Externally fired micro gas turbine (75kWe) for combined heat and power generation from solid biomass: Concept, efficiency, cost, and experiences from pilot and commercial plants in Italy

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Electricity from solid biomass

**Electrical efficiency from 10kW to 1000kW**

<table>
<thead>
<tr>
<th>ICE with gassification</th>
<th>ICE with alcohol</th>
<th>ICE with vegetal oil</th>
<th>Steam plants</th>
<th>Organic Rankine Cycle</th>
<th>Gas turbines with vegetal oil</th>
<th>Gas turbines with external combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-20%</td>
<td>15-25%</td>
<td>20-30%</td>
<td>8-10%</td>
<td>10-20%</td>
<td>25-33%</td>
<td>14-20%</td>
</tr>
</tbody>
</table>

- **Usual solutions**
  - Steam plants *(above 1MW)*
  - Gas turbines fed by *processed* biomass
  - Organic Rankine Cycles *(low efficiency)*
  - Reciprocating engines fed by *processed* biomass

- **Solution for small size and direct use**
  - Externally Fired Micro Gas Turbine *(EFMGT)*

- Large size of each unit or
- Large size of the processing plant
- Complex biomass handling and storage
- Large collecting area
- Small size
- Direct use of solid biomass
- Use of locally collected biomass
The Micro Gas Turbine

Ideal Brayton cycle

1. Compress.
2. Regen.
3. Comb.
4. Turbine
5. Exhausts
6. Compress.
The Externally Fired Micro Gas Turbine

- Use of an available gas fired industrial microturbine
- Replace of burners with an external heat generator
- Development of a fully automatic system
- Optimisation of the biomass logistics
Two schemes developed and tested

with surface air pre-heater

with mixer-pre-heater
Solutions for easy fuel storage and supply

Fuel according to CEN/TS 14961
Size: P45
Moisture: M40
Ash: A3.0

roll-on containers and automatic screw conveyor downloading system

buried reservoir and screw conveyor
Microturbine

- **Turbec T100**
  - Rated power: 100kW
  - Rated speed 70000 rpm
  - Permanent magnet synchronous with AC-DC-AC converter
  - Rated turbine inlet temperature 950°C
  - Efficiency at rated power and ISO conditions: 30%
  - Modified for external combustion
  - No natural gas needed even for start-up and shut-down
  - Now operates with around 850°C at turbine inlet
  - Turbine ISO efficiency 25-26%
Heat generator

- Rated thermal power: 500kW
- Temperature for turbine supply: 850°C

<table>
<thead>
<tr>
<th>Pollutant (mg/m³)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Italian limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulate</td>
<td>9.5</td>
<td>24.2</td>
<td>117.7</td>
<td>4</td>
<td>-</td>
<td>100</td>
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<tr>
<td>Carbon Oxide (CO)</td>
<td>183</td>
<td>366</td>
<td>132</td>
<td>422</td>
<td>535.2</td>
<td>350</td>
</tr>
<tr>
<td>Nitrogen Dioxide (NO2)</td>
<td>163</td>
<td>65</td>
<td>62</td>
<td>73</td>
<td>207.2</td>
<td>500</td>
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</table>

• at standard conditions and 11% O₂
Control system structure

Power demand

- Turbine controller
- DC voltage reference
- Turbine speed

Heat generator controller
- Fuel demand
- Temp demand

Screw conveyor controller
- Fuel flow

Fan controllers
- Exhaust flow
- Combustion air flow

Power regulator

Turbine speed regulator

Turbine speed

Fuel flow

DC voltage reference

Turbine speed

Heat generator controller

Screw conveyor controller

Fan controllers
Tests and measurements - 1

- Net power to the grid
- Power to auxiliary services
- Turbine speed

- Compressor inlet temp.
- Turbine inlet temp.
- Heat generator exhausts temp.
Tests and measurements - 2

- Wood chip with 38.8% moisture content
- Fuel HHV (referred to dry material): 17680 kJ/kg
- Fuel LHV (referred to dry material): 16880 kJ/kg
- Heat available with 150kg/h:
  - 450kW (HHV dry)
  - 413kW (HHV dry less heat for moisture evaporation)
  - 395kW (LHV as received)
- Heat to process air: 270kW
- Turbine net efficiency: 70kW/270kW = 25.9%

- Theoretical efficiency with 950°C at turbine inlet and ambient at 15°C: 30%
- 950°C -> 850°C means 30% -> 26%; 15°C -> 22°C means 26% -> 25%
- Heat exchanger efficiency: 270kW/395kW = 68%
- Total net efficiency: 70kW/395kW = 17.7% (70/413=17%; 70/450=15.6%)
Tests and measurements - 3

Process air

- Turbine inlet
- Turbine outlet
- Heat exchanger inlet
- Recuperator outlet
- Combustion air
- Heat exchanger outlet
- Heat generator outlet

Turbine power vs inlet temp.

- Theoretical
- Actual

Turbine power

- DC busbar voltage

Turbine speed
## Operating units

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Manuf. residuals</td>
<td>Silos</td>
<td>None</td>
<td>50kW</td>
<td>May '08</td>
<td>2500</td>
</tr>
<tr>
<td>Wood chip</td>
<td>Roll-on container</td>
<td>Warm water for district heating 200kW</td>
<td>75kW</td>
<td>Sept '09</td>
<td>1700</td>
</tr>
<tr>
<td>Wood chip</td>
<td>Buried reservoir</td>
<td>Warm water for district heating and cooling 200kW</td>
<td>75kW</td>
<td>Oct '09</td>
<td>1700</td>
</tr>
<tr>
<td>Manuf. residuals</td>
<td>Silos</td>
<td>Heat and cool</td>
<td>75kW</td>
<td>Apr '10</td>
<td>2000</td>
</tr>
</tbody>
</table>
Next steps

• **Increase of turbine inlet temperature**
  – Technological constraints on heat exchanger material

• **Cooling of compressor inlet**
  – Use of industrial electrical heat pump
  – Use of absorption chiller

• **Improve of electrical efficiency**
  – Reduction of harmonic losses in the generator

• **Optimisation of electrical auxiliary services**
  – Use of high efficiency motors and drives
  – Use of a common DC bus for all auxiliary services

• **Combined Cycle by ORC**
  – Energy in the exhaust used to add 15-20kW of electricity production
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