REAL-LIFE PERFORMANCE OF AUTOMATICALLY STOKED BIOMASS BOILERS – VALIDATION OF A STANDARD LOAD-CYCLE TEST METHOD THROUGH ROUND ROBIN

Sabine Feldmeier[1], Claudia Schön[1], Hans Hartmann[1], Markus Schwarz[2], Paul Roßmann[1]
[1] Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ)
Schulgasse 18, D-94315 Straubing, Germany, Tel.: +49-9421-300-152, Fax: +49-9421-300-211
Email: Claudia.schoen@tfz.bayern.de
[2] BEST Bioenergy and Sustainable Technologies GmbH, Inffeldgasse 21b, A-8010 Graz, Austria

ABSTRACT: Automatically stoked biomass boilers are currently only tested at constant nominal and partial load conditions, following EN 303-5. This method does not consider the ignition phase, load changes or burnout phases which may considerably contribute to emissions and reduce the boiler efficiency. To overcome this lack of relevance for real life operation, a standardized load cycle test method was developed and it was validated through an international round robin involving six test laboratories and using two different pellet boilers. The results show that the newly developed load cycle test method is as reproducible as the existing constant load method, provided that the general conditions for the test setup and procedure are compiled with and the measurement technology meets the required accuracy. As expected, the efficiency was lower during the load cycle test method compared to constant load conditions. Moreover, CO, OGC and TPM emissions increased if all combustion phases were considered. The validation of the novel load cycle test method showed that it can be recommended for the determination of real-life emission and efficiencies of automatically stoked pellet boilers in practice.
Keywords: biomass boiler, pellet combustion emissions real-life emission

1 INTRODUCTION

The emission behaviour and efficiency of small-scale biomass combustion units is typically determined following EN 303-5 [1]. This test standard only considers two different steady state load conditions, nominal load and 30 % partial load while determining emissions of carbon monoxide, organic gaseous carbon (OGC) and total particulate matter (TPM). Dynamic changes during boiler operation such as during ignition, load changes, burnout phases are not characterized when performing tests in accordance with EN 303-5. To receive a clearer picture on emissions, the European eco-design directive (EU directive 2015/1189) for solid fuel boilers tries to compensate the drawback of EN 303-5 while using specific weighting factors [2] but this calculation still only considers steady state boiler operation. Therefore, the load cycle test method was developed and validated through a round robin using one conventional pellet boiler and one condensing pellet.

2 METHOD DEVELOPMENT

2.1 Load Cycle Test Method

The two load levels of an EN 303-5-test, nominal load and partial load, are not the only heat output options of a boiler. A boiler start, for example, happens frequently, from either cold or warm boiler state; these phases are highly relevant for pollutant emissions and they were therefore included in the new load cycle test method. Moreover, the boilers do not operate at constant conditions over a certain duration, there are always transient conditions and the heat demand of the building varies constantly. In order to develop a reliable load cycle test method, the annual heat demand of heating and domestic hot water plants according to VDI 4655:2019 [3] were considered and summarized in Figure 1, they reflect the load demand pattern for 10 different standard type days.

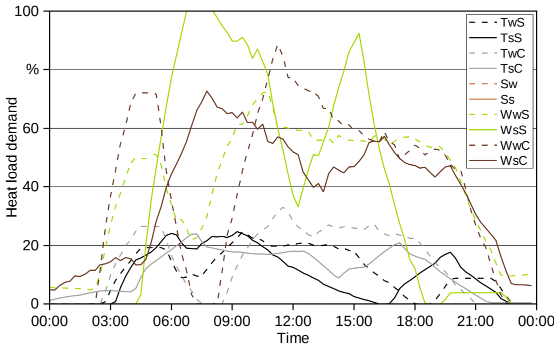

Figure 1: Heat load demand based on boiler heat output (TwS – transient weekday sunny, TsS – transient Sunday sunny, TwC – transient weekday cloudy, TsC – transient Sunday cloudy, Sw – summer weekday, Ss – summer Sunday WwS – winter weekday sunny, WsS – winter Sunday sunny, WwC – winter weekday cloudy, WsC – winter Sunday cloudy), Source: VDI 4655:2019

Based on this data a novel load cycle test pattern for automatically stoked biomass boilers was developed, it is displayed in Figure 2. This load cycle test pattern reflects all possible heat demand levels in a representative proportion throughout a full year. It was derived by making use of the mentioned standard type days and their proportional share during a typical year. The challenge was to arrange these load levels in a suitable order which will force the boiler to react to heat demand changes on a high, medium and low level while also introducing transient phases between the load levels at different gradients. Thereby, the load cycle considers the first ignition phase of the boiler while a target heat demand of 100 % is set for the first 42 minutes. Then the target heat demand is reduced to 48 % and lasts for 46 minutes. The heat demand is then further reduced to 39 % which lasts only for 17 minutes. An increase of heat demand to 63 % is then specified and this level lasts for 1:13 hours. Afterwards the heat demand is again reduced to 30 % (as it is a reverence point according to EN 303-5) and it lasts for 1:17 hours. At the end only 13 % of nominal heat load is pre-set for the boiler during a period of 2:04 hours. The load cycle test method lasts over 8 hours and then the boiler is shut down, followed by a 12 hour period of standstill phase for being conditioned to reference temperature.

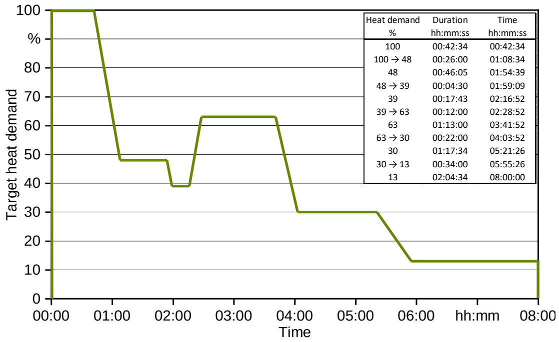

Figure 2: Standard load pattern of the load cycle test method (without the final 12 hours standstill phase)

2.2 Requirements and boundary conditions for performing the load cycle test

For a reliable determination of fuel consumption during the load cycle, a sufficient decoupling between the boiler (with storage tank) and the measurement section or between the storage tank and the boiler itself is essential. Moreover, the water content of the boiler changes its mass with increasing or decreasing temperature due to the changes in water density. Therefore, it is essential that the boiler is pre- and post-tempered to (45 ± 1) °C for conventional boilers and to (25 ± 1) °C for condensing boilers [4].

During the entire load cycle test including the standstill phase the flue gases are be analysed for CO, NO_X, OGC as well as H_2O, O_2 and CO_2. TPM emissions are continuously sampled isokinetically during the first 8 hours of the load cycle test, but not during the standstill phase. During TPM sampling, the filter holder and sampling line are heated to 180 °C. The deposition in the sampling line is considered and all collected TPM is thermally post treated at 180 °C before weight determination [4].

It is essential that the flue gas volume flow is correctly determined using a suitable device to determine flue gas velocity. The minimum flue gas velocity is set to 0.5 m/s. The volume flow shall be determined throughout the complete load cycle operation until the boiler is shut down. This volume flow varies depending on the actual load state during the test. A careful selection of the diameter of the flue gas duct is essential in order to guarantee an accurate volume flow determination also during low load phases of the test.

The TPM sampling starts when the boiler is turned and shall be continued without interruption, it is terminated when the fan of the boiler stops which will include the total 8 hour operation of the boiler and the shut-down procedure of the boiler.

Further information on the load cycle test can be found in [4].

3 ORGANIZATION OF A ROUND ROBIN

3.1 Boiler and fuel

For validation of the applicability of the method, a round robin was organized. Two pellet boilers out of serial production were selected: one condensing boiler and one conventional boiler both having a heat output between 15 and 20 kW. Each boiler was tested in advance, either at the Technology and Support Centre (TFZ) in Germany or at BEST-Bioenergy and Sustainable Technology GmbH in Austria in order to get a pre-used status of the boiler being comparable at all laboratories. This was done because the method requires a pre-use time of minimum 20 hours before performing the load cycle method. This allows the pellet boiler itself to adapt to the chosen fuel and to collect first operational experience with both pellet boilers in order to be able to provide support to the involved test laboratories. Precise configurations (settings) of the boiler were defined and communicated, and installation procedures were provided to the participating laboratories to guaranty the same starting conditions at each laboratory.

Wood pellets of EN*plus* A1 quality were procured for the round robin test. The pellets were well homogenized at TFZ before being divided into 6 homogeneous fuel portions which were delivered to the participating laboratories. This was the only fuel used in all combustion tests, thus any influence from fuel variation could be eliminated.

3.2 Work program

Apart from the project partners TFZ and BEST, four foreign laboratories (1x Austria, 1x Denmark, 2x Germany) participated in the round robin. Prior to the round robin itself, all laboratories were informed and trained for the new method, the novel load cycle test and it's special requirements were presented and discussed during an online meeting.

Furthermore, each laboratory also tested both pellet boilers at nominal load and at partial load, following EN 303-5 standard method, then they applied the novel load cycle test method by applying their specific testing infrastructure.

After the combustion tests were finalized, all data was evaluated in an evaluation program developed and provided by BEST in order to exclude any errors in calculation. All data were finally provided to TFZ for plausibility check and further evaluation.

4 RESULTS OF THE ROUND ROBIN

In the following, the results obtained at nominal and partial load (standard EN 3030-5-test) as well as after applying the load cycle test method were evaluated for the two different pellet boilers which had been traveling to each of the involved six laboratories. The results obtained by laboratory 4 during the load cycle test were excluded from the evaluation due to the missing volume flow determination.

4.1 Fuel properties

Wood pellets were analysed according to the relevant parameters listed in ISO 17225-2 and for other combustion relevant parameters (Table I**)**. Particularly the carbon content of the fuel is essential for quality check of the data obtained during the combustion tests since the overall carbon balance is calculated.

Table I: Fuel properties of wood pellets (d – dry, ar – as received)

Parameter	Unit	Wood pellets
Moisture content	w-%, ar	7.2 – 7.8
Ash content	w-%, d	0.34
Bulk density	kg/m³, ar	688
Durability	-	99.2
Net calorific value	kJ/kg, d	18,843
C content	w-%, d	50.5
H content	w-%, d	6.3
N content	w-%, d	0.07
K content	mg/kg, d	417
Si content	mg/kg, d	217

4.1 Results regarding carbon balance

As a parameter for data quality the carbon balance was evaluated for those combustion tests where the new load cycle test method was applied. In this balance, all carbon input via the applied pellet fuel is set in relation to all carbon emissions released via the flue gas. Numerous sources of error thus contribute to possible deviations between the two values compared: These are on the one side the accuracy of the fuel input determination, the fuel composition analysis and the moisture content determination. On the other side all carbon containing flue gas species (CO, OGC, CO_2) and the accuracy of the volume flow determination including corrections for water vapour content and temperature are the crucial parameters for the balancing.

The threshold of carbon balance was set to ± 5 % the results achieved are shown in Figure 3. For the condensing boiler only two laboratories achieved this threshold limit, while 5 out of 6 fulfilled this requirement using a conventional pellet boiler. Only laboratory number 5 failed due to wrong determination of the flue gas velocity. Laboratory number 4 did not measure the flue gas velocity, only calculation was applied.

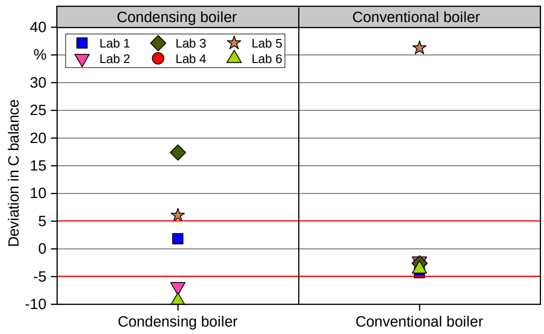

Figure 3: Deviation in carbon balance for all laboratories for both boilers during the load cycle test (Target boundaries in red).

4.2 Results on CO emission

The condensing boiler released lower CO emissions compared to the conventional pellet boiler, Figure 4. As expected, the lowest emissions were detected during nominal load operation, and slightly higher CO emissions were measured during partial load. Since the ignition process as well as load changes and possible restarts of the pellet boiler during low load are considered, the CO emissions are higher for the load cycle compared to steady state boiler operations. The result of laboratory 4 is here not included due to missing velocity determination during the load cycle test. Interestingly, the coefficient of variation is on a similar level for the load cycle test as for partial and nominal load test. This indicates a comparable repeatability of the load cycle test, although the majority of involved laboratories could not gain any routine in applying this challenging new method, compared to the well-established standard test method.

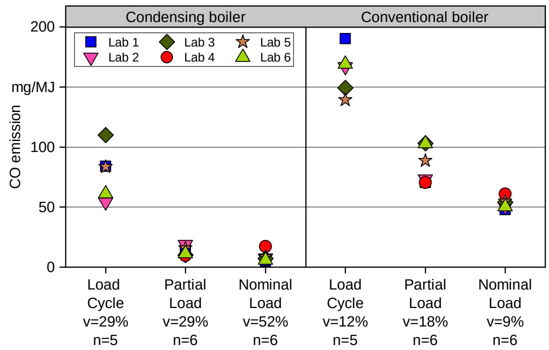

Figure 4: CO emissions for two pellet boilers during the load cycle test, at partial load and at nominal load. v = coefficient of variation, n = number of replication

4.3 Results on OGC emission

The emissions of organic gaseous carbon (OGC) are on a low range as expected for automatically stoked pellet boilers, Figure 5. No difference on OGC emissions between nominal and partial load was determined for the condensing pellet boiler. In contrast to that, a slight increase was measured for the conventional pellet boiler at partial load. Also, during the entire load cycle test, OGC emissions were on a low level but they were higher compared to steady state boiler operation.

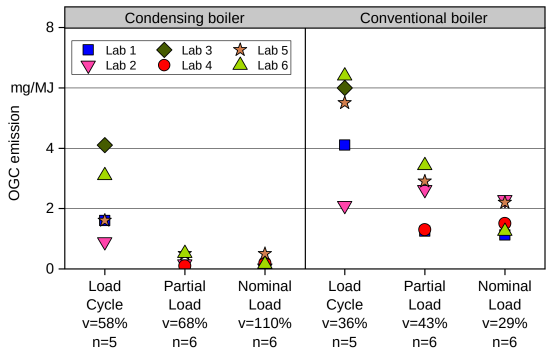

Figure 5: OGC emissions for two pellet boilers during the load cycle test, at partial load and at nominal load. v = coefficient of variation, n = number of replication

4.4 Results on NO_X emission

NO_X emissions were higher during nominal load conditions compared to partial load due to higher temperatures and an increased NO_X formation, Figure 6. The NO_X emissions released during the load cycle test were between the partial and nominal load since the heat demand for the boiler varied between 13 % and 100 %. Only laboratory 1 always detected the highest NO_X emissions which may be explained by an "expired" calibration gas that was used prior to combustion tests.

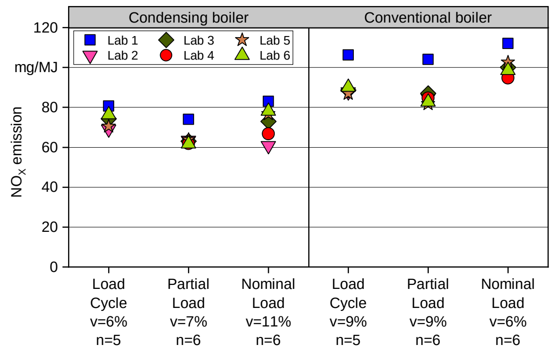

Figure 6: NOx emissions for two pellet boilers during the load cycle test, at partial load and at nominal load. v = coefficient of variation, n = number of replication

4.5 TPM emission

TPM emission were slightly higher during the load cycle test compared to steady state combustion conditions. Laboratory 4 provided no useful data in this comparison during load cycle test since no isokinetic sampling was possible due to missing flue gas velocity determination, Figure 7. A rather low TPM value was determined for laboratory 3 during load cycle test since the TPM measurement was terminated too early and therefore excluding the shut-down phase after the 8 hour load cycle test during the test at the conventional boiler and can therefore not be compared with the other results.

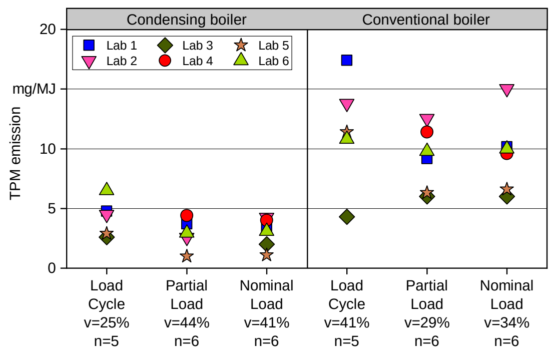

Figure 7: TPM emission for two pellet boilers during the load cycle test, at partial load and at nominal load. v = coefficient of variation, n = number of replication.

4.6 Efficiency

The efficiency was also determined during all combustion tests which was not straight forward. Teh round robin test prevailed that the determination of fuel consumption, especially for the condensing boiler was a challenge since the water flow in the boiler affects the boiler mass. Moreover, the determination of the flue gas velocity was challenging due to the condensation of the water at low temperatures. Therefore, the results of laboratory 4 were excluded since it was only based on pure calculation and weight recording for four times during the entire load cycle. As expected, the efficiency was higher for the condensing boiler compared to the conventional boiler. The coefficient of variation was on a comparable level for all test variants.

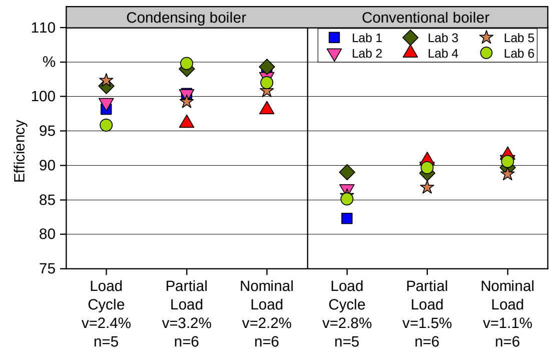

Figure 8: Efficiency for two pellet boilers during the load cycle test, at partial load and at nominal load. v = coefficient of variation, n = number of replication

5 CONCLUSIONS

The newly developed load cycle test for automatically stoked pellet boilers has proven it's applicability beyond the test labs of the two developing partners, TFZ and BEST. Foreign laboratories were able to implement this method and to follow the challenging infrastructural and operational requirements successfully, this was shown when applying the method using both, a conventional boiler and also a condensing pellet boiler which was operated at a lower temperature range.

The results regarding boiler efficiency and emission were in the similar range as determined in the usual boiler tests at nominal or partial load, which had followed the European standard method. This can be read from the coefficients of variation which were mostly comparable when regarding the gaseous and TPM emissions as well as for efficiency determination. Nevertheless, the comparability for the flue gas compounds is remarkable because the new and quite sophisticated load cycle method was mostly applied for the first time by the foreign laboratories in this study.

The also newly introduced quality check via calculating the carbon balance over the complete load cycle operation can be seen as a particularly effective tool for assuring high quality in measurement practice.

The entire validation process of the cycle test method comprised 12 combustion tests with two boilers, plus 24 combustion tests at steady state for both boilers, performed at the six laboratories. Apart from the validation of the novel test method, the round robin thus also provides valuable reliability data describing the current state of the art of measurements according to the conventional type testing method, the European EN 303-5.

6 REFERENCES

[1] DIN EN 303-5 (2018): Heating boilers – Part 5: Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW – Terminology, requirements, testing and marking. Berlin: Beuth 2018

[2] Commission Regulation (EU) 2015/1189 (2015): Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for solid fuel boilers.

[3] VDI 4655 (2019): Reference load profiles of residential buildings for power, heat and domestic hot water as well as reference generation profiles for photovoltaic plants. Berlin: Beuth 2019
[4] Feldmeier, S.; Roßmann, P.; Hartmann, H.; Schön, C.; Marks, A.; Schwarz, M. (2022): Load Cycle Test – Assessment of real-life performance of automatically stoked biomass boilers – Test Method. To be published in 2022.

7 ACKNOWLEDGEMENTS

- We thank our colleagues Tobias Rohrmeier, Alexander Marks, Elisabeth Rist, Stephan Winter-Thomas, Daniel Fera, Albert Maierhofer, Anja Rocktäschel for their support during the project.
- We thank all boiler manufacturers who provided a pellet boiler and gave support during the first combustion experiments.
- We thank all participating laboratories performing combustion tests following EN 303-5 and the newly developed load cycle test method.

8 FUNDING

This study is part of the "CycleTest" project which has been performed together with the German Pellet Institute (DEPI) and funded by the German Ministry of Food and Agriculture (BMEL) on behalf of a decision of the German Bundestag. Funding was administrated by the Fachagentur Nachwachsende Rohstoffe e. V. (FNR) (Grant number: 22409818).

9 LOGO SPACE

TFZ

BEST
Bioenergy and Sustainable Technologies

DEPI DEUTSCHES PELLETINSTITUT