Experiences from Commissioning and Test Operation of Vattenfall’s Oxyfuel Pilot Plant

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1. Introduction
2. Technical Concept of Oxyfuel Pilot Plant
3. Oxyfuel experiences from test operation
4. Outlook and summary
Decision process for the Oxyfuel Pilot Plant

2002
GAP Analysis
- Start of project
- Available components
- Known process steps
- Degree of development

2003
Technology Benchmark
- Evaluation of different steps of development
- Decision to develop Oxyfuel

2004
Feasibility Study
- Financial frame
- Comparing scales
- Possible sites
- Risks

2005
Decision for Oxyfuel Pilot Plant
- Building site: Lausitz area
- Scale: 30 MWth
- Complete process chain from ASU to CO₂ processing
Design considerations for Oxyfuel Pilot Plant

- Basic purpose is to provide operating information to be able to later scale-up the technology to a 400-600 MW demonstration power plant.

- Realization a complete process of coal input and oxygen production up to separation of CO₂.

- Possible to operate on full load in air-firing mode and oxyfuel mode.

- Designed to be able to operate on lignite and in a second phase on bituminous coal.
Location of the Oxyfuel Pilot Plant

Power plant “Schwarze Pumpe”

Building site
Time schedule and milestones

- July `05 project start
- 23.11.06 notice of approval
- March `08 end of construction
- 05.06.08 first fire (ignition burner)
- 26.06.08 first coal fire (main burner)
- 20.08.08 first Oxyfuel operation
- 03.09.08 first separation of CO₂
- 09.09.08 official inauguration

Planning
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011

Approval process
- 2006

Construction phase
- 2007

Commissioning
- 2008

Operation
View on the Oxyfuel Pilot Plant

- **Thermal capacity:** 30 MW<sub>th</sub>
- **Coal demand:** 5.2 t/h
- **Oxygen demand:** 10 t/h
- **CO<sub>2</sub> (liqu.) production:** 9 t/h
- **CO<sub>2</sub> Capture rate:** > 90%

Webcam: www.Vattenfall.de/CCS
Main Contractors

General planer

VATTENFALL

ALSTOM
Boiler / ESP
Oxyfuel technology

Linde
ASU / CO₂ plant
CO₂-process technology

FGD

SIEMENS
I&C system

TREMA®
FGC

HITACHI
Burner,
Combustion technology

2009-09-08 | IEA Oxyfuel Conference, U.Burchhardt (VE-G)
Main operating results (until August 2009)

- Summation Operating hours : 3.100 h
- Operating hours air mode : 1.500 h
- Operating hours Oxyfuel : 1.600 h
- Captured amount of CO₂ : 1.400 t
2. Technical Concept of Oxyfuel Pilot Plant
System overview of Oxyfuel Pilot Plant

- **Pulverised Coal**
- **Cold Recirculation**
- **Sealgas <1.2 bar**
- **Sealgas 6 bar**
- **Steam-HEx**
- **Air**
- **ASU**
- **Oxygen**
- **Nitrogen**
- **Fan 1**
- **Fan 2**
- **FGD**
- **FG-Condenser**
- **CO₂-Process**
- **Dry Ash**
- **ESP**
- **2. Pass**
- **DeNOx**
- **3. Pass**
- **Steam-HEx**
- **Hot Recirculation**
Specific plant features

Sep. start burner on gas basis (propane)

Coal-Input with dry and CO2 rich

Seal gas systems to reduction of air inleakage

30 MW burner performance good Scale-up possibility

Flue gas cooler test inlet temperature in FGD

O2-Mix with static mixers

Sulfur rich recirculation Assessment SO2-/SO3 enrichment in boiler and recirculation necessary
3. Oxyfuel experiences from test operation
Experiences with boiler

- Proven start burners (propane) having problems in Oxyfuel atmosphere due to high dust loads (Flame guards and installation situation had to be optimized)
- Authority demand: Individual burner examinations for all operating states
- Good flame stability in Oxidant at $O_2 > 21\% (w)$
- 25 -30 % humidity in hot recirculation
- Supplying of pure $O_2$ and mixture in the burner possible
- Use of a single burner influences the burning behavior and the flue gas composition
- Different burner swirls necessary for air and oxyfuel operation
Change load Air to Oxyfuel in 20 minutes
## Requirements on flue gas scrubbing

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition</th>
<th>Reduction from*</th>
<th>to*</th>
<th>Capture rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP</td>
<td>Ash</td>
<td>11.200 mg/m³</td>
<td>&lt; 20 mg/m³</td>
<td>&gt; 99 %</td>
</tr>
<tr>
<td></td>
<td>SO₂</td>
<td>11.500 mg/m³</td>
<td>&lt; 100 mg/m³</td>
<td>&gt; 99 %</td>
</tr>
<tr>
<td>FGD</td>
<td>SO₃</td>
<td>50 mg/m³</td>
<td>&lt; 20 mg/m³</td>
<td>&gt; 50 %</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td>20 mg/m³</td>
<td>&lt; 10 mg/m³</td>
<td>&gt; 50 %</td>
</tr>
<tr>
<td>FG-Condenser</td>
<td>H₂O</td>
<td>30 vol-%</td>
<td>4 vol-%</td>
<td>&gt; 85 %</td>
</tr>
<tr>
<td></td>
<td>SO₂</td>
<td>100 mg/m³</td>
<td>&lt; 20 mg/m³</td>
<td>&gt; 80 %</td>
</tr>
<tr>
<td></td>
<td>SO₃</td>
<td>20 mg/m³</td>
<td>&lt; 5 mg/m³</td>
<td>&gt; 75 %</td>
</tr>
<tr>
<td></td>
<td>Ash</td>
<td>10 mg/m³</td>
<td>&lt; 1 mg/m³</td>
<td>&gt; 90 %</td>
</tr>
</tbody>
</table>

All design data are fulfilled!

* all mg/m³ in Norm (dry)
CO₂ - Process  (Cleaning, compression, drying, liquefaction)

FG- Input
CO₂ ~ 85 %
O₂ ~ 5 %
N₂+Ar ~ 5 %
H₂O ~ 4 %
CO < 600 mg/m³
NOₓ < 750 mg/m³
SOₓ < 20 mg/m³

Use Ventgases for regeneration of Adsorber

Ventgas
CO₂ ~ 35-40 %
O₂ ~ 30-35 %
CO ~ 500 mg/m³
SO₂ ~ 10 mg/m³
NO ~ 10 mg/m³

CO₂ - Output
CO₂ > 99.7 %
17 bar, -25°C

> 90 % CO₂-recovery

CO₂-recovery

Coolant circulation
(Ammonia/CO₂)

FGC
Pre-Compressor
Activated carbon filter
Main-Compressor
Adsorber

0.3 bar
21.5 bar
19.0 bar

H₂O
H₂O
H₂O

SO₂, SO₃, HCl, Heavy metals (Hg, Cd, ….)
H₂O
H₂O

1 ppm H₂O

2-stage

All %-details in Vol.-%
## Attainable CO₂ purities

<table>
<thead>
<tr>
<th>Composition CO₂, liquid</th>
<th>Oxyfuel pilot plant (Technical CO₂)</th>
<th>Comparison to Food quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>&gt; 99.7 %</td>
<td>&gt; 99.99 %</td>
</tr>
<tr>
<td>N₂+Ar+ O₂</td>
<td>&lt; 0.3 %</td>
<td>&lt; 30 ppm</td>
</tr>
<tr>
<td>H₂O</td>
<td>&lt; 50 ppm</td>
<td>&lt; 50 ppm</td>
</tr>
<tr>
<td>SO₂</td>
<td>&lt; 2.5 ppm</td>
<td>&lt; 1 ppm</td>
</tr>
<tr>
<td>SO₃</td>
<td>&lt; 0.5 ppm</td>
<td>-</td>
</tr>
<tr>
<td>CO</td>
<td>&lt; 10 ppm</td>
<td>&lt; 10 ppm</td>
</tr>
<tr>
<td>NO</td>
<td>&lt; 5 ppm</td>
<td>&lt; 2.5 ppm</td>
</tr>
<tr>
<td>NO₂</td>
<td>&lt; 15 ppm</td>
<td>&lt; 2.5 ppm</td>
</tr>
</tbody>
</table>
4. Outlook and summary
Outlook on test program

- Variation of coal quality (moisture, sulphur content, particle size).
- Test of different burners with integrated ignition burner.
- Special measurement technique for flue gas composition and CO₂ monitoring.
- Material tests for demo plants and 700°C technology under Oxyfuel atmosphere.
- Tests of co-firing biomass and bituminous coal.
- DeNOₓ tests at the boiler and for the vent gas stream from the CO₂ plant.
- Test of an “alternative CO₂-Process”
Integration CO₂-plant Air Products (AP) in the Oxyfuel Pilot Plant (OxPP)

OxPP

Gips  Kreide

FGD

Pre-Compressor  Activated carbon filter  Main-Compressor  Adsorber

SO₂, SO₃, HCl, Heavy metals  H₂O  H₂O  H₂O

19 bar

1 ppm H₂O

Ventgas

3 % of FG

FGD

Cooler

FGC

Condensate

2-stage SOx/NOx separation

AP

15 bar

30 bar

H₂SO₄

H₂SO₄+HNO₃

Rest gasses

Condensate

Condensate

CO₂

57 bar

gas. CO₂

Ventgas

CO₂-Recycle Membrane
Area and layout of the „Alternative CO2-Process“
Roadmap for CCS

Testrigs: 0.1 – 0.5 MW<sub>th</sub>

Pilot plant: 30 MW<sub>th</sub>

Demonstration plant: 300 – 700 MW<sub>th</sub>

Commer. plant: ~ 1000 MW

2001
- theoretic Investigations

2004
- Research
- Basic principles
- Combustion characteristics

2008
- Demonstration of the complete process chain
- Interaction of components
- Validation of test rig results
- Investigation of scale up criteria

2014 – 2015
- Verification und Optimisation of components
- Reduction of risks
- Verification of commercial availability (subsidiaries necessary)

2020
- Economic and competitive power plant concept
- No need for subsidiaries
Layout of Vattenfall’s next generation power unit

CCS Demo Project Jänschwalde

- Oxyfuel boiler
- Amin scrubbing
- CO₂ plant
- ASU
- Coal drying
Summary

• Oxyfuel works in pilot scale, emission limits are kept, CO₂ quality reached
• Successful integration of plant components from chemical industry (ASU, CO₂ plant)
• Gained experiences from permission process and implementation of secondary clauses for CCS power plants
• CO₂ monitoring over the whole technology chain (capture – transport – storage) developed for the first time world wide
• First steps towards full scale CCS plants is successfully done
• Very important for the investment of the demo plant is the consent to the public funding.
Thank you for your attention!
## Available fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Pulverized lignite</th>
<th>Dryed lignite</th>
<th>Black coal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lay-out</td>
<td>Range</td>
<td>Lay-out</td>
</tr>
<tr>
<td>Granulation Spread</td>
<td>0 – 1 mm</td>
<td>60%&lt; 0,1 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td></td>
<td>13%&gt; 0,2 mm</td>
<td>3-18% &gt;0,2mm</td>
<td>&lt;5%&gt;2 mm</td>
</tr>
<tr>
<td>LHV</td>
<td>21,0 MJ/kg</td>
<td>20,4-22,5 MJ/kg</td>
<td>20,0 MJ/kg</td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>10,5 Mass%</td>
<td>8-12 M%</td>
<td>15 Mass%</td>
</tr>
<tr>
<td>Ash</td>
<td>6,0 Mass%</td>
<td>4,5-7,5 M%</td>
<td>5,7 Mass%</td>
</tr>
<tr>
<td>Carbon</td>
<td>56,5 Mass%</td>
<td>54-60 M%</td>
<td>54 Mass%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>21,5 Mass%</td>
<td>20-22 M%</td>
<td>20,5 Mass%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4,0 Mass%</td>
<td>3.5-4,5 M%</td>
<td>3,8 Mass%</td>
</tr>
<tr>
<td>Sulfur</td>
<td>&lt; 0,8 Mass%</td>
<td>0,4-1,2 M%</td>
<td>1,0 Mass%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0,7 Mass%</td>
<td>0,6-1,1 M%</td>
<td>0,7 Mass%</td>
</tr>
<tr>
<td>Chlorides</td>
<td>80-260 mg/kg</td>
<td>15-70 mg/kg</td>
<td></td>
</tr>
<tr>
<td>Fluorides</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CO₂- plant in detail

- Rectification
- Compressor building
- Activated carbon filter
- Analysis container
- CO₂-tanks (2x180 m³)
- Trailer docking station