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EFFECT OF AIR DISTRIBUTION AND PROCESS DURATION ON THE EMISSIONS DURING COMBUSTION OF ALTERNATIVE FUEL

WPŁYW ROZDZIAŁU POWIETRZA I CZASU REALIZACJI PROCESU NA EMISJE W TRAKCIE SPALANIA PALIWA ALTERNATYWNEGO

Abstract: One of the greatest problems of environmental protection is the problem of municipal waste management. As the experience of the richest European countries shows, a significant part of it must still be managed by thermal methods. However, currently, numerous countries, including Poland, are moving away from waste incineration processes towards the processes of energetic use of fuels based on them. One of the main combustion technologies of solid waste and fuels based on them is their combustion in grate furnaces. In the article the methodology and results of laboratory tests of the combustion process of refuse derived fuel are presented. The research was carried out on a test stand enabling simulation of processes occurring in furnaces with mechanical grates. In the presented research, variable factors were: the distribution of air flow along the grate length and the total duration of the process. In the research the influence of changes in these factors on CO and NO_x emissions was determined. The paper presents both the changes in the emissions of the gases mentioned above over time and the total emissions related to the unit of the formed fuel burnt.

Keywords: refuse derived fuel, primary air flow distribution, combustion time, emissions, grate furnace

Introduction

The main problems of civilization today include, among others, environment protection and meeting the growing energy needs of the world. One of the main environment protection issues is, in turn, the issue of waste management, including municipal waste. Despite the fact that in recent years, highly developed countries have tried to minimize the amount of municipal waste generated, the weight of waste generated per capita has slightly decreased in these countries at most. Table 1 shows the amount of waste generated per capita in selected European countries in years: 1995, 2000, 2006 and 2016. As can be seen from the data presented, over the last 20 years, the indicator has increased by 3 % in the EU-27, while Denmark, for example, has increased by 50 % and Switzerland and Norway by around 20 %. In turn, the biggest decline of 18 % was in Hungary, 8 % in Spain and 4 % in the Netherlands.

In addition, in medium developed and developing countries, there has been a sharp increase in the volume of waste generated during the period under consideration, which can only be quantified roughly. In its report [1], the World Bank estimates that in 2016 the mass of municipal waste generated worldwide amounted to over 2.1 billion Mg, 2/3 of which was generated by medium developed and developing countries themselves. In addition, this report predicts that the mass of municipal waste generated will increase to 3.4 billion Mg in 2050. Where the three-fold growth of the weights of produced waste is predicted

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in Sub-Saharan Africa, and two-fold growth in Southern Asia. In connection with the problem of the paper, it should also be noted that the share of plastics in municipal waste was estimated at ca. 12 % (240 million Mg), paper at 17 %, and biodegradable waste at 44 %.

A number of highly developed countries have already achieved zero-waste management in the field of municipal waste. In these countries, less than 3 % of the waste is landfilled. Such countries may include Austria, Denmark, the Netherlands, Germany, Switzerland and Sweden. These countries avoid landfilling by, inter alia, subjecting a significant proportion of their waste to thermal processing. In 2017, in Austria 39 % of weight of municipal waste, in Denmark and Sweden 53 %, Holland 44 %, Germany 31 %, Switzerland 47 % were thermally processed (own calculations based on [2]). In Poland, in 2017, 24 % of the weight of municipal waste was processed with the methods discussed [3]. Despite the transformation of the EU economy into a closed cycle economy, it is expected that thermal methods will remain an important element of the municipal waste treatment system for a number of years to come. They can also be expected to develop in less developed countries, which currently landfill more than 90 % of their waste. Currently, around 90 % of waste incineration plants worldwide are equipped with grate furnaces [4].

Table 1

Weight of generated waste per capita in selected European countries. Own elaboration based on [2, 3, 5]

Country/region	**Year**				
	1995	**2000**	**2006**	**2016**	**2016/1995**
	[kg per capita]				
EU-27	474	524	523	487	1.03
Czech	302	335	297	339	1.12
Denmark	521	664	740	783	**1.50**
Germany	623	642	564	633	1.02
Spain	505	653	590	463	0.92
France	475	514	535	515	1.08
Italy	454	509	559	497	1.09
Hungary	460	446	468	379	**0.82**
Netherlands	539	598	597	520	0.96
Poland	285	320	321	307	1.08
Portugal	352	457	465	474	1.35
Sweden	386	428	490	443	1.15
Switzerland	600	656	709	720	1.20
Norway	624	613	793	754	1.21

According to forecasts [6], in 2040 fossil and renewable fuels will still account for about 75 % of the primary energy used (today it is more than 80 %). At the same time, its consumption will increase by about 25 % in relation to the amount of primary energy used today. Thus, despite the rapid development of renewable energy, fuel combustion is, and will continue to be, a large-scale process.

Therefore, there is still a current issue of research on the incineration of waste and RDF (refuse derived fuel) in grate furnaces.

Testing methodology

The laboratory station used in the research enables simulation of combustion processes taking place in water boilers with a fixed grate and a mechanical grate. In addition, the station allows for relatively large scale testing. The burnt fuel mixture can have a maximum volume of more than 40 dm^3 and a weight of more than 20 kg. The diagram of the station is shown in Figure 1. The basic element of the station is a boiler consisting of two main parts:

- a lower one, with possibility to adjust (up to 1200 °C) the chamber heating temperature,
- an upper one, equipped with a water jacket.

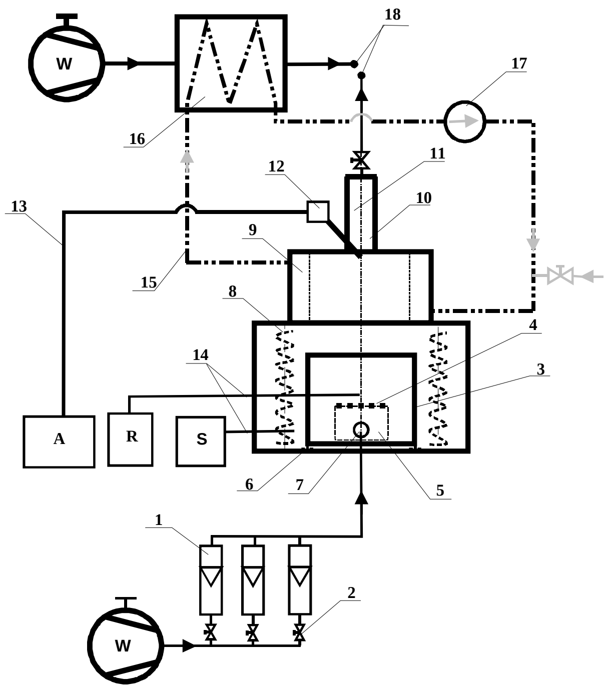

Fig. 1. Test stand scheme: A - flue gas analyser, S - boiler control system, R - recorder, W - fan, 1 - rotameter, 2 - valve, 3 - moveable bed with grate, 4 - grate, 5 - surge tank (firepan), 6 - rail, 7 - air supply nozzle, 8 - heating element (electrical), 9 - water jacket, 10 - discharge tunnel, 11 - measurement probe, 12 - probe head, 13 - heated hose, 14 - thermoelements with compensating leads, 15 - cooling water circulation, 16 - water/air heat exchanger (cooler), 17 - circulation pump, 18 - surroundings

The installation is equipped with a system of devices enabling measurement and control of the air flow rate.

In order to quickly load the fuel sample into the furnace chamber and to enable the fuel to be placed on the grate, the grate is located on a movable bed. After heating the lower chamber to the assumed temperature, the bed is inserted into it.

The results of laboratory tests presented in the paper were obtained for the following parameters of the combustion process:

- the mixture of combustible fractions of waste of 1 kg mass;
- the waste was burned in the layer 150 mm thick;
- during the tests, air was supplied in a quantity ensuring for the whole process an average ratio of excess air (λ) equal to: 2.6;
- recording of concentration measurements (on the basis of which the emissions were determined) was made in 2-second intervals;
- the moment of feeding the waste to the combustion chamber was applied as the beginning of the research,
- at the time of feeding the waste into the combustion chamber, the temperature in the chamber was 710 ± 30 °C;
- during the process (final phase) the heating of the chamber ensured that the minimum temperature of 600 °C was maintained.

The refuse derived fuel used in the research consisted of combustible fractions of municipal waste. The elementary composition of the fuel (dry substance) was as follows: carbon - 48.1 %, hydrogen - 6.7 %, nitrogen - 0.4 %, sulphur - 0.8 %, oxygen - 36.6 %, mineral substance - 6.8 %. The burnt fuel had a 15 % moisture content.

The course and energy and ecological effects of the combustion process in grate furnaces depend on several dozen factors. One of the factors, relatively rarely taken into account in the research, is the distribution of air fed under the grate (distribution of primary air). In the case of mechanical grates, a decrease in the speed of grate movement results in a longer residence time of the burnt fuel in particular zones of air supply. During the discussed studies 5 air supply zones were simulated. The research was carried out for two total times of the combustion process implementation: 900 and 1200 s.

In the course of the research, the flow of the primary air stream was changed accordingly:
- every 180 s for a total combustion time of 900 s,
- every 240 s for a total combustion time of 1200 s.

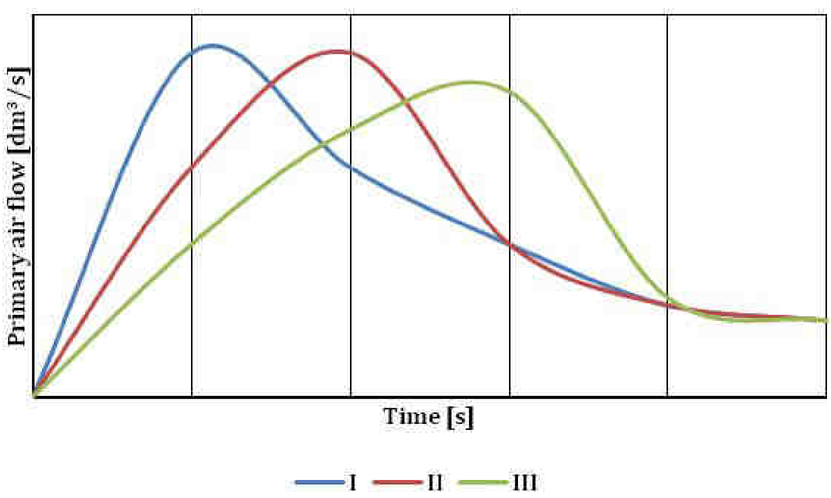

Fig. 2. Primary air exposure curve shapes reproduced during the tests

Three primary air distributions were taken into account in the studies. Approximate shapes of the simulated curves of the distribution of the air stream, reproduced during the tests, are shown in Figure 2.

It should be noted that the concentrations of the analysed gases in the flue gases were measured at the exit from the combustion chamber. Therefore, the values presented in the further part of the paper should not be identified with the values of emissions to the environment from e.g. waste incineration plants. Emissions to the environment from industrial facilities result from emissions from the combustion chamber (e.g. furnace, boiler) and the efficiency of the flue gas cleaning centre.

Test results

Figure 3 shows the changes in CO emissions during the research for the total duration of the process of 1200 seconds. Individual curves of emission changes were obtained with a different distribution of air streams subjected to different zones. The curves in the individual colours correspond to the airflow distributions shown in the same colours in Figure 2. Figure 4 shows the corresponding curves of NO_x emission changes.

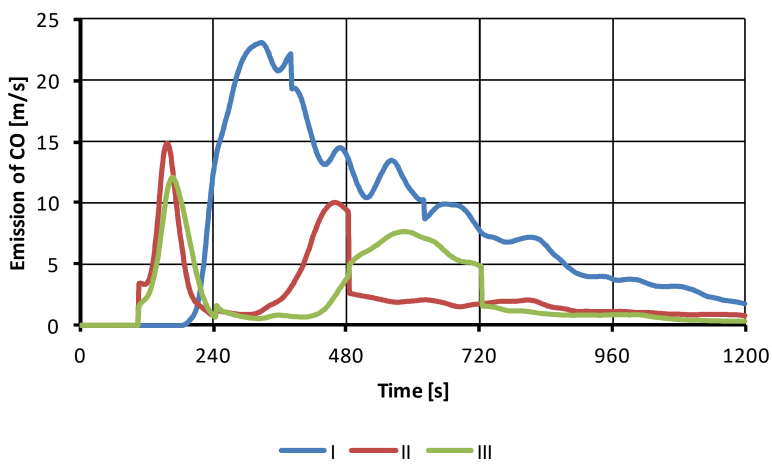

Fig. 3. Changes in CO emissions during the combustion process: process time = 1200 s, 5 primary air delivery zones (the individual curves correspond to the primary air distribution curves shown in Figure 2)

As can be seen from the discussed drawings, the curves describing the changes of emission of particular compounds differ significantly from each other in shapes. In several cases, the graphs clearly show abrupt changes in emissions due to a change in the primary air stream (e.g. curve III in Figure 3 for 480 and 720 s of the process and Figure 4 for the aforementioned times and for 240 s).

Due to the fact that samples of the same weight are burned in comparable conditions differing only in the distribution of the supply air stream and the total time of the process, it is interesting how the total emission of particular analysed gases change. Such data is presented in Table 2. This Table presents the total CO and NO_x emission values for the processes carried out for 900 and 1200 seconds (total process times). In addition, the Table shows the ratio of the maximum emissions of a gas to the minimum for processes of the same total time. The analysis of the data presented in Table 2 shows that only as a result of a change in the distribution of the supply air stream, it is possible to reduce CO emissions 3.3 times and NO_x emissions 2.2 times.

Considering the entirety of the studies in question, so also considering the changes in the total process time, the maximum CO reduction has not changed, but what is possible is to reduce the maximum NO_x by 2.9 times.

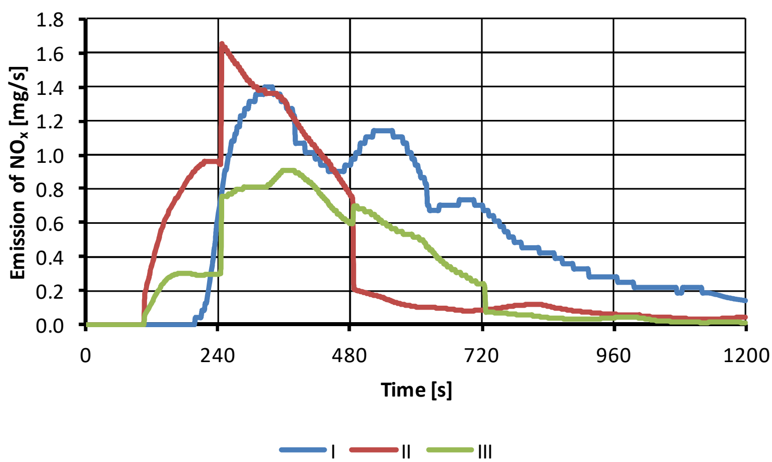

Fig. 4. Changes in NO_x emissions during the combustion process: process time = 1200 s, 5 primary air delivery zones (the individual curves correspond to the primary air distribution curves shown in Figure 2)

Table 2

Total emissions of CO and NO_x for the individual combustion processes of the refuse derived fuel and the ratios

Gas	Total emissions [g/kg fuel]			Ratio max./min.
Total process time 900 s				
CO	7.14	7.31	3.72	2.0
NO_x	0.29	0.33	0.39	1.4
Total process time 1200 s				
CO	9.30	2.84	2.97	3.3
NO_x	0.82	0.51	0.37	2.2

Conclusion

The combustion of fuels will be an important element of the energy economy both in Poland and in the world, for at least several decades to come. At the same time, in most parts of the world, the waste management system does not exist or is limited to the simplest forms of waste management. In some of these countries, thermal waste processing methods are likely to be intensively developed in the near future. Even in highly developed countries, thermal methods will remain an important element of the waste management system for a long time to come. Therefore, it is important to continue research on the course of thermal incineration and co-incineration of waste.

As part of the work, tests were carried out on a laboratory stand. As part of the research, refuse derived fuel was burned. Two times of the combustion process and three air distributions under the grate (primary air) were considered in the research. The conducted research has shown that as a result of selecting only two process parameters considered in the research, it is possible to reduce CO emission 3.3 times and NO_x reduction almost threefold.

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WPŁYW ROZDZIAŁU POWIETRZA I CZASU REALIZACJI PROCESU NA EMISJE W TRAKCIE SPALANIA PALIWA ALTERNATYWNEGO

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Abstrakt: Jednym z największych problemów ochrony środowiska jest problem zagospodarowania odpadów komunalnych. Jak wskazują doświadczenia najbogatszych krajów europejskich, metodami termicznymi zagospodarowywana wciąż musi być znacząca ich część. Jednak obecnie w szeregu państw - w tym w Polsce - odchodzi się od procesów spalania odpadów na rzecz procesów energetycznego wykorzystania paliw powstałych na ich bazie. Jedną z głównych technologii spalania odpadów stałych oraz paliw powstałych na ich bazie jest ich spalanie w paleniskach rusztowych. W artykule przedstawiono metodykę i wyniki badań laboratoryjnych procesu spalania paliwa alternatywnego. Badania przeprowadzono na stanowisku badawczym umożliwiającym symulowanie procesów zachodzących w paleniskach z rusztami mechanicznymi. W prezentowanych badaniach czynnikami zmiennymi były: rozkład strumienia powietrza wzdłuż długości rusztu oraz całkowity czas trwania procesu. W badaniach określano wpływ zmian tych czynników na emisję CO i NO_x. W pracy przedstawiono zarówno zmiany emisji wymienionych gazów w czasie, jak i wielkości emisji całkowitej odniesione do jednostki spalanego paliwa formowanego.

Słowa kluczowe: paliwa z odpadów, rozkład strumienia powietrza pierwotnego, czas spalania, emisje, palenisko rusztowe