Oxy-fuel Coal-Fired Combustion Power Plant System Integration

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CO2 Reduction Strategy

Short and medium term approach

- Increase of efficiency provides emission cuts and has a direct impact on the use of natural resources, generation of waste matter and economics.

- Co-firing of solid fossil fuels with CO₂ neutral fuels in highly fuel-flexible CFB boilers in repowering and greenfield applications

GHG emission trading systems, emission caps and taxes are expected to lead into demand for solutions to near Zero Emission Power (ZEP) production of fossil fuels

- Retrofits - ZEP ready new plants - greenfield ZEP plants

Long-term approach - Technologies offering potential

- Post-combustion capture

- Pre-combustion capture (IGCC with CO₂ separation)

- Oxy-fuel combustion  Our main focus - (Oxy-CFB, Oxy-PC)
Alliance to pursue certain projects that will incorporate clean coal technologies and integrated oxy-coal combustion systems into coal-fired electric generating plants to facilitate capture and sequestration of carbon dioxide (CO2).

Validate scale-up of oxy-fuel technology

Improve integration of boiler with ASU and CCS systems
Oxy-Fuel Technology
Main Advantages

- The established PC/CFB advantages exist also in oxy-combustion.
- Multi-fuel capability in CFB (coal, petroleum coke, lignites etc.)
- Emission control technology, e.g. SO$_x$ and NO$_x$ reduction (performed better in oxy-mode)
- Dual-firing capability: Design PC/CFB boiler for both air-firing and oxy-fuel-firing.

Oxy-fuel is considered technically viable. Accurate design and performance prediction are challenging → Current/Future Work:
- Experiments in bench scale and pilot test facilities
- Development and validation of design models
- Long-term demonstration runs
Oxy-fuel gas property increase in:
- gas density
- gas mass flow rate at the same Ug
- gas moisture
- gas thermal capacity, Cp
- energy requirement for Fg*Cp*dT
- energy carryover to HRA
- heat transfer coefficient

- Generated heat per volume is substantially higher than in combustion with air, as O2 concentrations increase
- Adiabatic combustion temperature rises
- Changes in hydrodynamics
- Materials in the high CO₂ and H₂O gas atmosphere
- Emissions prediction
Oxy-Fuel Technology
Furnace Heat Flux Control

- Balancing of temperature levels by fluegas recycling and firing rate
- Additional balancing of temperature levels by fluidized bed solid mixing in CFB
- FW CFB/INTREX and PC heat surface options available for higher energy absorption
Oxy-Fuel Retrofit Study
460 MWe Coal-Fired SC OTU CFB Boiler

Air-fired CFB reference plant:
- Coal-fired FW SC OTU CFB boiler being constructed in Poland, 460 MW_{e, gross}, 439 MW_{e, net}, \eta_{e, net} > 43%

Conversion to oxy-fuel firing studied with different design tools
- Aspen Plus® for process system integration
- FW boiler performance design and calculation programs for mass and energy balances, size and heat surfaces etc
Oxy-CFB Boiler Retrofit Study Layout
Penalty from Oxy-Fuel

Air separation and CO₂ compression require massive amounts of energy...

...resulting in 7-11 %-points lower efficiency, and 25% power derating → More new power plants req’d

- Original electricity output 42.7%
- Fuel input 100%
- Cooling 53.5%
- CO₂ compression 3.5%
- Air separation – 6.8%
- Auxiliaries – 2.2%

Output – 34%

Efficiency (net), %

Reference plant

O₂/CO₂ plant

Source: Chalmers / Andersson
Maximize component efficiency
- Advanced ST
- Advanced ASU configuration: 3-columns (wait for breakthrough technology)
- Advanced CPU configuration and with use of liquid CO2 pump if applicable

Maximize CO2 capture
- Enhance CO2 recovery by reducing inert gases
- Integration with vent gas recycling and purification

Increase power generation
- Fire-more to get more power (due to increased HTC and LMTD)
- Reduce aux power, and with use of more efficient steam driven compressors

Heat integration
- Recover and integrate low-grade heat for power and efficiency
- Dual-firing boiler for better availability
Process Model
for challenges of integration and optimization

Parameters Studied:

• Dual-firing boiler
• Fire-more concept
• Hot/cold (w/d) recycle
• O₂ purity (95 or 99.4%v)
• Air ingress (0 or 3%)
• Heat recovery priority (gases or boiler water)
• CO₂ purification on/off
• Compressors driven by extracted steam
Dual (Air/Oxy)-Firing Boiler

Dual-firing for both peak power and CO2 removal

- Air-Firing Mode: max power output for peak power in summer, daytime and weekdays
- Oxy-Firing Mode: low power demand in winter, weekends and overnight
- Potential for Oxy-ready boiler to be supplied before CO2 capture required

Dual-firing for better availability

- Power plant can fired in air-mode with 100% load in case of ASU, CPU, or pipeline trips
Dual-Firing PC 3D Modeling

Optimized amount of gas recycling and firing rate

Air-Fired | O2-Fired
---|---
Heat Flux (Btu/hr-ft²)

Heat Flux (Btu/hr-ft²)

Air-Fired | O2-Fired
---|---
Wall Temp. (F)
At the same gas velocity and temperature, the furnace heat transfer coefficient increases in oxy-fuel mode due to flue gas physical properties.

Firing-more to release more heat generates more steam using the same boiler, as a result of enhanced heat transfer coefficient, without increase of furnace temperature.

Fire-more to maintain furnace gas velocity and heat flux.

Extract extra steam from steam turbine to drive CO2 compressors to reduce auxiliary power load.
Firing - More Benefits

Reduces auxiliary power, increase net power
- Net power reduction: 25% to 10%
- Specific power penalty reduction: 333 to 126 kWh/tCO2

Allows operation in both air-mode and oxy-mode

Increases CO2 removal
- CO2 removal: 75 to 106 kg/s

Reduces cost per kW and COE
- Small increase in CAPEX and OPEX of ASU, CCU, Cooling, and solids handling
- Same boiler and auxiliaries
ASU Opportunities & Challenges

- Reduce ASU power by 10%
- Lower ASU capital by 20%
- Heat integration
- Optimum $O_2$ purity
- Match power plant operation
ASU Power Reduction

Increase thermal integration in distillation system
- Reduces air compression requirements

Reduce $\Delta P$s
- Compressor intercoolers
- Prepurifier
- Distillation columns

Reduce $\Delta T$s
- Primary heat exchanger for air cooling
- Cryogenic reboiler-condensers
Advancing Distillation Process

Double Column Cycle

- LP COLUMN
- N₂
- O₂
- Air

Side Column Cycle

- HP COLUMN
- N₂
- HP COLUMN
- Air

“Oxycoal Cycle”

- N₂
- O₂

10 - 12%
Less kW

7 - 10%
Less kW
CO₂ Processing Unit (CPU) Opportunities & Challenges

Meet emissions & CO₂ purity regulations

Integration of compression and purification

Impact of air ingress

Condensate treatment and disposal
Compression account for a majority of costs

- CO$_2$ purity specification will dictate compression
- Cold box process optimization to minimize parasitic power
CO₂ Purification in Cold Box

Min. 95% CO₂
One or two stage flash

99.9% CO₂
Distillation column needed
When major cuts of CO$_2$ emissions are required, CCS by oxy-fuel combustion appears technically feasible and cost competitive.

PC and CFB technologies provide flexibility for the design and operation under oxy-combustion conditions.

Experiments carried out so far have indicated good performance. More tests (emissions, heat transfer, materials, fouling...) are needed for further development and validation of design tools & solutions.

Technology demonstrations in fairly large scale and of extended periods are a necessary step when proceeding toward fully commercial size plants.