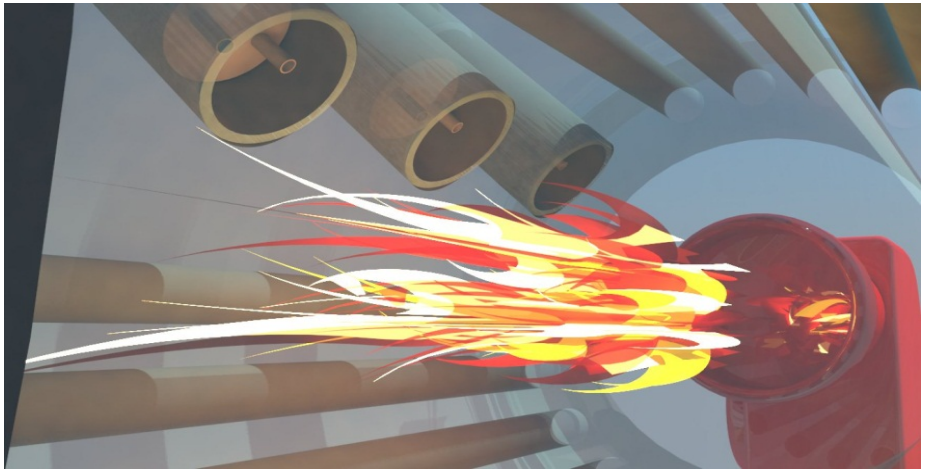
Investigation of Oxy-fuel Retrofit in a 250 KW CEN Boiler Using Various Fuels



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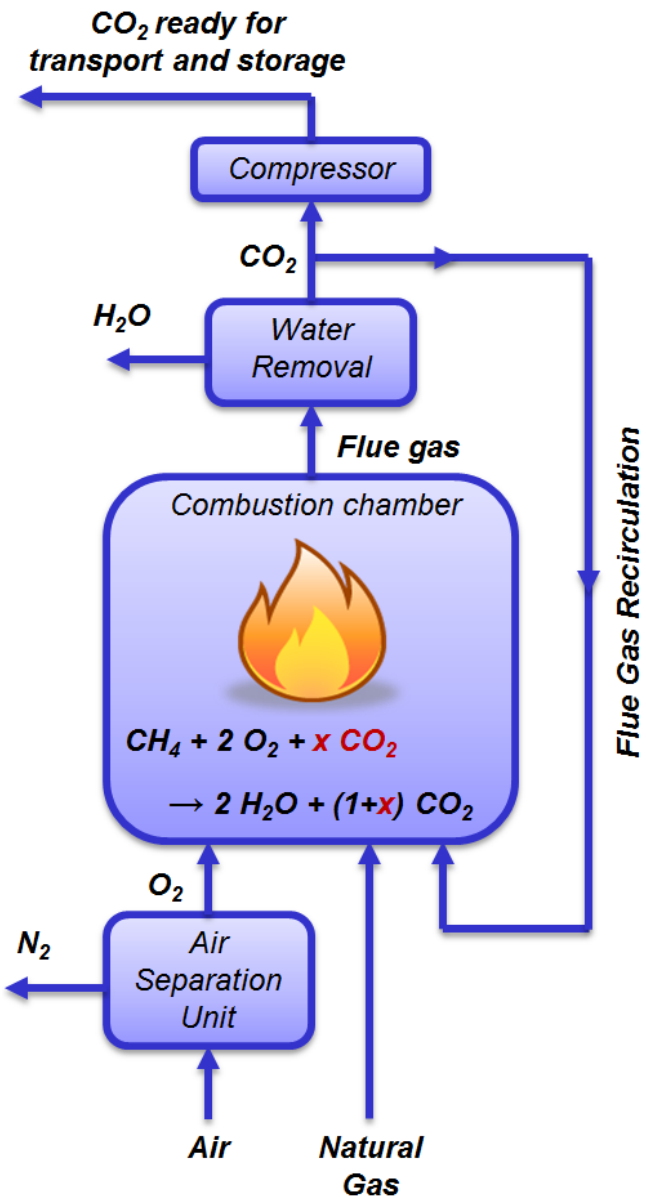
Background and Motivations

Project part of Task 1.5 in BIGCCS

- "Application to industry and offshore", evaluating CCS as an option for other CO_2 sources than power plants
  - CCS applied to refinery fired heaters

Main pros of oxy-fuel combustion

- Relatively simple **CO_2 capture** from flue gas
- **Flue gas recirculation** to regulate flame temperature
- Low **NO_x** emissions
- **Retrofit possible** to existing systems



Background and Motivations

Fired heaters

- Essential component in petrochemical plants
- Each refinery has 20-50 fired heaters
- Considerable source of CO_2 emissions:
  - About 65% of the total refinery emissions
  - About 4% of the total global CO_2 emissions
- Currently 2 refineries in Norway
  - *Mongstad is the most well-known (Statoil / Shell). The petrol production corresponds to 1.5 times Norwegian consumption.*

Main goal: ***Propose low-cost oxy-fuel retrofit solutions for fired-heaters used in refineries to reduce CO_2 emissions***

Approach

Light oil No.1

- Provide experimental results
  - Lab-scale base-case of 90 kW
  - Both for air- and dry oxy-fuel operation
- Chemical kinetics for base-case
  - Come up with an appropriate reaction scheme
  - Perform simulations using CHEMKIN©

Heavy oil No.6

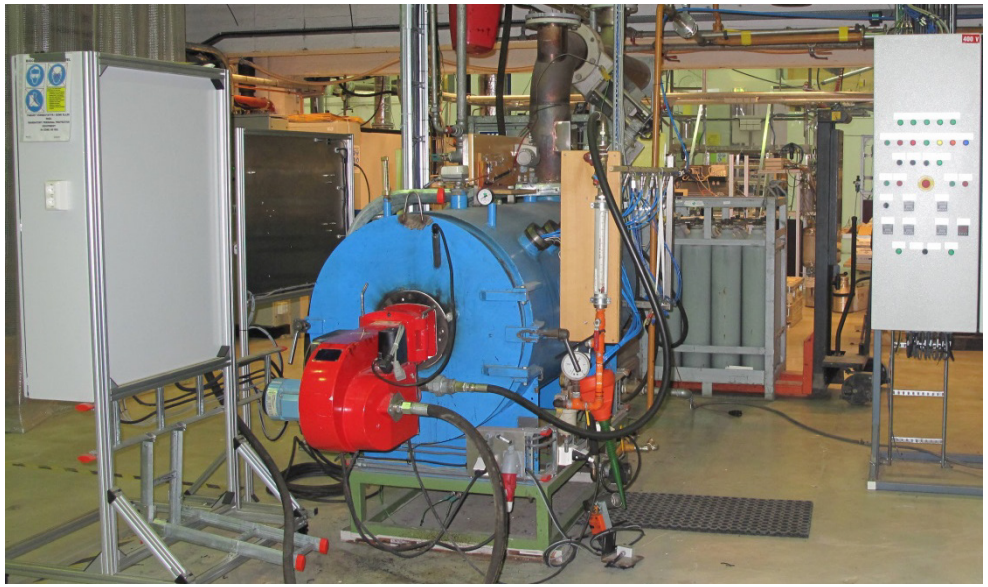
- Design and commissioning of appropriate system
  - Adapt setup to Fuel oil No 6 (RMG 380)
  - Lab-scale 150 kW
  - Primary/secondary heating system
- Run experimental tests with both air and dry O_2/CO_2

Refinery gas *(in progress)*

- Provide experimental results
  - Lab-scale base-case of 90 kW
  - Both for air- and dry O_2/CO_2
- CFD simulation with Ansys Fluent ©
  - Based on lab base-case of 90 kW
  - Model re-usable with various cases

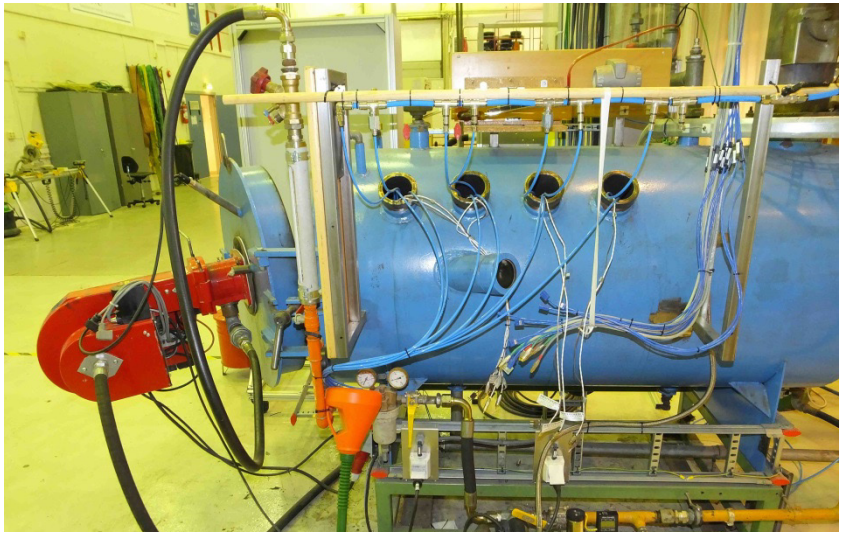
Name	Type/ Alias	Composition
No.1 Fuel oil	Diesel fuel / Light oil	9-16 long C chains
No.6 Fuel oil	Residual / Heavy oil	20-70 long C chains
Refinery gas	Gas	N_2, CH_4, H_2, C_3H_8, *(C_2H_4, CO_2)*

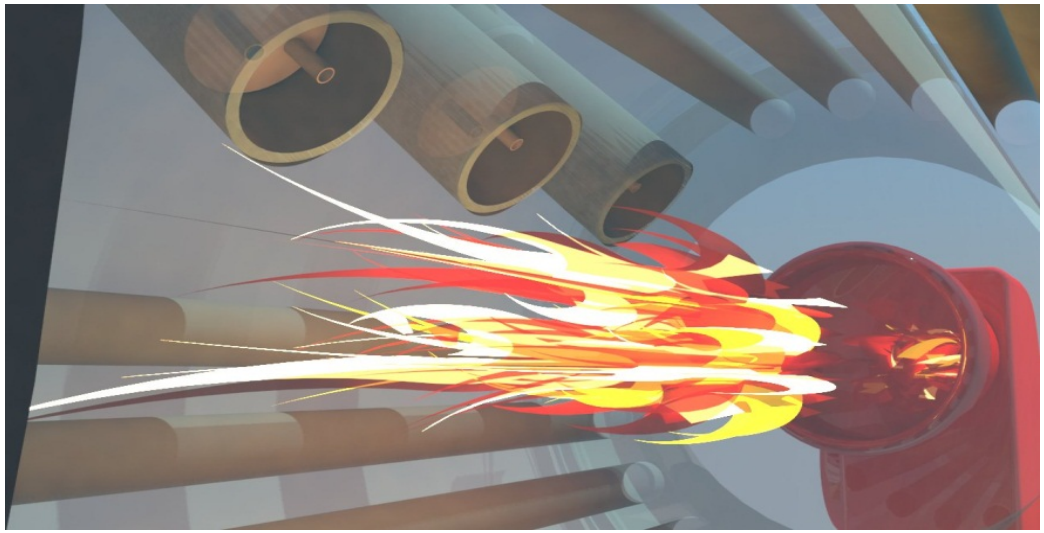
Experimental setup



250 KW CEN Boiler

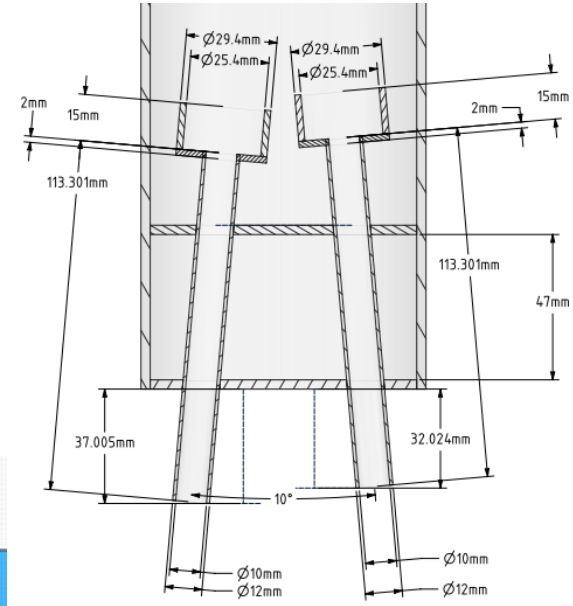
Boiler and burners are not modified

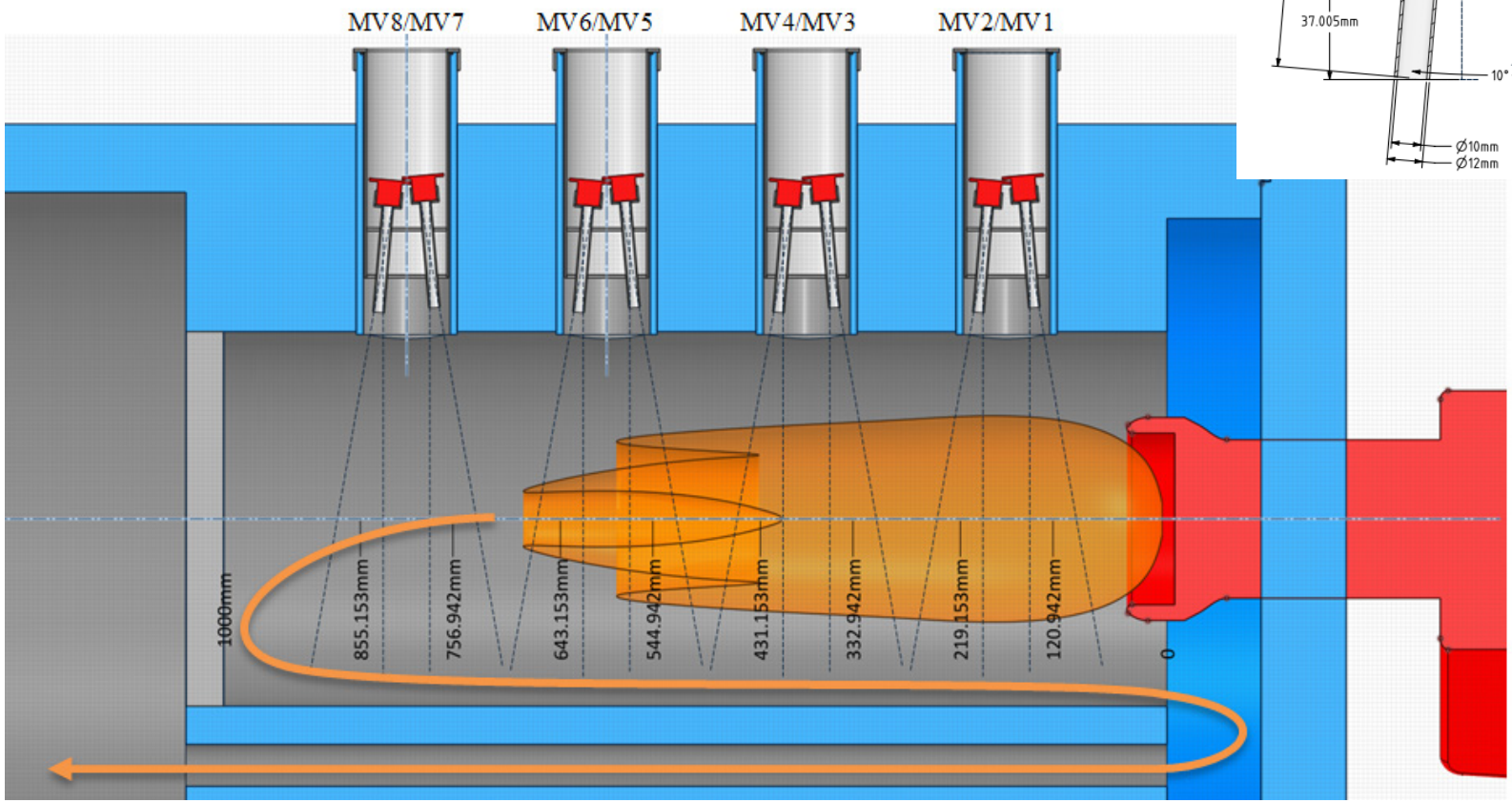


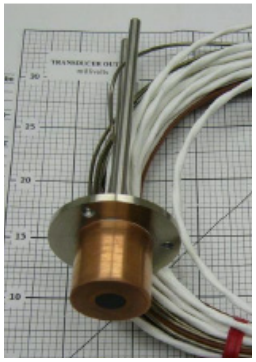


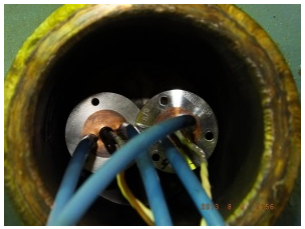
Experimental setup

- Measurements of wall heat flux with 8 Schmidt-Boelter heat flux sensors along the boiler axis
- Measurements of flue gas emissions (CO, O_2, NOx, CO_2)

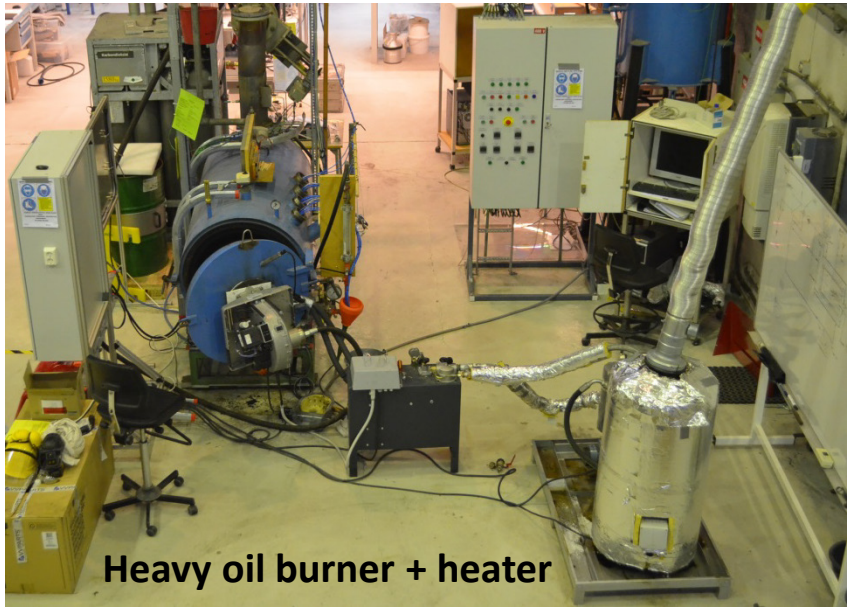


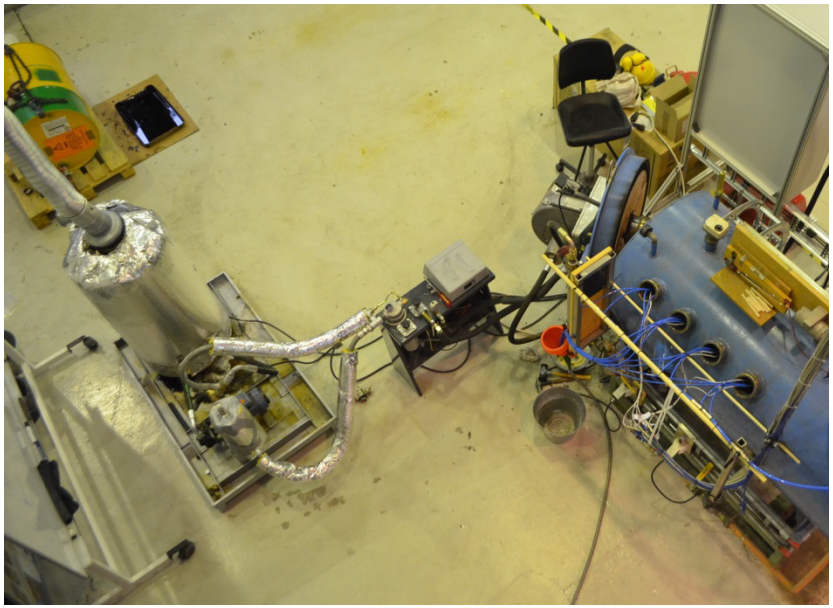


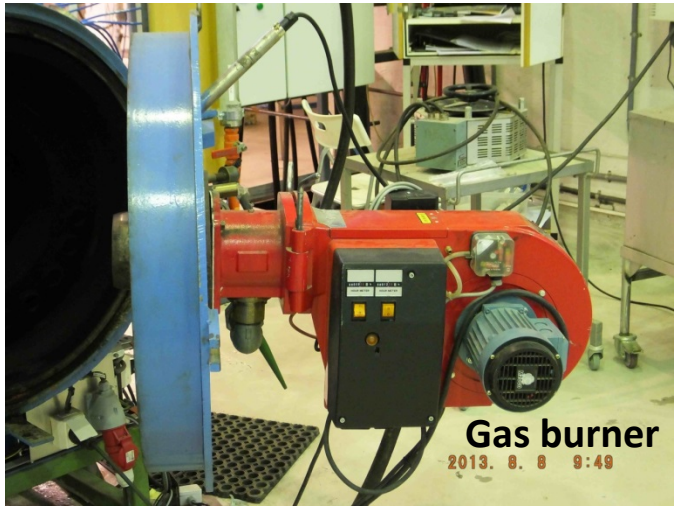


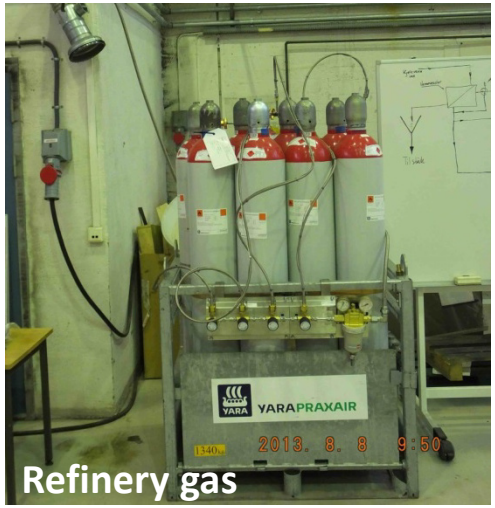


Experimental setup





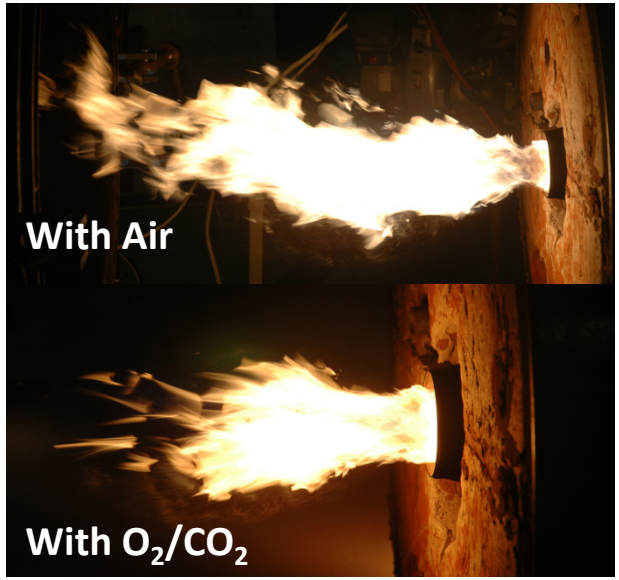




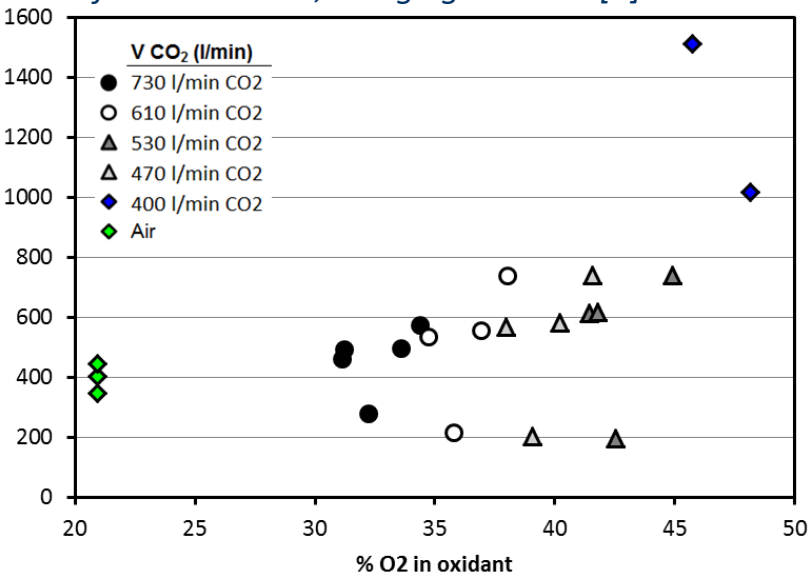
Main results and findings

Light oil #1 (90 KW)

- Oxy-fuel with 33-37 %O_2 in O_2/CO_2 oxidizer leads to flame temperatures similar to air-fired cases.
- Oxy-fuel conditions leads to about 80-90 $_{vol}$% CO_2 in flue gases (~15 $_{vol}$% CO_2 in air-fired conditions).
- Incident heat fluxes with 35-37 %O_2 in O_2/CO_2 oxidizer are similar to air-fired cases.



Incident heat flux (W/m²) for various air/oxy-fuel conditions, using light oil #1. [1]



[1] Seljeskog, M.; Sevault, A.; Ditaranto, M.; Energy Procedia, Volume 37, 2013, Pages 7231–7248, GHGT-11

Main results and findings

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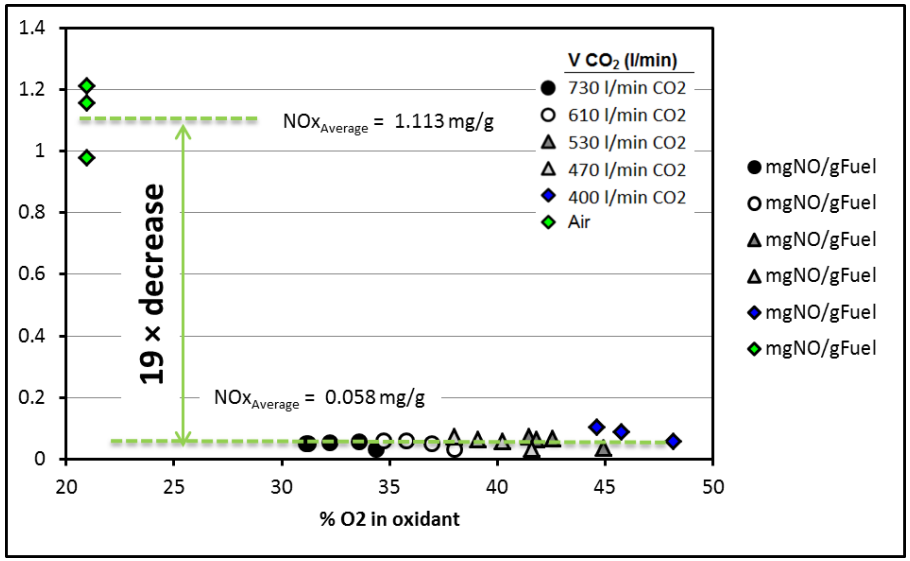

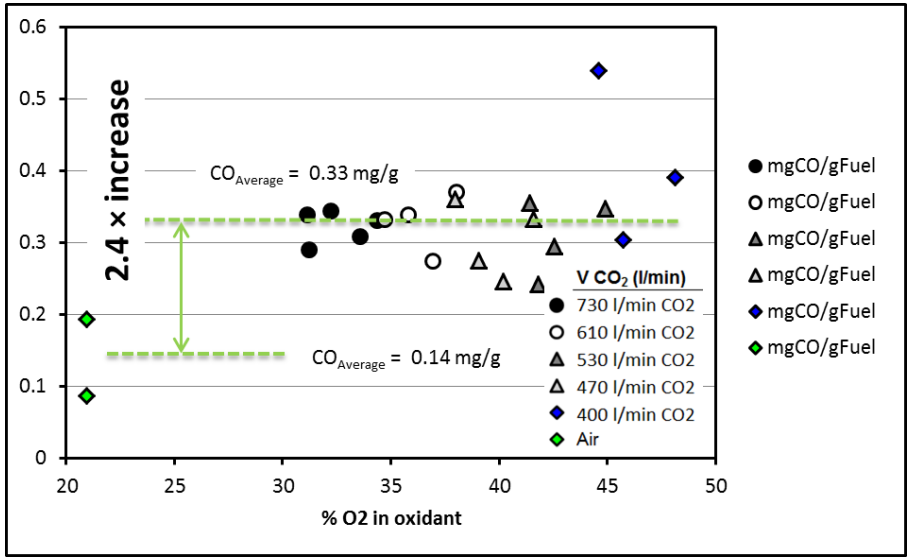

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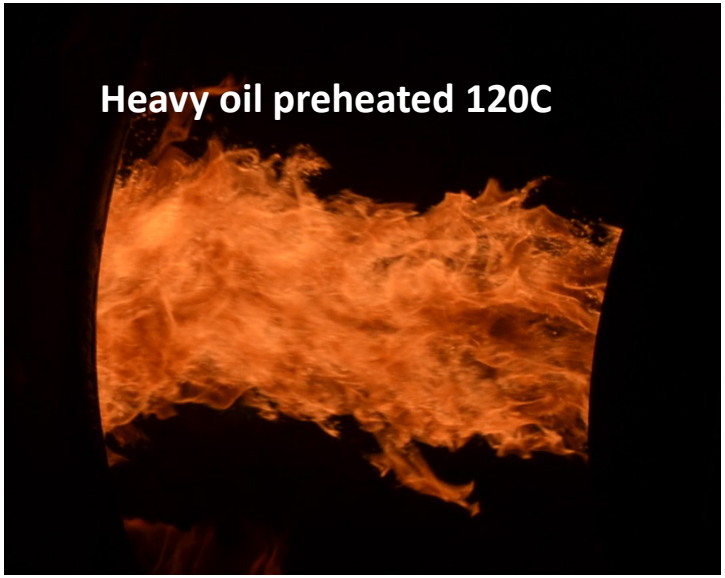
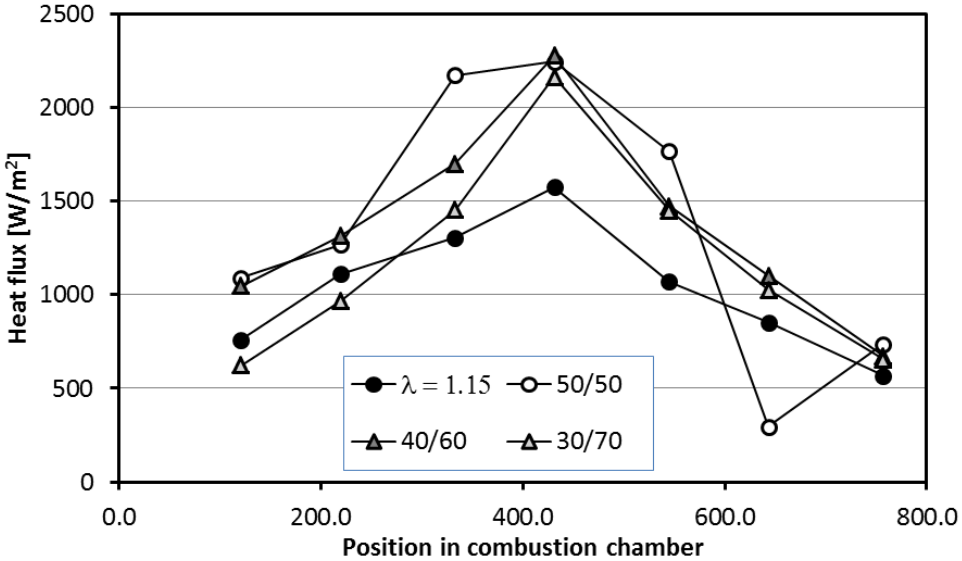
Main results and findings

Heavy oil #6 (130 KW)

- Stabilization issues below about 30 %O_2 in O_2/CO_2 oxidizer
- Overall heat flux intensity increases with the oxygen content in the oxidizer
- In tested conditions, overall heat flux intensity is higher than with air-fired conditions
  - However within the same range



Incident heat flux (W/m^2) along the combustion chamber for various air/oxy-fuel conditions, using heavy oil #6. [1]



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Main results and findings

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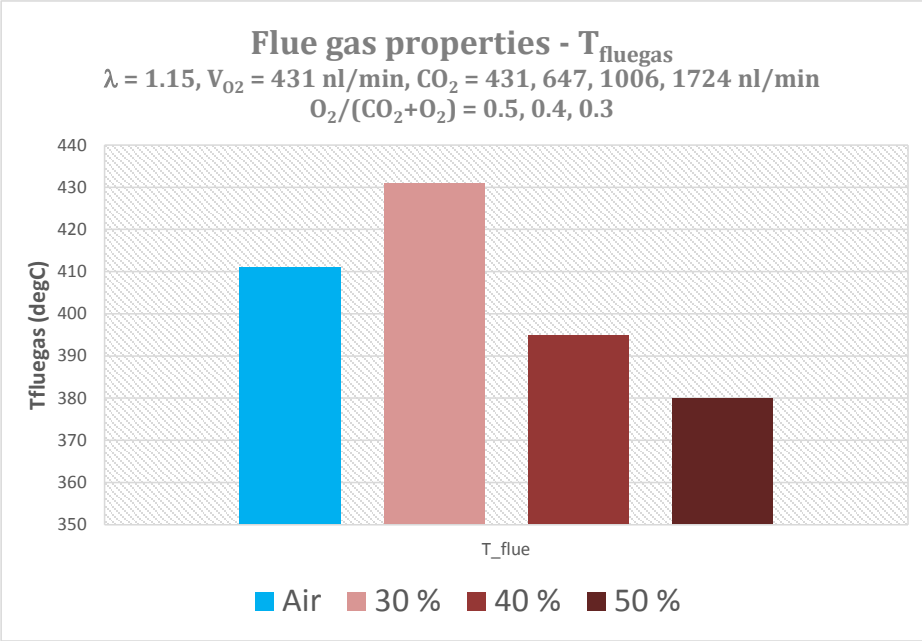
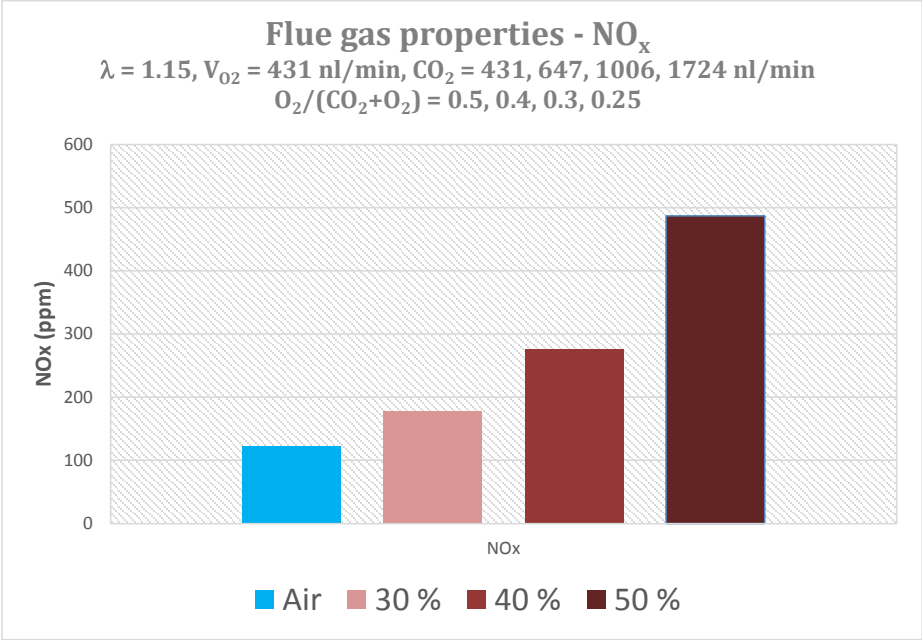
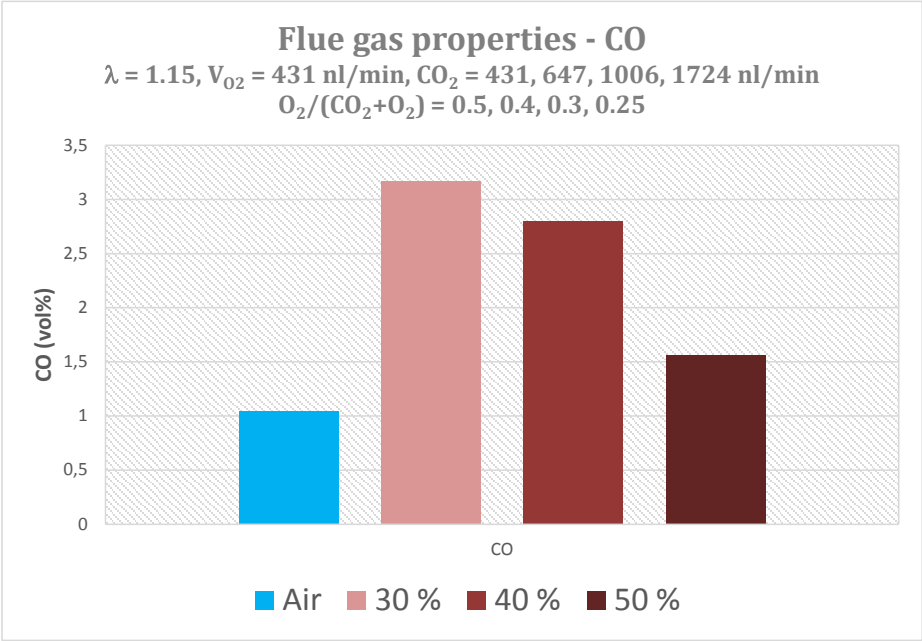
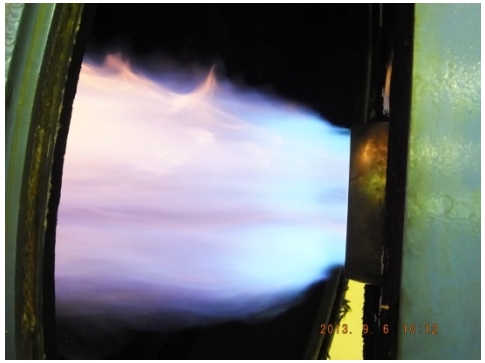






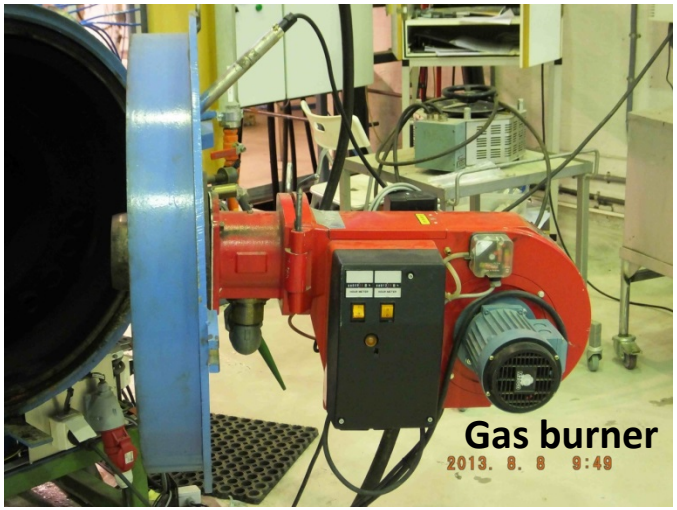
Work in progress

Refinery gas (90-150 KW)



- Fuel composition (volume): 25% H_2, 42% CH_4, 25% C_3H_8 and 8% N_2

- Experimental measurements:
  - Air and dry oxy-fuel fuel conditions
  - Incident heat flux along the combustion chamber walls
  - Flue gas emissions (CO, O_2, NOx, CO_2)
  - Comparison with fuels previously used



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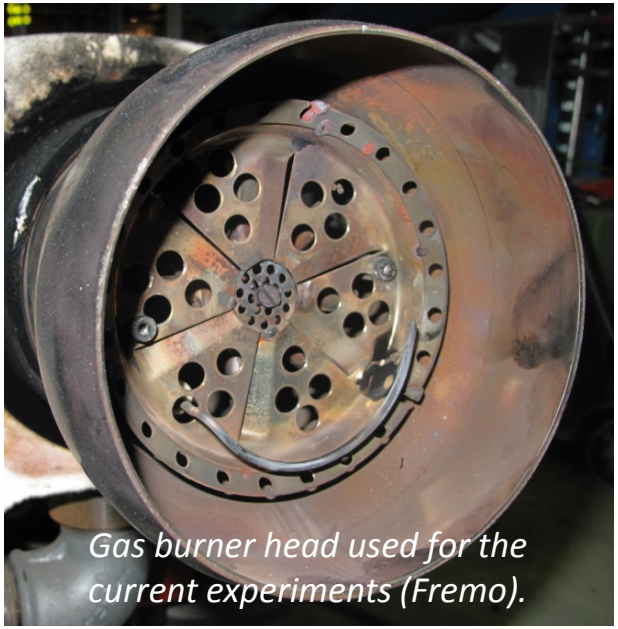
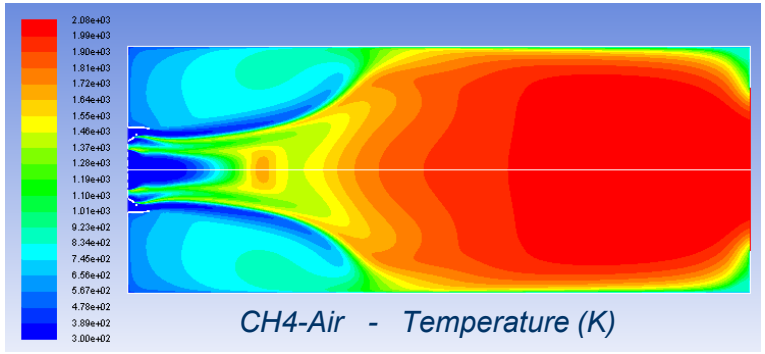


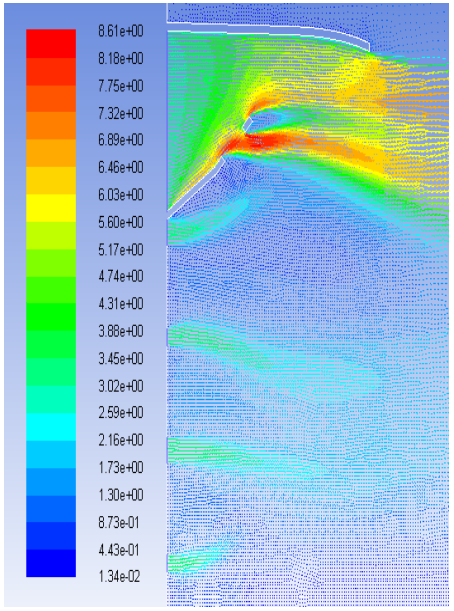
Gas burner head used for the current experiments (Fremo).

Refinery gas (90-150 KW)

- **Numerical comparisons** using simulations with Ansys Fluent©
- Use CFD model to test wider range of conditions
- Step 1: 2D axisymmetric model, turbulent non-premixed burner
- Step 2: 3D model, turbulent non-premixed burner
- Challenges:
  - Proper mixing vs. realistic burner geometry
  - In reality, partially premixed
  - Discrete Ordinates radiation
  - NOx and other gas emissions
  - Soot



CH4-Air - Temperature (K)



CH4-Air - Velocity magnitude (m/s)

Summary

- Tested oxy-fuel conditions in commercial light oil and heavy oil burners mounted on a commercial 250 KW boiler
- Retrofitted by simple means for operation at controlled dry oxy-fuel conditions
- Experimental results:
  - Heat flux profiles in oxy-fuel conditions (~35-37% O_2) similar to air-fired cases
  - NOx emissions are significantly lower with light oil, but higher with heavy oil (potential air leakages)
  - CO emissions remain higher than in air-fired case, probably insufficient mixing with lower flow rate of fresh gases
- The fuel/oxidizer mixing proved to be poor with heavy oil, due to lower flow rate of oxidizer, though it was not a critical issue with light oil
- Experimental and numerical work in progress with refinery gas

Main conclusions

- Using the proper mixture of O_2/CO_2 (i.e. recirculation rate), radiative heat transfer close to air-fired conditions can be achieved, **without modifying neither the burner nor the boiler**
- **Cost-saving for retrofit**
- ASU, FGR and CPU are still needed
- Next steps:
  - Numerical model to work with different gas fuels
  - Flue gas recirculation loop adapted to experimental setup

Thank you for your attention!

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