Load cycle test for biomass boilers

Markus Schwarz, Elisa Carlon

Graz, 19/02/2017
Current standard: EN 303-5

- Standard test method to certify efficiencies and emission factors of biomass boilers
  - Stationary operation: 6 hours at full load (100%) and 6 hours at part (30%) load
  - Currently used to rate performance and compare different products

LIMITS OF EN 303-5

- Today majority of boilers in the market show efficiency above 90% and low emission factors → EN 303-5 cannot be used any more to compare products
- Test in stationary operation does not reflect real conditions (dynamic regime)
Dynamic test methods

- Test methods to approach real life operating conditions:
  - Bales et. al: 6-day test based on realistic climate sequence
  - Haberl et al: 12-day Concise Cycle Test for combined biomass-solar systems

LOAD CYCLE TEST: new method to determine annual efficiency and emissions:

- Test is feasible in one working day with similar experimental set up as EN 303-5 tests → minimum expenses and effort in addition to EN 303-5
- All phases of boiler operation are included (ignition, different loads, stop, standby)
- Test results are representative of the boiler performance over the whole year
The test emulates the operating conditions of boilers installed in **residential buildings** and **without a buffer storage tank**.

Boiler used to heat a “virtual house”, represented by a time variable demand profile.
- Literature review and field measurement to find typical daily profiles of heating and DHW demand in different seasons (winter, summer, spring/autumn)
- Reduction to load levels defined in DIN 4702-8 (referred to the boiler’s nominal capacity)
- Weighted sum of the daily load levels to define an annual reference cycle
- Cycle is completed with load transitions and reduced from 24 to 8 hours

Load profile
Boiler control during the test

- Heat extracted by the heat exchanger, according to the load profile
- Constant set values of flow and return T
- Time variable water flow rate

\[ Q = mc_p(T_{\text{flow}} - T_{\text{ret}}) \]

as hydronic heating systems in real life

- Last load step 13% → below lower limit of modulation range → boiler response to extremely low demands
  - Heat exchanger dissipates 13% of nominal load
  - No buffer storage

Increase of water temperature in the circuit until boiler stops

Time variable water flow rate

**Figure:**
- Graph showing percentage of nominal load over time.
- Diagram illustrating boiler components, including pellet storage, screw auger, boiler, insulated pipe, and return temperature.
Complete test cycle

- **circulation pump**
  - on
  - off
- **exhaust fan**
  - on
  - off
- **boiler**
  - on
  - off

**Energy balance**

**Emission measurements**

- **Nominal boiler load [%]**
  - 100%
  - 90%
  - 80%
  - 70%
  - 60%
  - 50%
  - 40%
  - 30%
  - 20%
  - 10%
  - 0%

- **Temperature [°C]**
  - 100
  - 90
  - 80
  - 70
  - 60
  - 50
  - 40
  - 30
  - 20
  - 10
  - 0

- **Time**
  - \( t_0 \)
  - \( t_1 \)
  - \( t_2 \)
  - \( t_3 \)
  - \( t_4 \)
  - \( t_5 \)

- **Flow temperature / \( T_F \)**
- **Return temperature / \( T_R \)**

- **Reference cycle**

- 55°C
- 45°C
- 55°C
- 45°C

---

**Slide 7**
Example of test results: 12 kW boiler

Heat dissipated by heat exchanger, representing the DEMAND side.

Heat supplied by the boiler to fulfill the heat demand.

Boiler’s load modulation range: 30-100%.

Load levels equal and lower than 30% cause overheating in the water circuit.

When T inside boiler reaches 85°C, the boiler stops for safety reasons → cycling operation in the final part of the load cycle.
Reproducibility of test method

- Test repeated in different institutes in the EU (Austria, Germany, Spain, Greece)
  - 12 tests on 12 KW pellet boiler, 4 institutes
  - 5 tests on a 6 kw pellet boiler, 3 institutes
- Results shows reproducibility of test method

### 12 kW Boiler

<table>
<thead>
<tr>
<th></th>
<th>average</th>
<th>std deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>efficiency [%]</td>
<td>78.7</td>
<td>2.1</td>
</tr>
<tr>
<td>CO [kg/TJ]</td>
<td>173.7</td>
<td>45.5</td>
</tr>
<tr>
<td>NOx [kg/TJ]</td>
<td>79.9</td>
<td>11.3</td>
</tr>
<tr>
<td>OGC [kg/TJ]</td>
<td>4.7</td>
<td>3.0</td>
</tr>
<tr>
<td>Dust [kg/TJ]</td>
<td>16.1</td>
<td>2.1</td>
</tr>
</tbody>
</table>

### 6 kW Boiler

<table>
<thead>
<tr>
<th></th>
<th>average</th>
<th>std deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>efficiency [%]</td>
<td>73.9</td>
<td>1.7</td>
</tr>
<tr>
<td>CO [kg/TJ]</td>
<td>461.5</td>
<td>44.0</td>
</tr>
<tr>
<td>NOx [kg/TJ]</td>
<td>81.5</td>
<td>25.9</td>
</tr>
<tr>
<td>OGC [kg/TJ]</td>
<td>14.3</td>
<td>8.8</td>
</tr>
<tr>
<td>Dust [kg/TJ]</td>
<td>27.6</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Comparision with real life operation

<table>
<thead>
<tr>
<th></th>
<th>12 kW Boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type Test EN 303-5 (full load)</td>
</tr>
<tr>
<td>CO kg/TJ</td>
<td>21</td>
</tr>
<tr>
<td>NOx kg/TJ</td>
<td>79</td>
</tr>
<tr>
<td>OGC kg/TJ</td>
<td>1</td>
</tr>
<tr>
<td>Dust kg/TJ</td>
<td>7</td>
</tr>
<tr>
<td>Efficiency %</td>
<td>91.4*</td>
</tr>
</tbody>
</table>

* based on fuel consumption

- Real life operation:
  - Emissions: 24 h field measurements
  - Median values of 17 measurements
Results – 3: development of new product

- New version of a pellet boiler of an Austrian company
- EN 303-5 test results do not show improvements

- LCT results show significant emission reduction (OGC) and +6% efficiency

<table>
<thead>
<tr>
<th></th>
<th>EN 303-5 (full load)</th>
<th>EN 303-5 (part load)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Old</td>
<td>New</td>
</tr>
<tr>
<td>CO  kg/TJ</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>OGC  kg/TJ</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Dust kg/TJ</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Efficiency %</td>
<td>93.2</td>
<td>94.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Load cycle test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Old</td>
</tr>
<tr>
<td>CO  kg/TJ</td>
<td>287</td>
</tr>
<tr>
<td>OGC  kg/TJ</td>
<td>16</td>
</tr>
<tr>
<td>Dust kg/TJ</td>
<td>20</td>
</tr>
<tr>
<td>Efficiency %</td>
<td>75.2</td>
</tr>
</tbody>
</table>
Conclusions

- Load Cycle Test method was developed, to estimate annual efficiency and emissions at the test stand
  - Repeatability of method was demonstrated
  - Method validated in comparison to field data

- The Load Cycle Test method:
  - is a reliable tool to assess boiler performance under realistic operating conditions
  - can be used to evaluate the improvement of new products, in comparison to the current state of the art
Acknowledgments

- **ISEB Project**
  Funded by bmvit und bmwfj within the program „ENERGIE DER ZUKUNFT“
  Managed by FFG

- **BioMaxEff Project** ([www.biomaxeff.eu](http://www.biomaxeff.eu))  
  The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under Grant Agreement n° **268217**

**THANK YOU FOR YOUR KIND ATTENTION!**