

REGULATED EMISSIONS AND EFFICIENCY OF HEATING BOILERS FOR SOLID BIOFUELS OF NOMINAL HEAT OUTPUT UP TO 30 kW

Summary

Effective and environmentally friendly utilization of suitable solid biofuels requires introduction of modern mechanization evaluated on basis of severe and measurable ecological demands. The study presents results of measuring of emissions O_2 , CO_2 , CO , NO_x , C_xH_y during combustion of wooden pellets, billet poplar wood and wheat energy corn in the monitored prototypes of hot-water boilers with manual and automated fuel supply. For these devices with nominal heat output of 30 kW was simultaneously determined the heat effectiveness.

Introduction and purpose of the work

The energy utilization of renewable raw materials contributes to the climate protection and fossil resources savings. Besides this the connected activities represent significant possibilities for generation of local activity and working opportunities and thus to be an important contribution to the sustainable forestry and agriculture. Permanent introduction of biomass energy utilization must be connected with the modern mechanization application which is environmentally friendly [1-5]. As the central instrument are specified severe ecological requirements for the combustion devices operation to ensure effective conversion of energy with minimum content of emissions. Appropriate legislation regarding the protection against emissions and standards has to reflect the mechanization state for emissions reduction and quality of utilized solid biofuels [6, 7]. The purpose of this work is to evaluate the emissions limited values, heating effectiveness during the billet poplar wood, wood pellets and energy wheat corn for the hot-water boilers prototypes with nominal heat output of 30 kW.

Approach

For the hot-water boilers prototype with automated (see Fig. 1, 2) and manual (see Fig. 3) supply of solid biofuels the scope is to determine and evaluate CO_2 , O_2 , CO , NO_x , C_xH_y and heating values. The measuring was carried-out in accordance with standard ČSN EN 303-5 [6]. The tests were conducted by using measuring and testing devices with valid calibration CO_2 , O_2 , CO and NO_x with measuring deviation: $\pm 0,5\%$ and C_xH_y : $\pm 1\%$ of the range of measuring. The measuring uncertainty of tenzometric bridge carrier is $\pm 1\%$, analytical weight ± 0.0001 g and barometer $\pm 0,1$ kPa.

Nominal heat output of the automated boiler Pelling 27 (see Fig. 1) is 25 kW. A suitable fuel for this boiler is the wooden pellets of diameter 6-10 mm and length max. 30 mm. The fuel is stored in the fuel container where is discontinually transported from to the combustion chamber by means of the auger conveyor. In the combustion chamber is placed the ceramic board stabilizing burning, cast iron and retort burner. The burner consists of mixer and cast iron elbow. In the mixer occurs blending of the combustion air, supplied by ventilator, with fuel.

The burner of the boiler Verner A 25 of nominal heat output 25 kW of wooden pellets combustion and 18 kW of wheat energy corn combustion consists of the steel body with high-quality ceramic block lining (see Fig. 2). The side blocks of the burner are fitted by the holes for secondary air input. The primary air is supplied to the fuel by the gaps in the grate. The ceramic block is fitted by the hole of the ignition air. The combustion space bottom consists of the grate fitted by 6 moveable fire bars. The fire bars motion occurs in adjustable intervals by the electric motor reverse run.

The determined fuel for the boiler Atmos DC 25 GSE (see Fig. 3) is the billet wood or biofuels briquettes. The boiler nominal output is 25 kW. In the upper part of the boiler body is the fuel hopper fitted in the bottom by the refractory ceramic block with longitudinal hole for combustion products and gases passing through. In the boiler bottom is after-combustion space equipped again by the refractory ceramic block. In the boiler back part is a vertical channel for combustion products, fitted by the ventilator for regular discharging of the combustion products to the chimney. In the back part of the boiler is also primary and secondary air input and their distributing channel where the both types of air are heated to high temperature. For the safety reason the boiler is equipped by the integrated cooling exchanger.

The boiler efficiency η_k is determined by the direct and indirect method. In the direct method the boiler efficiency is determined by

$$\eta_k = \frac{Q}{Q_B} \cdot 100 \quad (\%) \quad (1)$$

where:

Q is the boiler heat output (kW)

Q_B is the boiler heat input (kW).

In the indirect method the boiler efficiency is given by:

$$\eta_k = 100 - q_A - q_U - q_S - q_B \quad (\%) \quad (2)$$

where:

q_A is the loss through sensible heat of the products of combustion (values relative to the heat input)

q_U is the loss through incomplete combustion (values relative to the heat input)

q_S is the loss through radiation, convection and conduction (values relative to the heat input)

q_B is the loss through unburned fuel in ash (values relative to the heat input).

By the standard [6] for the nominal heat output and the most severe class 3 of the boiler must not be less than

$$\eta_k = 67 + 6 \log Q_N \quad (\%) \quad (3)$$

where:

Q_N is nominal heat output (kW).

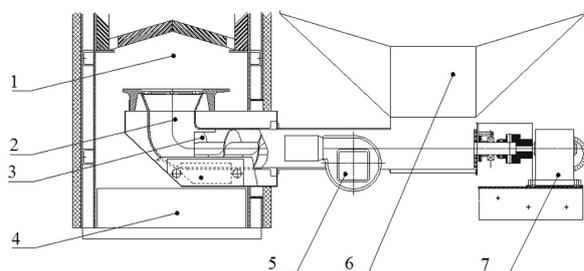


Fig. 1. Scheme of combustion system with bottom fuel supply (Pelling 27): 1 - combustion space with ceramics, 2 - retort burner, 3 - fuel auger conveyor, 4 - ash hopper, 5 - burning air ventilator, 6 - fuel container, 7 - electric motor with gear box

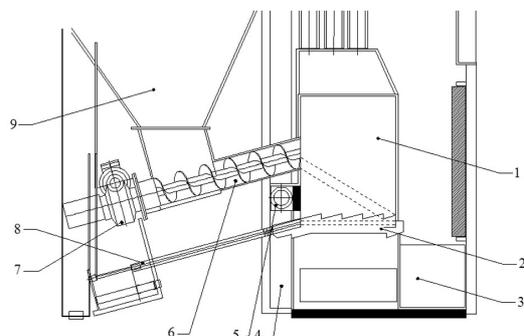


Fig. 2. Scheme of combustion system with self falling fuel supply (Verner A 25): 1 - combustion space with burner, 2 - grate bar, 3 - ash hopper, 4 - burning air ventilator, 5 - heating bar, 6 - fuel auger conveyor, 7 - electric motor with gear box, 8 - grate bars drive, 9 - fuel container

Scientific innovation and relevance

Determination of heat-technical parameters, gaseous emissions of O_2 , CO_2 , CO , NO_x , C_xH_y and their comparison in the three systems of the hot-water boilers of nominal heat

output of 25 kW during combustion of billet poplar wood, wooden pellets and wheat energy corn. Acquisition of initial basis for research and development of similar boilers allowing ecological and effective combustion of other standardized biofuels from biomass.

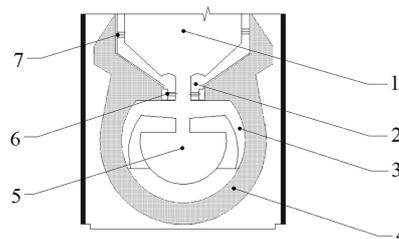


Fig. 3. Scheme of gasification combustion space with manual feeding of billet wood and bio-fuel briquettes (Atmos DC 25 GSE): 1 - space for fuel, 2 - refractory shaped piece with nozzles, 3 - combustion products off take, 4 - combustion products exchanger - water, 5 - after-burning space with ash pan, 6 - secondary air intake, 7 - primary air intake

Results

In table 1 are presented heating analyses of the tested biofuels in the verified boilers.

In table 2 are shown measured and calculated values of the tested boilers heat balance.

Table 3, 4, 5 comprise measured and converted values of O_2 , CO_2 , CO , C_xH_y and NO_x emissions for verified boilers with presentation of achieved heat output and biofuel consumption. In accordance with the standard [6] are conducted conversions for $O_{2V} = 10\%$, $O_{2V} = 13\%$ (deviation for Germany and Switzerland), for values of $mg.MJ^{-1}$ (deviation for Austria). For the combustion device with manual biofuel supply and heat output ≤ 50 kW are for the most severe class 3 the limit values $CO = 5000 mg.m_N^{-3}$ ($O_{2V} = 10\%$). For the combustion device with automated supply of biofuel and heat output ≤ 50 kW are for the most severe class 3 the limit values $CO = 3000 mg.m_N^{-3}$ ($O_{2V} = 10\%$) and $OGC (C_xH_y) = 100 mg.m_N^{-3}$ ($O_{2V} = 10\%$).

The standard [6] does not specify the limit values of NO_x emissions. Despite it the verified boilers belong to the category of small resources of pollution, for the medium resources is determined in the Czech Republic limit NO_x $650 mg.m_N^{-3}$ of the referential content of $O_{2V} = 11\%$ during the biomass combustion.

Table 1. Heating analyses of verified biofuels

	Unit	Billet poplar wood	Wooden pellets Ø 8 mm		Wheat energy corn
			No 1	No 2	
Water	% m/m	11,70	6,90	10,73	11,19
Ash	% m/m	0,74	0,10	0,52	1,58
Total carbon	% m/m	43,79	47,42	44,75	40,33
Total hydrogen	% m/m	6,08	5,74	6,36	7,17
Total sulphur	% m/m	0,02	0,01	0,00	0,00
Nitrogen	% m/m	0,16	0,11	0,15	1,96
Oxygen	% m/m	37,50	39,71	37,48	37,76
Gross calorific value	$MJ.kg^{-1}$	17,23	18,90	17,99	16,23
Net calorific value	$MJ.kg^{-1}$	15,61	17,47	16,33	14,39

Table 2. Measured and calculated values of heat balance of tested boilers

	Unit	Pelling 27		Verner A 25				Atmos DC 25 GSE	
		nomin. heat output	min. heat output	nomin. heat output	min. heat output	nomin. heat output	min. heat output	1. burning time	2. burning time
Type of fuel	-	wooden pellets No 1		wooden pellets No 2		wheat energy corn		billet poplar wood	
q _A	%	7,96	5,66	12,57	14,21	16,42	12,11	7,39	7,35
q _U	%	0,10	0,66	0,07	0,78	0,08	0,19	0,02	0,04
q _S	%	2,43	0,38	0,13	0,11	6,69	7,67	0,57	0,57
q _B	%	1,92	5,94	0,58	2,35	0,68	1,81	0,86	0,79
Loss sum	%	12,41	12,64	13,35	17,45	23,87	21,78	8,84	8,75
Boiler efficiency indirect method	%	87,59	87,36	86,65	82,55	76,13	78,22	91,16	91,25
Heat input	kW	28,87	8,57	31,57	9,30	23,30	8,23	28,24	28,62
Heat output	kW	25,82	7,64	26,35	7,30	18,54	6,35	25,29	25,57
Boiler efficiency direct method	%	89,43	89,14	83,46	78,49	79,57	77,16	89,55	89,34
Output / nominal heat output	%	103,28	30,56	105,4	29,2	103,0	35,27	101,16	102,28

Table 3. Value of gaseous emissions during combustion of wooden pellets No 1 (see table 1) in prototype of automated boiler Pelling 27

	O ₂ (% v/v)	CO ₂ (% v/v)	CO (ppm)	C _x H _y (ppm)	NO _x (ppm)	CO		NO _x		C _x H _y	
						O _{2V} =10% (mg.mN ⁻³)	^{+) (mg.MJ⁻¹)}	O _{2V} =10% (mg.mN ⁻³)	^{+) (mg.MJ⁻¹)}	O _{2V} =10% (mg.mN ⁻³)	^{+) (mg.MJ⁻¹)}
Heat output 25,82 kW , pellets consumption 5,95 kg.h⁻¹											
Aver.	5,9	14,3	235	11	100	211	98	150	70	6	3
Max.	7,6	16,6	1553	86	110	1242	-	-	-	40	-
Min.	3,4	12,9	119	5	88	107	-	-	-	3	-
Heat output 7,64 kW , pellets consumption 1,77 kg.h⁻¹											
Aver.	11,6	8,7	919	72	60	1400	665	144	68	63	30
Max.	15,1	13,7	3006	392	85	6124	-	-	-	492	-
Min.	6,1	5,3	427	26	30	506	-	-	-	19	-

⁺ Related to the used fuel heating value

Table 4. Value of gaseous emissions during combustion of wooden pellets No 2 (see table 1) and energy wheat in prototype of automated boiler Verner A 25

	O ₂ (% v/v)	CO ₂ (% v/v)	CO (ppm)	C _x H _y (ppm)	NO _x (ppm)	CO		NO _x		C _x H _y	
						O _{2V} =10% (mg.mN ⁻³)	^{+) (mg.MJ⁻¹)}	O _{2V} =11% (mg.mN ⁻³)	^{+) (mg.MJ⁻¹)}	O _{2V} =10% (mg.mN ⁻³)	^{+) (mg.MJ⁻¹)}
Heat output 26,35 kW , pellets consumption 6,96 kg.h⁻¹											
Aver.	10,39	9,83	115	28	84	144	75	-	90	21	11
Max.	16,00	12,24	702	108	97	764	-	-	-	78	-
Min.	8,07	5,05	0	17	45	0	-	-	-	13	-
Heat output 7,30 kW , pellets consumption 2,05 kg.h⁻¹											
Aver.	15,93	4,56	566	74	39	561	774	-	87	72	58
Max.	19,86	11,16	28931	830	83	9151	-	-	-	482	-
Min.	7,42	0,83	0	10	8	0	-	-	-	6	-
Heat output 18,54 kW , energy wheat consumption 5,83 kg.h⁻¹											
Aver.	13,83	6,58	90	17	313	192	94	924	536	19	10
Max.	17,69	10,95	401	25	413	1584	-	1318	-	38	-
Min.	8,83	2,88	15	9	148	29	-	585	-	9	-
Heat output 6,35 kW , energy wheat consumption 2,06 kg.h⁻¹											
Aver.	15,61	4,93	156	14	188	625	217	739	428	26	11
Max.	20,39	9,43	707	20	313	15756	-	1311	-	167	-
Min.	10,96	0,47	30	12	12	67	-	378	-	11	-

⁺ Related to the used fuel heating value

Table 5. Values of gaseous emissions during the billet poplar wood combustion (see table 1) in the boiler prototype with manual fuel supply Atmos DC 25 GSE (see Fig. 3)

	O ₂ (% v/v)	CO ₂ (% v/v)	CO (ppm)	C _x H _y (ppm)	NO _x (ppm)	CO		C _x H _y	
						O _{2V} =10% (mg.m _N ⁻³)	O _{2V} =13% (mg.m _N ⁻³)	O _{2V} =10% (mg.m _N ⁻³)	O _{2V} =13% (mg.m _N ⁻³)
Heat output 25,5 kW , billet poplar wood consumption 6,55 kg.h⁻¹									
Aver.	6,1	14,0	68	7	157	60	44	3	2
Max.	7,6	16,3	2160	57	226	1683	1224	21	15
Min.	3,3	12,3	0	1	113	0	0	0	0

Conclusions

Besides the energy biogenous carriers properties which can be evaluated highly positively from point of view of the climate protection, their extension and utilization could bring negative effects on environment. This has to be reduced. The exception could not be even the combustion devices of low outputs as the hot-water boilers with heat output to 50 kW. The hot-water boilers prototypes measuring of new generation with manual and automated fuel supply of the wooden pellets, billet wood and wheat energy corn combustion has confirmed that the high heat effectiveness can be reached, almost 90% of the billet wood combustion (Atmos DC 25 GSE) and wooden pellets (Pelling 27). At the same time the CO emissions were measured in amount of 1.2% of the limit value (Atmos DC 25 GSE) or 20% of the limit value (Pelling 27 and Verner A 25). With a significant reserve also are fulfilled the C_xH_y emissions. This is important because the CO low-values can be used as indicator of the after-combustion quality due to the hydrocarbon and other products which are imperfectly combusted behave similarly as CO. In comparison with the wood species the NO_x value of the wheat energy corn more that 6-time higher (Verner A 25). This is caused by the nitrogen high content in the fuel. The obtained results are important for proposal of similar heating devices for standardized solid biofuels with even better parameters and combustion process controlling which could bring other emissions reduction.

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