DOI: 10.2428/ecea.2013.20(07)085 ECOL CHEM ENG A. 2013;20(7-8):909-917

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ORGANIC COMPOUNDS EMISSION FROM MODIFIED, BIOMASS FUELED SMALL-SCALE BOILER

EMISJA ZWIĄZKÓW ORGANICZNYCH ZE ZMODYFIKOWANEGO KOTŁA MAŁEJ MOCY ZASILANEGO BIOMASĄ

Abstract: The low emission problem, visible not only in cities but also in agriculture areas, strongly concerns quality of human life and it is connected with small-scall boilers with are heat-suppliers for individual households. The exhaust gases emitted during incorrect fuel combustion process consist mutagenic, genotoxic, irritant and carcinogenic organic substances like volatile organic compounds (VOCs) or polyaromatic hydrocarbons (PAHs). Those substances are dangerous for human health, part of them are very reactive becoming source of secondary pollution, part of them have ability to cumulate in environment. To avoid health problems connected with low emission and toxic organic compounds pollution it is necessary to develop the solutions for non-effective fuel combustion process prevention.

The paper presents the results of research work which aim was investigation of small-scall, biomass fueled boiler modifications in aspect of volatile organic compounds emission reduction. The special catalytic-activated ceramic and metal construction was applied inside the combustion space. VOCs and PAHs in exhausts was determined by Varian 450 gas chromatograph. The results, presented in tables and figures, show that applied modification based on ceramic and ceramic activated fittings change significantly emission characteristic reducing VOCs and PAHs concentration in the exhaust but the changes trends are discussible.

Keywords: small-scall boiler, low emission, volatile organic compounds, inner catalyst

Introduction

The solid, biomass fuel combustion is complicated process that needs to be well controlled to achieve maximal efficiency and low production of toxic gaseous

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pollutants. Small-scale biomass combustion is a specific field of emission regulations issues because of the fact that combustion process in so small reactor is almost impossible to control [1].

The term “small-scale” is often interpreted differently in the literature. Here it is represented by the boilers not exceeding power output of about 50 kW.

Compared to relatively stable coal or oil combustion process in large boilers, small-scale biomass boilers are responsible for higher emission of unburned hydrocarbons, especially volatile aromatic and polyaromatic compounds. Emission limits for those heat sources are also less restrict than for boilers characterized by higher nominal power output (Table 1) [1].

Table 1

Emission limits according to EN-303-5

Nominal power output [kW]	Fuel type: biologic. Fuel feeding: automatic		
	CO	TOC	Particles
	mg/m^3 at 10 % O_2, dry gas, standard conditions		
≤ 50	3000	100	150
50–150	2500	80	150
150–300	1500	80	150

The exhaust gases emitted during incorrect fuel combustion process from small-scall boilers consist mutagenic, genotoxic, irritant and carcinogenic organic substances like volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs). Those substances are dangerous for human health, part of them are very reactive becoming source of secondary pollution, part of them have ability to cumulate in environment [2]. To avoid health problems connected with low emission and unburned hydrocarbons pollution it is necessary to develop the solutions for non-effective fuel combustion process prevention [3, 4].

One of the most important features on field of small-small boilers market is also cost effectiveness. It means that any kind of control system improvement should be done with the lowest possible additional costs [1].

The authors of the article presents the results of research work which aim was investigation of small-scall, biomass fueled boiler low-cost modifications in aspect of volatile organic compounds and polyaromatic compounds emission.

Materials and methods

Research object

Small-scale, 10 kW nominal power output, biomass boiler was applied as an research object. The unit is composed of a circular steel heat exchanger, tubular type of high efficiency and burner, which is designed to combust pellets with a thickness of 6–8 mm, and also cereals (oats) as an additional option.

The geometry and mechanics of the boiler is shown on Fig. 1.

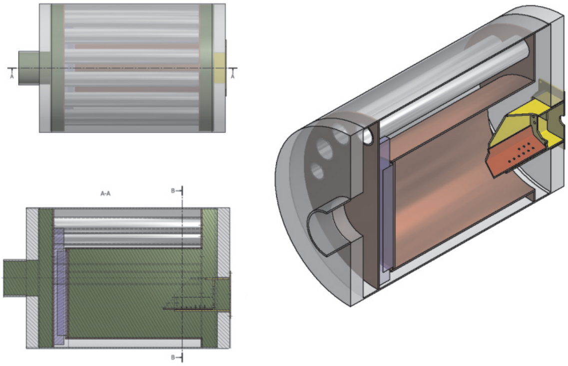

Fig. 1. The geometry and mechanics of the research object

The boiler was located in special-design laboratory equipped with constant heat receiving system in laboratories base of Institute of Machine Design and Operation of Wroclaw University of Technology.

Analytic method

VOCs and PAHs samples were up taken by tubes with active coal (SKC lot 2000). The analysis was done according to polish standard: PN-EN ISO 16017-1: 2006 and Emission Research Laboratory procedures 1/2010 and 2/2010 based on ISO directives. The qualitative and quantitative analysis was proceed on Varian 450 GC gas chromatograph with FID detector and capillary column was used for quantity and quality analysis. Carbone disulfide was used for VOCs, and dichloromethane for PAHs extraction from active coal. The chromatography conditions were: column temperature (110 ^{o}C) for VOCs and 60 ^{o}C up to 280 ^{o}C, dozers (250 ^{o}C) and detectors (250 ^{o}C).

The sampling scheme is presented in Fig. 2.

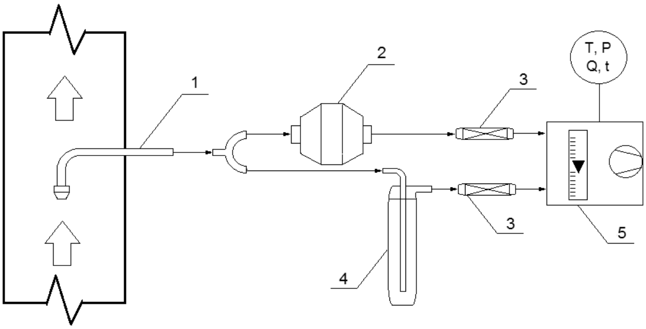

Fig. 2. The geometry and mechanics of the research object, where: 1 – aspiration lead, 2 – PM filter, 3 – active coal tube, 4 – absorption bulb, 5 – aspirator

For on-line measurement of basic exhaust components and combustion performance Kane May-9106 Quintox Upgradeable Combustion Analyser was applied.

Combustion chamber modifications

According to the aim of the research the combustion chamber was modified. The modifications based on applying special steel frame as a ceramic and further active ceramic fittings carrier (Fig. 3).

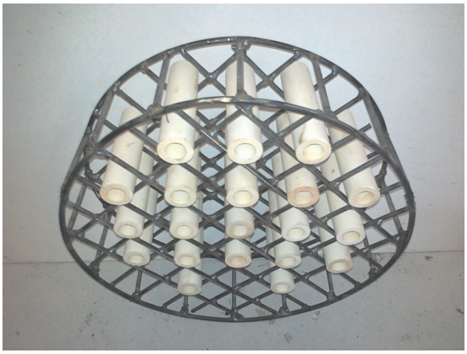

Fig. 3. The frame with ceramic fittings

As an active factor cuprum, manganese and potassium salts (solution of $Cu(NO_3)_2 \cdot 3H_2O$, $Mn(NO_3)_2 \cdot 4H_2O$ and KNO_3) was chosen (separate, laboratory research was provide for catalyst selection) and applied.

The tests was provided on 75 % of nominal boiler power load. As a fuel wooden pellets was applied. Four combustion chamber states was chosen for the research: chamber without any modification ("zero" state), chamber with the steel frame, chamber with the frame and ceramic fittings and chamber with the frame and active-ceramic fittings (Table 2).

Table 2

Combustion chamber states chosen for the tests

Combustion chamber state	Symbol
Chamber without any modification ("zero" state)	I
Chamber with the steel frame	II
Chamber with the frame and ceramic fittings	III
Chamber with the frame and active-ceramic fittings	IV

Results

In Table 3 average value of oxygen, carbon oxides, nitric oxides, sulfur dioxide and total hydrocarbons concentration is presented for all stage of the research.

Table 3

The average value of combustion gases compounds for each stage of the tests

Combustion chamber state	Concentration					
	O_2 [%]	CO [ppm]	CO_2 [%]	NO_x [ppm]	SO_2 [ppm]	C_xH_y [ppm]
I	11.22	583.75	8.94	72.37	36.46	170.73
II	10.71	1063.88	9.61	67.11	52.79	344.34
III	10.43	1178.25	9.70	70.84	63.39	358.22
IV	10.88	1043.32	9.21	70.50	55.84	311.03

It can be seen that combustion chamber modification were disadvantageous for combustion process. This phenomena is caused because of combustion gases flow disturbances effect. Only nitric oxides concentration slightly decrease what was correlated with insignificant decrease in combustion temperature of the process.

To investigate impact of implemented changes on VOCs and PAHs emission the analysis of this compounds was provided.

In Table 4 VOCs concentrations are presented in all chosen combustion chamber state.

Table 4

The VOCs concentration in combustion gases for each stage of the tests (two samples for one stage)

VOC	Concentration [mg/m^3]							
	I		II		III		IV	
	1	2	1	2	1	2	1	2
n-Pentane	2.93	3.38	2.63	2.99	1.69	1.70	4.15	3.62
2-Propanol	81.8	79.3	50.6	91.8	40.5	30.2	35.3	27.1
Benzene	14.2	15.9	0.00	0.00	0.00	4.32	17.7	16.8
2-Butanol	0.00	0.00	0.00	0.00	0.00	0.00	3.95	3.11
Toluene	15.9	17.0	1.29	9.82	0.828	2.62	10.2	9.68
1-Butanol	2.90	2.94	0.243	1.43	0.00	0.00	1.09	3.19
Ethylbenzene	0.00	0.00	0.00	0.00	0.00	0.00	1.94	0.00
Mesitylene	0.189	0.013	0.013	0.123	0.00	0.00	0.359	0.277
Xylene isomers	0.028	0.069	0.00	0.00	0.00	0.00	0.049	0.00
Unidentyfied VOCs	0.112	0.05	0.00	0.00	0.00	0.00	0.327	0.493
Total VOCs	118	119	54.8	106	43.0	38.8	75.1	64.4

According to the achieved results of the analysis the modifications seems to be advantageous in aspect of VOCs emission. The results of the analysis of VOCs group share (average for both samples for each state – Fig. 4) indicates that catalyst

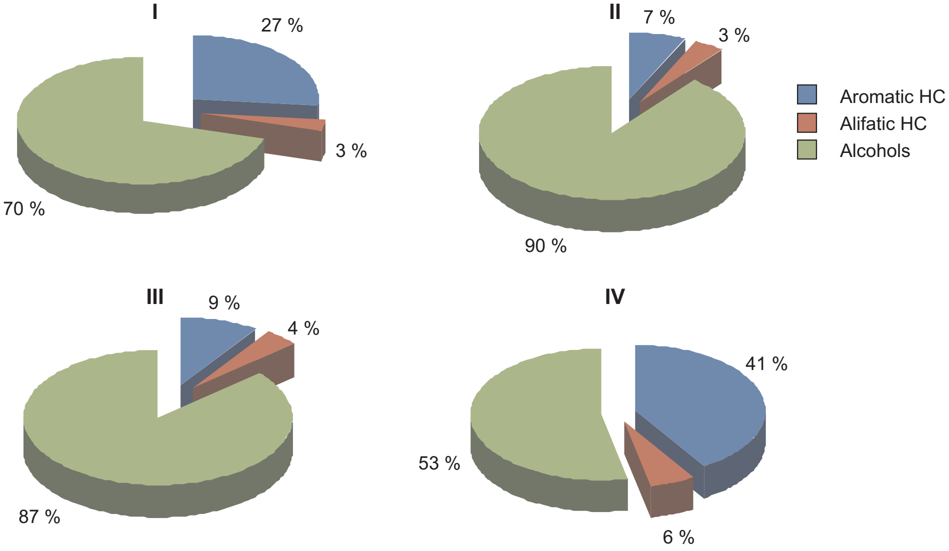

Fig. 4. The group share of VOCs concentration in various states of the combustion chamber

implementation (state IV) cause increase in aromatic compounds group. This group of compounds is most hazardous for humans [2].

In comparison analysis of total VOCs concentration (Fig. 5) the most advantageous configuration seems to be steel frame with ceramic fittings application inside combustion chamber, which cause about 60 % decrease in sum of volatile organic compounds concentration in the exhaust.

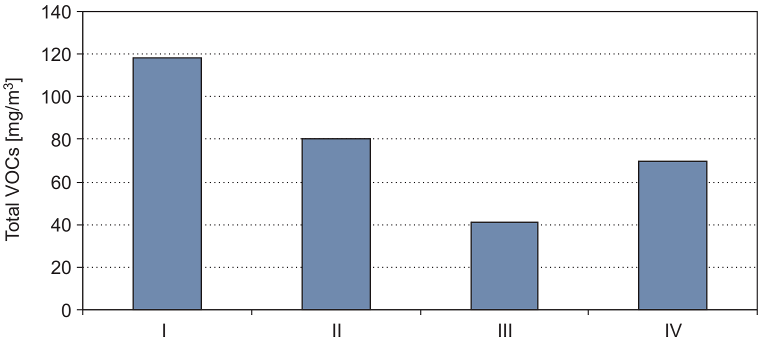

Fig. 5. The total VOCs concentration in various states of the combustion chamber

In Table 5 polyaromatic hydrocarbons concentrations are presented. Because of very toxic benzo(a)antracene and antracene appearance in some states, based on the chemical analysis results, Toxicity Equivalent Factor of individual composition was calculated (using Nisbet and LaGoy factors estimated for PAHs).

Table 5

The PAHs concentration in combustion gases and I_{TEF} for each stage of the tests

PAH	Concentration [mg/m^3]				TEF [Nisbet and LaGoy]	Individual Toxicity Equivalent Factor (I_{TEF}) I_{TEF} = TEQ × C			
	I	II	III	IV		I	II	III	IV
Naphthalen	0.00	20.0	5.14	0.00	0.001	0.004	0.021	0.000	0.015
Acenaphthylene	3.81	21.0	0.00	14.8	0.001	0.011	0.000	0.006	0.000
Acenaphtene	11.1	0.0	5.71	0.00	0.001	0.020	0.063	0.016	0.034
Fluorene	19.8	63.0	15.5	33.8	0.001	0.016	0.031	0.044	0.015
Phenanthrene	15.6	31.0	44.0	14.8	0.001	0.009	0.024	0.033	0.016
Anthracene	8.76	24.0	33.1	16.2	0.01	0.000	0.040	0.011	0.000
Fluoranthene	0.00	4.00	1.14	0.00	0.001	0.001	0.000	0.002	0.001
Pyrene	0.76	0.00	1.50	1.43	0.001	0.000	0.000	0.001	0.000
Benzo[a]antracene	0.00	0.00	0.50	0.00	0.1	0.000	0.000	0.000	0.048
Chrysenes	0.00	0.00	0.00	0.48	0.01	0.060	0.179	0.112	0.129
Total PAHs	59.8	162	107	81.0	—	0.060	0.179	0.112	0.129

The total PAHs concentration and Individual Toxicity Equivalent Factors for each PAHs mixture are shown in Fig. 6.

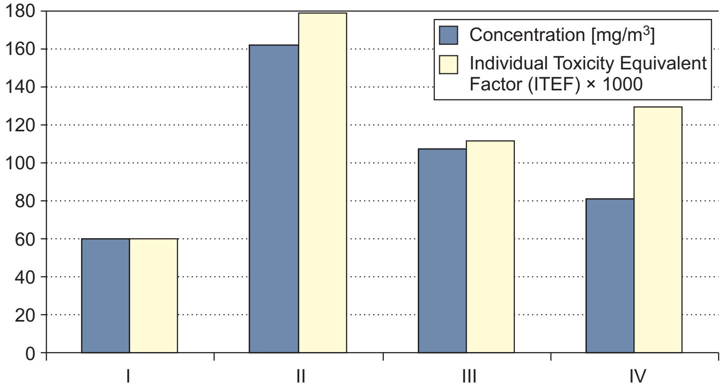

Fig. 6. The total PAHs concentration and Individual Toxicity Equivalent Factors for each PAHs mixture

The analysis of the results indicates that any modification of the combustion chamber cause increase in PAHs concentration and significantly increase mixture toxicity. Ceramic fittings implementation seems to impact on polyaromatic compounds decrease in comparison to state with "clear" steel frame. It may direct on ceramic implementation positive impact on those toxic hydrocarbons emission. Catalytic factor cause appearance of extremely hazardous for human health benzo[a]antracene.

Conclusions

The results of the research issue modification of the small-scale boiler combustion chamber by implementation active ceramic fittings of steel frame are ambiguous. The effect of aggravation of main emission parameters is probably caused by interferences of the combustion gases flow and distribution. Ceramic and active ceramic implementation into combustion space significant impact on combustion process and VOCs and PAHs emission. This impact is discussible and indicates on the need of further researches which should be focused especially on frame and fittings shape as a factor determining combustion process proceeding.

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EMISJA ZWIĄZKÓW ORGANICZNYCH ZE ZMODYFIKOWANEGO KOTŁA MAŁEJ MOCY ZASILANEGO BIOMASĄ

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Abstrakt: Problem niskiej emisji, dotykający w szczególny sposób jakości życia człowieka zarówno w aglomeracjach miejskich, jak i osadach wiejskich, związany jest nieodłącznie z kotłami małej mocy zasilającymi indywidualne gospodarstwa domowe w ciepło. Spaliny emitowane podczas niepoprawnego (niepełnego) prowadzenia procesu spalania paliw w tzw. małych kotłach zawierają groźne dla zdrowia ludzkiego związki z grup Lotnych Związków Organicznych (LZO). Substancje te charakteryzuje mutagenne oraz kancerogenne działanie na organizmy żywe i całe ekosystemy, nawet przy niewielkich poziomach stężeń oraz zdolność do kumulowania się w środowisku. W celu ochrony środowiska i zdrowia ludzi niezbędne jest opracowanie rozwiązań umożliwiających redukcję, tak charakterystycznych dla procesów spalania w nieefektywnych kotłach grzewczych, stężeń szkodliwych substancji węglowodorowych.

W artykule przedstawiono wyniki pracy badawczej, której celem było badanie wpływu modyfikacji przestrzeni spalania w kotle małej mocy zasilanego biomasą na emisję lotnych związków organicznych. W przestrzeni spalania kotła wprowadzono zmiany konstrukcyjne polegające na wprowadzeniu kształtek o własnościach katalitycznych. Oznaczenie LZO w spalinach wykonywano metodą chromatografii gazowej za pomocą aparatu Varian 450 GC. Wyniki zaprezentowano w postaci tabel i rysunków.

Słowa kluczowe: kotły małej mocy, niska emisja, lotne związki organiczne, katalizator wewnętrzny