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Annual efficiency and pollutant emission factors of wood boilers

A method for test stand based measurements of annual efficiency and emission factors was developed and tested. It is based on a defined 8-h load cycle operation where heat output and pollutant emissions (CO, NO_x, OGC, SO_2 und total dust) are monitored during continuous flue-gas volume flow measurements. Tests show that a high conformity of nominal and actual load can be achieved. As frequently observed in practise, the load cycle operation leads to about 10 % lower efficiencies and to higher pollutant emissions. The developed method allows a selective and more detailed assessment of biomass boilers. End-users are provided performance data which allow to evaluatate the boiler's capability to adapt to variable loads as prevailing in practice. Thus competition for highest fuel utilization and lowest emissions are enabled. However, validation in practice through comparative field measurements is still required.

Keywords
Annual efficiency, emission factors, wood boiler, load cycle, particle emission

Abstract
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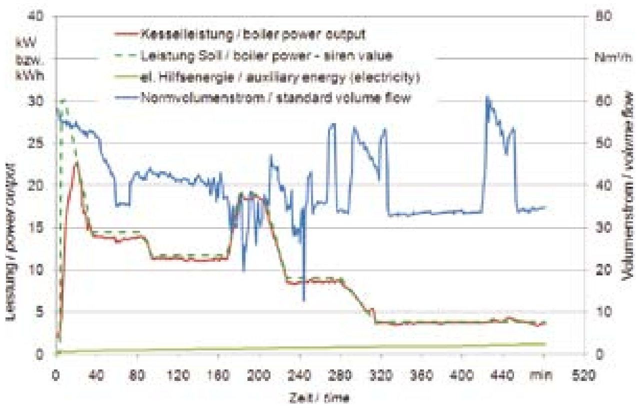
The developed method allows a selective and more detailed assessment of biomass-fuelled boilers. This makes available for end-users performance data allowing evaluation of boiler capability under the variable loads experienced in practice. The competition for highest fuel exploitation and lowest emissions is thus encouraged. Still required, however is validation through comparative measurements under practical conditions.

For determining annual efficiency and emission factors of small-scale biomass boilers on a test stand, a representative standard load measurement cycle and a suitable measurement method were developed [1]. This work took place in cooperation with BIOENERGY 2020+ GmbH, the Francisco Josephinum Higher Federal Education and Research Institute (FJ BLT) in Wieselburg and the Working Group Renewable Energy (Arbeitsgeneinschaft Erneuerbare Energie), Kärnten/Salzburg.

To evaluate phases with low exhaust gas flows according to their respective exhaust gas production over a work cycle, direct measurement of flow is required. For this reason various methods for determining exhaust gas flow were investigated and tested for suitability via error analysis. The selected methods were subsequently adapted for the intended use. Through the now possible volume flow based weighting of the emissions in the variable phases of an eight-hour measurement cycle (e.g. cyclical on/off operation under partial load), the emission totals can be determined as the sum of a typical heating process (**figure 1**).

Fig. 1

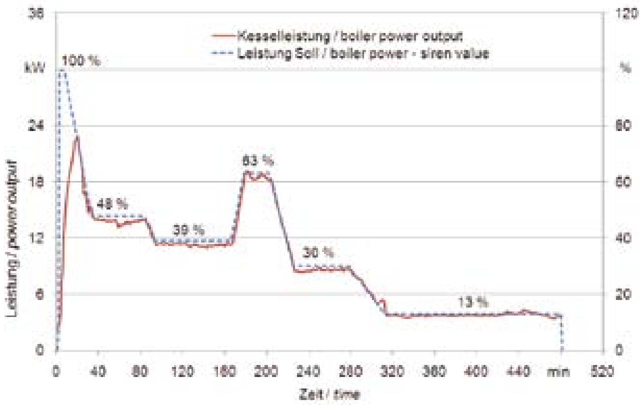


Heat power output, nominal power according to the load profile, electrical energy demand and standard volume flow of a wood chip boiler

Additionally, the dust emissions have to be measured in continuous operation under the load cycle. An automatic isokinetic dust suction system was developed with which several sequential gravimetric dust measurements enabled total dust content to be comprehensively recorded based on working cycles of several hours. The evaluation was also adapted because of the continual variation of exhaust gas volume flow during the load cycle compared with the otherwise standard measurement during constant performance.

The enclosed heat dissipation system on the test stand was further developed as programmable regulated system with time-variable nominal value guidelines, whereby dissipated heat amounts were only adjustable through variation of the return temperature. In this way a very good agreement between nominal and actual performance could be achieved (**figure 2**).

Fig. 2



Annual load cycle profile and realized heat power output with a wood chip boiler

Load cycle method

According to the new-developed test method, standard efficiency is determined by two measurements: One by applying the eight-hour standard load cycle which depicts annual load phases, including water heating, representatively in greatly shortened form and the other which requires additional data from an eight-hour recording under full load including heating-up and cooling-down phases. This full load measurement is carried out in the same way as conventional type-testing according to DIN EN 303-5 and differs only through the additional evaluation periods. The annual standard efficiency is calculated from these two measurements whereby also accounted for can be heat storage losses which are dependant on storage volumes. An appropriate method guideline as well as evaluation software were developed with the project partners and made available thus enabling its use by others.

Results of test stand measurements

For developing and testing the method (guideline) and evaluation software, trials were carried out at the TFZ with two automatically-fuelled small-scale biomass boilers, a pellet boiler (plant A) and a wood chip boiler (plant B). The pellet fuelled plant had a nominal output of 27 kW and the chip fuelled 30 kW. The results show that the annual standard emission factors of carbon monoxide and volatile organic bound carbon were higher than with the type-testing. Plant B had, e. g., an annual standard emission factor for CO of 916 mg/MJ compared with 168 mg/MJ at full load measurement. That for organic bound carbon was 54 mg/MJ against 1.8 mg/MJ (**table 1**). The amount of nitrogen oxide in the exhaust gas varied substantially less than results from a full load measurement.

In modulating load cycle operation the boilers showed annual standard efficiencies ($\eta_{modulierend}$) of 73.3 % (plant B) and 81.0 % (plant A). Compared with the recorded efficiency in the full load test cycle (i.e. evaluation including heating-up and cooling-down phases), annual standard efficiency achieved for, e. g., plant B is approx. 9 % less. Because of the multiple firing-up required, the auxiliary energy input (electrical) in intermittent operation with very low load is almost double that of operation with heat storage (buffer). In addition to the amount of heat from the exhaust gas flow, the heat radiation from the boiler itself, even with good insulation, is the most significant

Table 1

Results of type testing measurements and measurements following the developed

		Vollastmessung[2)] *Full load*[2)]		Jahreslastzyklus *Annual load cycle*		Pufferbetrieb[3)] *With water heat storage*[3)]	
		Kessel A *Combustion unit A*	Kessel B *Combustion unit B*	Kessel A *Combustion unit A*	Kessel B *Combustion unit B*	Kessel A *Combustion unit A*	Kessel B *Combustion unit B*
Nutzungsgrad *Efficiency*	%[1)]	-	83	81	73	-	87
El. Hilfsenergie *El. auxiliary energy*	%[1)]			0,9	1,4	-	0,8
CO	mg/MJ	-	168	274	916	-	779
NO_x	mg/MJ	-	112	75	128	-	142
Org. geb. Kohlenstoff *OGC*	mg/MJ	-	1,8	14	54	-	191
Gesamtstaub *Dust*	mg/MJ	-	33	15	55	-	68

[1)] Angabe bezogen auf Brennstoffenergiezufuhr/*Related to fuel energy input*.

[2)] 8 h Volllastbetrieb einschließlich Auswertung der Aufheiz- und Abkühlphase/*8 h full load operation and data evaluation including the heating-up and cooling-down phase.*

[3)] Aus Ergebnissen der Volllastmessungen und Pufferspeicherkenndaten berechnet/*Calculated from results for full load test and heat storage specifications.*

cause of efficacy or efficiency losses. These increase strongly in line with rising boiler temperature which is why in boiler type-testing the average value from storage water pre-temperature and return temperature has to be more than 40 °C above the ambient temperature so that all boilers can achieve comparable conditions. However, the furnace plants react very differently to load changes, which has substantial effects on the resultant efficiency. For this reason adaptability with regard to changing heat dissipation is only seen as a qualitative differentiating characteristic in changing load operation.

Despite this it can be seen that the annual standard efficiency calculated through the new method also represents the maximum, i. e. best possible, results whereby craftsman-like dimensioning of the heating system and regular servicing are assumed. Often in practice, however, neither of these conditions is fulfilled and this must be considered when comparing published results from practical measurements. Further variations in results are possible through electrical energy input often not being taken account of in practical tests.

Conclusions

The test results show that the developed method allows a selective and more precise assessment of biomass boilers under near-practical conditions without losing at the same time the advantages of replication possibilities at the boiler test stand. The boiler manufacturers are thus presented with a tool which gives more information on respective product quality, with further optimisation possibilities. With the results from this method, end-users and operators of furnaces get important criteria for assessing quality, establishing on a more solid and realistic basis the competition towards collecting the best environmental and efficiency data. For validation of the method further tests and comparative practical measurements must be carried out.

Literature

[1] Schwarz, M. (2010): Leitfaden zur Bestimmung von Jahresnormnutzungsgrad und Emissionsfaktoren am Prüfstand. Bioenergy 2020+, Wieselburg, Österreich, unveröffentlicht

Authors

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