The Oxyfuel Process with Circulating Fluidised Bed Combustion and Cryogenic Oxygen Supply
Advantages of Circulating Fluidised Bed Boilers

• Huge bandwidth of possible fuels

• Emission reduction by primary measures
  ▶ Low combustor temperatures and air staging reduce significantly the amount of NOx produced during combustion
  ▶ SO₂-emissions can be reduced by in-situ desulphurisation

• Oxyfuel → Next to the flue gas the circulated solids can be used as a heat sink for the process (in contrast to pulverised coal firing)

→ Potential to reduce the amount of flue gas recirculated
Available Heat Sinks for Oxyfuel Processes

PC:

$T_{O_2}$

$T_{Coal}$

$T_{adiabat}$

$\dot{Q}$

$2/3$

$1/3$

CFBC:

$T_{O_2}$

$T_{Coal}$

$T_{CC}$

$\dot{Q}_{CC}$

$\dot{Q}_{CHE}$

$\dot{Q}_{EHE}$

ATOS

TFG-Recirculation

Tadiabat

$Q$

$3/3$

$1/3$

CC – Combustion Chamber
EHE – External Heat Exchanger
CHE – Convective Heat Exchanger
Link of EBSILON and ASPEN via ProgDLL allows the simultaneous execution of both software applications.

- **Input CO₂ Processing Unit**
  - Composition
  - Flow

- **Input Overall Process**
  - Power requirements
  - Cooling demand
  - Steam demand
  - CO₂ purity

- **Process Evaluation**
  - Transferred heat quantities
  - Gas compositions
  - Efficiencies
  - etc.
Process Scheme

Air

Vent gas

Air Separation Unit (ASU)

N\textsubscript{2}

Air

O\textsubscript{2}

Goal

Identification of main influencing variables on feasibility and efficiency of the process under realistic boundary conditions
Basic Assumptions I

- State-of-the-art power plant with EHE (460 MW\textsubscript{el,gross} – about 1000 MW\textsubscript{th})
- South American hard coal (El Cerrejón – Burnout 99 %)
- CC-outlet: 880 °C
- EHE-outlet: 550 °C
- Steam parameters: 275 bar / 54 bar; 560 °C / 580 °C (SH/RH)
- Feed water temperature: 290 °C ; FG outlet temperature (CHE) 340 °C
- Temperature of recirculation (beneficial as hot as possible, limited by available fans)
  - To CC: about 340 °C; To EHE: about 150 °C (preheated to 290 °C)
- Oxygen ratio 1.15  - Oxygen purity 95 volume-%
  - 2 % air ingress at the convective heat exchangers
  - 0.5 % air ingress at the electrostatic precipitator
Reduction of the FG-Recirculation leads to a smaller cross sectional area of the CC and the CHE \((u_0=\text{const.})\).

Same effect for higher velocities leading to:

- Less available space for heat transferring areas \(\rightarrow\) walls and additional equipment in the combustor (e.g. wing walls).

Differences to Lagisza depend on simulated coal and \(u_0\).
Air Case

- About 32.5% of the heat are transferred in the CHE
- Approximately 28.5% are transferred in the CC (wing-walls with ribbed tubes and platen superheater)
- Remaining heat is transferred in the EHE (39%)

Transferred Heat Quantities in %

FG - Recirculation in %
Oxyfuel – Convective Heat Exchanger (CHE)

- Temperatures:
  - $T_{\text{CHE, in}} = 880 \, ^\circ\text{C}$,
  - $T_{\text{CHE, out}} = 340 \, ^\circ\text{C}$

- With a decreasing FG-recirculation there is less massflow through the CHE
  - Leading to less heat transferred in the CHE
A decrease in the FG-Recirculation leads to a smaller cross-sectional area \((u_0=\text{const.})\).

- Reduction of heat transferring area (wall and equipment)
  - Less heat can be withdrawn out of the CC
- More heat has to be transferred in the EHE
The amount of heat transferred in the EHE increases with a reduction of the FG-Recirculation.

The theoretical minimum of FG-Recirculation is about 35%.

- The whole recycled FG is necessary to fluidise the EHE.
- CC O₂-Conc. in the CC nozzle floor exceeds limits → hot-spots in the bed.
The restricting limit for the range of operation of the Oxyfuel-CFB is the state-of-the-art of the EHE

- Geometrical arrangement around the boiler is limited
- Design of Loop-Seal and EHE
- Minimum for the FG-Recirculation > 60 %
Minimum for the FG-Recirculation ≈ 60 %

Changes in the transferred heat due to Oxyfuel conditions:

- CHE ≈ 25 %
  (- 7.5 %-pt.)
- CC≈ 22 %
  (- 6.5 %-pt.)
- EHE≈ 53 %
  (+14 %-pt.)

\[\Rightarrow + \frac{1}{3}\]
Due to air ingress there is a maximum for the CO₂ concentration of 80 %

For lower recycle rates the CO₂ concentration decreases due to an increase in residual oxygen

The O₂ concentration in the flue gas increases accordingly

The O₂ concentration at the CC nozzle floor increases for decreasing FG-Recirculation
• Assumptions
  ▶ Live steam parameter: 275 bar, 560 °C
  ▶ Reheat: 54 bar, 580 °C
  ▶ Condenser pressure: 45 mbar
  ▶ ASU: 236 kWh/t\textsubscript{O_2,pure} (adiabatic compression)

• Calculated efficiencies for comparisons

\[
\begin{align*}
\text{Air Case PC:} & \quad \eta_{\text{el,net}} \approx 44.2 \% \\
\text{Air Case CFBC:} & \quad \eta_{\text{el,net}} \approx 43.3 \% \\
\text{Oxy-PC:} & \quad \eta_{\text{el,net}} \approx 34.1-35.0 \% \\
\text{Oxy-CFBC:} & \quad \eta_{\text{el,net}} \approx 34.1 \% - 34.4 \%
\end{align*}
\]
\[\Delta\eta = 0,9 \%\text{-pts.}\]
\[\Delta\eta = 0 - 0,6 \%\text{-pts.}\]
Oxyfuel – Efficiencies II

- For the chosen design, the efficiency is at 34.4% and by this comparable to PC-firing.
- Slight demand increase for ASU and GPU.
- The loss for higher recirculation is due to CC-Compressor.
- The electrical demand for the EHE fan is dominated by the CC-compressor for higher FG-Recirculation.
The efficiencies of the CFBC are comparable to those of pulverised coal combustion, as long as no secondary flue gas treatment is necessary.

- Efficiency loss in the order of 8 to 10 %-pts

Primary goal ➔ Reduction of FG-Recirculation seems realisable, but is limited by:

- The fluidisation of the CC and EHE,
- Arrangement of the boiler,
- Design of Loop-Seal and EHE,
- The solids entrainment
Thank you for your attention!!

COORETEC-Cooperative Project: ADECOS ZWSF
„Oxyfuel-Process with Circulating Fluidised Bed Boiler“

Duration: 1st January 2010 - 31st March 2013

Institutes:
IET TU Hamburg Harburg
IFK Universität Stuttgart
VWS TU Dresden

Industry Partners:
EnBW Kraftwerke AG
E.ON Energie AG
RWE Power AG
Vattenfall Europe Generation AG & Co. KG
Linde AG
Doosan-Lentjes

Supported by:
Federal Ministry of Economics and Technology

on the basis of a decision by the German Bundestag