Technologie- und Förderzentrum
im Kompetenzzentrum
für Nachwachsende Rohstoffe

Load cycle test method for the assessment of real-life performance of automatically stoked biomass boilers – Manual for test stands

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Table of content

1 Introduction and field of application

The objective of the CycleTest project was the development of a method to determine the efficiency and emissions of biomass boilers. In contrast to existing test methods, the Load Cycle Test is conducted under real-life operating conditions.

The Load Cycle Test simulates the operation of a boiler which is either directly connected to a building's heating circuit or connected via an accumulator storage tank. Therefore, the heat output of the boiler shall vary according to a standard load pattern. The duration of each dynamic boiler operating test is 8 hours with an additional 12-hour standby phase at the end of each test run, followed by a short timespan to reach a defined equilibrium temperature.

Due to dynamic measurements, the test stand setup is an enhanced version of the setup necessary for the type test method according to EN 303-5:2021 [23]. It requires additional measurement infrastructure, particularly in terms of the determination of flue gas velocity, a transient way of particulate matter (PM) sampling, and a heat transfer system which controls a defined and variable heat demand (i. e. is capable of water flow rate variation).

In order to cover particular implementation requirements of the manufacturer, the Cycle Test Method optionally allows to perform the test in combination with an accumulator storage tank or a configuration with a hydraulic separator to enable a higher range of return temperature.

The test procedure covers the measurement of several pollutant emissions and the annual system efficiency under varying operational conditions of the boiler. In contrast to the type testing procedure of EN 303-5:2021 [23], non-stationary operational conditions are also measured and evaluated.

Overall, some enhanced accuracy requirements need to be met for the Load Cycle Test and special measuring devices are required (e. g. accurate flow meters, sample gas pumps with highly variable flow amplitude, high-precision balance for fuel mass determination, additional electric power meter, etc.).

As the volume flow rate of the flue gas varies during dynamic operation, it is necessary to determine pollutant emissions proportionally to the dynamics of the flue gas flow as well. This volume flow varies considerably throughout the load cycle, e. g. when the boiler performs an on-and-off operation in order to achieve the heat output of the given load phase.

Method specifications are even more demanding for the determination of particle emissions. Not only the total particle mass shall be determined over a long period of time without major interruptions, but also the volume flow of the extracted gas for PM sampling shall be synchronized with the simultaneously measured dynamic volume flow in the flue gas duct.

The entire test cycle includes all boiler operation phases (cold start, warm start, varying heat demand, steady-state operation at different loads, shutdown, and standstill) and allows the annual standard efficiency and the annual standard emission factors to be measured in a short period of time. Each load change in the resulting 8-hour Load Cycle Test is provided with defined gradients.

2 Terms and definitions

For the purpose of this method, the following terms and definitions apply:

Accumulator storage tank

Container which stores excess heat (resulting from the difference between the boiler heat output and the actual heat load to the heating system)

Nominal annual efficiency

The nominal annual efficiency is equivalent to the value measured for the rate of efficiency throughout the test cycle. It also takes into account electricity demand of the boiler. It is related to the total energy supplied in the form of fuel and auxiliary electric energy consumed.

Nominal annual emission (level) (mass)

Nominal annual emission (level) corresponds to the emission freight of the boiler over a one-year period. It is the absolute level of emissions emitted by the boiler having a thermal energy output of 2000 full load hours.

Quality criteria

Results of additional calculations to rate the quality of measurement, on the one hand, how well balances are closed and, on the other hand, if the test stand fulfils the requirements of the Load Cycle Test.

Standard reference conditions, standard temperature, and pressure (STP)

According to DIN 1343 [5], standard reference conditions of temperature and pressure for expressing gas volumes are 0 °C and 101,325 kPa.

Flue gas measuring section

Flue gas pipe with reduced diameter to increase flue gas velocity to reach better performance in flue gas velocity measurement.

Reference temperature

This is the temperature to which the test setup is tempered prior to and after the Load Cycle Test. Furthermore, it is the set temperature of the return flow.

The reference temperature is 45 °C for conventional and 25 °C for condensing boilers.

Setpoint temperature

The setpoint temperature for operation is 70 °C for conventional and 50 °C for condensing boilers.

Standard load pattern

The standard load pattern considers the reference load profiles provided by VDI guideline 4655:2019 [28]. Varying daytime heat demand profile.

3 Reference to norms

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Table 1: References needed for load cycle test method

Norm	Title of norm
DIN 1343:1990	Reference conditions, normal conditions, normal volume; concepts and values
DIN EN 303-5:2021	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
DIN EN 304:2018	Heating boilers – Test code for heating boilers for atomizing oil burners
OIML R 75-1 Edition 2002 (E)	Heat meters – Part 1: General requirements
OENORM A 6403:2010	Rounding of numbers and results of measurements
VDI 4655-1:2019	Reference load profiles of residential buildings for power, heat and domestic hot water as well reference generation profiles for photovoltaic plants
DIN EN 12619:2013	Stationary source emissions – Determination of the mass concentration of total gaseous organic carbon – Continuous flame ionisation detector method
VDI 2066-1:2021	Particulate matter measurement – Dust measurement in flowing gases – Gravimetric determination of dust load
ISO 13284-1:2018	Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method
ISO 15456:2008	Heating boilers – Electrical power consumption for heat generators – System boundaries – Measurements
ISO 17829:2016	Solid biofuels – Determination of length and diameter of pellets
ISO 18122:2015	Solid biofuels – Determination of ash content
ISO 18134-1:2015	Solid biofuels – Determination of moisture content - Oven dry method – Part 1: Total moisture – Reference method
ISO 17831-1:2015	Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 1: Pellets

ISO 18846:2016	Solid biofuels – Determination of fines content in samples of pellets
ISO 21404:2020	Solid biofuels – Determination of ash melting behaviour
ISO 18125:2017	Solid biofuels – Determination of calorific value
ISO 17828:2015	Solid biofuels – Determination of bulk density
ISO 18847:2016	Solid biofuels – Determination of particle density of pellets and briquettes
ISO 16948:2015	Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen
ISO 16967:2015	Solid biofuels – Determination of major elements – Al, Ca, Fe, Mg, P, K, Si, Na and Ti
ISO 17225-4:2021	Solid biofuels – Fuel specification and classes – Part 4: Graded wood chips
ISO 17827-2:2018	Solid biofuels – Determination of particle size distribution for uncompressed fuels
DIN EN ISO/IEC 17025:2018	General requirements for the competence of testing and calibration laboratories

4 Boiler assembly and test setup

To conduct the standard Load Cycle Test (see section 6.3), a specific infrastructure and further requirements are necessary. They are described in the following.

4.1 Ambient conditions

The ambient temperature in the test facilities shall be between 15 °C and 30 °C. Changes in ambient temperature during the performance of tests shall not exceed 2 K/h. The test assembly is to be protected against any direct impact from other potential (external) heat or cold sources, e. g. adjacent test assemblies, sunlight, or accidently open doors. The ambient temperature shall be determined continuously throughout the Load Cycle Test. Atmospheric pressure shall be determined at least once. If significant fluctuations can be expected, repeated or continuous measurements should be conducted.

4.2 Hydraulic configuration

To consider different boiler systems, the setup includes several options for connecting the boiler with the heat transfer system (see section 4.5):

- If the boiler manufacturer requires the operation with accumulator storage tank → Integration of accumulator storage tank (see section 4.3).
- The manual of the manufacturer allows an operation of the boiler with a return temperature of 45 °C for conventional boilers and 25 °C for condensing boilers → Direct connection to heat transfer system.
- The boiler requires a higher return temperature and is equipped with an internal circulation pump and a mixer → A hydraulic separator shall be installed to connect the boiler.
- The boiler requires an increase of return temperature but is not equipped with an internal circulation pump → A hydraulic separator, an external circulation pump and a mixer shall be installed to connect the boiler.
- If the boiler manufacturer recommends the integration of a device (mixer and circulation pump) for increasing the return temperature when an accumulator storage tank is connected → This device shall be installed independent of temperature ranges.

Before designing the setup, the manuals and instructions shall be checked to answer the questions according to the boiler setup flow chart (Figure 1):

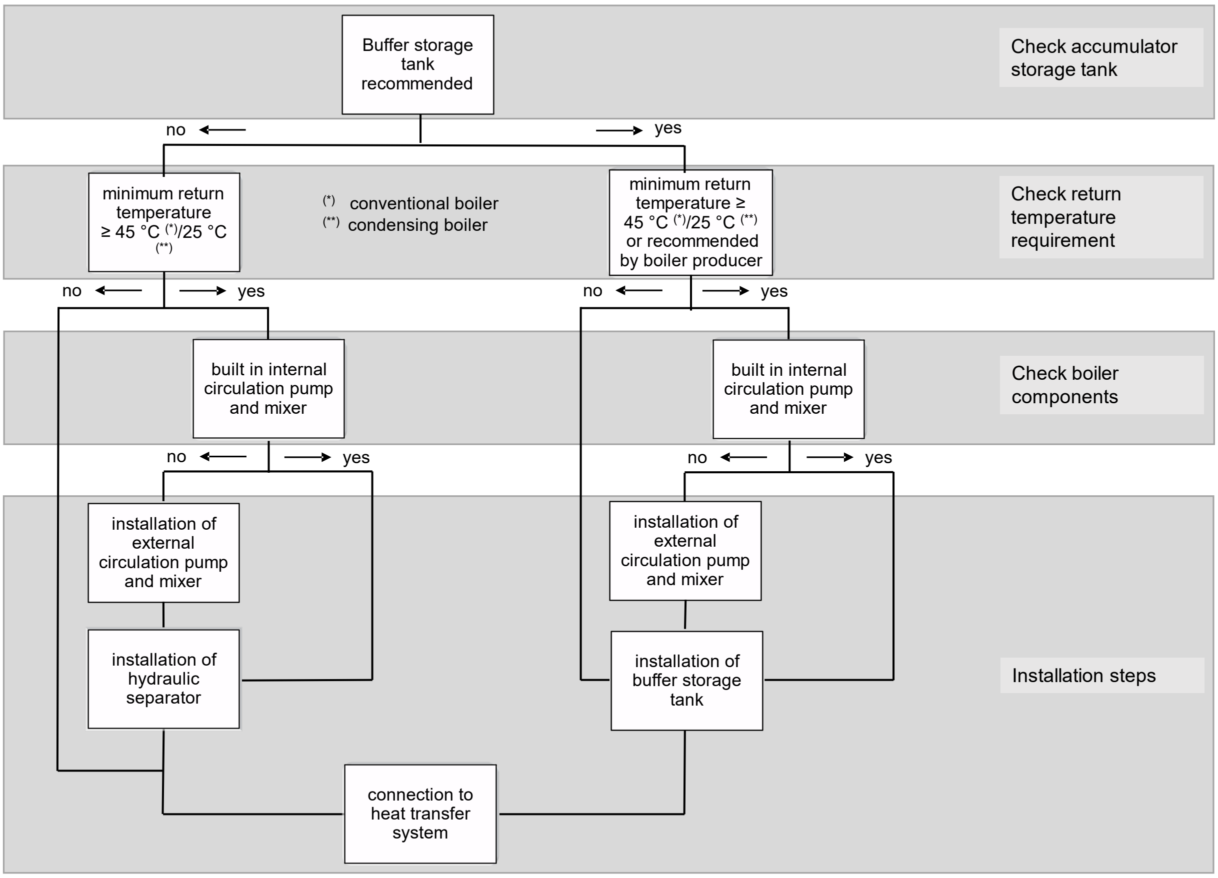


Figure 1: Flow chart boiler setup

The hydraulic separator enables the boiler to operate more independently by controlling the flow rate (circulation pump) and the temperature (mixer) of the return water. Thus, it decouples the mass flow of the primary circuit (boiler, within system boundaries) and the mass flow of the secondary circuit (heat transfer system). In this case, additional sensors for flow and return temperature of the boiler circuit are necessary.

Figure 2 shows these two options, i. e. with and without hydraulic separator, and indicates the respective system boundaries. For installation setup with an accumulator storage tank, additional specifications are given in section 4.3.

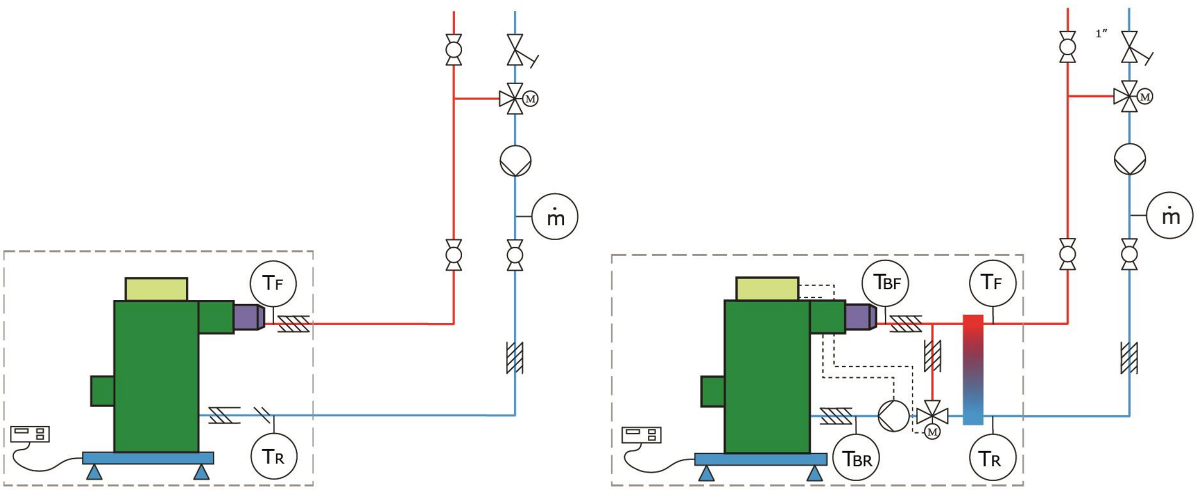


Figure 2: Boiler system without (left) and with hydraulic separator, external circulation pump and mixer (right) on the test stand, the system boundaries are indicated. T_F = flow temperature, T_R = return temperature, T_{BF} = flow temperature at boiler, T_{BR} = return temperature at boiler, $\dot{m}$ = water mass flow.

The insulation of the surfaces within the system boundary is shown in Figure 2. For pipe diameters of 25 mm, material with an insulation layer thickness of 30 mm shall be used, given that the thermal conductivity is 0.035 W/(m·K). For other materials, the minimum thickness of the insulation layer shall be adapted accordingly.[1]

4.3 Accumulator storage tank requirements

The volume of the accumulator storage tank shall be 25…35 L/kW nominal load. It shall fulfil the requirements of energy labelling category A or B according to EU Regulation 812/2013 [26]. When the installation of a device for increasing the return temperature is recommended by the boiler manufacturer or the required return temperature is higher than the reference temperature (see section 6.3), the integration of an additional mixer and a circulation pump is necessary.

The diameter of the connecting pipes shall be 25 mm or more, and the length of the flow and return temperature shall be 3 meters and 5 meters, respectively. The thermal insulation of the hoses or pipes shall meet the requirements as specified in section 4.2. Suitable insulation layer thicknesses are 20 mm (inner diameter up to 22 mm), 30 mm (inner diameter more than 22 mm), or 35 mm (inner diameter more than 35 mm) if material specifications are met. In the setup, an expansion vessel may be required.

The mode of operation shall be based on the settings of the boiler control, i. e. the temperature range of the accumulator storage tank, circulation pump, etc. Therefore, the boiler

[1] This is in line with the German Energy Act for Buildings (Gebäudeenergiegesetz – GEG [1], which implements the EU Directive on the energy performance of buildings – 2010/31/EU, [25]).

manufacturer shall provide suitable temperature sensors. These sensors shall be installed according to the boiler manufacturer's guideline.

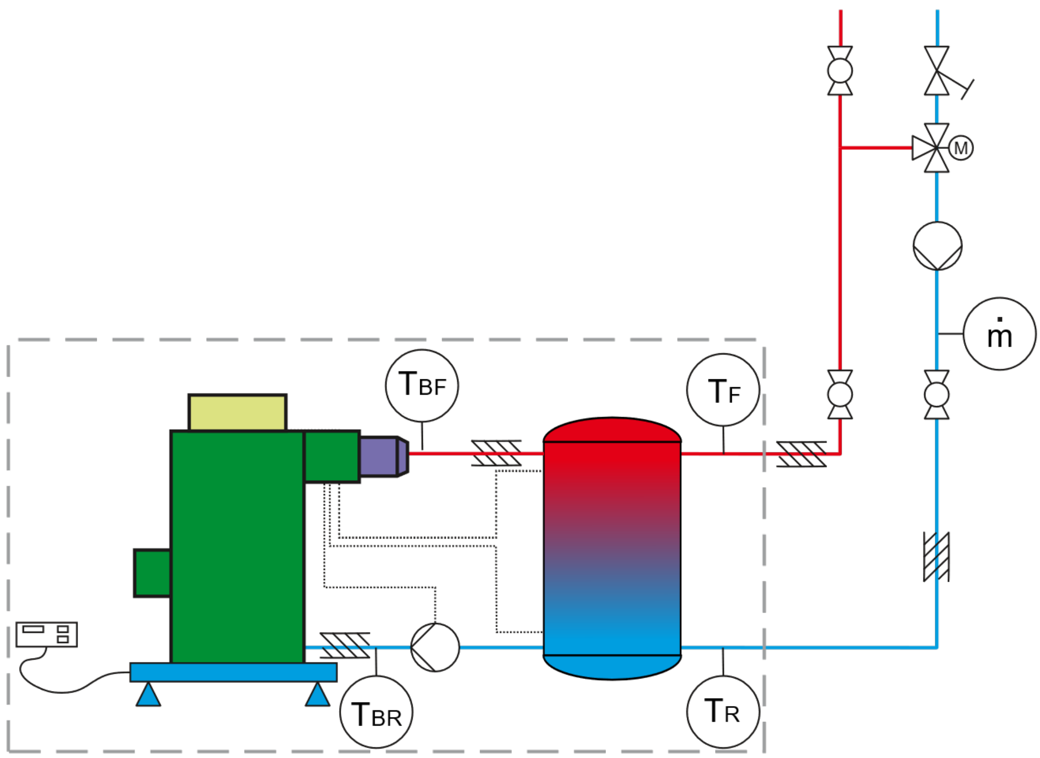


Figure 3: Boiler system with accumulator storage tank and buffer charge pump on the test stand, the system boundaries are indicated, the expansion vessel is not shown. T_F = flow temperature, T_R = return temperature, T_{BF} = flow temperature at boiler, T_{BR} = return temperature at boiler, $\dot{m}$ = water mass flow. This setup shows the installation with direct connection to the accumulator storage tank without increase of the return temperature.

4.4 Determination of fuel consumption

An accurate determination of fuel consumption is one of the most crucial tasks of the method. Fuel consumption shall be determined continuously and recorded over the complete observation period. The following methods are permitted:[2]

Setup A) The boiler is placed on a balance (Figure 4, left). The minimization of frictional connections via the flue gas ducts and water hoses (mass decoupling) shall be realized with great care[3] in order to meet the accuracy requirement set down in Table 2.

[2] Determining fuel consumption by recording the mass needed to refill the fuel supply container to the initial level is regarded as inaccurate.

[3] It is strongly recommended to ensure that all connections (flue gas, water, electricity) are positioned horizontally in order to prevent any impact from occurring forces on the balance. Be aware that heating and cooling of the flue gas duct and water hoses causes length variations that would in a vertical position severely affect measurement accuracy.

Further inaccuracies may occur due to the density differences of the boiler water, they are compensated by the fact that the observation period of the whole cycle begins and ends at a uniform temperature level.

Setup B) The fuel supply container is placed on a balance (Figure 4, right).

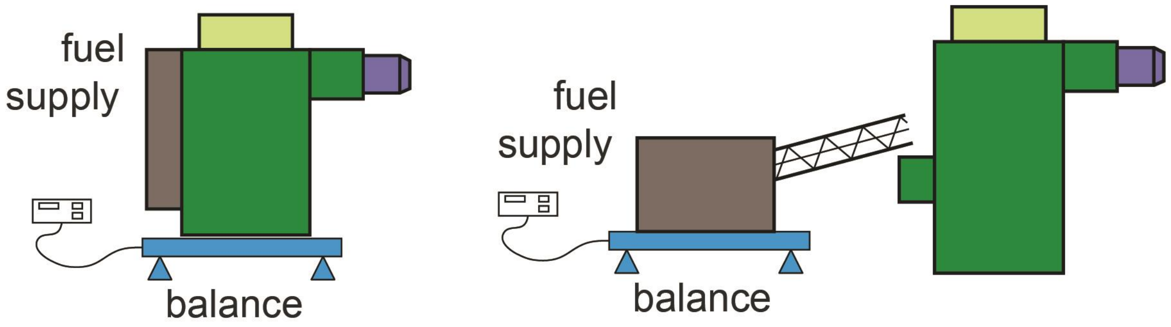


Figure 4: Boiler system with integrated fuel supply container (left) and boiler system with separate fuel supply container (right) on the test stand.

It shall be possible to determine the efficiency during stationary operation as well as through the standard load cycle within a tolerance threshold of ± 3 %, as also specified in EN 303-5:2021 [23].

For boilers which are installed on a balance, a correction for the remaining ash is required. The amount of ash formed during the test is calculated via the ash content and the combusted fuel (see equation in section 7.1.1). The evaluation software (Annex A) considers this correction automatically. For boilers equipped with an external fuel supply container, no correction for ash content is required.

4.5 Heat transfer system

The configuration of the heat transfer system shall allow for continuous, sufficiently fast, and accurate control of heat transfer. The facilities for the measurement of the following parameters shall be provided: flow temperature, return temperature and mass flow rate of the water. The hydraulic configuration is described in section 4.2 and section 4.3.

Flow and return temperatures shall be measured, using appropriate sensors, right at the boundaries of the system (Figure 2). The determination of water mass flow rate, or alternatively, the calculation via volume flow and water density, is required.

The return temperature from the heat transfer system shall be set at 45 °C for conventional boilers or 25 °C for condensing boilers. In case the boiler control system requires a higher return temperature, the temperature increase should be controlled by the boiler system (installation with hydraulic separator, see section 4.2), if possible. The heat output is calculated according to EN 304:2018 [21].

Requirements regarding heat output variation. The heat transfer system shall be fitted with suitable controls allowing for continuous adjustment of the heat output according to the set values of the load cycle. This adjustment should preferably be performed automatically by variations of water mass flow proportional to the standard load pattern (Figure 6, see section 6.3). The test stand shall provide an appropriate infrastructure that allows to follow the standard load pattern accurately. The spread between flow and return temperatures at rated capacity shall be held constant at 25 K. Therefore, the return temperature shall increase if boiler temperature is above 70 °C or 50 °C for condensing boilers but shall not fall below the defined return temperatures. The heat output delivered by the boiler system shall correspond to the target heat demand specified by the standard load pattern. This criterion shall be verified by the evaluation of the mass flow dynamics.

The Flow deviation criterion:

The variable heat demand is controlled by variation of water mass flow. The dynamics shall be proportional to the standard load pattern (dQ ~ dT·dm/dt). The proportionality shall be realized and proven by the test stand.

The normalized average deviation of realized mass flow shall deviate by a maximum of 2 % compared to the corresponding target mass flow values as defined by the standard load pattern.

For the calculation, see section 7.3.3.

Preheating of boiler water. To enable the compilation of an energy balance between initial and final state, the initial and final conditions shall be comparable. Thus, prior to and upon completion of testing, the whole test setup (= system boundary) including boiler water shall be heated to 45 °C for conventional boilers and 25 °C for condensing boilers. A suitable heating device (e. g. electrical heating cartridge or hot water storage tank) should be used for this purpose. The procedure is described in section 6.3.

Determination of auxiliary electric energy supply. The auxiliary electric energy required by the boiler, e. g. for ignition, forced draught fan or fuel supply, is also determined. In addition, the electricity demand of any boiler-installed circulation pump and/or external feeding system (e. g. fuel supply container for wood chips) shall be recorded separately in order to allow for corrections of the measured total electricity requirement and to achieve compatible results for different boiler types (see section 4.7).

4.6 Flue gas measuring section

The inner diameter at the entrance to the flue gas measuring section shall correspond to the outside diameter of the flue gas socket of the boiler system, as required by EN 304:2018 [21]. The flue gas duct shall be connected in compliance with the requirement to avoid frictional connections from the balance, in accordance with section 4.2.[4] Examples for measuring sections are shown in Figure 5.

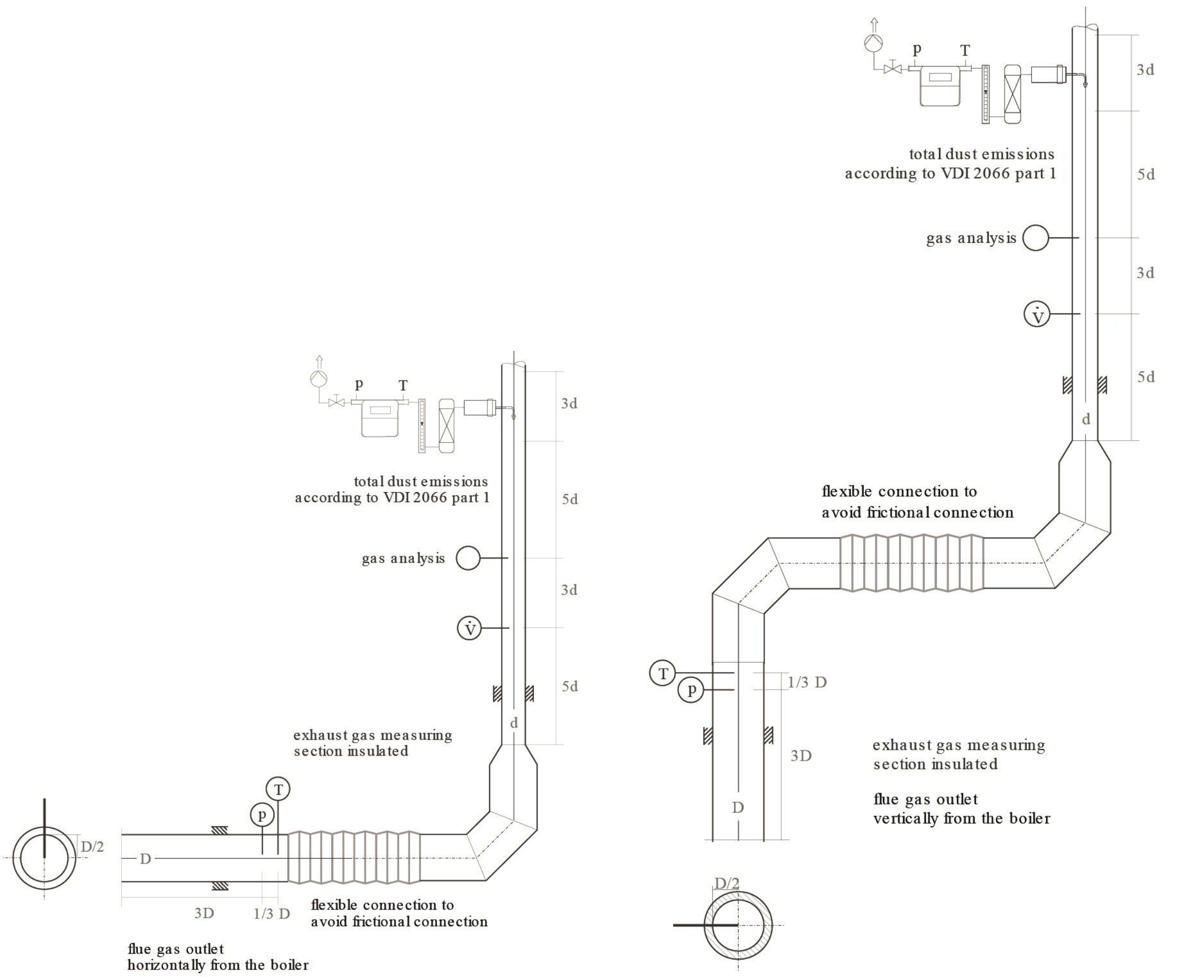


Figure 5: Examples for flue gas measuring sections: Connection socket either at the back (left) or on top of the boiler (right) of the boiler. D = diameter of connection socket, d = diameter of measuring section, p = chimney draught, T = flue gas temperature, $\dot{V}$ = flue gas volume flow.

It may be necessary to reduce the diameter of the measuring section (i. e. below the diameter of the boiler's flue gas socket) in order to increase the velocity of the flue gas flow and thus to achieve a better accuracy of flow meter measurements. Such tapering, however, shall not cause any hindrance for the easy installation and disassembly of the particle sampling units and other measuring devices (e. g. flow rate measuring instruments). No measurements by way of extraction shall be taken upstream of the measuring point for the determination of the volume flow rate, since this would affect the measurement of flue gas flows.5 The flue gas measuring section should be completely encased for insulation with

[4] Pre-tests showed that a temperature-resistant textile hose has proven to be an appropriate solution for this purpose.

[5] An extraction of flue gas would reduce the volume flow of the remaining gas in the measuring section and lead to wrong results.

a 40 mm layer of mineral fibre material (thermal conductivity: 0.035 W/(m·K)) or similar materials. The connecting piece should be encased with the same thermal insulation material used for the measurement section.

For the determination of the chimney draught, a pipe with an inner diameter of 6 mm should be inserted in the flue gas measuring section, as specified under EN 304:2018 [21]. Controls for the adjustment of the draught system should be installed in order to maintain a constant chimney draught (e. g. exhaust fan controls). The chimney draught at the measuring point shall be set according to the boiler manufacturer's specifications. If corresponding specifications are not available, the required chimney draught shall be specified according to EN 303-5:2021 [23].

The chimney draught shall be controlled during the complete Load Cycle Test. The actual chimney draught should not deviate by more than max. ± 3 Pa on average from the rated value specified according to EN 303-5:2021 [23].

Flue gas temperature shall be determined continuously in accordance with EN 304:2018 [21].

The flue gas volume flow rate can be measured either directly or by measuring flue gas velocity and calculating the nominal volume flow rate. Depending on the applied device, the measurement of flue gas temperature and atmospheric pressure, as well as other values at the point of measurement, may additionally be considered to enable the determination of the standard volume flow (in m^3/h). It shall be ensured that the selected test equipment is capable of determining flue gas velocities as low as 0.5 m/s and that the utilized equipment meets the accuracy requirements in accordance with section 4.7 under operating conditions with very low flue gas velocity.

The analysis of the flue gas components CO, O_2, CO_2, H_2O, NO_X and OGC (organic gaseous carbon) shall be performed continuously. For data evaluation, OGC values shall be converted to C1 equivalent values, corresponding to DIN EN 12619:2013 [8].[6]

[6] Conversion and reporting of C1 values is essential to provide the data in a correct format for uniform data evaluation.

Carbon balance criterion:

The total deviation of all carbon input to all carbon output shall not exceed 5 % in each Load Cycle Test.

The total carbon which is released to the gas phase or remains as residue in the ash shall be equal to the total carbon input via the fuel. Deviations are due to inaccuracies along the measurement process. In order to assess the overall accuracy and data quality of each Load Cycle Test, a carbon balance calculation is introduced as a novel quality criterion.

Several individual measurement parameters contribute to the total deviation from a perfect carbon balance. These parameters are fuel analysis (carbon and moisture content), fuel consumption, flue gas analysis (CO_2, CO, OGC, H_2O), flue gas volume flow and temperature. Other minor parameters can be neglected: inorganic and unburnt carbon in the ash residues and inorganic and unburnt carbon in particle emissions.

The equation for calculating the carbon balance is given in section 6.7.3.2.

The volume flow extracted for PM sampling shall be proportionally (preferably in an isokinetic way) controlled in relation to the nominal flue gas volumetric flow rate throughout the whole measuring cycle. Continuous sampling can be performed through alternating operations of two PM sampling devices arranged in tandem. If only one sampling unit is available and the load threshold of the filtration medium has been exceeded, it is also possible to perform a quick change of filtration media during phases of constant boiler operation. In this case, interruptions may not exceed 4 % in total of the overall sampling duration. The PM sampling installation shall be configured in accordance with VDI 2066-1 [27] or EN 13284-1 [20]; i. e. the required sampling temperature is (180 ± 10) °C. The same temperature7 shall also be applied for filter pre- and post-conditioning. Drying shall be done for a minimum of 1 hour and desiccator cooling for a minimum of 8 hours.

The suction of PM samples is done at the centre of the cross-section of the measurement section. If there is a lower limit for the volumes which can be extracted by the measuring device, the minimum amount will be extracted continuously from this point forward. The selection of the appropriate nozzle diameter can be a useful measure to adapt to phases with higher or low flue gas velocity. If flue gas flow is below the measurement range of the used metering device, measurement shall be continued at the flue gas flow that corresponds to the threshold value of the device.

According to EN 13284-1 [20], the probe shall be rinsed once, i. e. after the Load Cycle Test is completed.

[7] The sampling temperatures of OGC and particles shall be equal to prevent that any organic substances can be determined twice, i.e. in solid and in volatile phase.

4.7 Measuring accuracy

The applied measurement devices shall be selected in such a way that the requirements concerning uncertainty of measurement (Table 2) are met.

The demand for electric power during start, stand-by and normal operations is to be determined in accordance with DIN EN 15456:2008 [7]. The boiler circulation pump (if installed, see 4.2 for hydraulic configuration) serves the heat distribution. Thus, the energy consumption of the circulation pump shall not be considered when determining the auxiliary electric power. Similarly, the energy consumption of the external feeding system (e. g. fuel supply container for wood chips) shall not be considered as auxiliary energy demand.

Table 2: Maximum uncertainty of measurement of the test method

Measurement value	Unit	Max. uncertainty of measurement or range
Atmospheric pressure	mbar	± 10 mbar
Ambient temperature	°C	± 1 K
Flue gas water vapour content	vol-%	± 0.5 vol-%
Flue gas temperature	°C	± 1 K
Chimney draught (static pressure)	Pa	± 1 Pa
Flue gas volume flow	m^3stp/s	± 10 % for the lowest recorded value
Min. measurement range of flue gas velocity	m/s	max. 0.5 m/s
CO concentration	ppm	± 10 % of measured value but with a maximum of ± 10 ppm at a measuring range of 500 ppm; ± 45 ppm at a measuring range of 3,000 ppm
O_2 and CO_2 concentration	vol-%	± 5 % of measured value but max. ± 0.4 vol-%
NO_X concentration	ppm	± 5 % of measured value but max. ± 15 ppm
OGC concentration	ppm	± 10 % of measured value but max. ± 5 ppm
Particle concentration	mg/m^3	± 15 % of measured value but max. 10 mg/m^3
PM sampling gas volume flow		Suitable to fulfil the flue gas velocity requirement above
Fuel mass	kg	± 0.2 % of the total fuel consumption
Generated heat output	kW	± 1.5 % of measured value
Auxiliary electric power (active power)	W	± 1.0 % of measured value
Water volume of the boiler	L	± 1 %

5 Requirements on test fuel properties

5.1 Wood pellets

The properties of pellet fuels were defined according to EN*plus* certification [24] or within the ISO 17225-2 [3]. Further limitations are based on pre-tests during the development process of the Load Cycle Test method, see Table 3. The energy density (bulk density multiplied by net calorific value of the fuel) may require an adaption of the boiler settings regarding fuel supply and fuel-to-air-ratio (depending on control strategy). This affects the transient behaviour of the combustion appliance in particular. Quality-related parameters (ash content, content of fines, K, Si) were defined to eliminate the fuel-related influence on the combustion process and the release of emissions.

Table 3: Properties of pellet test fuel, d = dry basis, ar = as received

Parameter	Standard	Unit	Range of value
Diameter	ISO 17829:2016 [13]	mm	6 ± 0.5
Distribution of length	ISO 17829:2016 [13]	mm	< 20 m-% ≤ 10 mm
Ash content	ISO 18122:2015 [16]	w-%, d	0.2 … 0.45
Moisture content	ISO 18134-1:2015 [12]	w-%, ar	5 … 10
Mechanical durability	ISO 17831-1:2015 [11]	w-%, ar	≥ 99.0
Content of fines	ISO 18846:2016 [17]	w-%, ar	< 0.5
Ash deformation temperature (DT)	ISO 21404:2020 [22]	°C	≥ 1,300
Net calorific value	ISO 18125:2017 [19]	kWh/kg, ar	≥ 4.8
Bulk density	ISO 17828:2015 [14]	kg/m^3, ar	660 … 720
Particle density	ISO 18847:2016 [18]	kg/dm^3, ar	≥ 1,250
Nitrogen content	ISO 16948:2015 [9]	w-%, d	≤ 0.15
Potassium content	ISO 16967:2015 [10]	mg/kg, d	≤ 500
Silicon content	ISO 16967:2015 [10]	mg/kg, d	≤ 300

5.2 Wood chips

The fuel quality of wood chips varies strongly depending on raw material and as-delivered condition. Thus, properties of the test fuels were further limited to reduce the effect on the combustion process. The basis for these limitations are combustion tests and a resulting sensitivity analysis.

Table 4: Properties of wood chips test fuel, d = dry basis, ar = as received

Parameter	Standard	Unit	Range
Origin and source	ISO 17225-1 [2]	-	1.1.3.2 and 1.2.1.2 (coniferous with bark) and 1.2.1.3 (Broad-leaf without bark) and 1.2.1.4 (coniferous without bark)
Particle size 1*	ISO 17225-4:2021 [4]	mm	P31s; additional requirement: ≤ 40 w-% < 16 mm
Particle size 2*	ISO 17225-4:2021 [4]	mm	P45s; additional requirement: ≤ 40 w-% < 31 mm
Content of fines	ISO 17827-2:2016 [15]	w-%, ar	≤ 5
Ash content	ISO 18122:2015 [16]	w-%, d	≤ 1.0
Moisture content 1*	ISO 18134-1:2015 [12]	w-%, ar	≥ 10 to ≤ 25
Moisture content 2*	ISO 18134-1:2015 [12]	w-%, ar	≥ 30 to ≤ 45
Nitrogen content	ISO 16948:2015 [9]	w-%, d	≤ 1.0
Net calorific value	ISO 18125:2017 [19]	kWh/kg, ar	≥ 4.7

- * Particle size and moisture content shall be chosen by the boiler manufacturer.

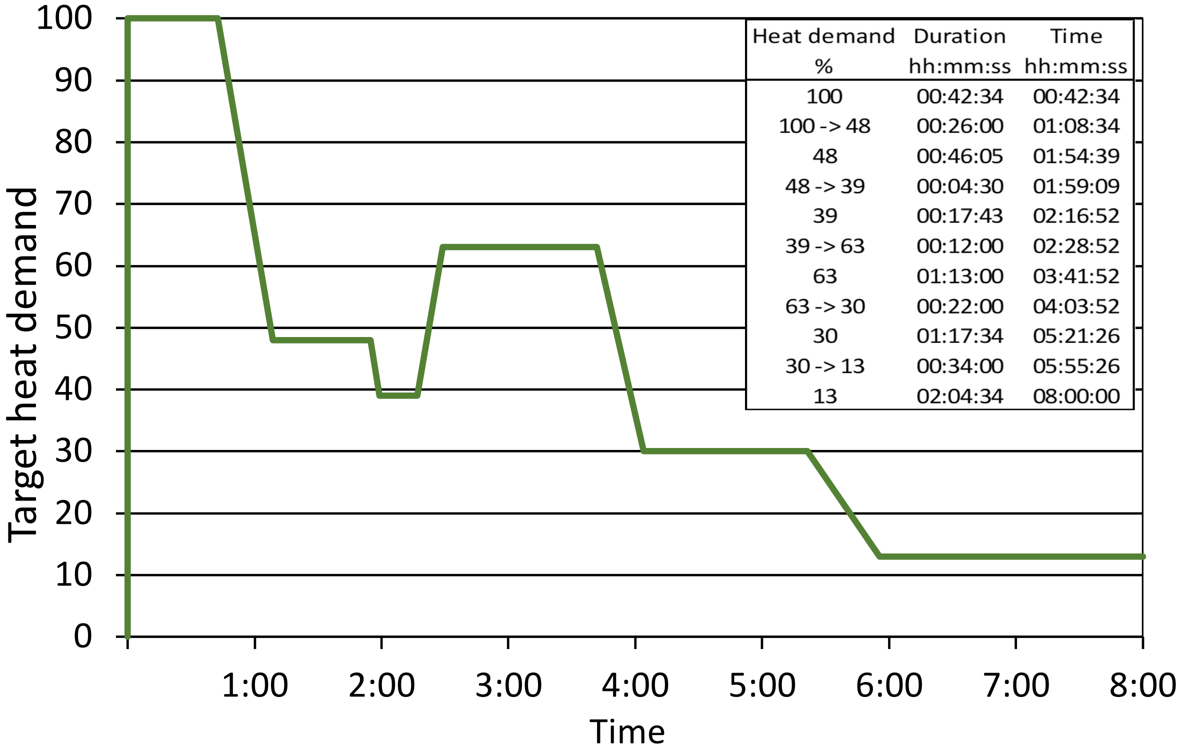
5.3 Required fuel analysis data

In addition, the compilation of an energy balance requires a fuel analysis with regard to moisture content [12] and carbon and hydrogen content by way of CHN analysis [9].

6 Test procedure

6.1 Standard load pattern

During the Load Cycle Test, the boiler's heat output shall follow a standard load pattern representing a varying heat demand. The Load Cycle Test is based on reference load profiles as provided by VDI 4655:2019 [28]. The standard load pattern is presented in Figure 6, where 100 % utilization of boiler capacity is equivalent to the nominal heat output of the boiler specified by the manufacturer.



Heat demand %	Duration hh:mm:ss	Time hh:mm:ss
100	00:42:34	00:42:34
100 -> 48	00:26:00	01:08:34
48	00:46:05	01:54:39
48 -> 39	00:04:30	01:59:09
39	00:17:43	02:16:52
39 -> 63	00:12:00	02:28:52
63	01:13:00	03:41:52
63 -> 30	00:22:00	04:03:52
30	01:17:34	05:21:26
30 -> 13	00:34:00	05:55:26
13	02:04:34	08:00:00

Figure 6: Standard load pattern of the Load Cycle Test method (without 12 hours of standby phase)

6.2 Boiler condition and settings

The type label shall indicate the nominal load of the boiler as declared by the manufacturer. The boiler shall be prepared according to the manufacturer's specification and the pre-use time of the boiler shall be 20 hours minimum before performing a Load Cycle Test. Prior to the Load Cycle Test, the boiler (grate, combustion chamber, and heat exchanger) shall not be cleaned to avoid resuspension of ash and residues.[8]

[8] Some boilers are designed to use the formed bottom ash to seal the ash container and to use the formed grate ash to improve ignition behaviour.

The heat exchanger of a condensing boiler shall be rinsed with fresh water prior to the test. To avoid differences in mass caused by refilling or evaporation, care shall be taken that the filling level of any condensate containers is equal before and after the test. Determination of the amount of condensate is not necessary.

When performing the Load Cycle Test, the boiler controls shall be set to a temperature of 70 °C (for conventional boilers) or 50 °C (for condensing boilers) (see section 4.5) or higher.

Setpoint Temperature Criterion

Flow temperature at boiler exit (TBF) shall remain above the setpoint temperatures over a minimum of 60 % of the duration of the test for all hydraulic configurations (i. e. direct connection, hydraulic separator, or accumulator storage tank).

Flow temperatures at boiler exit are:

- 70 °C for conventional boilers.
- 50 °C for condensing boilers.

For the calculation, see section 7.3.4.

The method development process has shown that there is a considerable effect of specific control settings (hysteresis, shut down criteria as boiler temperature, flue gas temperature, inertia of control parameters, etc.) on the transient behaviour. The control settings shall be chosen by the manufacturer.

6.3 Procedure of the Load Cycle Test

The boiler should be tested in the condition and configuration as intended for normal use. Operating and assembly instructions shall be followed. All phases and associated times of the Load Cycle Test are defined in Table 5 and visualized in Figure 7 and Figure 8.

Identical conditions for the initial and final state are a prerequisite for accurate weight measurements.

Reference temperature requirements

At the start and the end of a test, the reference temperature shall be:

- **45.0 °C for conventional boilers.**
- **25.0 °C for condensing boilers.**

The equations in section 7.3.1 define the tolerances in terms of reference temperature. The conformity with this requirement is relevant for the energy and carbon balance.

Adjustment to start temperature: The water in the whole test system needs to be set to a temperature of 45.0 °C for conventional and 25.0 °C for condensing boilers with the assistance of an external source of heat. At the start time of the Load Cycle Test, the circulation pump is switched on and through external heating the boiler is brought to a stable initial starting temperature (t0), with both flow and return temperatures set at 45 °C or 25 °C (for conventional boilers and condensing boilers, respectively). Measurements, i. e. data recording, will be started at this point at the latest. Practical trials have shown that a suitable starting and end point is achieved when the average flow and return temperature is close to 45 °C (or 25 °C) and when the difference between flow and return temperature is below 0.5 K.

Start of load cycle operation: After the required chimney draught has been set by the regulated exhaust fan, the boiler is started simultaneously with the load cycle. Emission measurement and PM sampling shall begin at this point as well. During the heat up phase of the boiler, the external heating device shall be switched on until the boiler's heat production is higher than the test stand's heat losses. Typically, the external heater can be switched off as soon as the flow temperature exceeds 55 °C for conventional or 35 °C for condensing boilers (i. e. 10 K above the initial state).

Load cycle operation: The heat output of the boiler shall follow the standard load pattern of the CycleTest method, according to the profile and the corresponding data given in Figure 6. Water mass flow and temperature spread both shall be set according to section 4.5. The measurement and gas sampling shall be continued during this phase without interruption, if possible, see section 4.6.

Cool-down phase: At the end of the load pattern, the boiler is switched off (t2) and heat transfer is continued until the flow temperature has declined to 55 °C for conventional or 35 °C for condensing boilers (t4). Heat transfer of up to nominal heat output is acceptable. Subsequently, the circulation pump of the heat transfer system (HTS) is switched off.

Measurements of emissions (gaseous and particles) shall be continued until the boiler is in standby mode (t3), which can either be determined by an appropriate message on the boiler's operation display or if the boiler stops its internal fan (which can also be identified if flue gas volume flow drops to a minimum).

Completion of testing: After 12 hours in standby phase (t5), the boiler water needs to be 45 °C for conventional or 25 °C for condensing boilers, reached through further heating up or cooling down, before testing is completed (t6). The determination of mass at this state is required to close the mass and energy balance. Finally, the cleaning process shall be started and residual ashes have to be removed.

Table 5: Definition of time intervals, testing conditions and sequence of test procedures under standard load cycle conditions

Time interval	Testing conditions	Testing operation
t_0	Boiler temperature 45 °C/25 °C for conventional/condensing boiler	Start of boiler and load cycle
t_1	Flow temperature above 55 °C/35 °C for conventional/condensing boiler	Stop of external heating
t_2	End of load cycle, start of cool-down phase	Transfer of usable heat at 100 % of nominal heat output
t_3	Boiler operation stopped	End of emission measurements
t_4	Flow temperature below 55 °C/35 °C for conventional/condensing boiler	Termination of heat transfer, determination of heat loss
t_5	End of 12-hour standby phase	Activation of heat transfer for temperature equalization
t_6	Boiler temperature 45 °C/25 °C for conventional/condensing boiler	End of testing

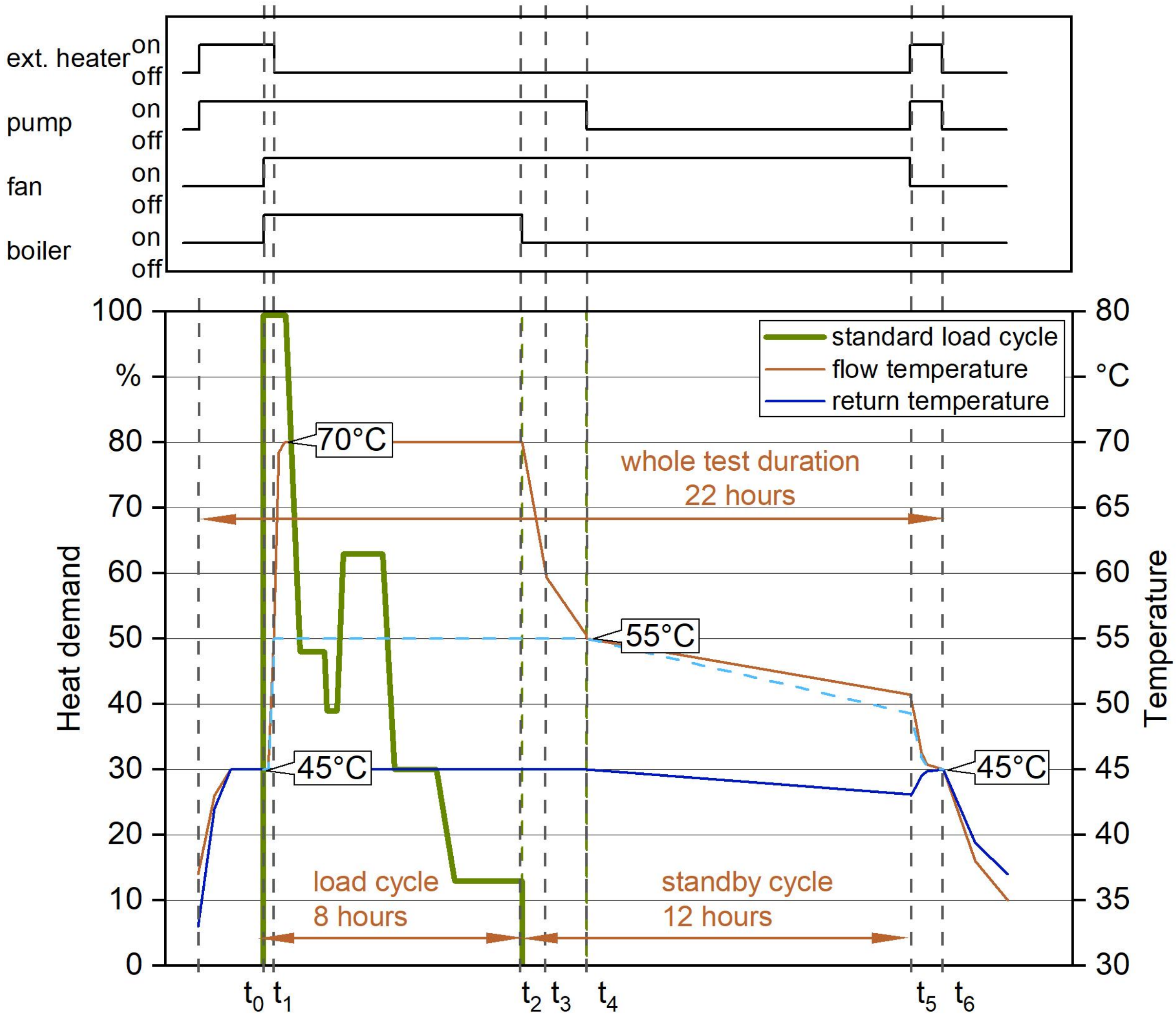


Figure 7: *Flowchart of test sequences during a Standard Load Cycle Test for a conventional boiler*

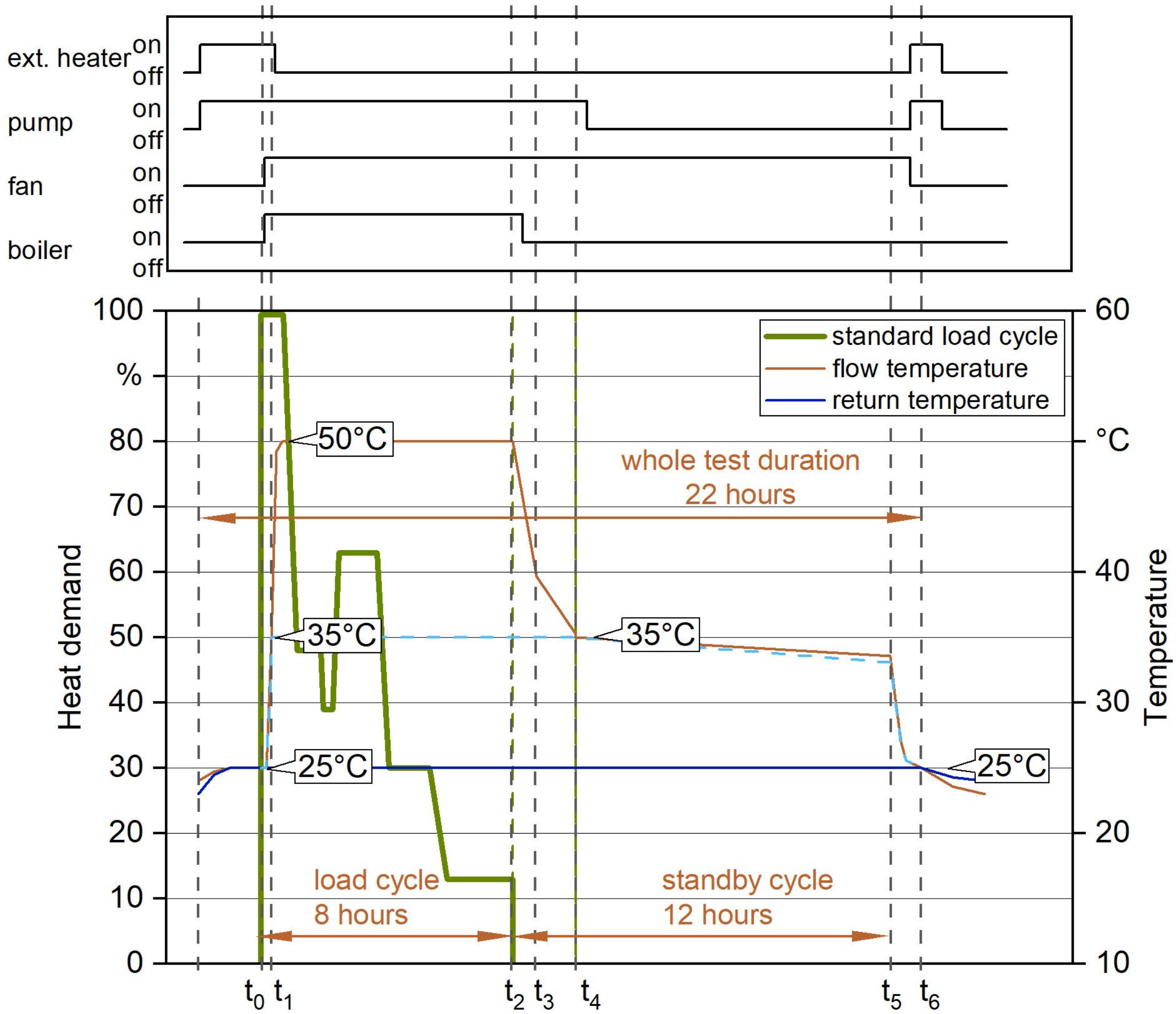


Figure 8: Flowchart of test sequences during a Standard Load Cycle Test for a condensing boiler

6.4 Data acquisition

At least the following measurement values shall be logged/recorded.

Continuous data recording: The following parameters shall be recorded in maximum intervals of 10 s and recorded as mean values at maximum intervals of 30 s. The time intervals are to be chosen in such a way that fluctuations in the measured values are recorded with sufficient accuracy:

- Date and time in DD.MM.YYYY and hh:mm:ss format
- Flue gas composition:
- Oxygen content – dry flue gas
- Carbon dioxide content – dry flue gas
- Moisture content – flue gas

- Carbon monoxide content – dry flue gas
- Nitrogen oxides content – dry flue gas
- C1 equivalent of OGC – moist flue gas
- Flow and return temperature at boiler (if directly connected)
- Flow and return temperature of heat transfer system (when hydraulic separator or accumulator storage tank is installed)
- Mass flow rate of water of heat transfer system
- Flue gas temperature
- Standard volume flow of moist flue gas
- Chimney draught
- Fuel balance (with or without boiler or fuel supply container)
- Heat output
- Auxiliary electric power
- Auxiliary electric power of circulation pump, if installed in boiler
- Ambient temperature

Individual data documentation:

- Atmospheric pressure
- PM emission in flue gas (no reference value for oxygen specified)
- Nominal heat output of boiler (according to type label)
- Used water volume of accumulator storage tank (if applied)
- Lower limit of PM sampling volume flow rate[9]

If the provided evaluation software for Load Cycle Test is applied, the units of the above parameters are specified.

[9] The lower limit is determined by either of two devices: the velocity determination or the lowest possible volume flow rate of the sampling pump. Select the highest of both which shall always be below the required 0.5 m/s (in consideration of temperature range, diameter of nozzle and measuring section).

7 Data evaluation and calculations

Due to the dynamic nature of the Load Cycle Test method, the data evaluation is more complex compared to the evaluation of a combustion test conducted under stationary conditions. The method defines several relevant points in time which are used to define the evaluation periods. These time points are described in section 6.3. Different time intervals are considered for evaluation. Overall, the evaluation includes the calculation of results and computation of quality criteria, which provide information to rate the quality of the measurement. The evaluation itself is performed by importing the logged measurement data into the evaluation software tool (see section 7.4).

7.1 Determination of heat output and boiler efficiency

7.1.1 Determination of fuel mass and fuel energy input

The amount of consumed fuel (m_{fuel}) is calculated based on the change in mass (difference in the total mass, as received, on the balance between the start of the test and the end of the test). To exclude the influence of the change of the density of the boiler water, the boiler shall be tempered prior to and after the test (see section 7.3.1, reference temperature).

Setup A) Fuel supply container on balance

$$\mathrm{m_{fuel}} = \mathrm{m_{t_0}} - \mathrm{m_{t_6}}$$	in kg	1

m_{fuel} Mass of fuel consumed, in kg

m_{t0} Mass of fuel supply container at t_0, in kg

m_{t6} Mass of fuel supply container at t_6, in kg

Setup B) Boiler on balance

When the boiler is installed on a balance, it is assumed that the formed ash remains in the boiler. Thus, the determined amount of consumed fuel shall be corrected.

$$\mathrm{m_{fuel}} = \frac{\mathrm{m_{t_0}} - \mathrm{m_{t_6}}}{1 - \mathrm{a} \cdot (1 - \mathrm{M})}$$	in kg	2

m_{fuel} Mass of fuel consumed, in kg ar

m_{t0} Mass of fuel supply container at t_0, in kg

m_{t6} Mass of fuel supply container at t_6, in kg

a Ash content of the fuel, in kg/kg d

M Moisture content of fuel, in kg/kg ar

Energy supply in the form of fuel (Q_{fuel})

The fuel energy input during the complete test period is calculated based on the mass of the fuel consumed and the net calorific value of the fuel (ar).

$Q_{fuel,NCV} = m_{fuel} \cdot NCV_{ar}$	in kJ	3
$Q_{fuel,GCV} = m_{fuel} \cdot GCV_{ar}$	in kJ	4

- NCV_{ar} Net calorific value of fuel as received, in kJ/kg
- GCV_{ar} Gross calorific value of fuel as received, in kJ/kg

Based on the net calorific value (NCV), the moisture content of the fuel as received and the hydrogen content from the lab analysis of the dry fuel, the gross calorific value (GCV) can be calculated using the following equation:

$GCV_{ar} = NCV_{ar} + \frac{r \cdot 9 \cdot H}{1 - M} + r \cdot M$	in kJ/kg	5

- NCV_{ar} Net calorific value of fuel, in kJ/kg ar
- r Heat of evaporation of water; 2.442 kJ/kg
- H Hydrogen content of fuel, in kg/kg d
- M Moisture content of fuel, in kg/kg ar

7.1.2 Determination of heat output

The usable heat output delivered to the heat transfer system (HTS) is determined by measuring the mass flow of water circulated in the boiler circuit and its temperature increase.

$P_{HTS} = \dot{m}_{H_2O} \cdot Cp_{m,H_2O} \cdot (T_F - T_R)$	in kW	6
$Q_{heat} = \sum_{t_0}^{t_6} (P_{HTS} \cdot \Delta t)$	in kJ	7

- $\dot{m}_{H_2O}$ Mass flow of water, in kg/s
- Cp_{m,H_2O} Average specific heat capacity over temperature range from T_R to T_F, in kJ/(kg·K)
- T_F Exit temperature of water (flow temperature), in °C
- T_R Temperature of water on cold side (return temperature), in °C
- P_{HTS} Power to water released measured at the heat transfer system (HTS), in kW
- Δt Duration of time step of recording, in s

7.1.3 Calculation of nominal annual efficiency (□NEA)

Efficiency. The boiler efficiency in the load cycle operation is calculated as the ratio of energy provided by the hydraulic system and the energy provided as fuel based on its lower heating value. The nominal annual efficiency is then related to the sum of energy supplied as fuel and as auxiliary electric energy consumed. To close the energy balance, the whole test setup including the boiler shall have the same temperature at the beginning and at the end of the Load Cycle Test (= reference temperature, see section 6.3).

Time interval from t_0 to t_6: Determination of efficiency: Mass and energy balance are considered from t_0 to t_6, whereby auxiliary electric energy is only considered during boiler operation and standby, i. e. from t_0 to t_5.

The auxiliary electric energy required by the boiler, e. g. for ignition, forced draught fan or fuel supply is the product of the measured supply of power and the corresponding time interval from t_0 to t_5. Electric power demand for circulation pumps is not taken into consideration.

$W_{el} = \sum_{t_0}^{t5} \left(P_{el} - P_{e.cp}\right) \cdot \Delta t$	in kJ	8

- W_{el} Auxiliary electric energy, in kJ
- P_{el} Measured supply of electric power for operation of the boiler, in kW
- $P_{e.cp}$ Measured supply of electric power of circulation pump, in kW
- Δt Duration of time step of recording, in s

Nominal annual efficiency is calculated on the basis of energy transferred by the water and energy stored in the boiler, as well as energy supplied by fuel and auxiliary electric energy.

$\eta_{NAE,G} = \frac{Q_{heat}}{Q_{fuel,GCV} + W_{el}} \cdot 100$	in %	9

- $\eta_{NAE,G}$ Nominal annual efficiency of the boiler in % (based on GCV)

$\eta_{NAE,N} = \frac{Q_{heat}}{Q_{fuel,NCV} + W_{el}} \cdot 100$	in %	10

- $\eta_{NAE,N}$ Nominal annual efficiency of the boiler, in % (based on NCV)

7.2 Determination of emission factors

Due to dynamic boiler operation and the resulting variation in flue gas volume, emission values cannot be stated as simple average values. They shall be determined as momentary mass flows in relation to flue gas volume flow, based on which the overall mass flow is then aggregated for the complete evaluation period. For the calculation of nominal annual emission factors, the overall mass flow of the measured gaseous components and particle emissions are related to the total amount of energy supplied by the fuel.

Time interval from t_0 to t_3: Determination of emissions: Only considered during time of potential boiler operation, i. e. from t_0 to t_3.

7.2.1 Calculation of aggregated emission load over the Load Cycle (m_{EM})

Emission release is calculated by multiplying the pollutant concentration with the flue gas volume flow, the density of the pollutant at standard temperature and pressure (STP) and the duration of each time interval. CO and NO_X are determined through measurement of the flow of dry flue gas. As the volume flow is determined based on wet flue gas, the values shall be converted from dry STP to wet STP conditions by the factor (1-w_{fg}).

$$m_{Em} = \sum_{t_0}^{t_3} \frac{c_{Em}}{1000000} \cdot \rho_{Em,STP} \cdot \dot{V}_{fg,STP} \cdot \left(1 - w_{fg}\right) \cdot \Delta t \qquad \text{in kg} \qquad 11$$

- c_{Em} Concentration of emission, in ppm (CO, NO_X)
- $\rho_{Em,STP}$ Density of gases emitted under standard testing conditions, in kg/m³
- w_{fg} Water vapour content of flue gas, in m³/m³
- $\dot{V}_{fg,STP}$ Flue gas volume flow at standard temperature (273 K) and pressure (1.013 bar), in m³/s
- Δt Duration of time step of recording, in s

The gas densities (STP conditions) are:

Compound	O_2	CO_2	H_2O	CO	NO_X	SO_2	OGC
□ in kg/m³	1.429	1.977	0.803	1.251	2.054	2.857	0.536

Multiplication with the factor (1-w_{fg}) is not required for gaseous organic carbon, as measurements are taken from the flow of moist flue gas.

$$m_{OGC} = \sum_{t_0}^{t_3} \frac{c_{OGC}}{1000000} \cdot \rho_{OGC,STP} \cdot \dot{V}_{fg,STP} \cdot \Delta t \quad \text{in kg} \quad (12)$$

- c_{OGC} Concentration of organic gaseous carbon, in ppm
- $\rho_{OGC,STP}$ Density of organic gaseous carbon under standard testing conditions, in kg/m³
- $\dot{V}_{fg,STP}$ Flue gas volume flow under standard temperature (273 K) and pressure (1.013 bar), in m³/s
- Δt Duration of time step of recording, in s

Total particulate matter (PM) emissions are already determined as mass concentration. The calculation follows equation 13. All PM filters and the corresponding sampled volume are considered. As PM sampling is conducted based on dry flue gas, the values shall be converted to wet STP conditions by the factor (1-w_{fg}).

$$m_{PM} = c_{PM} \cdot \left(1 - w_{fg}\right) \cdot \dot{V}_{fg,STP} \cdot \Delta t \quad \text{in kg} \quad (13)$$

- c_{PM} Emission of particulate matter, in kg/m³
- w_{fg} Water content of flue gas, in m³/m³
- $\dot{V}_{fg,STP}$ Flue gas volume flow under standard temperature (273 K) and pressure (1.013 bar), in m³/s
- Δt Duration of time step of recording, in s

7.2.2 Calculation of nominal annual emission factors (NAEF)

The nominal annual emission factors (NAEF) are easily applicable key results which illustrate annual boiler emissions. These NAEF indicate the real-life-related performance parameter. They are determined for all measured pollutants (CO, NO_X, PM, and OGC) and are denominated as CO_{NAEF}, NOx_{NAEF}, PM_{NAEF}, and OGC_{NAEF}. In the calculation, the emission loads are divided by the fuel energy input (based on net calorific value, NCV).

$$Em_{NAEF} = \frac{m_{Em}}{Q_{fuel,NCV}} \quad \text{in kg/TJ} \quad (14)$$

- Em_{NAEF} Nominal annual mission factor of each measured pollutant (CO, NO_X, PM, OGC), in kg/TJ
- m_{Em} Determined total mass of measured pollutant emissions (CO, NO_X, PM, OGC) during the Load Cycle Test, in kg
- $Q_{fuel,NCV}$ Energy supply in the form of fuel related to net calorific value (NCV), in TJ

7.3 Assessment of data quality

Several indicators are used to assess the quality of the test. These indicators include criteria that not only describe boiler performance, but also assess the testing infrastructure.

7.3.1 Reference temperature requirements

Identical conditions for the initial and final state are a prerequisite for accurate weight measurements. To fulfil this prerequisite, the system temperature shall be set at a reference temperature of either 45 °C for conventional or 25 °C for condensing boilers (see section 6.3). Compliance with this requirement is determined by considering flow and return temperature before (t_0) and after (t_6) the test. The calculation is done according to equation 14 and equation 15. The requirements are described in equation 16 and 17.

$\mathrm{T_{avg}} = \frac{\mathrm{T_{F,t_0}} + \mathrm{T_{R,t_0}} + \mathrm{T_{F,t_6}} + \mathrm{T_{R,t_6}}}{4}$	in °C	15
$\Delta\mathrm{T_{dev}} = \frac{\left\lvert \mathrm{T_{F,t_0}} - \mathrm{T_{avg}} \right\rvert + \left\lvert \mathrm{T_{R,t_0}} - \mathrm{T_{avg}} \right\rvert + \left\lvert \mathrm{T_{F,t_6}} - \mathrm{T_{avg}} \right\rvert + \left\lvert \mathrm{T_{R,t_6}} - \mathrm{T_{avg}} \right\rvert}{4}$	in K	16

- T_F Flow temperature of water, in °C
- T_R Return temperature of water, in °C
- T_{avg} Average water temperature of test stand setup, in °C
- ΔT_{dev} Average difference of deviations of water temperature of test stand setup, in K
- T_{ref} Reference temperature according to method: 45 °C or 25 °C

The following two requirements for these values are shown below:

Absolute reference temperature criterion:

$$\left\lvert \mathrm{T_{avg}} - \mathrm{T_{ref}} \right\rvert \leq 0.25\ \mathrm{K}$$

Relative reference temperature criterion:

$$\Delta\mathrm{T_{dev}} \leq 0.50\ \mathrm{K}$$

7.3.2 Carbon balance criterion

This criterion is the balance of the mass of carbon supplied by fuel towards the mass of carbon released throughout the flue gas pipe. It is calculated on the basis of the quotient of the sum of carbon in CO_2, CO and OGC released and the total carbon supplied in the form of fuel. It is a good indicator for the quality of measurement because it combines several measurement parameters, including elemental analysis of fuel.

The carbon balance is based on flue gas volume flow and flue gas analysis over the period from t_0 to t_3 and fuel consumption determined over the period from t_0 to t_6.

$$\Delta C = \left(\frac{\left(\frac{m_{CO_2}}{\rho_{CO_2}} + \frac{m_{CO}}{\rho_{CO}} \right) \cdot \rho_{OGC} + m_{OGC}}{m_{fuel} \cdot C \cdot (1 - M)} - 1 \right) \cdot 100 \qquad \text{in } \% \qquad 17$$

- m_{CO_2} Mass of carbon dioxide released during whole test, in kg
- m_{CO} Mass of carbon monoxide released during whole test (see section 7.2.1), in kg
- m_{OGC} Mass of organic gaseous carbon released during whole test (see section 7.2.1), in kg
- m_{fuel} Mass of consumed fuel (see section 7.1.2), in kg
- C Carbon content of the fuel, in kg/kg d
- M Moisture content of the fuel, in kg/kg ar

This criterion shall fulfil the following specification:

$$|\Delta C| \leq 5\ \%$$

7.3.3 Flow deviation criterion

This criterion is used to rate the performance of the heat transfer system. It is a value which describes the proportionality of the water mass flow dynamics towards the variations in the standard load pattern (SLP).

The criterion is evaluated by the average value of the deviations in mass flow from the set value. It is calculated for each time increment as absolute value of the deviation of actual water mass flow to the set value during the standard load pattern between t_0 and t_2.

$\Delta\dot{m} = \left\lvert \frac{\dot{m}_{H_2O} - \dot{m}_{H_2O,SLP}}{\dot{m}_{H_2O,Nom}} \right\rvert \cdot 100$	in %	18

- $\dot{m}_{H_2O}$ Actual water mass flow through heat transfer system, in kg/s
- $\dot{m}_{H_2O,SLP}$ Set value of water mass flow from the standard load pattern (SLP), in kg/s
- $\dot{m}_{H_2O,Nom}$ Water mass flow at nominal heat output, in kg/s

This criterion shall fulfil the following specification:

$$|\Delta\dot{m}| < 2\ \%$$

7.3.4 Setpoint temperature criterion

The time portion of the total time in which the minimum target temperature is met is expressed by the setpoint temperature criterion. Thus, the boiler control set values shall be chosen in such a way that during 60 % of the time during standard load pattern (from t_0 to t_2) the flow temperature is at a minimum temperature of 70 °C for conventional boilers, or at a minimum of 50 °C for condensing boilers.

This criterion shall fulfil the following specification:

$$T_{SP} > 60\ \%$$

7.3.5 General requirements

Draught variation

The setpoint for chimney draught (p_{SP}) shall be specified by the manufacturer. The average value over the whole measurement from t0 to t5 and an average value of the deviation are determined. The deviation of the chimney draught from the set value (see section 4.6) is calculated according to equation 19 and the standard deviation is determined.

$\Delta p = \lvert p_{chimney} - p_{chimney,avg} \rvert$	in Pa	19

- $p_{chimney}$ Actual chimney draught, in Pa
- $p_{chimney,avg}$ Set value of chimney draught, in Pa

The following two performance requirements shall be met:

Chimney draught setpoint deviation:

$$|p_{chimney,avg} - p_{SP}| \leq 3 \text{ Pa}$$

Chimney draught standard deviation:

$$|SD_{dev}| \leq 3 \text{ Pa}$$

Ambient temperature changes

This requirement defines the tolerable changes in ambient temperature (see section 4.1). It consists of an average value over the whole measurement from t_0 to t_5, and an average value of the deviation (equation 20).

$$\Delta T_{amb} = \left|T_{amb} - T_{amb,avg}\right| \quad \text{in °C} \qquad (20)$$

- T_{amb} Actual ambient temperature, in °C
- $T_{amb,avg}$ Mean value of ambient temperature, in °C

The Load Cycle Test shall be performed in the following ambient temperature range:

$$15\ °C \leq T_{amb,avg} \leq 30\ °C$$

PM sampling: Tolerable interruptions

The aggregated period of interruptions between sequential PM samplings may not exceed 4 % of the overall sampling duration.

7.4 Evaluation of measurements using the evaluation software

Analysis of the measurement data is performed automatically using the evaluation software. This software operates based on MS Excel and Visual Basic, with only a few operating procedures being required.

7.4.1 Interpolation of data points

In order to be able to evaluate the actual points in time (t_0 to t_5) of the evaluation cycle, the values for these points in time must be calculated through linear interpolation.

7.4.2 Preparing the evaluation

In order to be able to perform the data analysis, the measurement values must be available in the form of a table in an MS Excel compatible format (e. g. .csv, .asc, .xls, etc.).

The following data are required and must be entered in the table for the evaluation tool in section 7.4.3.

- Date + time in d
- Oxygen content – flue gas in vol-%
- Carbon dioxide content – flue gas in vol-%
- Moisture content – flue gas in vol-%
- Carbon monoxide content – flue gas in ppm
- Nitrogen oxides content – flue gas in ppm
- Optional: sulphur dioxide – flue gas in ppm
- OGC (C1 equivalent) – wet flue gas in ppm
- Flow temperature in °C
- Return temperature in °C
- Flue gas temperature in °C
- Fuel scale (with or without boiler) in kg
- Water heat output in kW
- Water mass flow rate in kg/min
- Standard volume flow – wet flue gas in m^3/h
- Auxiliary electric power consumption in W

If an accumulator storage tank or a hydraulic separator is installed, additional channels are necessary:

- Flow temperature in boiler circuit in °C
- Return temperature of boiler circuit in °C
- Electric power consumption of circulation pump in W

The following data can be entered continuously or in the form of single values for the purpose of evaluation:

- Ambient temperature in °C
- Air pressure in mbar

The following channel can be either entered as continuous values or as a list of values

- Total particle emission in flue gas in mg/m^3

Missing columns should be added (if required), e. g.

- In the case of separate recording of date and time: Insertion of one column giving the sum of date and time (simple addition: value = “date” + “time”)

- In the case of measurements supplied in a different format, the data must be converted to the required unit (attention must be paid to ensure the new column can be recognized in the header)

The table must furthermore indicate references to the channels in the first row, so that appropriate allocations can be made in the evaluation process.

7.4.3 Excel evaluation tool

BEST created an Excel evaluation tool during the research phase of the method development. Upon request, it could probably be made available (currently only in German).

8 Test report

The following documents and information shall be handed over to the test institute:

- Installation and operating manual as well as other relevant documents of the manufacturer,
- Relevant settings for the test stand: Draught, minimum return temperature, etc.
- Relevant settings for the boiler: Boiler temperature, configuration of control system, configuration of accumulator storage tank.

The report shall be issued based on EN ISO/IEC 17025 [6] requirements. The test report shall include at least:

a) Name and address of the test laboratory, name of test engineer, and the location where the tests have been conducted,
b) Identification number of test report,
c) Identification of the boiler (name, type, nominal heat output),
d) Name and address of manufacturer,
e) Picture of boiler on test stand,
f) Note if an accumulator storage was used and give the volume, if applicable,
g) Note which setup was used (with or without hydraulic separator),
h) Mode of determination of fuel consumption (boiler or fuel supply container positioned on a scale?),
i) Specification of test fuel: moisture content, GCV, NCV, CHN analysis and ash content,
j) For wood chips: Chosen particle size (Table 4),
k) Date of testing,
l) Results concerning data quality and test performance:
    a. Reference temperature requirement
    b. Carbon balance criterion
    c. Dynamic mass flow criterion
    d. Setpoint temperature criterion
m) Results with indication of the unit:
    a. Nominal annual efficiency, in %, related to GCV and NCV
    b. Auxiliary energy consumption of total energy input (related to GCV and NCV), in % and in kWh
    c. Nominal annual emission factors (CO, NO_X, OGC, PM), in mg/MJ, related to GCV and NCV,

Any deviation from the requirements from this handbook that occurred during the test shall be documented.

The test report shall be signed by the head of the test station or the test engineer responsible for carrying out the test.

Literature

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