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 CO₂ sources than power plants
  - CCS applied to refinery fired heaters

Main pros of oxy-fuel combustion

- Relatively simple CO₂ capture from flue gas
- Flue gas recirculation to regulate flame temperature
- Low NOₓ 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\textsubscript{2} emissions:
  - About 65% of the total refinery emissions
  - About 4% of the total global CO\textsubscript{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\textsubscript{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

<table>
<thead>
<tr>
<th>Name</th>
<th>Type/ Alias</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1 Fuel oil</td>
<td>Diesel fuel / Light oil</td>
<td>9-16 long C chains</td>
</tr>
<tr>
<td>No.6 Fuel oil</td>
<td>Residual / Heavy oil</td>
<td>20-70 long C chains</td>
</tr>
<tr>
<td>Refinery gas</td>
<td>Gas</td>
<td>N$_2$, CH$_4$, H$_2$, C$_3$H$_8$, (C$_2$H$_4$, CO$_2$)</td>
</tr>
</tbody>
</table>
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, O₂, NOₓ, CO₂)
Experimental setup

Heavy oil burner + heater

Gas burner

Refinery gas
Main results and findings

Light oil #1 (90 KW)

- Oxy-fuel with 33-37 %O₂ in O₂/CO₂ oxidizer leads to flame temperatures similar to air-fired cases.
- Oxy-fuel conditions leads to about 80-90 vol% CO₂ in flue gases (~15 vol% CO₂ in air-fired conditions).
- Incident heat fluxes with 35-37 %O₂ in O₂/CO₂ oxidizer are similar to air-fired cases.

Main results and findings

Light oil #1 (90 KW)

Main results and findings

Heavy oil #6 (130 KW)

- Stabilization issues below about 30% O₂ in O₂/CO₂ 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/m²) along the combustion chamber for various air/oxy-fuel conditions, using heavy oil #6. [1]
Main results and findings

Heavy oil #6 (130 KW)

Flue gas properties - $T_{\text{fluegas}}$
\[ \lambda = 1.15, V_{O_2} = 431 \text{ nl/min}, CO_2 = 431, 647, 1006, 1724 \text{ nl/min} \]
\[ O_2/(CO_2+O_2) = 0.5, 0.4, 0.3 \]

Flue gas properties - NOx
\[ \lambda = 1.15, V_{O_2} = 431 \text{ nl/min}, CO_2 = 431, 647, 1006, 1724 \text{ nl/min} \]
\[ O_2/(CO_2+O_2) = 0.5, 0.4, 0.3, 0.25 \]

Flue gas properties - CO
\[ \lambda = 1.15, V_{O_2} = 431 \text{ nl/min}, CO_2 = 431, 647, 1006, 1724 \text{ nl/min} \]
\[ O_2/(CO_2+O_2) = 0.5, 0.4, 0.3, 0.25 \]
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Work in progress

Refinery gas (90-150 KW)

- Fuel composition (volume): 25% H₂, 42% CH₄, 25% C₃H₈ and 8% N₂

- Experimental measurements:
  - Air and dry oxy-fuel fuel conditions
  - Incident heat flux along the combustion chamber walls
  - Flue gas emissions (CO, O₂, NOx, CO₂)
  - Comparison with fuels previously used
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Work in progress

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

![Gas burner head used for the current experiments (Fremo).](image)
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% O₂) 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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