

Evaluation of the hazardous emissions from different types of RDF combustion in low power boilers

N V Kornilova¹ and P A Trubaev²

¹Department of Electric Power Engineering and Automation, Belgorod State Technological University of V.G. Shukhov, Kostyukov St., 46, Belgorod, 308012, Russia

²Department of Energy Engineering of Heat Technologies, Belgorod State Technological University of V.G. Shukhov, Kostyukov St., 46, Belgorod, 308012, Russia

E-mail: trubaev@gmail.com

Abstract. Content evaluation of the hazardous substance emission from different types of waste combustion in two solid-fuel water heating boilers was carried out. For 100 kW pyrolysis boiler the content in exhaust gases of the following compounds was determined: NO₂, NO, CO, CH₄, phenol, benzol, SO₂, formaldehyde, HCl. For 200 kW stoker grate boiler the content in the exhaust gases of the following compounds was determined: CO, NO₂, NH₃, mercaptans, H₂S, phenol. For the targeted factors, the calculated hazardous substance ground-level concentrations don't exceed the maximum allowable concentration limit. The hazardous substance emissions in low power boilers are comparable with high power analogs but have lower combustible efficiency. Waste combustion in the pyrolysis boilers creates 2-10 times less hazardous substances than in grate firing. It was established that combustion mode influences only the carbon monoxide content. The content of other hazardous compounds in the exhaust gases doesn't depend on the combustion parameters. The additive criterion of total emissions was suggested, which presents the sum of the ratio of the calculated ground-level hazardous substance concentrations to maximum allowable concentrations. Unlike the existing dimensionless concentration, the criterion considers hazard class and compound fraction in gases. The highest criterion value of the total emissions was noted during wood waste combustion (windows, doors, furniture) and RDF fuel, which contains a large amount of plastics

1. Introduction

At this time, there are two main technologies of waste thermal recycling that exist, which most of the waste incinerating plants are using – combustion, mostly in the grate stokers, and gasification [1].

As recently as at the 20th-century beginning, people were complaining about smell from the waste incinerating plants, and doctors were saying that smoke from the waste combustion is not more harmful than a waste landfilling [2]. The problems of emissions control at the waste incinerating plants grown worse in 1960s, after discovery of strong organic poisons and cancerogens – dioxins (PCDD) and furans (PCDF), and large-scale researches in the US, England, and Netherlands, which detected an increased number of diseases in the areas where waste incinerating plants were located.

Concern about the harmful effect on human health from the dioxin and furan emissions generated a large number of studies on this kind of emissions control, in order to keep it under the allowable limits [3]. At the same time, on a practical level, this situation is not that simple - popular and ecological magazines claim that waste incinerating plant emissions have a very harmful effect on the environ-



ment, while scientific papers, based on the experiments, claim that emissions are much lower than the allowable limits.

In 1987, the United States Environmental Protection Agency (US EPA) published a report, where it noted very high risks from the waste incinerating plant emissions for human's health. But the papers [4, 5] showed that the expected cancerogen and non-cancerogen risks from the emissions are by several orders of magnitude less than the values presented in the US EPA report, and by several orders of magnitude less than concentrations that can be harmful to human's health. Substantial differences are caused by the fact that the US EPA report used unrealistic and overestimated conditions.

The main harmful substances, which combustion products contain, and their limit values are presented in Table 1. But unlike coal burning, where the main contaminating substances are SO₂, NO_x, HCl, SO₃, HF, and macroparticles, in MSW and RDF combustion the main contaminating substances are particles of heavy metals and organic emissions [6].

Table 1. Limit values of emissions, mg/m³.

Emissions	Content in the uncleaned combustion products [7]	Limit values [7]			Threshold values of emissions into the air for waste incinerating plants (Directive 2010/75/EU), mg/m ³	
		USA	China	Japan	Average-daily	Average half-hourly
Dust	1000-5000	24	80	10-50	10	30
TOC ^a	1-10	—	—	—	10	20
HCl	500-2000	25	75	15-50	10	60
HF	1-10	—	—	—	1	4
SO ₂	150-400	30	260	10-30	50	200
NO _x ^b	200-500	150	400	30-125	200 400	400
CO	<10-30	100	150	50	50	100
Hg	0.1-0.5	0.08	0.2	0.03-0.05	—	0.05
Cd (and Tl)	0.1-0.5	0.02	0.1	—	—	0.05
Other ^c	—	—	—	—	—	0.5
PCDD/F	1-10·10 ⁻⁶	0.3·10 ⁻⁶	0.1·10 ⁻⁶	0.1·10 ⁻⁶	—	0.1·10 ⁻⁶

^a Organic substances expressed as a total organic carbon content

^b Calculated in terms of NO₂

^c Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V (total)

As stated in the paper [1], the environmental impact from modern waste incinerating plants is comparable with the industrial emissions and electrical plants, which use mineral fuel. The paper [8], published in 1998, presents a comparison of the sorted municipal solid waste (MSW) and fuel, made of recycled waste (RDF) combustion in the same low-tonnage furnace with inclined grate and with capacity 0.5-0.8 MW. The authors concluded that the combustion of RDF, made by 25-100 mm fractionation of MSW, is characterized by much higher energy efficiency and less amount of emissions, but the content of harmful emissions during MSW and RDF combustion is substantially lower than the allowable values [8]. The paper [9] examined the emissions during combustion in the furnace with 11 kW capacity of four fuel mixtures, which consisted of wood construction waste, MSW and RDF. The results showed that the presence in the fuel of the wood construction waste has a dominant influence on the content of harmful emissions, their presence increased emission amount more than three times. Food waste didn't have much influence on the emission amount. The opposing data was presented in the paper [10], which studied the combustion of waste collected in two Sweden regions – with a separate collection of waste and without separation. This paper established that an increase in food waste content leads to increased dioxin and furan emissions.

Analysis of the emissions shouldn't be concentrated on its content in the exiting gases, but instead, consider emission dispersion in the atmosphere [7]. Based on the actual measurements from the literature data, the paper [11] presented emissions comparison for seven thermal recycling technologies of MSW and RDF. Distinct advantages on emissions have technology of RDF pyrolysis, where emissions three times lower than at direct MSW combustion. RDF combustion is characterized by a slight emission reduction in comparison with MSW combustion. The authors determined the ratio of the emission concentration in the environmental air and at the ground level to limit values, which can be found in the Directive 2008/50/EC. All technologies had emissions that are much lower than the values that can create health risks (assumed as not more than 5% of the maximum allowable concentrations for residential areas).

The difficulty of monitoring dioxin and furan emissions is in high prices of the equipment for their detection [7]. Therefore, several papers have carried out the determination of factors that influence their formation. The paper [3], based on the actual data from 14 factories in the US, established that the lowest dioxin and furan content (concentration in the uncleaned gases less than 1 ng/m³) can be achieved when the combustion product temperature is 800°C and CO content in the exiting gases is 10 ppm (which corresponds to combustion efficiency 99.9%). In some factories, the temperature increase over 900°C lead to dioxin and furan content increase [3].

Besides CO and organic compounds, emissions of which are determined by the combustion mode, the rest emissions are determined individually by the specific technology and fuel [12]. The paper [3, 13] concluded that the achievement of the allowable emission values is possible by creating the required combustion mode and monitoring it. At the same time, the reduction of energy and exergy losses leads to a reduction of the emission's impact on the environment [14]. The paper [9] suggests for the MSW combustion efficiency increase and emissions reduction use not only the steady required combustion mode but also perform afterburning using an additional fuel, which allows the reduction of NO_x and organic compounds emissions.

The paper [15] claimed that as of now, the dioxin emissions are being reduced not by limiting chlorine content in the incinerated waste but by the combustion process control. This requires not only furnace operating mode control but also getting full information using mathematical modeling.

Therefore, it can be concluded that:

- a) most of the measured emissions from the waste combustion are within limits and don't pose risks for human health;
- b) none of the technologies give an obvious ecological advantage during waste combustion;
- c) obtaining the allowable emission values is possible by keeping the required combustion mode (combustion with excess air, when oxygen content is 6-12% in the combustion products for MSW incineration and 3-9% for RDF incineration; ensuring complete mixing of fuel and combustion products with air; keeping gas temperature at 800-900°C; CO content in the exiting gases less than 50 ppm).

2. Measured substances and the method of calculations

In this paper, evaluation of the individual emissions during different types of wastes combustion in two low power water heating boilers was carried out. In the process of the industrial experiment the measurements of harmful substances in the chimney stuck after boiler were conducted, the calculated ground-level substances concentration was also determined, which was then compared with the norms of maximum allowable concentration (MAC) of emissions in the atmosphere of the populated place.

The tests were conducted using two boilers, which TC «Ecotrans» (Belgorod city) operates:

- 100 kW pyrolysis heating boiler «KO-100» made by LLC «Borkotlomash» (Voronezh region);
- 200 kW solid-fuel heating boiler with the stoker grate and forced-flow fan made by TC «Eco-trans».

The values of emissions were compared with the following allowable values:

- MAC s.t. – maximum allowable short-term concentration of a harmful substance in the atmospheric air (concentration that throughout whole life doesn't have direct or indirect harmful

effect on the present or future generation, doesn't degrade human performance, doesn't worsen their health conditions and sanitary-and-household living conditions);

- MAC a.d. – the maximum allowable average-daily concentration of a chemical substance in the air of populated places (this concentration shouldn't have a direct or indirect harmful effect on human when inhaled for an indefinitely long period);
- MAC w.s. – maximum allowable concentration of harmful substances in the workspace air (concentrations that affect humans daily, except weekends, during 8 hour work period (or different duration, but not more than 41 hrs. per week) within whole working life and doesn't induce disease or health problems, which can be detected by the modern health examination methods, in workers during professional activities and after retirement, and also in the next generations).

MAC values are given in accordance with the Russian normative:

- Hygienic normative GN 2.1.6.3492-17 «Maximum allowable concentration (MAC) of pollutants in the atmospheric air of urban and rural settlements», approved by a decision of the Chief State Medical Officer of the Russian Federation on 22.12.2017 № 165;
- State standard GOST 12.1.005-88. Occupational safety standards system. General sanitary requirements for working zone air;
- Hygienic normative GN 2.2.5.3532-18 «Maximum allowable concentration (MAC) of harmful substances in the working zone air», approved by a decision of the Chief State Medical Officer of the Russian Federation on 13.02.2018 № 25.

To calculate the surface concentration of the harmful substance, which was estimated relative to the MPC, the paper "Methods for calculating the dispersion of harmful (polluting) substances in air" (2017) approved by the Ministry of Natural Resources and Ecology of the Russian Federation was used.

Maximum value of the ground-level harmful substance concentration c_m , mg/m³, during air-gas mixture discharge from the single point source with a round opening, was calculated by the formula:

$$c_m = \frac{AMFm\eta}{H^2 \sqrt[3]{V_1 \Delta T}} \quad (1)$$

where A – coefficient that depends on the thermal stratification of the atmosphere (for Belgorod city $A = 180$); M – mass of the harmful substance, which is discharged into the atmosphere per unit time, is calculated by using the measured concentration in the smokestack g/s; F – non-dimensional coefficient, which considers settling velocity of harmful substances in the atmospheric air (for gaseous harmful substances $F = 1$); m and n – coefficients which consider conditions of the gas-air mixture discharge from the opening of emission source; H – above ground height of the emission source, m; η – non-dimensional coefficient, which considers surface topography influence, in case of flat or moderately rugged terrain with elevation difference not more than 50 m per 1 km, $\eta = 1$; ΔT – difference between the discharged air-gas mixture temperature T_{gas} and temperature of the outside atmospheric air T_{air} ; V_1 – volumetric flow rate of the air-gas mixture, m³/s,

$$V_1 = \frac{\pi D^2}{4} \omega_0, \quad (2)$$

where D – diameter of the emission source opening, m; ω_0 – average exit speed of the air-gas mixture at the emission source opening, m/s.

In case of concurrent combined presence in the atmospheric air of n substances, which possess summation of the harmful effect, the paper "Methods for calculating the dispersion of harmful (polluting) substances in air" suggest to calculate the non-dimensional summarized concentration q or reduce conditionally the concentration values to the concentration value of one of them.

The non-dimensional concentration q in the paper is determined by the formula

$$q = \sum \frac{C_i}{MAC_{s.t.i}}, \quad (3)$$

where C_i – calculated concentrations of harmful substances in the air; $MAC_{s.t.i}$ – corresponding maximum allowable short-term concentration of harmful substances in the atmospheric air.

3. Emission value evaluation during different type of wastes combustion in the pyrolysis boiler

In the process of tests, that lasted for 3 days, content analysis of the following compounds in the gases exiting a boiler was carried out: carbon oxide, methane, phenol, benzol, sulfur dioxide, formaldehyde, chlorine hydride. Measurements were conducted using the multicomponent portable gas analyzer GANC-4 (Gas Analyzer Cassette based).

Based on the measurement results according to the method paper “Methods for calculating the dispersion of harmful (polluting) substances in air” the maximum value of the ground-level harmful substances concentration was calculated for conditions of the air-gas mixture emission from the single point source with a round opening. The following data was used for the calculation: smokestack opening is 10 m above the ground; smokestack opening diameter 0.25 m; gas temperature in the opening is 200°C; outside air temperature 0°C; average speed of the air-gas mixture exiting from the emission source opening 1 m/s.

The obtained values were compared with the maximum allowable concentration (MAC) of harmful substances which can be found in the norms [14]. For all considered measures the calculated ground-level concentration of harmful substances doesn't exceed MAC. In most of the cases, it is much lower than the allowable values. This confirms mentioned in some papers statement that the advantage of pyrolysis, in comparison to direct waste combustion, is in substantial emission reduction [15-17].

Table 2. Ratio of the calculated ground-level concentration of harmful substances to maximum short-term MAC in the atmospheric air of the populated places.

№	Item name	NO ₂	NO	CO	CH ₄	Phenol	Benzol	SO ₂	Formaldehyde	HCl
2-a	Railway sleepers	0.7%	0.3%	0.3%	–	0.0%	3.7%	0.1%	0.4%	0.1%
2-b	Wood (pine tree)	0.0%	0.0%	0.5%	–	0.9%	0.1%	0.0%	0.0%	0.4%
2-c	Wood waste (window, door, furniture)	0.5%	1.5%	0.6%	–	13.5%	6.2%	0.1%	3.3%	0.1%
2-d	Wood pellets	0.7%	0.4%	0.6%	–	0.9%	0.1%	0.0%	0.2%	0.4%
3	RDF fuel	0.1%	0.2%	0.2%	–	0.1%	1.1%	0.0%	1.8%	0.0%
5	Mixture of wood pellets and RDF fuel	0.5%	1.6%	0.6%	–	0.0%	2.5%	0.0%	2.1%	0.2%

Table 3. Ratio of the calculated ground-level concentration of harmful substances to average-daily MAC in the atmospheric air of the populated places.

№	Item name	NO ₂	NO	CO	CH ₄	Phenol	Benzol	SO ₂	Formaldehyde	HCl
2-a	Railway sleepers	3.4%	2.1%	0.5%	–	0.0%	11.1%	1.5%	2.2%	0.4%
2-b	Wood (pine tree)	0.1%	0.1%	0.8%	–	1.5%	0.3%	0.01%	0.0%	1.3%
2-c	Wood waste (window, door, furniture)	2.5%	10.0%	1.0%	–	22.5%	18.4%	1.1%	16.4%	0.2%
2-d	Wood pellets	3.3%	2.6%	1.0%	–	1.5%	0.3%	0.01%	1.0%	1.2%
3	RDF fuel	0.3%	1.2%	0.4%	–	0.1%	3.3%	0.01%	8.9%	0.1%
5	Mixture of wood pellets and RDF fuel	2.4%	10.7%	1.0%	–	0.0%	7.3%	0.01%	10.2%	0.7%

Table 4. Ratio of the harmful substance concentrations in flue gases to MAC in the workspace air.

№	Item name	NO ₂	NO	CO	CH ₄	Phenol	Benzol	SO ₂	Formaldehyde	HCl
2-a	Railway sleepers	6.1	2.3	6.2	–	0.0	6.6	–	3.9	0.1
2-b	Wood (pine tree)	0.3	0.1	10.2	–	2.6	0.2	–	0.0	0.3
2-c	Wood waste (window, door, furniture)	4.5	10.7	13.4	–	40.0	11.1	–	29.2	0.1
2-d	Wood pellets	5.8	2.7	13.4	–	2.6	0.2	–	1.8	0.3
3	RDF fuel	0.5	1.3	4.7	–	0.2	2.0	–	15.8	0.0
5	Mixture of wood pellets and RDF fuel	4.3	11.5	13.4	–	0.0	4.4	–	18.2	0.2

The relationship between harmful emissions content is presented in Table 5.

Table 5. Correlation between content of different harmful substances.

Compound	NO ₂	NO	CO	CH ₄	Phenol	Benzol	SO ₂	Formaldehyde	HCl
NO ₂	–	0.40	0.38	0.01	0.16	0.43	0.54	0.03	-0.05
NO		–	0.64	0.59	0.55	0.67	0.16	0.80	-0.31
CO			–	0.27	0.43	0.14	0.19	0.24	0.47
CH ₄				–	0.70	0.50	0.00	0.88	-0.55
Phenol					–	0.77	0.44	0.71	-0.32
Benzol						–	0.79	0.74	-0.67
SO ₂							–	0.21	-0.51
Formaldehyde								–	-0.69
HCl									–

Based on the analysis of the measured compounds, it may be concluded that waste combustion doesn't have a noticeable impact on the environment.

4. Results of measurements in the boiler with grate firing

To determine the possibility of using RDF briquettes for combustion the industrial experiment was conducted for the purpose of gas content analysis, which is generated when briquettes incinerated in the 200-kW heat output water-heating boiler with grate firing, which is located at the LLC TC «Eco-trans» (Belgorod city) [16].

To determine emissions characteristics a series of measurements were carried out during different boiler's operational modes. The following fuel was used:

RDF: wood 70% and plastic 30% (fuel № 6);

RDF: wood 50% and plastic 50% (fuel № 7).

The fuel was prepared in the form of briquettes with 50 mm diameter and random length (up to 400 mm). The measurements were done during combustion at the boiler's exit using the measuring system GANC-4 and lasted 3 days. In the process of tests, the analysis of the boiler's operational efficiency was also carried out.

The temperature of the fuel's layer, measured on the grate by pyrometer, was 670-760°C.

The obtained values were compared with the maximum allowable concentration (MAC) of harmful substances; which can be found in the norms [14]. For all considered measures the calculated ground-

level concentration of harmful substances doesn't exceed MAC. In most cases, it is much lower than the allowable values.

Table 6. Ratio of the calculated ground-level concentration of harmful substances to maximum short-term MAC in the atmospheric air of the populated places.

Fuel №	Item name	CO	NO ₂	NH ₃	Mercaptan R-SH	H ₂ S	Phenol
6	Ratio of maximum concentration to MAC	2.5%	2.8%	3.0%	0.05%	2.7%	0.1%
6	Ratio of average concentration to MAC	1.2%	1.7%	2.3%	0.2%	1.9%	0.0%
7	Ratio of maximum concentration to MAC	3.5%	0.8%	8.2%	3.0%	2.4%	2.1%
7	Ratio of average concentration to MAC	1.8%	0.6%	4.7%	1.9%	1.4%	1.1%

Table 7. Ratio of the calculated ground-level concentration of harmful substances to average-daily MAC in the atmospheric air of the populated places.

Fuel №	Item name	CO	NO ₃	NH ₃	Mercaptan R-SH	H ₂ S	Phenol
6	Ratio of maximum concentration to MAC	4.1%	14.2%	14.9%	3.5%	13.6%	0.1%
6	Ratio of average concentration to MAC	2.0%	8.6%	11.6%	1.2%	9.5%	0.0%
7	Ratio of maximum concentration to MAC	5.9%	3.8%	40.9%	20.7%	12.0%	3.5%
	Ratio of average concentration to MAC	2.9%	3.0%	23.4%	13.3%	6.8%	1.9%

Table 8. Ratio of the harmful substance concentrations in flue gases to MAC in the workspace air.

Fuel №	Item name	CO	NO ₂	NH ₃	Mercaptan R-SH	H ₂ S	Phenol
6	Ratio of maximum concentration to MAC	62	29	3	3	0.2	0.2
6	Ratio of average concentration to MAC	32	18	3	1	0.2	0.1
7	Ratio of maximum concentration to MAC	72	8	10	19	0.2	8.1
7	Ratio of average concentration to MAC	42	6	5	13	0.1	4.0

To analyze the amount of emissions dependence on the fuel combustion mode, the data from series of tests were used, where the values of harmful substances content are the results of one-time measurements, and the temperatures and excess air coefficients were averaged for the time interval when the gas analysis was performed [17].

Figures 1 and 2 present the emissions content at different gas temperatures after the boiler and different excess air coefficient.

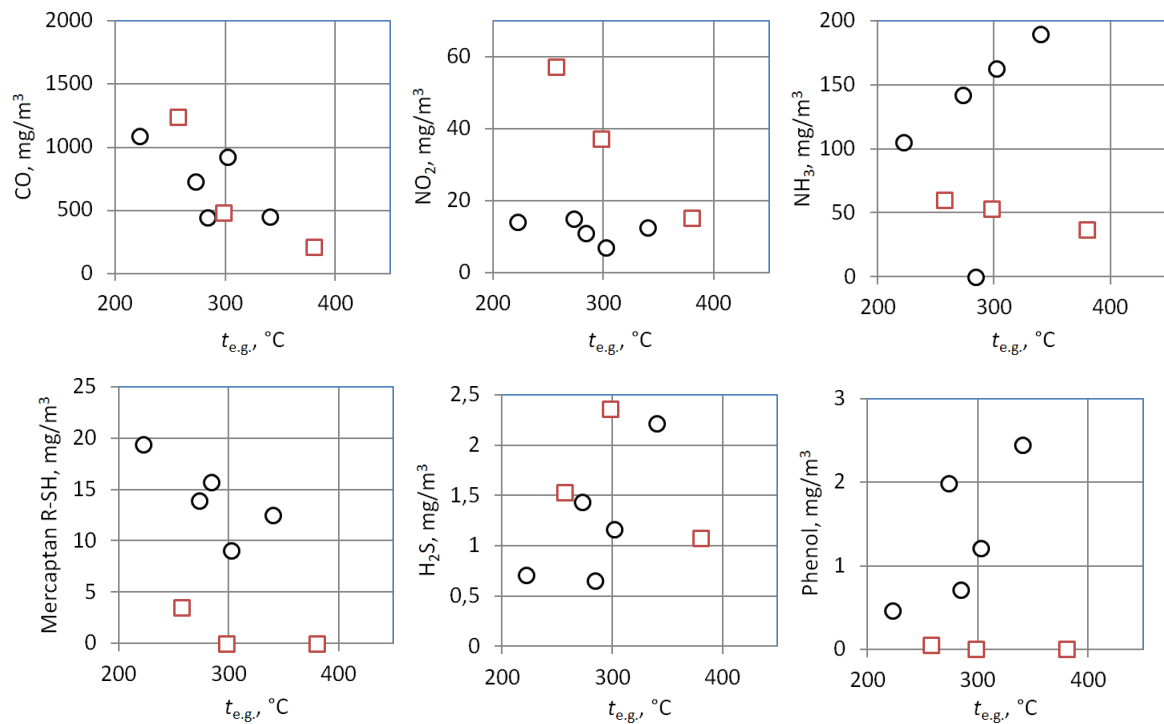


Figure 1. Dependence of the emissions amount on the exiting gas temperatures.

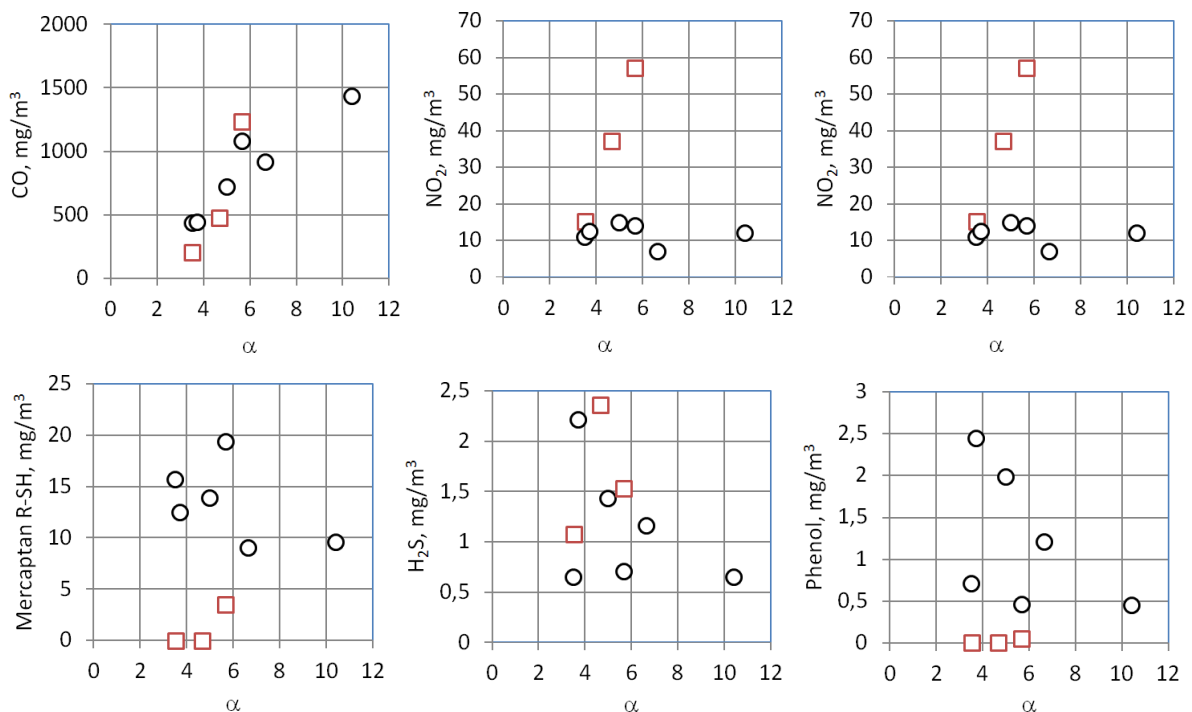


Figure 2. Dependence of the emissions amount on the excess air coefficient.

Dependence of the content of the harmful substances on the mode parameters of the boiler was detected only between CO content and the exiting gas temperature (correlation coefficient – 0.9) and excess air coefficient (0.9). Between the rest of emissions content and $t_{e.g.}$ (α) there is no dependence

(module of the correlation coefficient doesn't exceed 0.39). Also, there is no dependence between different emissions content. Therefore, apart from the combustion efficiency, which is characterized by the CO content, the emissions content in the operational range of water-heating boiler functioning doesn't depend on the mode of its operation.

Table 9. Correlation between the mode parameters and harmful substances content.

Parameter	Fuel №	CO	NO ₂	NH ₃	Mercaptan R-SH	H ₂ S	Phenol
Exiting gas temperature (average) $t_{e.g.}$	6	-0.90	-0.99	-1.00	-0.76	-0.52	-0.76
	7	-0.88	-0.28	0.68	-0.05	0.74	0.76
	6 and 7	-0.88	-0.06	0.31	-0.41	0.46	0.18
Excess air coefficient α	6	0.95	1.00	0.99	0.84	0.39	0.84
	7	0.94	-0.15	-0.38	-0.52	-0.45	-0.51
	6 and 7	0.85	-0.07	-0.21	0.06	-0.38	-0.16

Note: Correlation coefficient between $t_{e.g.}$ and α – for the fuel № 6; -0.99; №7: -0.80; № 6 and 7: -0.8

For fuel № 6 (3 points of measurement) it can be seen that mode parameters and harmful substances content have practically direct dependence. For fuel № 7 (6 points) and the whole sample (9 points) dependence on the combustion mode is observed only for the incomplete combustion characteristics – CO. There is no dependence between the rest of the emissions content and $t_{e.g.}$ (α) (module of the correlation coefficient for the whole sample doesn't exceed 0.31). Also, there is no dependence between different emissions content (Table 10).

Table 10. Correlation between the content of different harmful substances.

Compound	CO	NO ₂	NH ₃	Mercaptan R-SH	H ₂ S	Phenol
Carbon monoxide CO	–	0.21	-0.10	0.23	-0.38	-0.17
Nitrogen dioxide NO ₂		–	-0.22	-0.55	0.43	-0.48
Ammonia NH ₃			–	0.28	0.46	0.77
Mercaptan R-SH				–	-0.45	0.52
Hydrogen sulfide H ₂ S					–	0.28
Phenol						–

Therefore, apart from the combustion efficiency, which is characterized by the CO content, the emissions content in the operational range of water-heating boiler functioning doesn't depend on the mode of its operation.

5. Averaged criterion of emissions

To compare emissions from different waste types the criterion of total emissions q was calculated (Figure 3, 4), which represented the additive sum of ratios of the calculated ground-level concentration of harmful substances C_i to maximum allowable concentrations MAC_i considering coefficient k_i , which equals to the hazardous substance's classification:

$$q = \frac{\sum k_i C_i \left(\frac{C_i}{MAC_i} \right)}{\sum k_i C_i} 100\% = \frac{\sum \frac{k_i C_i^2}{MAC_i}}{\sum k_i C_i} 100\%.$$

The biggest emissions were observed during the fuel № 2-c combustion (wood waste – windows, doors, furniture), which can be explained by resins and paint presence in the waste. The fuels № 6 and 7 also showed large emissions, because of the large amount of plastic.

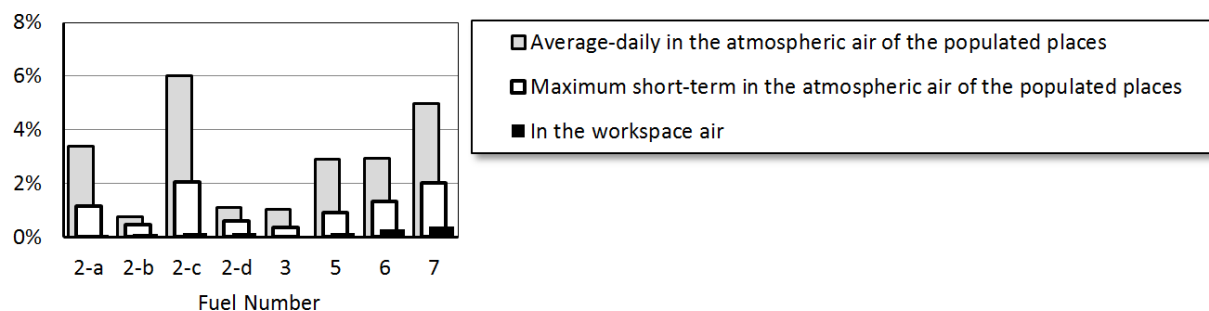


Figure 3. Criterion of the total emissions for the calculated ground-level concentration of harmful substances, which is calculated on values of MAC in the atmospheric air of the populated places and workspace.

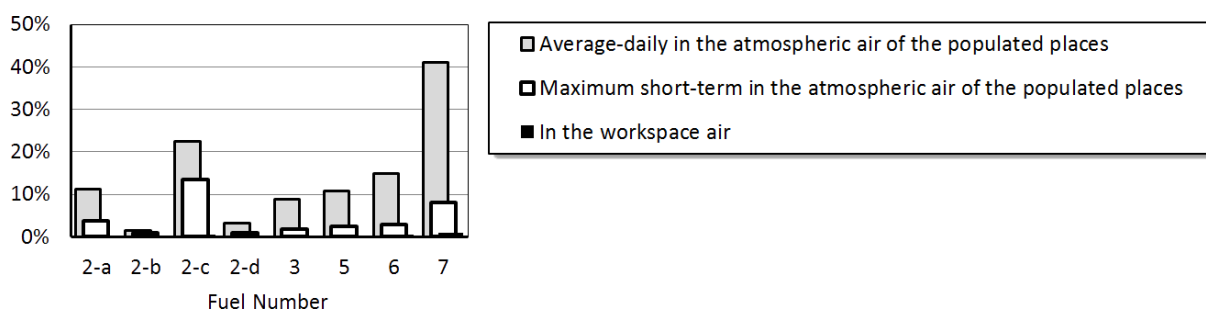


Figure 4. Maximum value of the ratio of the calculated ground-level harmful substances concentration content to MAC in the atmospheric air of the populated places and workspace.

The obtained results cannot fully characterize the above-mentioned fuels, because besides the fuel’s content the mode of combustion (temperature and excess air) also has an impact on the emissions content, but they allow a qualitative comparison of the ecological characteristics of fuels.

Conclusion. The results of the gas content measurements after the boiler, which incinerates a mixture of wood and municipal wastes, showed that on all targeted measures the calculated ground-level concentrations are within MAC limits. Therefore, the combustion of wood waste and MSW doesn’t have a harmful impact on the environment and humans. But it should be noted that the content of dioxins and furans wasn’t measured during the experiments.

6. Conclusion

1. The results of the gas content measurements after the boilers, which incinerate different types of wastes, showed that on all targeted measures the calculated ground-level concentrations are within MAC limits.

Table 11 presents harmful substances concentration during MSW combustion both at the foreign and domestic waste incineration plants and also obtained by the authors during the experiments at low power water-heating boilers, located at the TC «Ecotrans» (Belgorod city) when different types of waste were incinerated.

Table 11. Harmful substances concentration in the uncleaned exiting gases during MSW incineration, mg/m³.

Substance	Typical concentrations at the foreign plants [9]	Waste incinerating plant № 2 [9]	Low power water-heating boiler at the TC «Ecotrans»	
			Pyrolysis	With a grate stocker
NO _x	75-600	320	1.2-96	18.6-27.4
CO	<30	30	94-267	582-920
SO ₂	50-400	120	0-6.44	Not determined
HCl	50-1000	120	0.151-1.73	Not determined

As can be seen from the measurement results, the low power boilers on the harmful substance emissions are comparable with the analogs, but at the same time have much lower combustion efficiency (large amount of CO). Waste combustion in the pyrolysis boilers creates 2-10 times less hazardous substances than in grate firing.

The emissions content in the exiting gases, apart from the carbon monoxide that characterizes the quality of combustion, doesn't depend on the boiler's mode parameters.

But it should be noted that the dioxin content wasn't measured during the experiments.

2. The additive criterion of total emissions was suggested in the paper, which presents the sum of the ratios of the calculated ground-level hazardous substance concentrations to maximum allowable concentrations, and, unlike the existing dimensionless concentration defined in the normative GN 2.1.6.3492-17, considers hazard class and compound fraction in gases.

The highest value of the total emissions criterion was observed during the combustion of wood waste (windows, doors, furniture) and RDF fuel, which contains a large amount of plastic.

3. Therefore, it may be concluded that the thermotechnical properties of waste are comparable with the traditional types of fuel. The main requirement for the waste incineration is the desired mode of combustion enforcement, meaning thermotechnical organizing and monitoring of the processes. When these requirements are fulfilled, the environmental risks from waste combustion won't exceed risks from its disposal at landfills. Therefore, wood waste and MSW incineration in the low power boilers doesn't have a harmful impact on the environment and humans.

Considerable reduction of emissions allows using the recycling method by waste combustion in the pyrolysis boiler for residential heating, for example in the automation systems of heat supply for buildings and residential communities.

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