Conceptual Design for an Industrial Prototype
Graz Cycle Power Plant

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History of the Graz Cycle

• 1985: presentation of a power cycle without any emission - H2/O2 internally fired steam cycle

• 1989/91: thermodynamic improvement and combustion chamber design

• Cooperation with Japanese research institutes and companies - name GRAZ CYCLE defined

• 1995: change from H2 to fossil fuels like methane (CH4)

• 2000: presentation of thermodynamically optimized cycle for fuel gases from gasification processes

• 2002: conceptual layout of turbomachinery relevant components of prototype Graz Cycle power plant
Design Goals of Graz Cycle

- High thermal efficiency similar to modern combined cycle power plants
- Avoidance of any emission to atmosphere, retention of CO2
- Only use of progressively developed gas turbine components
- Use of fossil fuels
Cycle Scheme

- **O2**
- **CO2**
- **fuel**
- **steam**
- **HPT**
- **HTT**
- **C3**
- **C2**
- **C1**
- **Deaerator**
- **Feed. P.**
- **HRSG**
- **Cond.**
- **Cond. P.**
- **H2O**
## Balance of Graz Cycle

<table>
<thead>
<tr>
<th>Turbines</th>
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<tbody>
<tr>
<td>Name</td>
<td>HPT</td>
<td>HTT</td>
<td>LPT</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Power [MW]</td>
<td>9.3</td>
<td>91</td>
<td>10.7</td>
<td>111</td>
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</table>

<table>
<thead>
<tr>
<th>Compressors and Pumps</th>
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</thead>
<tbody>
<tr>
<td>Name</td>
<td>C1</td>
<td>C2</td>
<td>C3</td>
<td>Cond.P.</td>
<td>Feed P.</td>
<td>Total</td>
<td></td>
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<tr>
<td>Power [MW]</td>
<td>5.5</td>
<td>4</td>
<td>8.9</td>
<td>0.01</td>
<td>0.4</td>
<td>18.8</td>
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</table>

- Total heat input: 143.3 MW
- Thermal efficiency: \((111-18.8)/143.3 = 63.9\%\)
- Including generator / mechanical losses
  - 0.3 kWh/kg O2 production effort (half considered)
  - O2 compression to combustion pressure

Thermal efficiency: 57.5 %
Advantages of Graz Cycle

- The high efficiency of the cycle follows mainly from the low compression work, the steam part of the cycle medium is generated from the feed water which can be pumped
- The highest cycle pressure only slightly surpasses the maximum pressure used in aircraft engines
- The highest temperature is similar to temperatures of high power stationary gas turbines
- The cycle medium is a variable mixture of CO2 and H2O, thus allowing CO2 retention by condensation
- The heat exchangers incorporated in the cycle have high temperature differences, thus will lead to low cost HE with limited amount of high temperature tube alloy
Combustion Chamber Design

- Stoichiometric combustion of fossil fuel and O2 at 40 bar
- Combustor exit temperature: 1400 °C
- Very low NOx generation (only nitrogen from fuel)
- Annular flame casing with 6 quadruples of burner tubes
- Tangential arrangement provides additional flow path length for better mixture and preswirl for first turbine stage
- Cooling of burner by steam and of liner by CO2
- Steam is fed tangentially into the burner forming a vortex
- Expected vortex breakdown induces strong backflow, thus continuous ignition
High Temperature Turbine HTT

- Pressure drop: 40 bar - 1 bar
- High specific enthalpy drop compared to conventional gas turbines demands high rotational speeds to keep number of stages low
- First stage connected to HP turbine and C3 compressor overhang design
  - 20 000 rpm
  - Generator driven via planetary gear box
- 2nd and 3rd stage overhang design carried by pinion of the main gear box
  - 12 000 rpm
- Steam cooling of blading of 1st and 2nd stage
High Pressure Turbine

- Expansion of steam from 180 to 40 bar
- One radial and two axial stages to reduce shaft length
- Arranged between C3 compressor and HTT first stage
- 20 000 rpm
Low Pressure Turbine

- Conventional design
- Expansion of CO2/H2O mixture to condensation pressure (0.25 bar)
- Connection to C1 compressor
- 3 000 rpm
CO2 compressors C1, C2, C3

- Compression of CO2 from 0.25 bar to 40 bar
- Extraction of CO2 from combustion after C1 compressor
- Due to high volume change of CO2 during compression three different rotational speeds (3 000, 12 000, 20 000) are necessary
- Due to low sonic speed of CO2, C2 and C3 have an inlet tip Mach number of 1.3 - 1.4
Heat Recovery Steam Generator

- Maximum temperature of 640 °C leads to high temperature alloys
- Layout with high temperature differences to reduce costs
- Problems due to CO2 solubility in feed water in the low temperature region can occur (this can lead to corrosion)
Conclusions

• Presentation of the Graz Cycle as “closed gas turbine cycle“ with CO2 retention

• Thermodynamic layout promises efficiencies up to 64 % (57.5 % if expenses of O2 supply are considered)

• Possible arrangement of turbomachines is presented which allows short flow paths in the hot sections

• Two sets of turbomachines
  1st set at 20 000 rpm
  2nd set at 12 000/3 000 rpm

• The work shows the feasibility of building a Graz Cycle power plant which allows full CO2 retention only with the use of turbomachines

• The next step would be the erection of a demonstration plant through an international cooperation