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The influence of combustion of various types of hard coal on the level of pollutant emission

Introduction

According to statistics, coal and carbon-derived fuels account for the largest, share among the types of fuels used in solid fuel boilers in Poland, amounting to as much as 55.5% (Statistics CEEB 2022). When adding in the share of other heating devices that use coal, for example tile stoves, coal stoves, fireplaces, and other solid fuel air heaters, the share is increased by several more percent (Statistics CEEB 2022). In the last several years, there has been a gradual shift from heating buildings with coal to using natural gas, heat pumps or electric energy (Mei et al. 2021). However, considering the current geopolitical situation in Poland, the return to solid fuel-based heating might provide a solution to the problem of shortages of energy obtained from other sources. In general, the easy availability of coal from reliable suppliers and the relatively low price of such fuel are undoubted advantages of

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coal-based heating. The exception was the last heating season, when there was a destabilization on the market of fuels, energy and raw materials, resulting from the outbreak of war in Ukraine (Report 2023).

Heating buildings with solid fuels is associated with the emission of pollutants to the environment. Low-stack emission is a problem due to releasing large amounts of various pollutants in a diffusing manner, including primarily carbon oxides, nitrogen oxides, sulfur oxides, hydrocarbons, volatile organic compounds, particulate matter and heavy metals. These compounds are changing the natural composition of the atmosphere and creating smog. They also have a harmful effect on living organisms and biological processes. They can cause disease reactions, including carciogenic reactions (Das and Ravi 2022). The low-stack emission mainly concerns the use of coal in combustion processes in households. Because of this, using coal as fuel in household heating boilers is gradually being abandoned. However, there are many ways to prevent the negative effects of coal combustion. Actions are being taken around the world to reduce emissions of particularly harmful compounds released during coal combustion, for example, carbon oxides, nitrogen oxides, sulfur oxides, hydrocarbons and solid particles. Various types of additives are often used during coal combustion. The use of iron (II, III) oxide Fe_3O_4 has reduced the emission of polycyclic aromatic hydrocarbons from coal combustion in household heating furnaces and mitigated the agglomeration of coal ash particles (Yao et al. 2020). In another study, the use of aluminum oxide Al_2O_3 and titanium dioxide TiO_2 led to the melting and condensation of small ash particles, and therefore to the emission of only large solid particles that are less harmful to organisms (Xu et al. 2022). The power and type of heating boiler also has an impact on the level of pollutant emissions. Automatic boilers provide the most stable combustion of both coal (Křůmal et al. 2021) and other fuels (Křůmal et al. 2019). Reducing emissions from coal combustion can be achieved very effectively as a result of co-firing biomass with coal. This topic is widely recognized in the literature (Wielgosiński et al. 2017; Akhmetshin et al. 2020; Pawlak-Kruczek et al. 2020). By burning municipal waste with coal, CO_2 emissions can be significantly reduced (Xu et al. 2020). The emission of sulfur and nitrogen oxides for fuel mixtures with biomass can be 12–35% lower compared to burning coal without the addition of biomass (Nikitin et al. 2021). Research on the emission of harmful compounds from coal combustion most often concerns nitrogen oxides (Kuang et al. 2021) and polycyclic aromatic hydrocarbons (Yao et al. 2020).

The problem of low-stack emission is largely caused by the poor quality parameters of fuels available on the market. When choosing coal at the coal deposit, we are not able to assess its quality. We can, however, make our choice based on the type of coal. Type 31 flame coal with low caking capacity and a high content of volatile matter, and type 32 gas-flamed coal with medium caking capacity and equally high content of volatile matter can be used in household furnaces. Type 33 gaseous coal with high sinterability can only be used in top-combustion charging boilers (Basic parameters of hard coal 2019). In this research, the concentrations of emitted compounds during the combustion of various types of hard coal were measured in order to compare the levels of pollutant emissions.

1. Material and methods

The scope of the research covered gases obtained from the combustion of three types of hard coal (sortiment: walnut) from five different fuel depots in Lower Silesia. Information about the covered samples is summarized in Table 1.

Table 1. Data of tested hard-coal samples

Tabela 1. Dane badanych próbek węgla kamiennego

No. of sample	Coal type	Coal deposit	Mine	Input mass (g)		Ash mass (g)
				Coal	Wood	
31/1	31	S1	Piast	750.6	294.9	463.9
31/2		S2	Ziemowit	757.7	297.8	461.2
31/3		S3	Piast	756.4	305.7	482.8
31/4		S4	Piast	749.1	297.6	471.9
32/1	32	S3	Wujek	767.7	299.0	539.5
32/2		S4	Chwałowice	749.3	308.9	772.5
32/3		S2	Wesoła	750.6	301.1	715.9
32/4		S1	Bobrek	750.4	304.3	648.2
33/1	33	S1	Jankowice	767.3	298.2	661.8
33/2		S4	Marcel	762.7	311.8	669.7
33/3		S3	Jankowice	748.8	297.9	625.0
33/4		S3	Marcel	756.2	299.8	664.0

The combustion of test samples was carried out using an up-draft research furnace (Figure 1). The dimensions of the combustion chamber were: 30 × 30 × 40 mm. The fuel samples were fragmented before being placed in the furnace. Wood (acacia) was used as kindling. Compressed butane was used for igniting the furnace. In each case, the combustion procedure was started by weighing a pre-established fuel sample (750 g) and kindling portion (300 g). The mass of ash obtained from the combustion of samples was also weighed. The lowest values of the ash mass compared to the other coal type samples was obtained for type 31 coal. This may be related to the lowest caking ability of type 31 coal. The ignition time was two minutes. In each case, the combustion time was sixty minutes.

During the sample combustion, a pipe was inserted into the chimney, therefore allowing measurement of the emission of the harmful compounds that were the main components

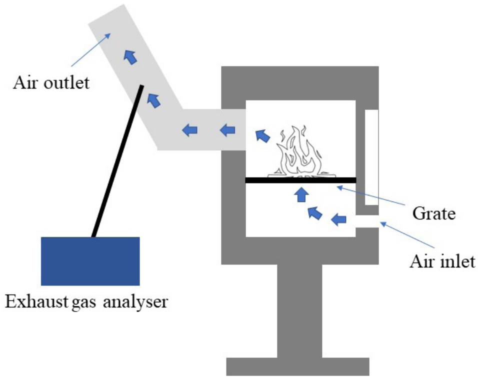

Fig. 1. Scheme of the research system

Rys. 1. Schemat układu badawczego

of the smog (carbon monoxide CO, nitrogen oxides NO_X, sulfur dioxide SO_2 and hydrocarbons HC), and the temperature of the tested gasses. The ambient temperature was also measured and remained at 25–30°C during combustion. The results were recorded every ten minutes, beginning from the start of the combustion. A Kane KM9106 Quintox exhaust gas analyzer was used for the tests. Measurement uncertainties of the device are given in Table 2. After sixty minutes, the burned material was removed from the furnace into heatproof containers and left to cool. The cool ash was placed in clean jars. After each test combustion, the furnace was cleaned from the remains of ash and other impurities.

Table 2. Exhaust gas analyzer measurement accuracy

Tabela 2. Dokładności pomiarowe analizatora spalin

Parameter	Accuracy
O_2	–0.1% + 0.2%
CO_2	±0.3%
CO	5% of reading < 2,000 ppm ±10% of reading >2,000 ppm
HC	±0.3%
NO_X	±5%
SO_2	±0.5%
Temp.	1.0°C ±0.3% of reading

2. Results and discussion

The charts below present concentration values of the tested compounds, based on the data obtained from the exhaust gas analyzer registered during the combustion of coal samples. The percentage of O_2 in the flue gas ranged from 18.9% to 20.3% for each sample. In turn, the percentage of CO_2 ranged from 0.6% to 2.5%. The highest CO concentration values were registered for samples of type 31 coal (Figure.2). The highest registered value was 2,898 ppm. The courses of CO emission on the charts for most samples of type 31 and 32 coal show two concentration increase points, the first being around the tenth minute of combustion. In most cases, for the type 33 coal samples, a single CO concentration increase point was registered in the second half of the combustion time. Increased values of CO concentration for samples 31 in the last stage of combustion may indicate inaccurate flushing of the analyzer with air.

The lowest HC concentration values were registered for samples of type 32 coal (Figure 3). The HC emission was highest for samples 31/1 and 31/4, with registered concentration values above 150 ppm. For the remaining samples, the concentration values on the charts are linear, with a single concentration increase point registered around the tenth minute of combustion.

The lowest nitrogen oxide concentration values were registered for samples of type 33 coal (Figure 4). Differences in times of the occurrence of concentration increases were registered for the course of combustion of type 33 samples. For samples 31 and 32, the maximum instantaneous NO_X concentrations were about 70 ppm. The maximum emission was reached at around the twentieth minute of combustion.

Along with chimney smoke, harmful sulfur dioxide was also emitted (Figure 5). The highest SO_2 concentration values were registered for samples of type 31 coal. The course of points on the chart shows major differences for individual samples. The repetition of compound concentration levels over time can be observed for samples 32 and 33.

The measured values of temperature of the emitted gases indicate that the emission of some of some of the compounds is temperature-dependent (Figure 6). The maximum concentration values of the NO_X concentration were observed for the maximum temperature in the 20^{th} minute of the combustion. The highest HC and SO_2 concentration values for most samples were registered when the temperature increased to the maximum temperature. The highest combustion temperatures of type 33 coal samples were lower than the values obtained for type 31 and 32 coal samples. It should be remembered that flue gases with a temperature below about 105°C contain water (in liquid form) and water vapor above it. This interferes with the measurement of SO_2 concentration.

Table 3 summarizes the results of the average concentrations of the tested compounds recorded at seven measurement points. The average of the sums of concentrations was calculated for the compounds emitted during the combustion of each sample for each type of coal. Standard deviation error was included. The results were compared in a form of a percentage difference in emission levels of the tested pollutants. The highest average sum of concentrations of compounds for type 31 coal samples was marked as 100% emission level of the

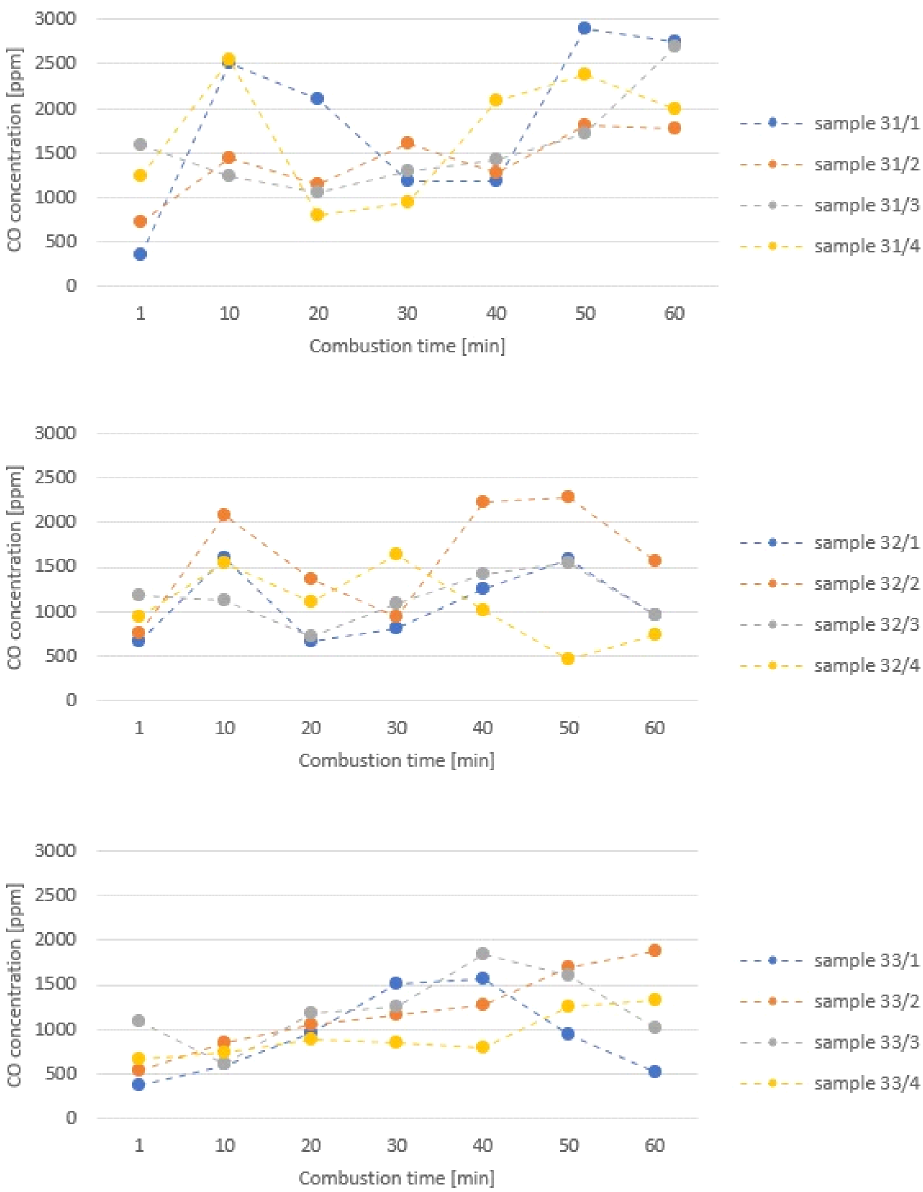

Fig. 2. CO emission during hard-coal combustion

Rys. 2. Emisja CO podczas spalania węgla kamiennego

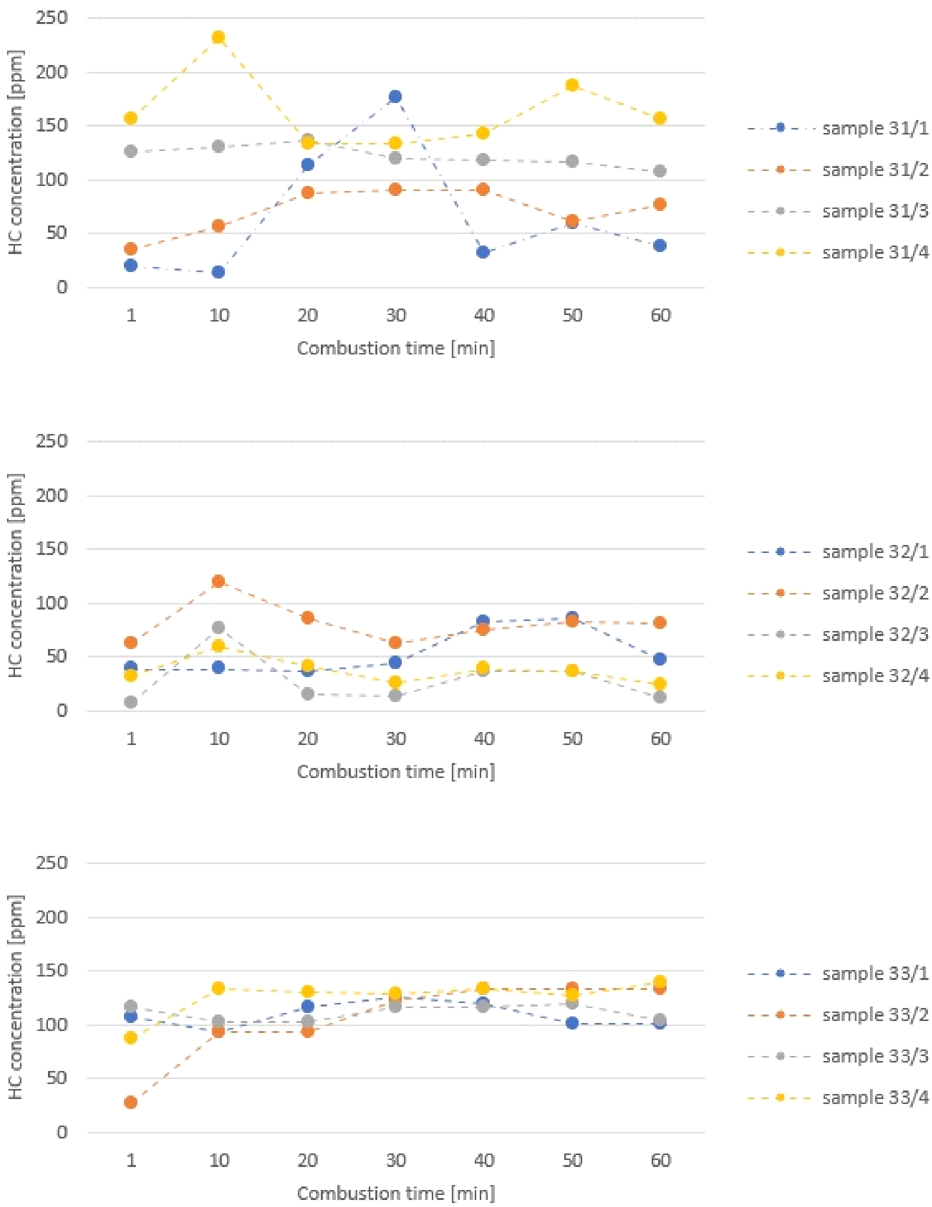

Fig. 3. HC emission during hard-coal combustion

Rys. 3. Emisja HC podczas spalania węgla kamiennego

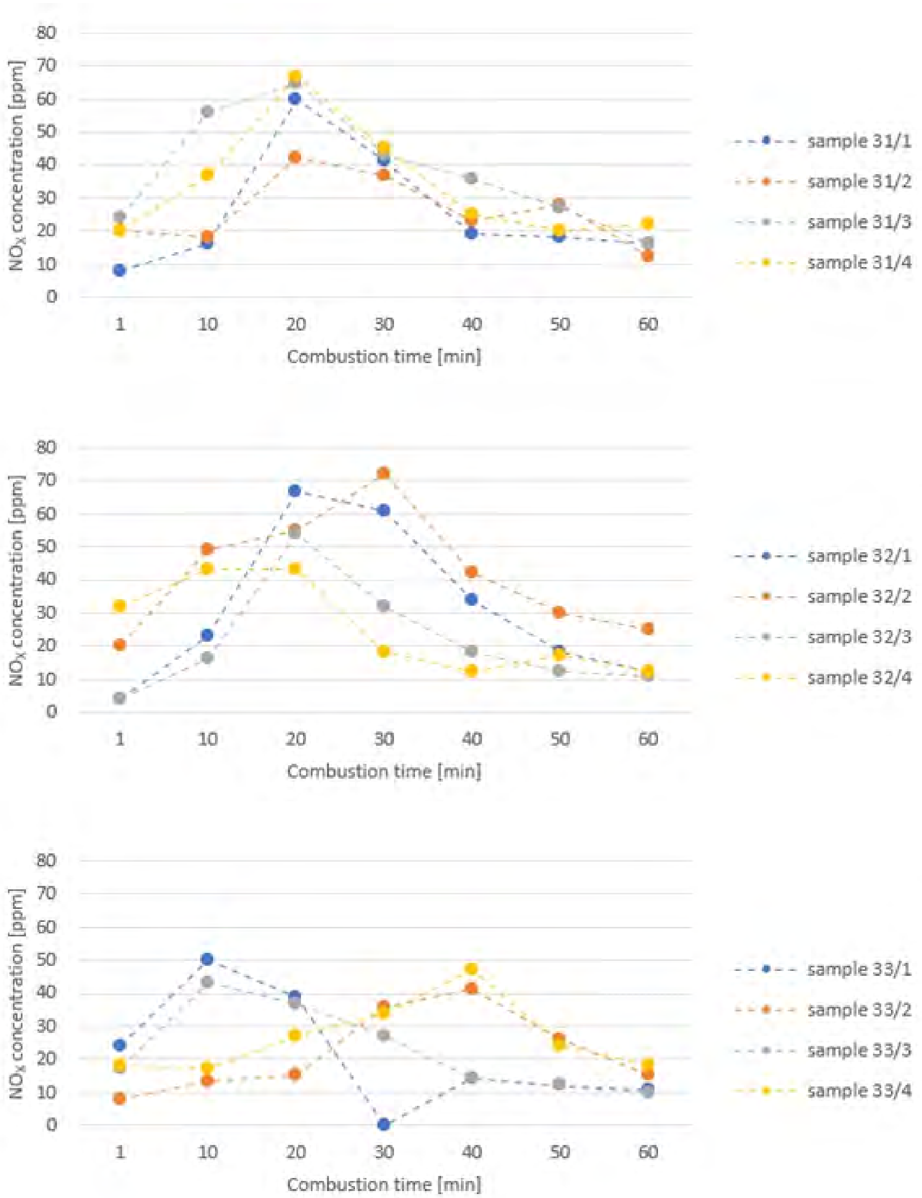

Fig. 4. NO_X emission during hard-coal combustion

Rys. 4. Emisja NO_X podczas spalania węgla kamiennego

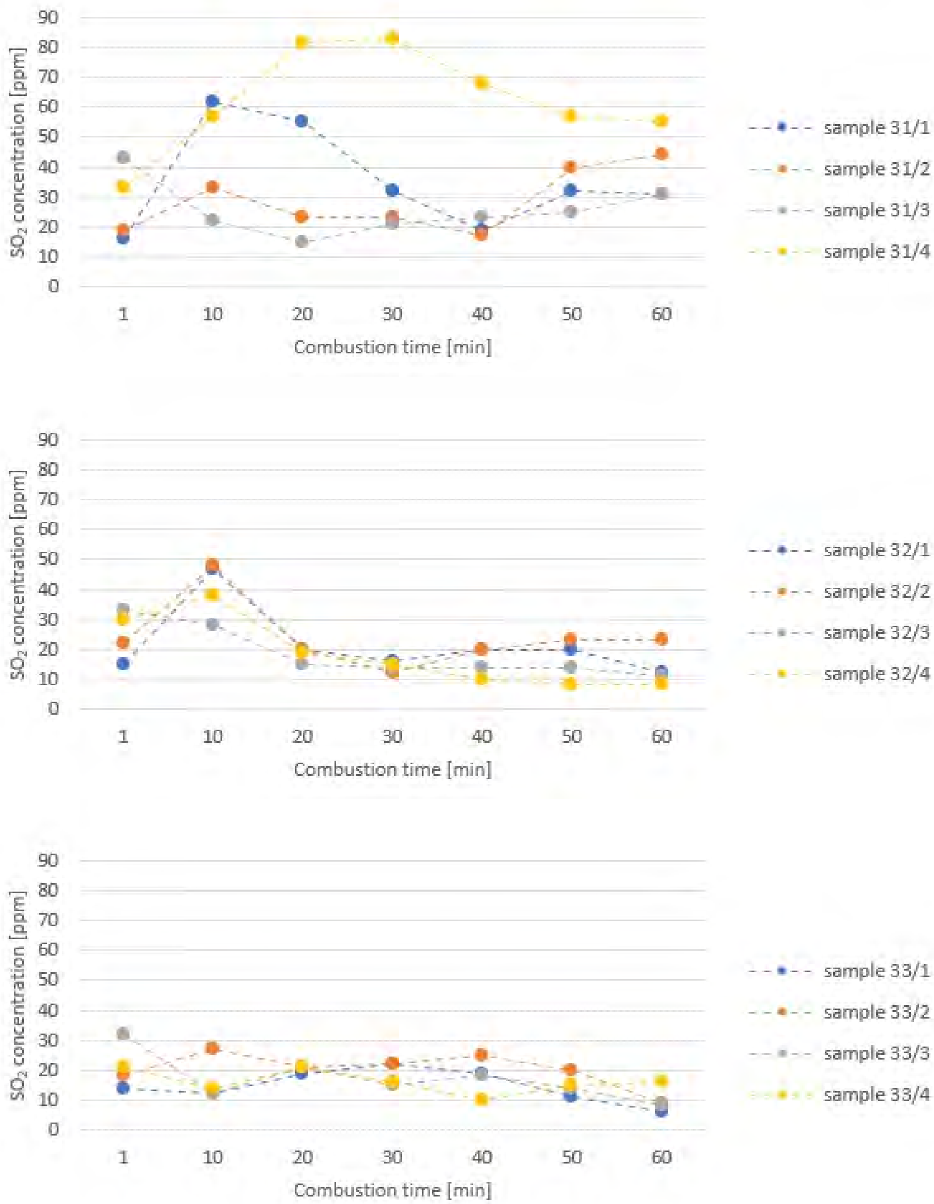

Fig. 5. SO_2 emission during hard-coal combustion

Rys. 5. Emisja SO_2 podczas spalania węgla kamiennego

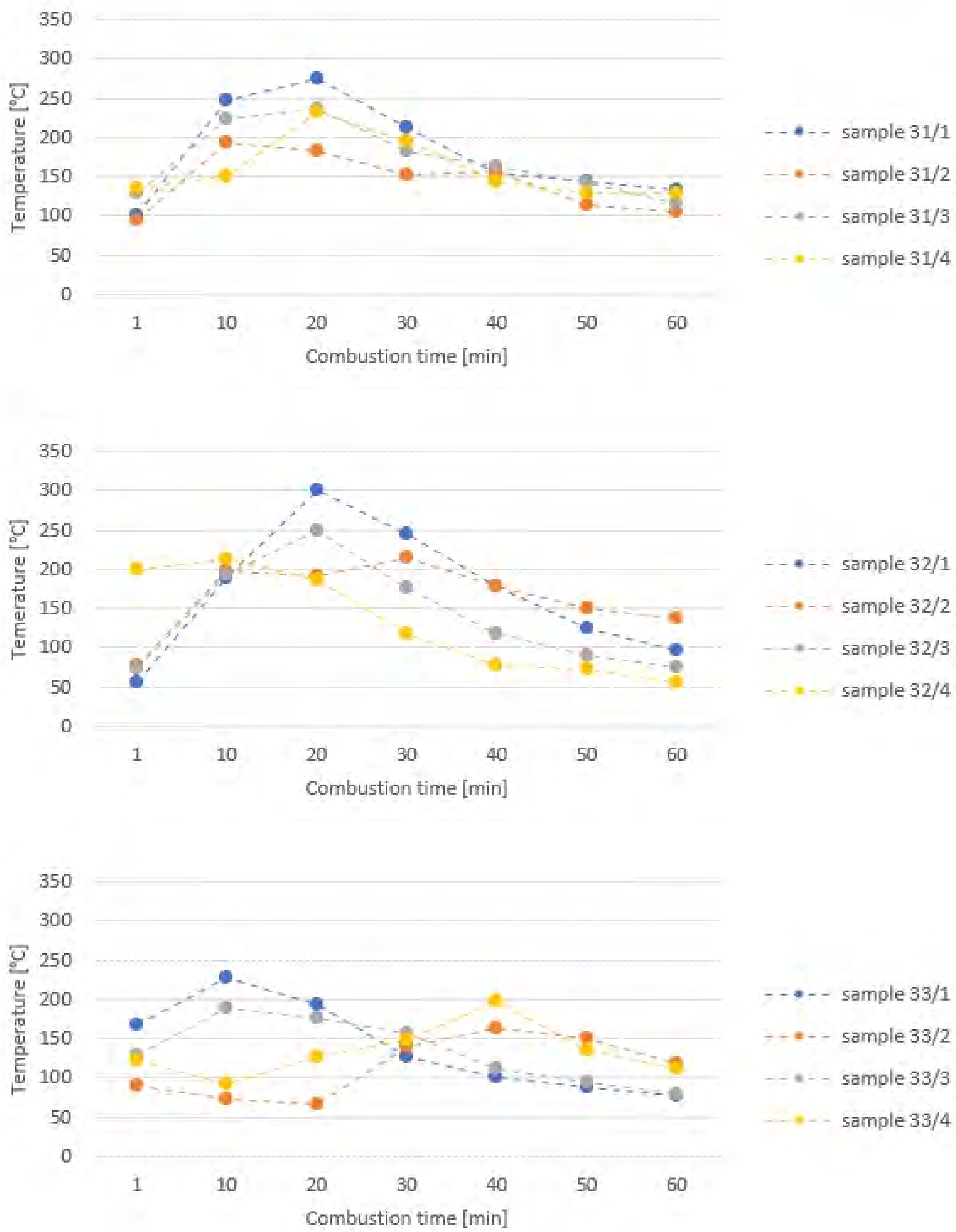

Fig. 6. Temperature of emitted gases during hard-coal combustion

Rys. 6. Temperatura emitowanych gazów podczas spalania węgla kamiennego

Table 3. Comparison of average concentrations of tested compounds of different types of hard coal

Tabela 3. Porównanie średnich stężeń badanych związków różnych typów węgla kamiennego

No of sample	Average compound concentration (ppm)				Sum of compound concentrations (ppm)	Average of sums of compound concentrations (ppm)	Pollutant emission level (%)
	CO	HC	NO_X	SO_2			
31/1	1,851	65	25	35	1,977	1,805 ±215	100
31/2	1,397	71	26	28	1,522		
31/3	1,569	122	38	26	1,755		
31/4	1,709	163	34	62	1,968		
32/1	1,074	54	31	21	1,181	1,321 ±287	73
32/2	1,601	82	42	24	1,749		
32/3	1,146	28	21	18	1,213		
32/4	1,061	37	25	18	1,142		
33/1	918	109	21	15	1,064	1,366 ±166	76
33/2	1,208	105	22	20	1,356		
33/3	1,226	111	23	17	1,377		
33/4	928	126	26	16	1,096		

tested pollutants. It was concluded that the combustion of coal type 32 and 33 can impact the harmful compounds emission reduction by even more than 20%.

According to the Polish Smog Alert, in 2021 the most polluted cities in Poland due to persistent smog were: Nowa Ruda, Nowy Targ and Sucha Beskidzka (GIOŚ 2022). In those cities, the air quality often significantly deviates from the applicable standards. According to WHO reports, it has been noted for years that regions with a particularly high level of pollution in Poland are Silesia and Małopolska (Air pollution in Poland 2022). According to the European policy which isaimed at limiting the emission of harmful chemical substances to the atmosphere in the heating process, new solid fuel boilers must meet the requirements set out in the Ecodesign directive (What is the Ecodesign Directive? 2021) and meet the current legal standard, which provides emission standards for heating boilers of various classes (PN-EN 303-5:2021-09). In Poland, an anti-smog resolution is also in force as an act of local law, which defines, among other things, the types and quality of fuels approved for use, as well as the emission parameters of installations in which fuels approved for use in a given area can be burned (Anti-smog resolution 2018).

Conclusion

The results presented in this research indicate that the pollutant emission levels generated during the combustion of hard coal intended for household heating boilers may vary depending on the type of coal. The average sum of the concentration of compounds emitted during the combustion of type 31 coal samples was 1,805 ppm, which is 20% higher than the concentration values obtained for type 32 coal samples, which were respectively 1,321 ppm and 1,366 ppm. Moreover, the highest average concentration values of carbon monoxide, the permissible concentration of which is covered by the emission standards, was registered for type 31 coal samples.

Being aware of the fact that the smog pollution level depends on the region, including the terrain and weather conditions, it is worth considering changes to local law, regarding the use of a specific type of coal in a given region. It could result in locally reducing the emission levels in places, where the permissible air quality indicators are most often exceeded.

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THE INFLUENCE OF COMBUSTION OF VARIOUS TYPES OF HARD COAL ON THE LEVEL OF POLLUTANT EMISSION

Keywords

hard coal type, low emission, combustion, smog

Abstract

Human-induced climate change is caused by the emission of pollutants into the environment. One of the sources of the formation of harmful compounds is the combustion of solid fuels in heating boilers. These contribute to the occurrence of respiratory and circulatory system diseases, allergies, cancer and developmental disorders in children. In this research, the concentrations of carbon monoxide, nitrogen oxides, sulfur dioxide and hydrocarbons in samples obtained from the combustion of hard coal intended for fuel in household furnaces were measured using an exhaust-gas analyzer equipped with electrochemical sensors. The combustion of test samples was performed using an up-draft research furnace. The results show that the average total concentration of the tested pollutants emitted from the combustion of type 32 and type 33 coal is over 20% lower compared to the emission from the combustion of type 31 coal. Moreover, the concentration of carbon monoxide, the permissible levels of which are regulated by the chimney emission standards, is significantly lower during the combustion of type 32 and type 33 coal compared to the combustion of type 31 coal. Therefore, one of the ways to locally reduce pollutant emission from the combustion of solid fuels in home heating boilers might be the accurate choice of the type of hard coal used for heating. Before the use of coal stoves in households is completely dismissed, local regulations can be introduced to limit emissions in places where air quality indicators are exceeded and improve the health of the population.

WPŁYW SPALANIA RÓŻNYCH TYPÓW WĘGLA KAMIENNEGO NA POZIOM EMISJI ZANIECZYSZCZEŃ

Słowa kluczowe

typ węgla kamiennego, niska emisja, spalanie, smog

Streszczenie

Zmiany klimatyczne, do których prowadzi działalność człowieka, są wynikiem emisji zanieczyszczeń do środowiska. Jednym ze źródeł powstawania szkodliwych związków jest spalanie paliw stałych w kotłach grzewczych. Przyczyniają się one do występowania chorób układu oddechowego i krążenia, alergii, nowotworów oraz zaburzeń rozwojowych u dzieci. Przeprowadzono pomiary stężeń tlenku węgla, tlenków azotu, dwutlenku siarki oraz węglowodorów ze spalania próbek węgla kamiennego przeznaczonego do opału w piecach domowych z wykorzystaniem analizatora spalin wyposażonego w czujniki elektrochemiczne. Próbki spalano w piecu badawczym górnociągowym. Wyniki badań wskazują, że średnie sumaryczne stężenie badanych zanieczyszczeń emitowanych ze spalania węgla typu 32 oraz 33 jest o ponad 20% niższe w porównaniu z emisją ze spalania węgla typu 31. Ponad to, poziom tlenku węgla, którego dopuszczalne stężenie objęte jest normami emisji kominowych, podczas spalania węgla typu 32 oraz 33 wykazał znacznie niższe wartości względem typu 31. Zatem, jednym ze sposobów lokalnego obniżenia emisji zanieczyszczeń ze spalania paliw stałych w przydomowych kotłach grzewczych może okazać się właściwy wybór typu węgla kamiennego. Zanim nastąpi całkowite odejście od stosowania pieców węglowych w gospodarstwach domowych, co przyniesie znaczną poprawę stanu zdrowia ludzi w relatywnie krótkim czasie, można wprowadzić lokalne przepisy ograniczające emisję w miejscach, gdzie przekraczane są wskaźniki jakości powietrza.