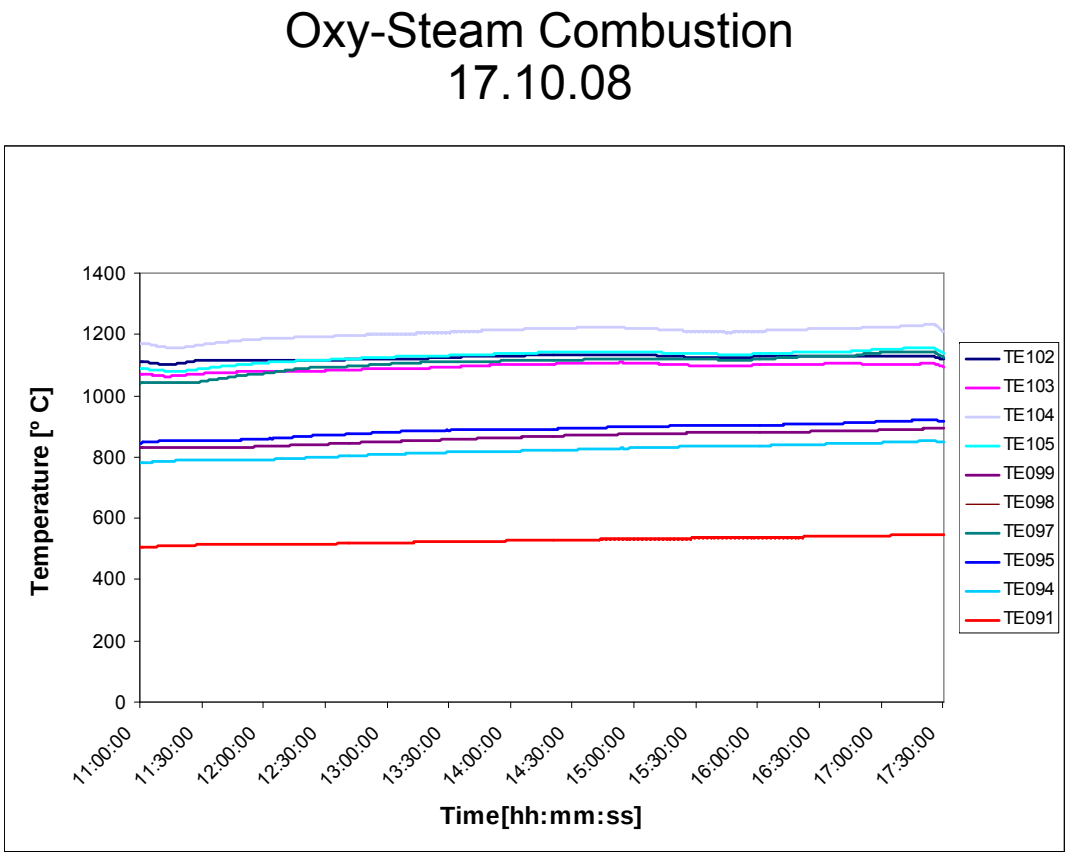
Results – Oxy-steam Temperature Profile





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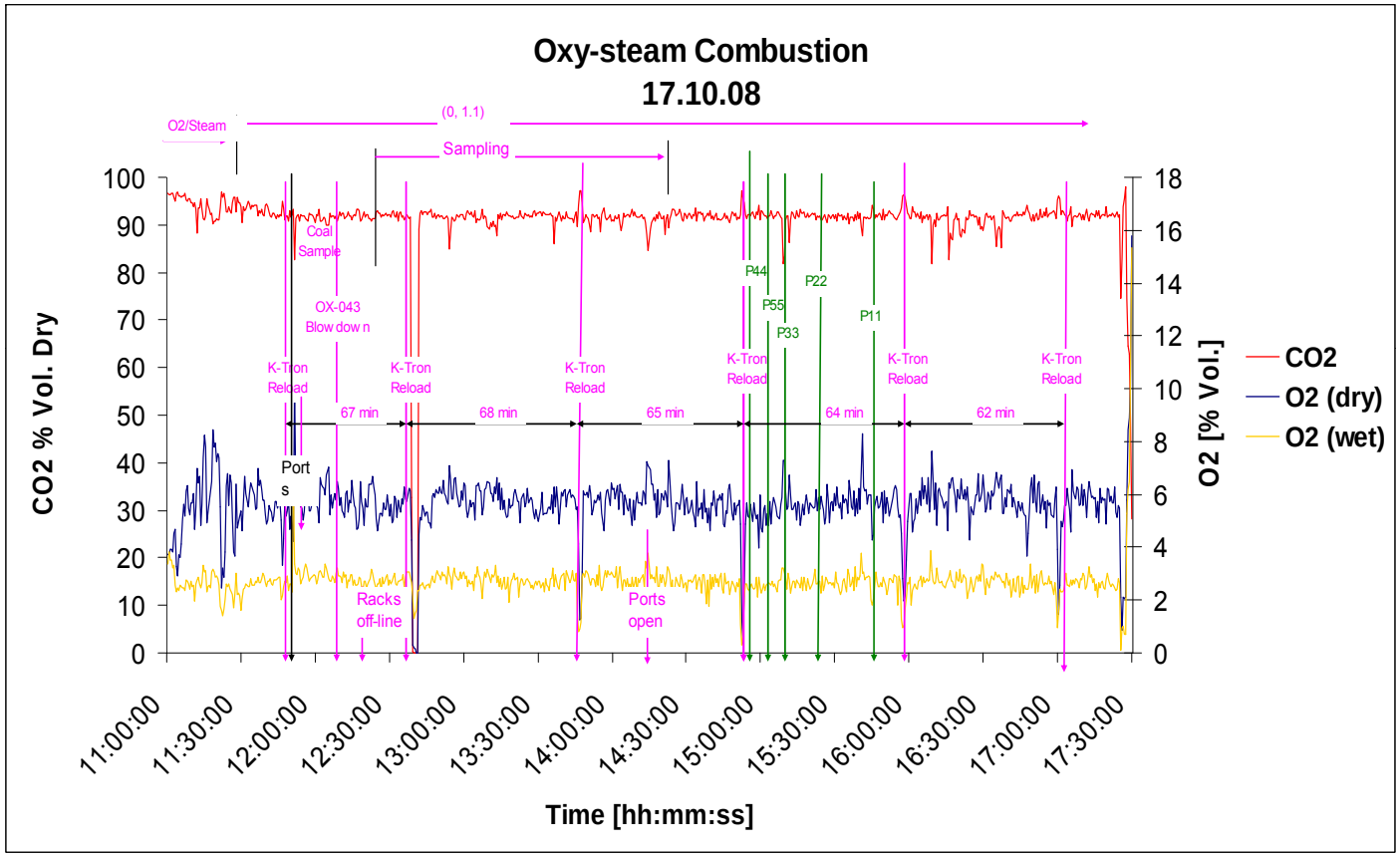
Results – Oxy-steam Combustor Exit



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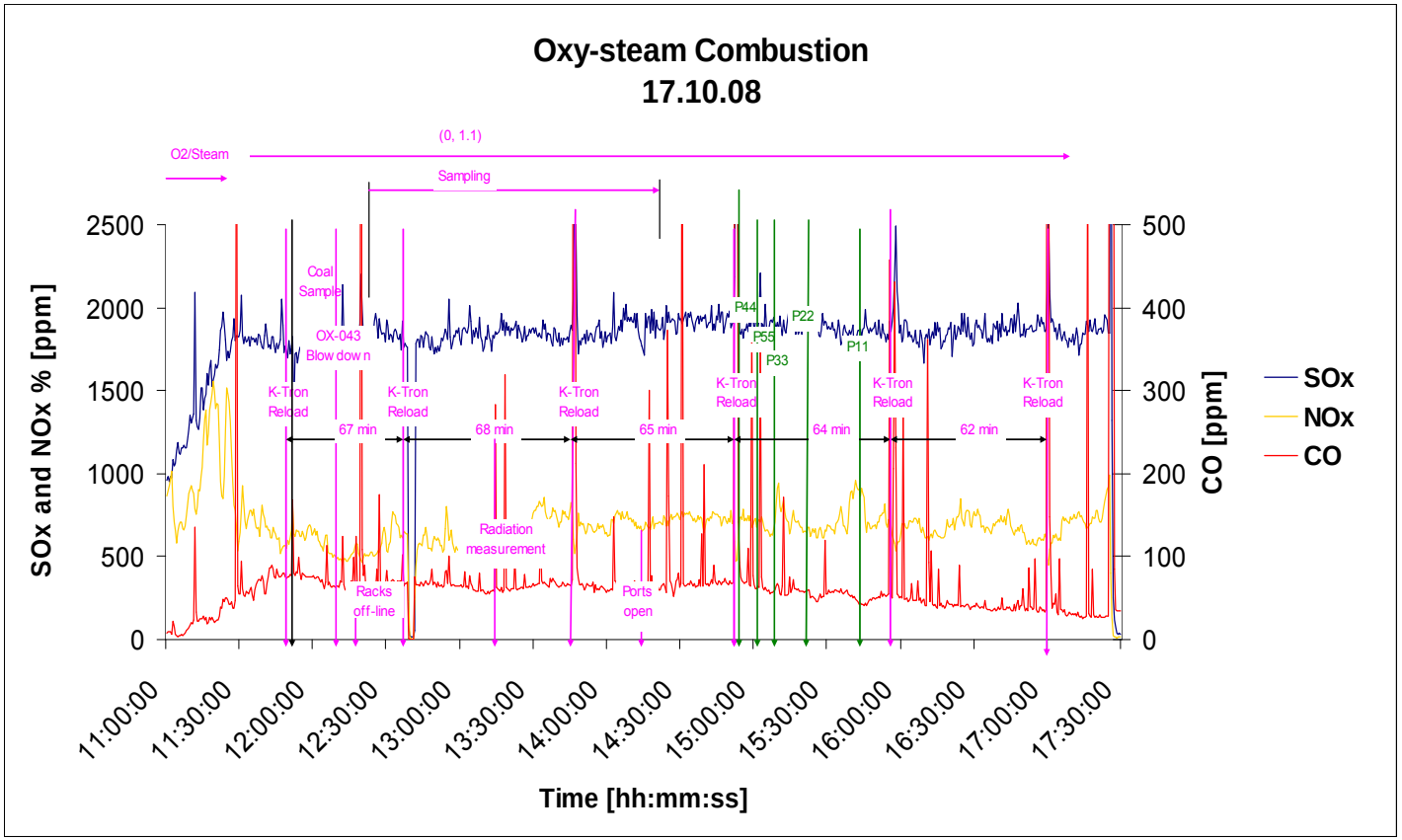
Results – Oxy-steam Combustor Exit *(cont'd)*



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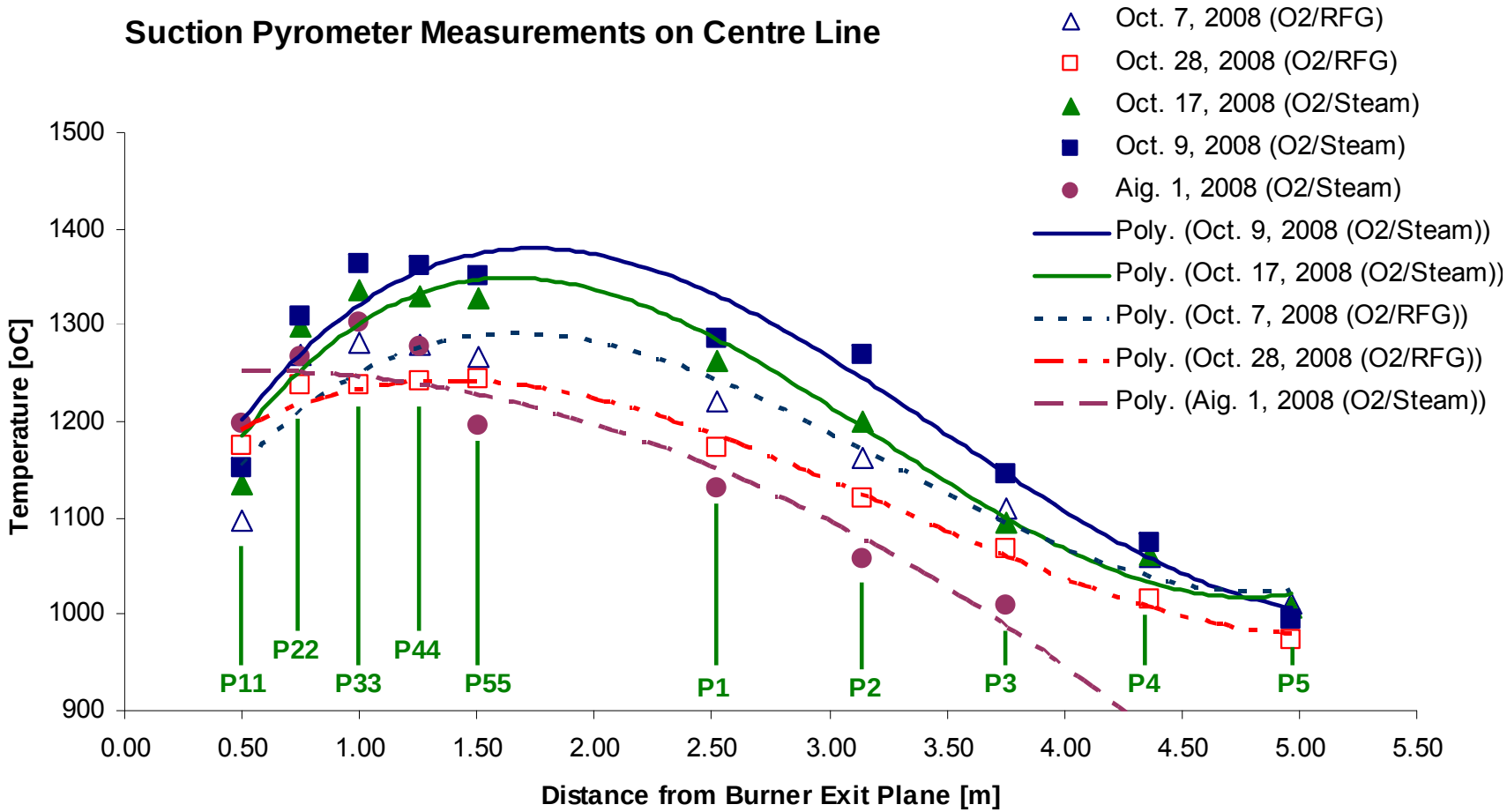
Results *(cont'd)*



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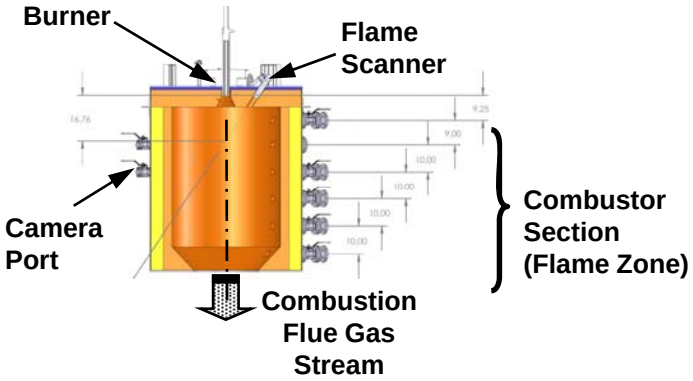
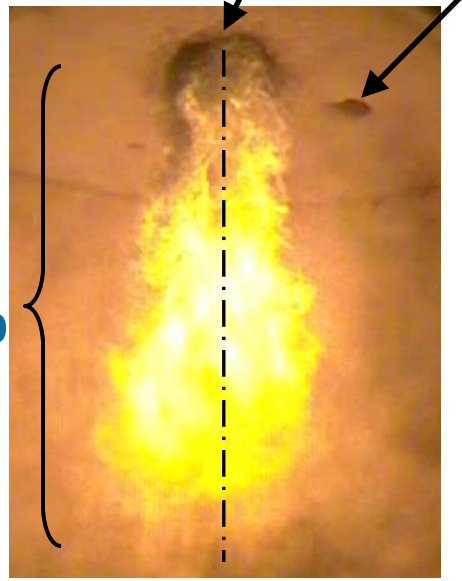
Results – High Swirl Oxy-Steam Flame



Flame Envelop



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Conclusions

- Best results, for oxy-steam, was achieved when all of the O_2 was sent via the outer annulus and moderate to high swirl numbers where used; best results, for oxy-fuel, was achieved when all of the O_2 was sent via the inner annulus.
- Oxy-steam combustion resulted in high CO_2 concentrations (~ 90%), low CO, moderate NO_x and typical SO_x levels.
- Elimination of recycle stream, in oxy-steam mode, reduced air infiltration issues boosting CO_2 concentrations by 5-10%.
- Combustor outlet moisture content approximately was 60%

Acknowledgement

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CO_2 Capture Project

ONTARIOPOWER GENERATION

SaskPower

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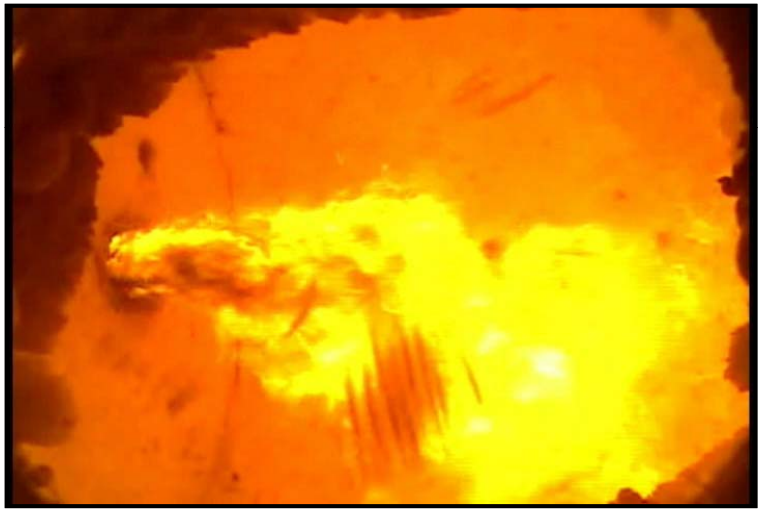
Oxy-steam Flame

Low Swirl



High Swirl

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