

Concentration of Nitrogen Oxides When Burning Wood Pellets of Various Origins

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ABSTRACT

The paper examined the impact of wood pellets of different type on the emission of nitrogen oxides (NO_x) formed during the combustion process in a low-power heating boiler. The study aim was to determine the dependencies of the NO_x emission levels on the chemical composition of fuel. The test was carried out using a model of a combustion chamber equipped with a dedicated burner. The analysis of the results confirmed the relationship between flue gas and the formation of NO_x. The obtained results prove the possibility of reorganizing the combustion process in order to reduce the NO_x emission by selecting a proper composition of raw materials when producing wood pellets.

Keywords: nitrogen oxides, heating boiler, emission, wood pellet

INTRODUCTION

The environmental aspect of combustion processes has been long analysed by the scientists studying the ecological properties of combustion processes [Fiedler and Persson 2009; Hardy et al. 2012; Musialik-Piotrowska et al. 2010; Zhang and Smith 2007]. The basic principle of reviewing a heating boiler in relation to thermodynamics is to consider it as an open thermodynamic system with a strong impact on the environment, which results from the conversion of the chemical energy contained in the fuel into the thermal energy that is partially exchanged with the environment [Khodaei et al. 2015]. An inherent element of these processes, both in industrial and local power section, is the emission of harmful substances during combustion, which are closely related to the technical parameters of boilers [Boman et al. 2011; Hroncová et al. 2016; Morán et al. 2006; Müllerová et al. 2010; Rabczak and Proszak-Miąsik 2016]. Another element that regulates the concentration of toxic compounds in flue gas is the type and chemical composition of fuel [Ciupek et al. 2019; Holubcik et al. 2018; Junga et al. 2017; Koniecznyński et al. 2017].

The research conducted so far confirms that the combustion of fossil fuels and biomass of various sources has a direct impact on the environment [Ciupek 2019; El-Sayed and Khairy 2018; Filbakk et al. 2011; Joseph et al. 2018; Mitchell et al. 2016; Wiinikka and Gebart 2005]. Apart from introducing innovative methods of boiler construction and analyzing the diversity of the element contents in fuels, scientists have been conducting the research to increase the efficiency of the combustion process and minimize its negative environmental effects [Eskilsson et al. 2004; Kirsanovs et al. 2014; Polák and Neuberger 2008]. The main impact on the efficiency of the combustion process results from the method of supplying fuel to the furnace [Juszczak 2016]. On the other hand, limiting the emission of toxic compounds is associated with a proper organization of the combustion process, which directly affects the characteristics of the emitted harmful substances related to the air-fuel equivalence ratio (λ) [Ciupek et al. 2019].

Due to a limited amount of naturally occurring fossil fuels and higher concentrations of toxic compounds released when burning, efforts are currently being made to increase the use of renewable

fuels. An essential benefit of the biomass fuel combustion is that the process emits trace amounts of sulfur dioxide and significantly less particulate matter. The importance of using different types of pellets for energy purposes in Poland and around the world has been described in the cited publications [Cao and Pawłowski 2013; Piaskowska-Silarska 2014; Ratajczak et al. 2012].

The study was divided into three stages. The first stage involved determining the NO_x emissions while burning the wood pellets made from deciduous tree waste – beech. The second part of the research examined the NO_x emission levels during the pine pellet combustion, while the last stage involved burning the two previously mentioned fuels in the 50:50 ratio. The obtained test results were displayed in graphs as mass distributions of NO_x and in tables containing the minimum, maximum and average measurements. Additionally, the relationship between the flue gas temperature changes and the NO_x emissions for individual fuels was presented in the form of a chart.

METHODS

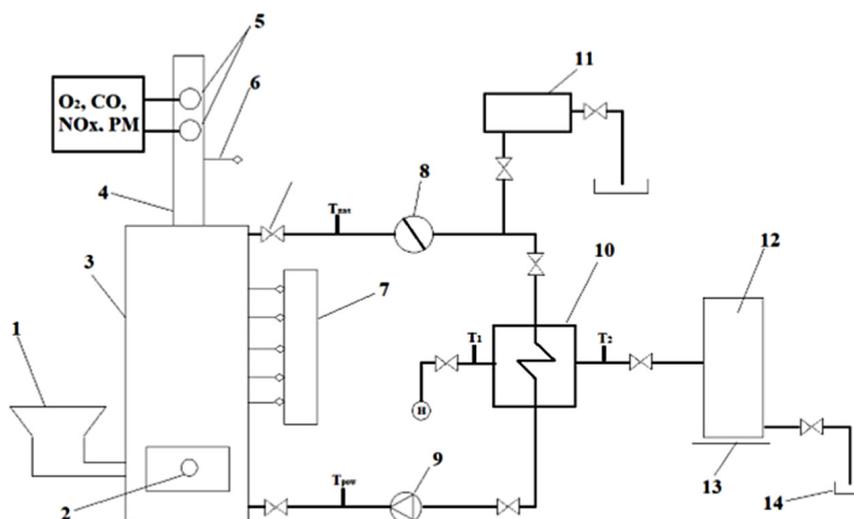
The test stand used in the study was a model of a cylindrical combustion chamber equipped with a burner assembly (a retort furnace and a blowing fan). The test system was connected to a water installation along with the required fittings.

Figure 1 presents the complete test setup diagram with a description.

Three types of fuel were supplied to the combustion process. The first fuel was the beech wood pellets, followed by the pine wood pellets, and the third fuel was a 50:50 mixture of the beech and pine pellets. The comparison of chemical compositions as well as the calorific values and the heat of fuel combustion are presented in Table 1.

The combustion chamber is equipped with an electronic controller that allows programming individual components. In consequence, before the measurement started, the combustion process had been stabilized in order to maximize efficiency and minimize the emission of pollutants. Fuels were periodically delivered by a drive unit with a screw feeder. Additionally, the system was equipped with an additional blowing fan speed controller that steadily supplied the air needed for the combustion process.

The measuring probe of the TESTO 330-2 LL flue gas analyzer was placed in the openings of the exhaust gas installation. The device was used to measure the composition of the flue gas and NO_x concentration changes analyzed in the article. The PT100 sensor was used to measure the temperature of the flue gas. The obtained values of the NO_x contents in the flue gas were subsequently calculated for 10% residual oxygen and converted to mg/m^3 . The test method was based on the guidelines of the PN-EN 303-5: 2012 standard.



Specification: 1 – fuel tank with burner, 2 – viewing hole, 3 – combustion chamber, 4 – measuring exhaust outlet, 5 – set of exhaust gas analyzers, 6 – exhaust gas temperature measurement (thermocouples), 7 – thermocouple system for measuring temperatures inside the combustion chamber, 8 – flowmeter, 9 – circulation pump system, 10 – plate heat exchangers system, 11 – expansion vessel, 12 – water tank, 13 – weight, 14 – cooling water outflow

Fig. 1. Specification and diagram of the test setup

Table 1. Technical parameters of fuels

Fuel	Carbon, %	Hydrogen, %	Oxygen, %	Nitrogen, %	Ash, %	Moisture, %	Calorific value, MJ/kg	Combustion heat, MJ/kg
Beech wood pellet	41.50	4.77	31.73	1.90	2.10	18.00	16.06	17.58
Pine wood pellet	40.33	4.97	34.54	1.40	1.76	17.00	14.32	15.86

RESULTS

The results of the conducted test generated parameters of the combustion process and the NO_x content in the flue gas for individual fuels. The results of the first test stage are presented in Table 2. The obtained flue gas temperature was in the range of 103.40–121.70 °C. The average value of the NO_x concentration obtained through continuous measurement was 265.86 mg/m³, while the air-fuel equivalence ratio (λ) oscillated within 1.61 ± 0.30. The mass distribution of NO_x emission for the first test stage is presented in Figure 2.

The results of pine pellets combustion in the second stage of the study are shown in Table 3. The obtained flue gas temperature was in the range of 79.00–92.60 °C. In comparison to the first stage of the study, the average NO_x emission decreased by 30.5%. The obtained air-fuel equivalence ratio (λ) revealed a significant increase reaching value 2.54 ± 0.30. The mass distribution of NO_x emission is presented in Figure 3.

The measurement results obtained in the third test stage are presented in Table 4. The mixed pellets achieved a flue gas temperature of 100.70–117.70 °C, an intermediate between the first and the second stage. The NO_x concentration was slightly lower than in the case of the first stage of the study and its average value

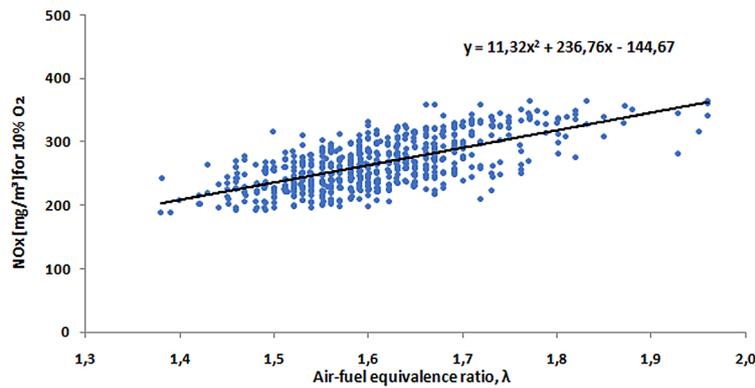


Fig. 2. NO_x mass distribution in the first test stage

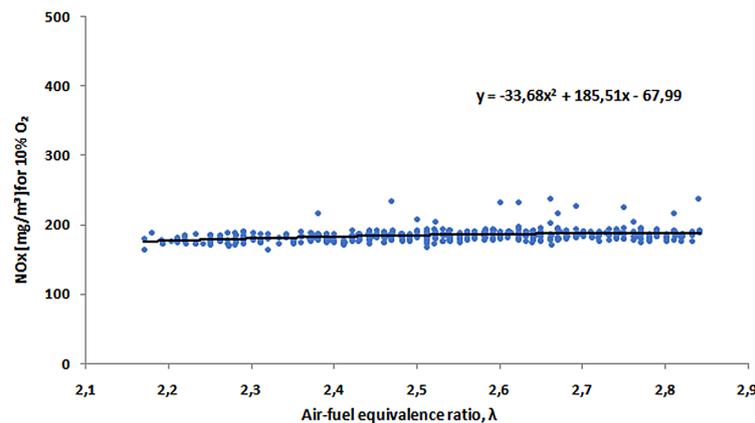


Fig. 3. NO_x mass distribution in the second test stage

Table 2. Measurement results of the first test stage

Value	O ₂ , %	NO _x , mg/m ³	T _{SP} , °C	λ
Minimum	5.99	189.22	103.40	1.38
Maximum	10.36	364.38	121.70	1.96
Average	7.97	265.86	114.44	1.61

Table 3. Measurement results of the second test stage

Value	O ₂ , %	NO _x , mg/m ³	T _{SP} , °C	λ
Minimum	11.31	164.22	79.00	2.17
Maximum	13.60	238.59	92.60	2.84
Average	12.68	184.83	82.32	2.54

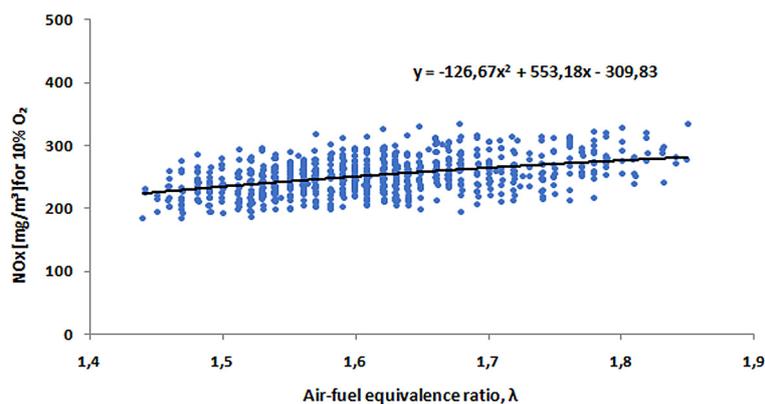


Fig. 4. NO_x mass distribution in the second test stage

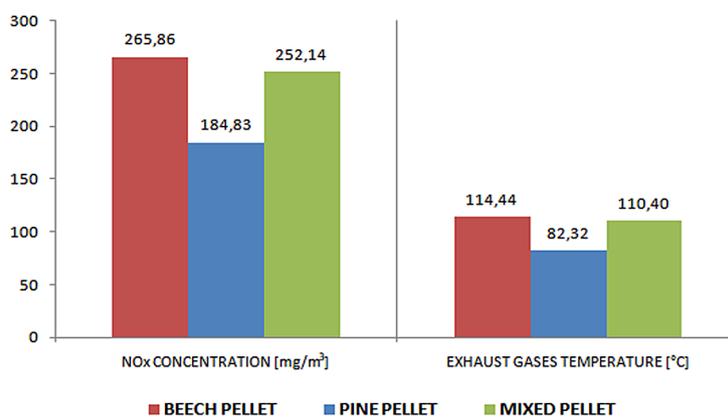


Fig. 5. Exhaust gas temperatures and NO_x concentrations for three types of pellets

Table 4. Measurement results of the third test stage

Value	O ₂ , %	NO _x , mg/m ³	T _{SPR} , °C	λ
Minimum	6.46	183.91	100.70	1.44
Maximum	9.67	333.59	117.70	1.85
Average	8.01	252.14	110.40	1.61

was 252.14 mg/m³. The air-fuel equivalence ratio (λ) was similar to the first stage and its average value also reached 1.61 ± 0.20. The NO_x mass distribution for the third stage is shown in Figure 4 and the relationship between the flue gas temperature and NO_x emissions for all test stages is presented in Figure 5.

CONCLUSIONS

This study investigated the impact of different pellet types on the NO_x emissions during the combustion processes in a low-power heating boiler. The obtained results demonstrate lower NO_x concentrations in flue gas when using the wood pellets originating from the pine tree waste. The higher content of elemental oxygen in this fuel achieved an increased air-fuel equivalence ratio (λ) and, the lowest temperature of flue gas among all stages of the study. The flue gas

temperature was higher while burning the beech pellets due to a higher calorific value of this fuel and the highest NO_x content in flue gas. While studying mass distributions, it was observed that the NO_x concentration increases noticeably along with an increase of the air-fuel equivalence ratio (λ). On the other hand, combustion of the mixed fuel shows a mild and small increase of emissions when the air-fuel equivalence ratio (λ) increased. Therefore, the presence of pine in fuel has a positive effect on the combustion process, because it reduces the NO_x formation. From the point of view of thermodynamic parameters and chemistry of combustion processes, the conducted study confirmed the existence of a strong dependency between the changes of the flue gas temperature and the formation of NO_x. The highest flue gas temperature during the beech pellet combustion went hand in hand with the most elevated level of the NO_x generation. The study is the basis for further research on the reorganization of the combustion process in terms of the NO_x reduction and it is also a good way to expand the knowledge in this area.

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