THE ROLE OF CFB IN CO-COMBUSTION

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CONTENT

• A general survey of co-combustion

• Judgement on advantages and disadvantages of co-combustion in general, including CFB

• The role of CFB
Co-combustion or co-firing is to burn or to convert two or more fuels together in one boiler system.
PURPOSE OF CO-COMBUSTION

• Spontaneous—many applications in FBC depending on available fuels and prices

• Substitution of fossil fuels ---utilization of biomass and waste for CO$_2$ reduction

• Waste reduction with energy utilization
REDUCTION OF CO2 EMISSION BY INCREASED EFFICIENCY AND CO-COMBUSTION

![Graph showing CO2 emissions vs. net efficiency for different biomass percentages.]

- 100% coal
- 10% biomass
- 20% biomass
- Average Europe
- Reference plant
- Thermie SR
- Thermie Ultimo

% biomass on LHV

Net efficiency (lHV, %)

CO2 emission (g/kWh)
FOUR SITUATIONS:

1. A small fraction of fuel (biomass or waste) is burned together with the base fuel (coal) in a utility boiler.

2. A small amount of high-value fuel (coal) is added to support combustion of a low-value fuel (waste).

3. Any fuel proportions are mixed in a furnace for industrial or district heating.

4. Gas from the additional fuel is produced in a gas generator to partially replace gas, pulverized coal in one or several burners in a boiler.
FIVE TECHNIQUES OF CO-COMBUSTION:

a) Together with the base fuel (PC and FBC)
b) Additional bed to a PC furnace
c) Additional combustor connected on the steam side
d) Additional combustor connected on the gas side
e) Additional fuel for reburning or afterburning
a) TOGETHER WITH THE BASE FUEL (PC AND FBC)
Example: The power plant in Heilbronn, Germany, coal/municipal sewage sludge, 760 MWₑ, max 4%)
Variations of a) for co-firing in PC and FBC boilers
Alholmen, Finland
(Manufacturer: Kvaerner Pulping OY)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine</td>
<td></td>
</tr>
<tr>
<td>Live steam</td>
<td>194 kg/s, 162 bar, 545°C</td>
</tr>
<tr>
<td>Reheat</td>
<td>177 kg/s, 37 bar, 545°C</td>
</tr>
<tr>
<td>Power</td>
<td>240 MWₑ</td>
</tr>
<tr>
<td>Capacity to produce process steam</td>
<td>100 MWₜₜ</td>
</tr>
<tr>
<td>District heating capacity</td>
<td>60 MWₜₜ</td>
</tr>
</tbody>
</table>

### Annual fuel consumption

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Source</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood based fuels</td>
<td>Pulp and paper mill</td>
<td>30-35%</td>
</tr>
<tr>
<td>Sawing and forest residues</td>
<td>Sawmills within short distance, forestry sector</td>
<td>5-15%</td>
</tr>
<tr>
<td>Peat</td>
<td>Production sites close to the plant</td>
<td>45-55%</td>
</tr>
<tr>
<td>Coal or oil</td>
<td>Imported fuel, mostly for start-up or support fuel</td>
<td>10%</td>
</tr>
</tbody>
</table>
b) ADDITIONAL BED TO A PC/GAS/OIL-FURNACE
St Andrä, Austria (124 MW\textsubscript{e}, 2\times5\text{MW\textsubscript{th}}=22m^2 )
b) FB/Pulverised fuel boiler at Kaipola paper mill

Not circulating bed!

Boiler output: 104 MW
Supplyer: Kvaerner (Metso)
Fuels: Sludge, bark, peat and coal (max 50%)
c) PARALLEL BOILER FOR GAS/STRAW-WOOD
AVEDÖRE, DENMARK

Figure 29. Avedore facility schematic\textsuperscript{101}
c) PARALLEL BOILER, AVEDÖRE, DENMARK
d) ADDITIONAL COMBUSTOR CONNECTED ON GAS SIDE, Kymijärvi power station, Finland (300 MWth coal, 50MWth additional gas)
e) REBURNING (Reduction of NO emission)
THE CONSEQUENCES OF CO-COMBUSTION DEPEND ON FUEL PROPERTIES

1. Energy content (moisture) and volatiles. Heat balance of a furnace. Combustion conditions

2. Precursors to gaseous emissions (N, S, Cl). Emissions, including dioxin

3. Ash-forming elements (K, Na, Ca, Mg, Al, Si, P). Deposits on tubes and corrosion

4. Trace elements (As, B, Cd, Hg, Pb, Se, ....). Emission of volatile compounds, deposition of ashes
1. THE HEAT BALANCE OF AN FB
## 2-4. COMPOSITION OF FUELS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coals</th>
<th>Biofuels</th>
<th>Wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur</td>
<td>Medium to high</td>
<td>Low</td>
<td>Low to medium</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Medium</td>
<td>Low to medium</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Potassium</td>
<td>Medium (bound)</td>
<td>Medium to high</td>
<td>Low</td>
</tr>
<tr>
<td>Other alkali</td>
<td>Normal</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Alumina, silica</td>
<td>High</td>
<td>Low to high</td>
<td>High</td>
</tr>
</tbody>
</table>
Synergy effects

Fuel property

S  SO$_2$ emissions
Ca  NH$_3$, NO, N$_2$O emissions
N  dioxins + furans
Cl  deposits and corrosion of the super heater
Cu  agglomeration of bed material
Na+K  fate of trace elements
Zn  Si  Trace elements
Options

A judicious choice of fuel combinations may have advantages:

- Dioxin formation may be avoided
- Sintering and deposits may be avoided
- Emissions can be affected
2. CONDITIONS FOR FORMATION OF DIOXIN/FURAN FROM COMBUSTION

- Presence of chlorine
- Inadequate combustion conditions
- Insufficient residence time above 800 °C
- Presence of catalyst surfaces at 250-450 °C
SYNERGY EFFECTS INVOLVING COAL

The dioxin emission from coal-fired boilers is surprisingly small. Griffin (1986) therefore suggested

\[ \text{Cl}_2 + \text{SO}_2 + \text{H}_2\text{O} \leftrightarrow 2\text{HCl} + \text{SO}_3 \]  \hspace{1cm} (2)

removing chlorine from formation of dioxins and furans

- Will reaction (2) prevent formation of precursors?
- Will the catalysts, for instance copper, be sulfated and thereby their activity will be reduced?
SO2 → CATALYST → 2HCl + ½O2 ↔ Cl2 + H2O → Cl2 → CATALYST → CHLORINATION → CHLORINATED AROMATICS → PCDD & PCDF → CARBON PRECURSORS
CONCLUSION ON THE EFFECT OF S ON DIOXINS

The results from several large-scale tests claim that sulphur has a beneficial effect on the reduction of dioxins, but the documentation of the tests is not convincing.
2,3. DEPOSITS & CORROSION

Influencing factors:

• Tube surface temperature, material and location

• Gas temperature

• Fuel composition, especially ash and S/Cl ratio

• Combustion conditions, total and local oxygen availability
Ash behaviour

Equilibrium calculations give an idea of the behaviour of some ash components (potassium in straw in this example) (From Nielsen et al., 2000)
RELATION BETWEEN SULPHUR AND CHLORINE

• It is often proposed that an alkali chlorid MCl reacts with sulphur to form sulphate

\[ 2\text{MCl} + \text{SO}_2 + \frac{1}{2}\text{O}_2 + \text{H}_2\text{O} = \text{M}_2\text{SO}_4 + 2\text{HCl} \]

• At higher temperatures alkali may be bound in aluminosilicates
CHLORINE IN DEPOSITS AS A FUNCTION OF SULPHUR ADDITION

\((O_2 3\%, \text{ gas } 1000 \degree\text{C}, \text{ probe } 540 \degree\text{C}. \text{ Robinson et al., 2002})\)
KRAUSE’S CO-COMBUSTION RESULTS (1986)  
(Waste combustion)
OBSERVATIONS OF KRAUSE et al. (1975-...):

- Conversion of chlorides to sulphates by SO$_2$ in waste incinerators reduces serious corrosion.

- The impact of chlorine on corrosion can be reduced by increasing available sulfur S/Cl > 4.

- Sulfur can be added directly or by co-combustion with coal.
INFLUENCE OF CHLORINE AND SLUDGE ON DEPOSITS FROM WOOD

(Åmand et al. 2007)
2. Precursors to gaseous emissions in fluidized bed (N,S,Cl)
SULPHUR EMISSION (CFB)

- Chalmers-92
- Load: 8 MW
- Tb: 850 C
- m: 1.25

- Fir chips/coal
- Saw dust/coal

Energy fraction, %

Sulphur dioxide ppm (6%O₂)
CARBON MONOXIDE EMISSION (CFB)

- Chalmers-92
- Load: 8 MW
- Tb: 850°C
- m: 1.25

Graph showing carbon monoxide ppm versus energy fraction. The graph includes data points for fir chips/coal and saw dust/coal. The energy fraction ranges from 0 to 100%.
NITROUS OXIDE EMISSION (CFB)

Chalmers-92
Load: 8 MW
Tb: 850 °C
m: 1.25

- Fir chips/coal
- Saw dust/coal

Energy fraction, %

Nitrous oxide ppm (6% O₂)
NITRIC OXIDE EMISSION (CFB)

- Chalmers-92
- Load: 8 MW
- Tb: 850 °C
- m: 1.25

Graph showing nitric oxide ppm (6% O₂) as a function of energy fraction. The graph compares fir chips/coal and saw dust/coal with data points and a curve. The x-axis represents energy fraction (%), with 0% for coal and 100% for wood.
CONCLUSIONS ON SYNERGY EFFECTS

• Emissions of $\text{SO}_2$, $\text{NO}_x$, and $\text{CO}$ are only moderately influenced by synergy

• Sulphur may have a decisive influence on dioxin emission

• Sulphur, chlorine, potassium and Al-Si influence deposits on tubes

• Etc—there are several other synergy effects that also need to be further investigated
ADVANTAGES OF CO-COMBUSTION

• It is the cheapest method available for CO$_2$ reduction from energy conversion of fuels

• It is cheaper than monocombustion of biofuels

• Wastes can be utilized

• Biofuels and wastes can be converted at a high efficiency and with efficient flue gas cleaning

• There may be positive synergy effects

• Seasonal variations in the supply of additional fuels can be handled, and the impact of quality variations can be mitigated
DISADVANTAGES OF CO-COMBUSTION

• The additional fuel ash can make secondary utilization of ashes less favourable.

• Biofuels can be more expensive than coal

• There may be negative synergy effects

• Lack of experience, particularly in case of extreme steam data

• Inactivation of SCR catalysts could occur
CO-COMBUSTION PROPERTIES OF CFB

+ Independent of the fuel mix as long as the thermal balance of the furnace is fulfilled

+ No problems with grinding and preparation of the fuel, but fuel transportation systems of the plant must be adapted.

+ CFB is a chemical reactor where synergy effects can be exploited

+ Most mentioned advantages and disadvantages are valid for CFB

- CFB is not yet developed in large utility scale