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COMPARISON OF COMBUSTION GAS EMISSION BY LOW POWER BOILERS FIRED BY BIOMASS OBTAINED FROM WOOD – PELLETS

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Key words: wood derived biomass, combustion gas composition, emissivity of low power boilers, furnace structure.

Abstract

This paper discusses the relationship between the furnace structure in low power boilers fired by biomass and the composition of combustion gas emitted to the atmosphere. The emissivity of the boilers was also assessed by determination of a generalised criterial parameter of a boiler evaluation and a ranking of boiler emissivity was drawn up. A significant correlation was found to exist between the content of nitrogen oxides and carbon monoxide in the combustion gas. The carbon dioxide content was also found to affect CO and NO_x content in the emitted combustion gas.

PORÓWNANIE EMISYJNOŚCI SPALIN KOTŁÓW MAŁEJ MOCY OPALANYCH BIOMASĄ DREWNOPOCHODNĄ – PELETY

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Słowa kluczowe: biomasa drewnopochodna, skład spalin, emisyjność kotłów małej mocy, konstrukcja paleniska.

Abstrakt

W artykule zbadano zależności między konstrukcją paleniska w kotłach małej mocy opalanych biomasą a składem spalin emitowanych do atmosfery. Określono również emisyjność badanych kotłów przez wyznaczenie uogólnionego parametru kryterialnego oceny kotła i wykonano ranking emisyjności badanych kotłów. Stwierdzono istotną korelację między zawartością tlenków azotu i tlenku węgla w spalinach. Wykazano również wpływ zawartości dwutlenku węgla w emitowanych spalinach na zawartość CO i NO_x.

Introduction

Owing to the development of technology of renewable energy production, it is possible to use such energy to replenish the national energy balance, in which primary energy accounts for about 95% of the entire energy consumption. There is high energy potential in Poland contained in biomass, which can be used as a substitute for primary fuels. Using biomass for energy production more positively affects the natural environment than primary energy carriers because, according to BIERANOWSKI and PIECHOCKI (2005), each megawatt hour (MWh_{el}) produced from such primary energy carriers as hard or brown coal is accompanied by 15 kg of sulphur dioxide, 7 kg of nitrogen oxides and 150 kg of fly ash emitted to the environment.

The benefits from substituting primary energy with renewable energy have been pointed out by BIERANOWSKI and OLKOWSKI (2007), who claim that by producing biogas from waste biomass in individual farms and by using the biogas for energy production in co-generation, the energy demands of such a farm can be satisfied:

- 27% of the current consumption of primary thermal energy can be replaced – which makes possible the complete substitution of heating oil and coal as well as partial substitution of another renewable energy carrier – firewood;
- energy obtained from co-generation with electrical energy may satisfy the demand for such energy in a selected household. This electrical energy surplus may reach 150% of the energy supplied from the power network and may provide additional income for the household.

Substituting solid fossil fuels with biomass fuels aims at reducing emissions to the atmosphere of noxious gases which are produced during the combustion process. However, the problem of hazardous substances in combustion gas cannot be eliminated by mere substitution of primary energy carriers with biomass. To make biomass combustion more efficient, devices are needed which – owing to their structure – will provide appropriate conditions for complete combustion of the gas and dust produced in the process. Hence, studies have been conducted into the effect of the structure of commercially available heating equipment (low power water boilers) on the combustion gas composition.

Aim of the study

– To examine the effect of the furnace structure in selected low power boilers, fired with biomass (wood pellets) and manufactured in Poland, on the amount of substances emitted in the combustion gas.

– To examine the emissivity of the boilers by determination of a generalised criterial parameter of a boiler assessment and drawing up a ranking of emissivity of the boilers under study.

Object of the study

The nine boilers fired with pellet fuel used in the study are shown in Table 1. The boilers differ in the structure of the burner and the amount of thermal achieved in them. All are equipped with automatic fuel dispensers, which helps to carry out the burning process in a precise manner. In addition, one of the boilers (see Table 1, item 7) is equipped with a lambda probe to precisely regulate the air excess index. The study was based on the results of measure-

Table 1

Characteristics of the boilers under study

No.	Marked in figures as	Boiler manufacturer	Furnace structure	Boiler power (kW)	Type of fuel
1	*A*	Fu-Wi	Grate furnace with drawer, amount of air for combustion – adjusted manually, fuel dispensed automatically.	30	Wood pellets
2	*B*	HKS Lazar	Furnace with rotating retort, amount of air for combustion – adjusted manually, fuel dispensed automatically.	38	Wood pellets
3	*C*	Fu-Wi	Grate furnace with drawer, amount of air for combustion – adjusted manually, fuel dispensed automatically.	15	Wood pellets
4	*D*	HKS Lazar	Furnace with rotating retort, amount of air for combustion – adjusted manually, fuel dispensed automatically.	72	Wood Pellets
5	*E*	Klimosz	Retort furnace, amount of air for combustion – adjusted manually, fuel dispensed automatically.	72	Wood pellets
6	*F*	Klimosz	Retort furnace, amount of air for combustion – adjusted manually, fuel dispensed automatically.	25	Wood pellets
7	*G*	PPH Kostrzewa	Retort furnace, regulation of amount of air for combustion – lambda probe, fuel dispensed automatically.	25	Wood pellets
8	*H*	HKS Lazar	Furnace with rotating retort, amount of air for combustion – adjusted manually, fuel dispensed automatically.	18	Wood pellets
9	*I*	ZGM Zębiec	Retort furnace, amount of air for combustion – adjusted manually, fuel dispensed automatically.	20	Wood pellets

ments made and supplied by Instytut Energetyki (2009). Fuel (wood pellets) of the same quality parameters were used for each of the boilers under study.

Study results

The noxious substances found in combustion gas include mainly:
- sulphur dioxide (SO_2),
- nitrogen oxides (NO_x),
- carbon monoxide (CO),
- polycyclic aromatic hydrocarbons (PAH) (KUBICA 2007).

Due to the type of fuel applied in the boilers under study – wood pellets – sulphur dioxide and PAH were not taken into account for the result analysis as only traces of them are found in combustion gases. The gases were only analysed for the content of CO_2, as well as that of noxious gases, such as CO and NO_x.

The results of measurements carried out by Instytut Energetyki (2009) are presented in Figure 1. The names of boilers on the *X*-axis are replaced with capital letters (*A-I*), referred to in Table 1.

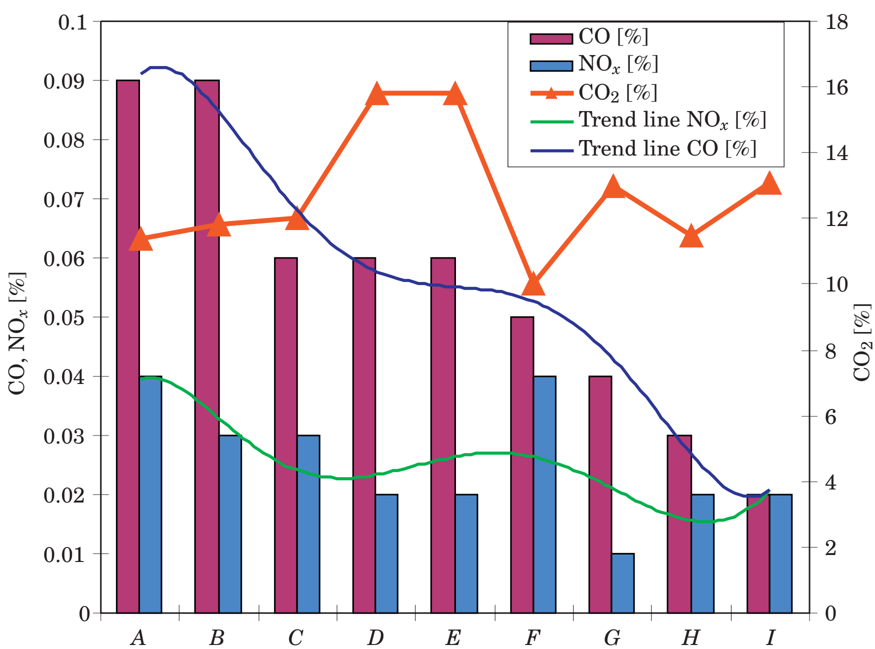

Fig. 1. Comparison of noxious gas emission from the boilers under study, according to the results of Instytut Energetyki measurements (2009)

The diagram in Figure 1 shows that an increase in NO_x content is accompanied by a strong increase in CO content, which is clearly indicated by the trend lines.

ALBERS et al. (2007) claim that too high NO_x content suggests too high temperature in the combustion chamber (>1200°C) and too long time that the air for combustion spends in it, which facilitates formation of so-called "thermal" NO_x. An increase in CO content is favoured by disturbances in the operation of a combustion gas runoff system or an insufficient amount of air supplied for combustion (too low value of λ coefficient).

The desired amount of air for combustion and the maximal reduction of NO_x concentration in combustion gas seems to be ensured by controlling the furnace by a lambda probe. This solution is applied in the *G* boiler furnace.

A significant relationship has also been found to exist between NO_x, CO and CO_2 content in gas combustion – an increase in CO_2 content is accompanied by a decrease in NO_x and CO content (see: *A* and *B* boilers as compared to *C* and *D*).

A ranking of emissivity for the boilers under study was prepared based on the methodology presented below of the generalised criteria parameters of boiler emissivity, as proposed by KUBICA and SZLĘK (2007). In order to determine the parameters, they adopted the energy (thermal) efficiency of the boiler and the level of emission of CO, NO_x and total dust – the substances that pollute the environment. The generalised criteria parameters of a boiler evaluation are calculated from the following formula:

$$O_i = 3.75\ Ws_i + 1.25\ We_i \tag{1}$$

where:

O_i – evaluation criterion index for the *i*-th boiler, where $i \in \{A, B, C, D, E, F, G, H, I\}$,

Ws_i – determinant characterising the efficiency of the *i*-th boiler,

We_i – determinant characterising emission of noxious substances from the *i*-th.

The determinants are described by the following formulae:

$$Ws_i = \frac{\eta_i - \eta_{\min}}{\eta_{\max} - \eta_{\min}},\ Ws_i \in (0,1) \tag{2}$$

$$We_i = \frac{e_{\max} - e_i}{e_{\max} - e_{\min}},\ We_i \in (0,1) \tag{3}$$

where:

η_i – the actual efficiency achieved by the *i*-th boiler, expressed in percentage,

e_i – the actual equivalent emission, expressed in mg/m^3, achieved by the *i*-th boiler at the rated power,

$\eta_{\min}$ – the minimal boiler efficiency, expressed in percentage, below which the boiler is not included in the ranking list,

$\eta_{\max}$ – the maximal boiler efficiency, expressed in percentage, depending on the current state of technology and physical limitations,

$e_{\min}$ – the minimal equivalent emission, expressed in mg/m^3, depending on the current state of technology,

$e_{\max}$ – the maximal equivalent energy, expressed in mg/m^3, which cannot be exceeded due to the standards of environment protection and standards of heating device testing.

The following values for low power water boilers with automatic fuel dispensing were adopted after KUBICA and SZLĘK (2007): $\eta_{\min} = 74\%$; $\eta_{\max} = 92\%$; $e_{\min} = 119$ mg/m^3; $e_{\max} = 518$ mg/m^3.

The actual equivalent emission e_i for the *i*-th boiler is calculated from the following formula:

$$e_i = k_{NO_x} e_{NO_x} + k_{CO} e_{CO} + k_p e_p \tag{4}$$

where:

k_{NO_x} – coefficient of harmfulness of NO_x, determined from the threshold limit value for a workplace, according to current regulations,

k_{CO} – coefficient of harmfulness of CO, determined from the threshold limit value for a workplace, according to current regulations,

k_p – coefficient of harmfulness of total dust, determined from the threshold limit value for a workplace, according to current regulations,

e_{NO_x} – emission of NO_x, expressed in mg/m^3, converted to the comparable oxygen content in combustion gas,

e_{CO} – emission of CO, expressed in mg/m^3, converted to the comparable oxygen content in combustion gas,

e_p – emission of total dust, expressed in mg/m^3, converted to the comparable oxygen content in combustion gas.

The emission of SO_2 is not taken into account in calculations of the actual equivalent emission e_i because it depends on the fuel quality rather than on the boiler structure.

The ranking of emissivity of the boilers under study is presented in Table 2. The position in the ranking is determined by the value of O_i – the generalised criteria parameter of evaluation of the *i*-th boiler.

Table 2

Ranking of emissivity of the boilers under study

No.	Boiler manufacturer	Boiler power (kW)	CO (mg/m³)	NO_x (mg/m³)	η_i (%)	Dust (mg/m³)	Ws_i	e_i	We_i	O_i	Place in the ranking
A	Fu-Wi	30	1125	821.6	88.0	7	0.78	443.89	0.19	3.15	**3**
B	HKS Lazar	38	1125	616.2	74.5	4	0.03	355.73	0.41	0.61	**9**
C	Fu-Wi	15	750	616.2	85.8	6	0.66	325.98	0.48	3.06	**4**
D	HKS Lazar	72	750	410.8	77.8	5	0.21	241.82	0.69	1.66	**7**
E	Klimosz	72	750	410.8	78.0	5.1	0.22	242.02	0.69	1.70	**6**
F	Klimosz	25	625	821.6	82.0	133	0.44	650.89	-0.33	1.25	**8**
G	PPH Kostrzewa	25	500	205.4	87.0	89	0.72	305.16	0.53	3.38	**2**
H	HKS Lazar	18	375	410.8	77.8	1.35	0.21	200.77	0.80	1.79	**5**
I	ZGM Zębiec	20	250	410.8	88.7	94	0.82	374.82	0.36	3.51	**1**

Results and conclusions

1. The greatest effect on CO_2 content in the combustion gas was exerted by the furnaces in the HKS Lazar (72 kW) and Klimosz (72 kW) boilers. As the results and calculations show, the boilers are similar in terms of most parameters.
2. The lowest NO_x content was found in the combustion gas produced in the retort furnace with a lambda probe (the boiler manufactured by PPH Kostrzewa).
3. The lowest CO content was found in the combustion gas produced in the HKS Lazar (18 kW) and ZGM Zębiec (20 kW) boilers.
4. The lowest emissivity was determined for the ZGM Zębiec (20 kW), PPH Kostrzewa (25 kW) and Fu-Wi (30 kW) boilers; the first two are equipped with retort furnaces and the third – with a grate furnace with a drawer.
5. The highest emissivity was determined for the following boilers: HKS Lazar (38 kW) – 9th in the ranking of emissivity, Klimosz (25 kW) – 8th, HKS Lazar (72 kW) – 7th.

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Reference

ALBERS J., DOMMEL R., MONTALDO-VENTSAM H., NEDO H. 2007. *Systemy centralnego ogrzewania i wentylacji. Poradnik dla projektantów instalatorów*. WNT, Warszawa.

BIERANOWSKI J., OLKOWSKI T. 2007. *Koncepcja substytucji energii pierwotnej energią odnawialną z odpadowej biomasy w wybranym gospodarstwie rolnym.* Inżynieria Rolnicza, 7(95): s. 23–30.

BIERANOWSKI J., PIECHOCKI J. 2005. *Program ekoenergetyczny dla województwa warmińsko-mazurskiego na lata 2005–2010*.

Instytut Energetyki. 2009. Wyniki pomiarów udostępnione grzecznościowo przez Instytut Energetyki, Zakład Kotłów i Urządzeń Grzewczych, 93-231 Łódź, ul. Dostawcza 1.

KUBICA K. 2007. *Efektywne i przyjazne środowisku źródła ciepła – ograniczenie niskiej emisji. Poradnik*. Polski Klub Ekologiczny – Okręg Górnośląski, Katowice.

KUBICA K., SZLĘK A. 2007. *Zasady wyznaczania parametru kryterialnego oceny energetyczno-ekologicznej kotłów małej mocy*. Projekt PBR-16/RIE-6/2007 finansowany z NFOŚiGW.