The effect of the ratio of excess air and the process time on CO and NO_x emissions from the combustion of alternative fuel in a grate furnace

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Abstract. One of the basic problems of environmental protection is the problem of municipal waste management. As the experience of the richest developed countries shows, it is possible to achieve a zero-landfill level of economy. However, such a level can only be achieved if several dozen percent of municipal waste generated is subjected to processes of energy utilisation. At the same time, at present, the EU countries are moving away from waste incineration processes towards the processes of energetic use of fuels based on them. In the first part of the article, the problem of thermal utilisation of municipal waste in Poland is highlighted. The results of analyses of selected fuel parameters of municipal waste and formed fuels have been presented. The second part of the paper outlines the issue of fuel combustion in grate furnaces. In the further part of the article the methodology and results of laboratory tests of combustion of formed fuel are presented. The research has been carried out on a test stand enabling simulation of processes occurring in furnaces with mechanical grates. Within the framework of the presented studies, the influence of total process duration and excess air ratio on the amount of CO and NO_x emissions was taken into account. The paper presents both the changes in the emissions of the abovementioned gases over time and the total emissions related to the unit of the formed fuel burnt.

1 Refuse derived fuels

One of the basic problems of environmental protection is the problem of municipal waste management. In Poland in 2017, 12 million Mg of municipal waste was generated [1]. Although they account for slightly less than 10% of the total waste stream generated in the country, their management still poses a number of problems. This may be proved by the

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fact that in Poland 42% of municipal waste is deposited at landfills [1]. A number of highly developed countries have already achieved zero-waste management level. This means that in these countries, municipal waste is not de facto landfilled (less than 3% of waste is landfilled). Such countries include: Austria, Belgium, Denmark, the Netherlands, Germany, Switzerland and Sweden. These countries avoid landfilling by subjecting a significant proportion of their waste to thermal management. In 2015, in Austria 38% of municipal waste mass was thermally managed, in Belgium 43%, Denmark 53%, the Netherlands 47%, Germany 31%, Switzerland 47%, Sweden 51% (own calculations based on [2]). In Poland, in 2017, 24% of the mass of municipal waste was managed with the methods discussed [1].

For many years now, the processes of energy management of mixed municipal waste have been abandoned in favour of combustion of selected fractions of such waste. The mixture has been created on the basis of selected, fragmented, combustible fractions of municipal waste, referred to as a refuse derived fuel. Sometimes such mixture is additionally subjected to drying processes and processes of palletization and briquetting. The processes of refuse derived fuel production allow to ensure homogeneity and repeatability of its properties. Additionally, fuels from waste may be produced to meet the expectations of individual customers. An important feature of some refuse derived fuels, including fuels containing a small amount of moisture, is their storage capacity. Reducing the moisture content slows down biological processes, allowing, among other things, longer storage of the obtained fuel and reduces its odour nuisance. Refuse derived fuels are most commonly used in the cement industry, multi-fuel power boilers and waste incineration plants.

An important feature of alternative fuels is their average calorific value decreasing every year. This process is the result of directing more and more of the high-calorific fractions of waste to processes other than thermal ones.

Table 1 presents the results of analyses conducted under the direction of the author [3], showing the variability of parameters (composition and calorific value) of refuse derived fuels produced in Poland. These properties were compared with average values obtained for combustible fractions of domestic municipal waste. The comparison shows that individual properties of combustible fractions of municipal waste are within the range of variability observed for refuse derived fuels. It can also be considered that combustible fractions of municipal waste constitute a form of refuse derived fuel, capable of being produced in the largest quantity in domestic conditions.

Table 1. Indicative parameters of alternative fuels and dry combustible fractions of municipal waste

Parameter	Alternative fuels	Combustible fractions of municipal waste (dry mass)	Parameter	Alternative fuels	Combustible fractions of municipal waste (dry mass)
coal, %	29 - 65	48.1	chlorine, %	0.03 – 1.43	0.6
hydrogen, %	4.5 – 12.0	6.7	oxygen, %	3 – 43	36.6
nitrogen, %	0.01 – 4.50	0.4	ash, %	3 - 42	6.8
sulphur,%	0.1 – 1.9	0.8	moisture, %	< 21	-
Calorific value**, MJ/kg	14 - 30	19.0			

** calculated value

2 Basic information about the combustion process in grate furnaces

The basic technology of waste management is its combustion in grate furnaces. The ecological and energetic effects of this process depend on a number of factors. The basic ones are as follows:
- the parameters of the fuel burnt;
- the parameters of the primary air;
- the parameters of the secondary air;
- thickness of the combustion fuel layer;
- boiler load;
- speed of grate movement (combustion time of the mixture);
- structural parameters of the combustion chamber and the combustion line.

Some of these factors are characterised by a number of further parameters. Thus, taking into account the description of some of the basic factors by more than one parameter and the relationships of some parameters and factors among themselves (such as the temperature in the combustion chamber and heat losses to the environment, or the calorific value and elementary composition), in a full description of the phenomenon there are at least a dozen or so independent factors influencing the process under study. It is practically impossible to take into account such a large number of factors in research. The paper presents research in which independent factors are taken into account: the influence of the process duration and the ratio of excess air. The constant factors included: composition of the burnt fuel, furnace construction, shape of the distribution curve during the air flow, thickness of the burnt air layer.

One of the main negative environmental effects of the implementation of combustion processes is the emission of gaseous pollutants, including CO and NO_x. Therefore, the article deals with the emission of precisely these pollutants (dependent factors).

3 Research 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 Fig. 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.

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 and the composition reproducing the one presented in Table 1 was burned;
- 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: 2.1 and 2.6;
- the process time was set at 1200 and 1500 s;
- recording of concentration measurements (on the basis of which the emissions were determined) was made in 10-second intervals;
- the moment of feeding the waste to the combustion chamber was applied as the beginning of the research,

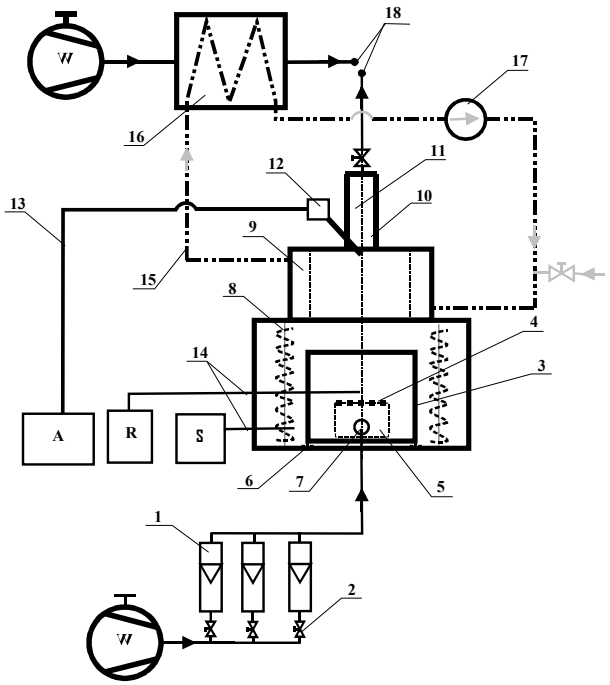

Fig. 1. Test stand scheme: A - flue gas analyzer, S – boiler control system, R recorder, W - fan, 1 - rotameter, 2 - valve, 3 - moveable bed with grate, 4 - grate, 5 surge tank (firepan), 6 - rail, 7 - air supply nozzle, 8 - heating element (electrical), 9 water jacket, 10 - discharge tunnel, 11 - measurement 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.

- 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.

In the course of the research, the flow of the primary air stream was changed accordingly:
- every 240 s for a total combustion time of 1200 s,
- every 300 s for a total combustion time of 1500 s

The procedure of changing the air stream in time was aimed at simulating the displacement of fuel burned on a mechanical grate, through successive zones of primary air supply. The approximate shape of the curve of air intake, reproduced during the tests, is presented Figure 2.

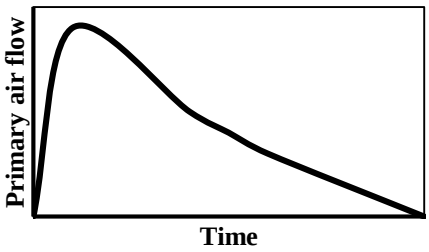

Fig. 2. The shape of the curve of air intake, reproduced during the tests, is presented

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.

4 Research results with a discussion

Fig. 3 shows exemplary diagrams of changes in CO emissions during the combustion process. Fig. 4 shows the corresponding curves for NO_x emissions. As can be seen from the figures, in the case of an increase in the amount of air supplied for combustion (test: λ=2.6, time 1200 s) CO emissions have increased significantly, compared to a test of the same duration and λ=2.1.

Table 2 presents total CO and NO_x emission indices from the combustion processes discussed in the paper. The highest CO and NO_x emissions were observed in the process with shorter combustion time and higher average λ value (λ=2.6, time 1200 s.). Three of the analysed combustion processes were characterized by similar NO_x emission values. In the context of this, it can be concluded that the best combustion process with respect to the emission of the analysed compounds is carried out in conditions of longer time and lower average λ value (λ=2.1, time 1500 s). The lowest observed CO emissions were below 9% of the highest. In the case of NO_x, the analogous relationship is about 40%.

Table 2. Total emissions of CO and NO_x from waste combustion.

Test	Emission, g/kg		Test	Emission, g/kg	
	CO	NO_x		CO	NO_x
λ=2.1, time 1200 s	1.9	0.28	λ=2.1, time 1500 s	0.8	0.27
λ=2.6, time 1200 s	9.3	0.64	λ=2.6, time 1500 s	2.3	0.25

The absence of a relationship in the research, indicating an increase in NO_x emissions with a decrease in CO emissions, results from the study of a research area characterised by high values λ. In the range λ>2, NO_x emissions may behave in a relatively stable way and even decrease for even higher values λ [3]. The range of independent factors in the course of the research was selected in an attempt to imitate conditions similar to those in industrial facilities.

5 Final conclusions

Despite the implementation of the circular economy, waste incineration will still be a necessary element of the waste management system for a number of years to come. However, the role of burning refuse derived fuels is already growing, and the role of burning unsorted and unsorted waste is being reduced.

Individual refuse derived fuels are usually characterised by constant parameters, but there are significant differences in properties between the individual refuse derived fuels. Currently in Poland there is no legal distinction between combustible fractions of municipal waste and refuse derived fuels.

The paper presents research on the combustion of combustible fractions of municipal waste. The properties of the burnt sample corresponded to the average properties of such a

fraction in Poland. At the same time, these properties are within the ranges observed for refuse derived fuels.

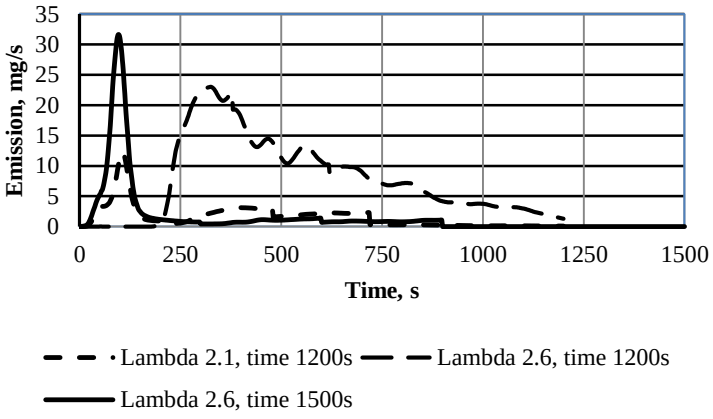

Fig. 3. Exemplary diagrams of changes in CO emissions during the combustion process.

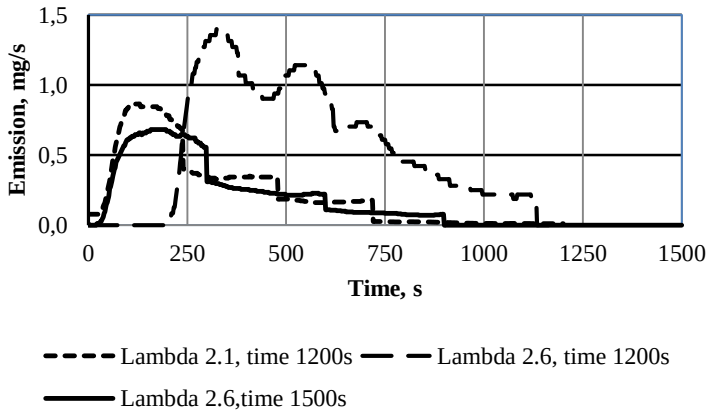

Fig. 4. Exemplary diagrams of changes in NO_x emissions during the combustion process.

As a result of the conducted research and their analysis, CO and NO_x emission factors per weight unit of the burnt fractions have been obtained. The lowest emission of the analysed compounds was observed in the conditions of combustion taking place at the ratio of excess air λ=2.1 and combustion time of 1500 seconds. Moreover, within the framework of the presented studies, it was found that the lowest emission was observed:
- CO was below 9% of the highest,
- NO_x was about 40% of the highest.

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