V94.2 Buggenum Experience and Improved Concepts for Syngas Applications

F. Hannemann, U. Schiffers, J. Karg, Siemens AG Power Generation
M. Kanaar, Nuon
Content

- Buggenum Plant Concept and Performance Data
- Gas Turbine and Interconnected Syngas Fuel System
- Plant Availability and Measures for Improvement
- V94.2 Syngas Features
- Lessons Learned and New Standardised Concept
- New Developments/ Future Plants
| **Location:** | Buggenum / Netherlands |
| **Feedstock:** | Import Coal |
| **Secondary Fuel:** | Natural Gas |
| **Gasifier:** | Shell |
| **Air Separation Unit:** | Air Products |
| **Gas Cleaning:** | Schumacher Candle; Sulfinol Desulfurization, Claus |
| **Combined Cycle:** | Siemens Single Shaft Configuration |
| **Gas Turbine:** | Siemens V94.2 |
| **Steam Turbine:** | Siemens KN |
| **Generator:** | Siemens (THLR, Hydrogen Cooled) |
| **I&C for IGCC:** | Hartmann & Braun |
| **IGCC Configuration:** | Fully Integrated |
| **Net Plant Capacity:** | 253 MW |
| **Net Efficiency:** | 43 % |
| **Start-up Date:** | With Natural Gas 1993 |
| | With Syngas 1994/95 |
| **Operating Hours:** | 42,500 h (09/2002) |
| | 33,700 h (09/2002) |
| **Syngas Operation:** | Commercial Operation |

**Plant Integration**

- Fully Integrated Concept on the Air and Nitrogen Side
- W/S integration between Gasifier with Syngas Cooler and Combined Cycle
## Performance Data

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design coal</td>
<td>-</td>
</tr>
<tr>
<td>Cold gas efficiency</td>
<td>%</td>
</tr>
<tr>
<td>Composition upstream GT (wet syngas)</td>
<td></td>
</tr>
<tr>
<td>H₂</td>
<td>%vol.</td>
</tr>
<tr>
<td>CO</td>
<td>%vol.</td>
</tr>
<tr>
<td>CO₂</td>
<td>%vol.</td>
</tr>
<tr>
<td>N₂</td>
<td>%vol.</td>
</tr>
<tr>
<td>CH₄</td>
<td>%vol.</td>
</tr>
<tr>
<td>Ar</td>
<td>%vol.</td>
</tr>
<tr>
<td>H₂O</td>
<td>%vol.</td>
</tr>
<tr>
<td>O₂</td>
<td>%vol.</td>
</tr>
<tr>
<td>H₂/CO ratio</td>
<td>-</td>
</tr>
<tr>
<td>Lower heating value (LHV)</td>
<td></td>
</tr>
<tr>
<td>BTU/scf</td>
<td></td>
</tr>
<tr>
<td>kJ/kg</td>
<td></td>
</tr>
<tr>
<td>Ambient pressure</td>
<td>bar/psia</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>°C/°F</td>
</tr>
<tr>
<td>Elevation above sea level</td>
<td>m/ft</td>
</tr>
<tr>
<td>Condenser pressure</td>
<td>bar/psia</td>
</tr>
<tr>
<td>GT output</td>
<td>MW</td>
</tr>
<tr>
<td>ST output</td>
<td>MW</td>
</tr>
<tr>
<td>Gross Power Output</td>
<td>MW</td>
</tr>
<tr>
<td>Auxilliary power</td>
<td>MW</td>
</tr>
<tr>
<td>Net power output</td>
<td>MW</td>
</tr>
<tr>
<td>Net efficiency (LHV)</td>
<td>%</td>
</tr>
</tbody>
</table>
Process Flow Diagram of Buggenum IGCC Plant
Main Features of V94.2 Gas Turbine

Siemens Hybrid Burner

- Natural gas (diffusion)
- Air

Siemens Syngas Burner

- Fuel oil (diffusion)
- Natural gas + steam (diffusion)
- Syngas
- Air

Diffusion Burner with Swirl Perturbators
Gas Turbine Syngas Supply and Conditioning System of Buggenum IGCC Plant

Scope and Task:

- Extracted Air Heat Flow Recovering/ Low Temperature Utilisation for Saturation
- Syngas Conditioning with Preheating and Dilution for NO\(_x\) Control (Saturation, DGAN and Steam supply)
- Heating Value, Flow and Pressure Control on the Coal Gas and Air Extraction Side

Saturator and Heat Exchanger
Operating Hours per Year and per Fuel

**Forecast**

Coal gas operating hours

Natural and Coal gas oper. hours (accumulated)

**Accumulated Syngas hours in total: 33700**

**Availability jan. – aug. 2002 (% time)**

<table>
<thead>
<tr>
<th></th>
<th>Syngas operation</th>
<th>syngas and natural gas operation (cum.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>86.1</td>
<td>96.4</td>
</tr>
<tr>
<td>Foreseen unavailability</td>
<td>8.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Unforeseen unavailability</td>
<td>5.6</td>
<td>0.3</td>
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</tbody>
</table>

**Significant Improvement 2002**
Important Overall Plant Improvements (Hardware)

**Gas Turbine:**
- Modified gas turbine burners (swirl Perturbators added)

**ASU:**
- Better structure and better material of mol sieves (CO2 breakthrough at elevated temperatures)

**Gasifier and Gas Cleaning:**
- Modified construction of hot gas filter
- Modified design of slag bath heat skirt
- Conceptual Change for Slag Fine Separation
- Increased valve diameters for the slag sluicing system
- Modified pulverised coal transport system
- Modified Construction of Syngas Cooler to prevent leakage problems
Disadvantage of Fully Integrated Concept:

- Extensively Start up time due to Sequential Start Sequence
- High Probability of Overall Plant Trip when one Island fails
- Limited Load Gradients

Measures to Compensate Disadvantages and to Improve Plant Availability

- Oxygen and Nitrogen Buffer (corresponds to 6h Gasifier operation) to maintain Gasifier Operation in case of Gas Turbine or ASU Trip
  
  ➡️ Shortening of potential Coal Gas Break

- Third Coal Mill Train

- Heating Value Control and Capability of DGAN Replacement by steam and vice versa
  
  ➡️ Continues Coal Gas Operation when DGAN trips
  
  ➡️ Shortening of Start up Time

- Natural Gas Injection
  
  ➡️ Increase of Load Gradients and Improve Operational Flexibility
Reduced Start up Time for Coal Gas Operation

- ASU Start up with DGAN compressor independently of GT operation
- ASU operation with air extraction from Gas Turbine when appr. 150MW are achieved
- GT switch over with steam as diluent
- Drying of DGAN compressor
- Diluent change from steam to DGAN and load increase to base load

Air Inlet for DGAN Compressor
Special Control Features of GT with Interconnected Syngas Fuel System

Control Features

- GT Air Pressure Control Function to support ASU Operation
- Change from steam to DGAN
- Syngas pressure control
Increasing Load Change Capability by Natural Gas Injection

Improving Load Gradients  →  Peak Shaving Operation

Natural Gas Injection in the Range from 0 to 1.6 kg/s
Increase of Load Gradient from 1.5 to 3.5 MW/min

30 MW increase
Overall Control Strategy of Buggenum IGCC Plant

Gasifier

Gas Cleaning

Saturator

Load Dispatcher

Select

Secondary Plant Setpoint

Gas Turbine

Primary Plant Setpoint

Oxygen

Waste Nitrogen

IP Steam

Extracted Air

ASU

LHV

Natural Gas

PC

FC

TC

LC

G

M

Load Dispatcher

Select

Secondary Plant Setpoint

Gas Turbine

Primary Plant Setpoint

Oxygen

Waste Nitrogen

IP Steam

Extracted Air

ASU

LHV

Natural Gas

PC

FC

TC

LC

G

M
Robust Syngas Operation over a wide operational Range has been proven in Buggenum

Advantages:

- Low syngas burner pressure drop
- Capability of full air extraction
- Single Digit NO\textsubscript{x} Values (< 9ppm)
- Major Inspection after 33000 equivalent operating hours (EOH)
- Minimum auxiliary power Consumption
- No additional Air Compressor
- Meets Future Emission Levels
- Profitable due to reduced Maintenance cost and High Availability
NOx Emission of V94.2 in Syngas Mode

Power Output [MWe]

NOx [ppm] dry 15% O2

2002

GTC 2002

28.10.2002 PG CTET-HAN
### Syngas Experience with Siemens and Siemens Westinghouse Technology

<table>
<thead>
<tr>
<th>Plant/Project</th>
<th>Electrical Output (net)</th>
<th>Gas Turbine</th>
<th>Main Features</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hörde Steelworks (Germany)</td>
<td>8 MW</td>
<td>VM5</td>
<td>Blast-furnace-gas-fired, gas turbine as mechanical drive</td>
<td>1960</td>
</tr>
<tr>
<td>U. S. Steel Corp. (Chicago, USA)</td>
<td>20 MW</td>
<td>CW201</td>
<td>Blast-furnace-gas-fired gas turbine</td>
<td>1960</td>
</tr>
<tr>
<td>Kellermann (Lünen, Germany)</td>
<td>163 MW</td>
<td>V93</td>
<td>First CC plant in the world with integrated LURGI coal gasification (hard coal)</td>
<td>1972</td>
</tr>
<tr>
<td>Plaquemine (Lousiana, USA)</td>
<td>208 MW 4)</td>
<td>2 x W501D5</td>
<td>CC plant with integrated DOW coal gasification</td>
<td>1987</td>
</tr>
<tr>
<td>Buggenum 1) (Netherlands)</td>
<td>253 MW</td>
<td>V94.2</td>
<td>CC plant with integrated SHELL coal gasification (hard coal)</td>
<td>1993 3)</td>
</tr>
<tr>
<td>Puertollano 1) (Spain)</td>
<td>300 MW</td>
<td>V94.3</td>
<td>CC plant with integrated PRENFO coal gasification (coal and petroleum coke blend)</td>
<td>1996 3)</td>
</tr>
<tr>
<td>ISAB (Priolo, Italy)</td>
<td>521 MW</td>
<td>2 x V94.2K</td>
<td>CC plant with integrated TEXACO heavy-oil gasification (asphalt)</td>
<td>1998 2)</td>
</tr>
<tr>
<td>Servola (Italy)</td>
<td>180 MW</td>
<td>V94.2K</td>
<td>CC plant with steel-making recovery gas</td>
<td>2000</td>
</tr>
</tbody>
</table>
Buggenum Burner design proven in ISAB and Puertollano

**Special ISAB Feature:**

Load Rejection to Idle Operation in Syngas demonstrated and proven

Burner Design capable to burn Syngas with completely different H2/CO ratio without design modification

Design: $\text{H}_2/\text{CO} \text{ ratio } = 0.85$

Operation: $\text{H}_2/\text{CO} \text{ ratio } = 1.06$

**Syngas Operating hours:**

Puertollano $> 13000 \text{ h}$

ISAB $> 30000 \text{ h}$

IGCC Puertollano
# Lessons Learned/ Gas Turbine Syngas Fuel and Conditioning System

<table>
<thead>
<tr>
<th>System</th>
<th>Experience</th>
<th>Consequences (Lessons learned)</th>
</tr>
</thead>
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| Syngas Burner           | • Low pressure loss possible  
                          • Swirl perturbator  
                          • Stable combustion over a wide heating value range | • Increase of overall plant efficiency  
                          • Suppress of flame induced pressure oscillation  
                          • Burner and Combustor design proven |
| Syngas Dilution         | • Redundant dilution systems  
                          • Capability for diluent replacement | • Providing of IP steam system beyond DGAN system/ heating value control  
                          • Location of syngas/nitrogen mixing upstream saturator |
| GT Syngas Fuel System   | • Optimal heat recovery in distinct load cases | • Optimised modular design for simple and reliable operation |
| Flushing system         | • Corrosion of piping/ high temperature gradients | • Nitrogen flushing where IP nitrogen is available |
| GT Controller           | • GT compressor exit pressure control  
                          • Syngas pressure Control  
                          • Switch over capability at distinct load cases | • Compressor exit pressure control features proven  
                          • Additional GT control features depends on selected overall plant concept |
| Unit Control/ Plant Integration | • Manual operation necessary  
                          • Limited load gradients/ operational Flexibility improvable | • higher automated level based on Buggenum and Puertollano experience  
                          • Air-side partially integrated, Natural gas or Fuel Oil Admixing |
Modular Gas Turbine Syngas Fuel System Design

- **Nitrogen Flushing Vessel**
- **IP Steam for H₂ Control**
- **Flare**
- **Block and Bleed**
- **Nitrogen Flushing**
- **IP Steam to ASU**
- **Natural Gas**
- **HRSG**
- **V94.2 Gas Turbine**
- **Inlet Guide Vane**
- **Kettle Boiler**
- **LP Steam**
- **Vent**
- **To W/S System**
- **To ASU**
- **From W/S System**
- **from Saturator**
- **Syngas**
- **Dilution Nitrogen from ASU**
- **Natural Gas from W/S System**
- **Flare**
- **Vent**
- **Vent to Air Cooler**

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Standardised IGCC for Refinery Application
Next Steps for further Economic Improvement

Buggenum

Peak Shaving Operation
Gasifier and ASU not 100%

Feasibility Study to separate Combined Cycle from Gasifier and ASU Operation
Production of Alternative Fuels

Biomass Gasification
(demolition wood, sewage sludge, chicken litter)

Phase 1: 30 wt % co-gasification early 2004
Phase 2: 50 wt % co-gasification 2005

Advanced Gas Turbine Combustor

Joint Effort to develop an Advanced Syngas Burner Design for High Efficient Gas Turbine Application (EC funded Program)
Based on Plaquemine Experience Syngas Combustion Tests were performed (intermediate Pressure)

Results:

- Combustor is extremely stable during syngas operation over a wide range of loads and gas compositions
- NO$_x$ target of 25 ppm at base load can be achieved with steam as a diluent
- Carbon monoxide emissions are low (usually below 5 ppm across all loads)
Conclusion

Buggenum

- Mature Operational Status is reached and the plant operates compatible
- Biomass Gasification gives a high benefit
- Further Economic Improvements are possible

Future Concepts

- Implementation of Lessons learned into future Design Features
- Joint effort from the beginning between client and main suppliers
- As much as possible standardised design to reduce investment and ensure availability