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USEFULNESS ASSESSMENT OF AUTOMATIC AIR FLOW CONTROL SYSTEM WITH OXYGEN SENSOR IN A 20 KW BOILER WITH PERIODIC WOOD PELLET SUPPLY

The benefits of applying automatic air flow control system with oxygen sensor in a 20 kW heating boiler with a retort furnace supplied periodically with wood pellets were examined. Boiler combustion chamber was not lined with ceramic blanket and therefore the fuel supply cycle duration (operation and stand-by) was set by the producer to just 20 seconds. Variation in time of carbon monoxide, nitric oxide, nitrogen oxides and oxygen concentrations in the flue gas, as well as correlations between: pollutant concentrations and temperature in the combustion chamber or oxygen concentration, temperature in the combustion chamber and oxygen concentration, nitric oxide and carbon monoxide concentrations were compared for different scenarios: with automatic air flow control and with constant air flow. It was concluded that applying automatic air flow control system with oxygen sensor did not significantly reduce carbon monoxide concentration (only by 10-15%). Most probably it is because the stand-by in fuel feeding is too short for the air supply fan to react. In order to reduce carbon monoxide concentration, instead of applying automatic air flow control it is preferable to obtain higher heat outputs (above 60% of its maximum value) and use higher capacity water heat storages.

Keywords: wood pellet combustion, pollutant emission, heating boiler, heat station, air flow control, oxygen sensor

Introduction

Environment-friendly waste wood combustion can be defined as such that generates the minimum possible emission of incomplete combustion products, namely carbon monoxide (CO) and hydrocarbons (HC). Numerous studies have shown that firing waste wood in form of pellets presents much lower CO concentrations in the flue gas [Olsson et al. 2003; Olsson and Kjallstrand 2004; Eskilsson et al. 2004; Fiedler 2004; Kjallstrand and Olsson 2004; Fiedler et al.

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2007; Gible et al. 2008; Musialik-Piotrowska et al. 2010; Verma et al. 2011a, 2013; Juszczak 2011a; Juszczak and Lossy 2012] than in case of firing wood in form of logs or chips [Johansson et al. 2004; Olsson and Kjallstrand 2006; Boman et al. 2011; Pettersson et al. 2011; Ozgen et al. 2014; Vincente et al. 2015]. In boilers commonly used in Poland, the concentration of CO in the flue gas generated from log wood combustion varies between 1000 and 8000 mg/m^3 [Juszczak 2010, 2011b], whereas for wood pellet combustion worldwide it is usually between 200 and 900 mg/m^3 [Fiedler and Persson 2009; Verma et al. 2011b], all values being presented for 10% O_2 concentration in the flue gas.

It is worth keeping in mind that frequently residential heating boilers with low heat output (of approximately 20 kW) used in detached houses are equipped with furnaces supplied with pellets periodically, as this solution is much cheaper than constant fuel supply. The higher price of constant fuel feeding system, as compared to periodic fuel supply, results mainly from the fact that a higher power motor for pellet screw conveyor propulsion needs to be used. Also, a device for fluent regulation of pellet screw conveyor revolutions needs to be applied.

In boilers with periodic fuel feeding system where combustion chamber is not lined with ceramic blanket, the cycle duration is small (usually set by the boiler producer to 20 seconds) in order to prevent the combustion chamber from cooling down too quickly. The operation and stand-by time need to be adjusted manually to obtain the desired boiler heat output. The relation between operation time and stand-by time, as well as air flow rate affects the magnitude of CO concentration in the flue gas [Juszczak 2014].

Periodic fuel supply system is problematic, as with constant air supply – which is the typical scenario – the combustion chamber is cooled down during the stand-by time and oxygen concentration increases. This causes a considerable increase in CO concentration in the flue gas. A factor that could potentially solve this problem and therefore help to reduce the pollutant emission is the automatic air flow control system with oxygen (Lambda) sensor (located in the flue gas downstream the boiler). The aim of equipping a boiler with this system is to limit air flow during the stand-by in fuel feeding by reducing fan revolutions and therefore prevent the combustion chamber from cooling down. Applying the aforementioned device, however, considerably increases boiler price, it is thus only being used in more costly boilers [FJBLT Wieselburg 2010].

For the analysis of the studied topic, it is important to understand the Polish context. A 20 kW wood biomass pellet heating boiler is rather expensive for the Polish user (as compared to a gas-supplied boiler). Just to give an example, the price of a 20 kW biomass-fed boiler in Poland varies between approx. 3 000 EUR for Polish brands without the automatic air control with oxygen sensor and 9 000 EUR (3 times as much) in case of German, Austrian, Swedish or Danish boiler brands equipped with the automatic air flow control system. Gas-fed boilers are much cheaper: a high quality 20 kW gas-supplied heating boiler costs approx. 600 euro (both in Poland and in other European countries). In Germany, for instance, the user is automatically reimbursed the difference in price between gas-fed boilers and wood pellet-fed boilers is by the state. In Poland, however, the user can only apply (with no guarantee of success) for a reimbursement of 40% of the boiler price from the state. It is worth taking into account that Polish medium monthly salary is approx. 800 EUR. For these reasons, a lot of pellet boilers in Poland are not equipped with combustion chambers lined with ceramic material nor do they use automatic air flow control device with oxygen sensor. Recently, there are attempts being made to introduce air flow control device with oxygen sensor to the boilers produced in Poland in order to decrease CO emission.

The aim of the study described in this paper was to determine if applying automatic air flow control system with oxygen sensor in case of periodic pellet supply with a 20 second feeding cycle – in a boiler where combustion chamber is not lined with ceramic blanket – always causes the reduction of CO concentration in the flue gas. It was also analyzed if it is worthwhile installing automatic air flow control system in boilers in spite of its high price.

Material and methods

Material

The fuel used in the study were wood pellets (fig. 1) produced by a Polish manufacturer Barlinek. The pellets were composed of a mixture of deciduous and coniferous wood in a ratio of 30:70. Pellet chemical composition was examined in an accredited laboratory according to the standard procedure [EN 15104:2011] and gave the following results (in wt% with SD standing for standard deviation): C – 48.87 ±0.57 SD, O – 40.60, H – 7.14 ±0.84 SD, N – 0.55 ±0.06 SD. Other pellet properties (tab. 1) were determined by the pellet manufacturer according to the standards [EN 14961-2:2011, EN 14774-1:2007, EN 14775:2009, EN 14918:2009] and are as follows:

Fig. 1. Wood pellets manufactured by a Polish pellet producer Barlinek

Table 1. Technical parameters of Barlinek pellets (manufacturer technical data)

Parameter	Unit	Value
Pellet diameter	[mm]	8
Pellet length	[mm]	≤ 40
Total moisture content	[%]	≤ 10
C	[wt%]	48.87 ±0.57 SD
H	[wt%]	7.14 ±0.84 SD
S	[wt%]	–
N	[wt%]	0.55 ±0.06
O	[wt%]	40.6
Ash content	[%]	≤ 0,7
Lower heating value	[MJ/kg]	No less than 18
Density	[kg/m^3]	≥ 600

Experimental set-up

The experiments were carried out in a full scale heat station connected with a very short (approx. 40 m) district heating network, heat transfer unit and heat receivers: (radiators and water heat storages, located in a small detached house with a surface of 100 m^2 (fig. 2). The heat station (fig. 3) is located in a laboratory belonging to the Poznan University of Technology (Division of Heating, Air Conditioning and Air Protection, Institute of Environmental Engineering).

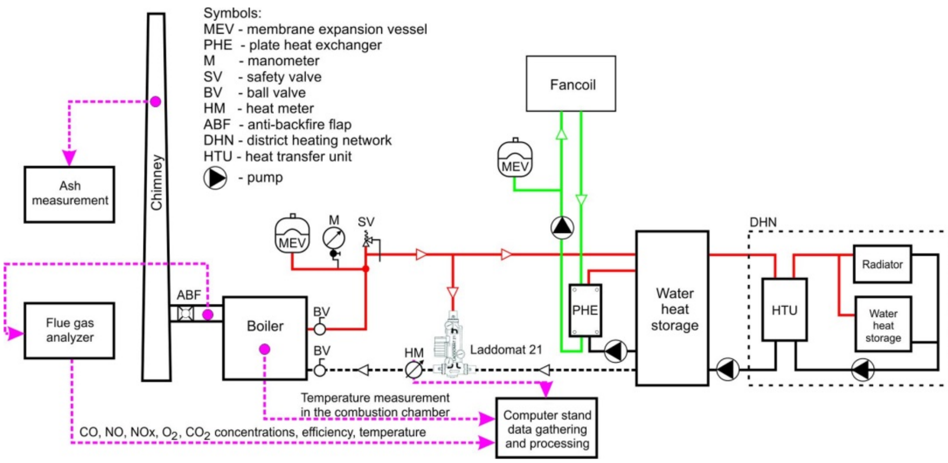


Fig. 2. Schematic layout of the experimental set up – biomass fed heat station, district heating network and heat receivers (radiator, water heat storage)

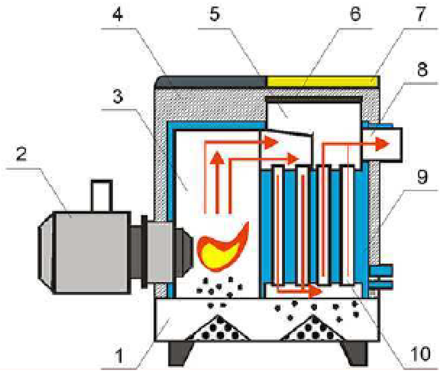
Fig. 3. View of the heat station located in a laboratory belonging to the Poznan University of Technology (Division of Heating, Air Conditioning and Air Protection, Institute of Environmental Engineering)

In all my studies special attention is paid to create conditions as similar to the real ones as possible and therefore simulate domestic boiler operation in Polish conditions (variable heat demand). Such conditions can be obtained in a full scale heat station described above. The huge benefit of such approach is that the results are much more realistic (usually higher pollutant concentrations) than the ones obtained in studies commissioned by boiler producers, performed in controlled stationary states in accredited laboratories [FJBLT Wieselburg 2010].

The equipment used in the study was a heating boiler Biomax manufactured by a Polish brand Lumo Mosina with a nominal heat output of 20 kW (fig. 4). The boiler is equipped with a pellet-supplied retort furnace of Swiss production, type Bioline [Fiedler 2004]. Pellets were supplied periodically in a 20 s cycle, with constant air flow within the cycle that can be regulated manually by end user.

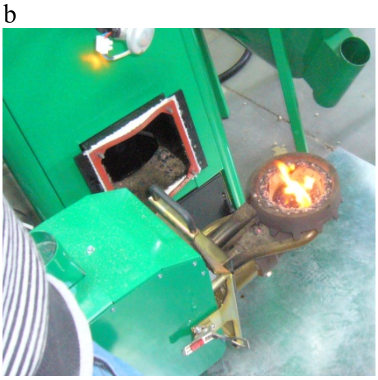
For the purpose of the study an automatic air flow control system was applied with oxygen sensor installed in the flue gas downstream the boiler.

a

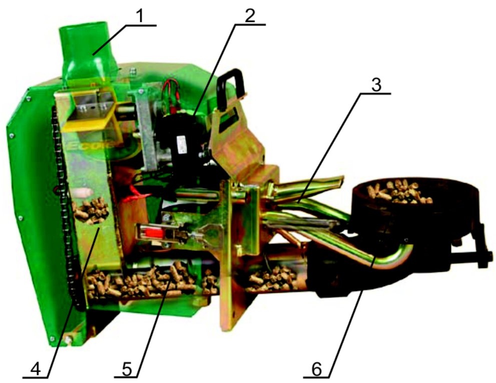


1 – dust container
2 – furnace
3 – combustion chaber
4 – insulation
5 – dust colector
6 – berth for cleaning
7 – boiler cover
8 – flue gas outlet
9 – water jacket
10 – heat exchanger

b



c



1 – fire lock, 2 – fan, 3 – secondary air tube,
4 – furnace pellet container, 5 – screw conveyor,
6 – fire region, primary air

Fig. 4. Biomax boiler with a nominal heat output of 20 kW: a – schematic layout, b – Biomax boiler with Bioline 20 retort furnace, c – Retort furnace type Bioline 20, Eco Tec, Sweden [Fiedler 2004]

Experimental procedure

While examining the combustion process in a boiler fed periodically with wood pellets, a few different pellet screw conveyor settings were applied, that differed in operation and stand-by time ratio within the total cycle duration of 20 s (which was fixed by the furnace producer and could not be changed). Such cycle duration (20 s) was suitable for the boiler used in the study, because the walls of the combustion chamber – that in this case function as heat exchange surfaces (fig. 4a) – were not coated with any ceramic material. If the cycle was longer (e.g. 60 s), meaning also a longer stand-by time, the combustion chamber would quickly and significantly cool down and, as a result, CO concentration would increase drastically.

Two of the examined settings were taken into account to compare the combustion parameters, namely: 15/5 seconds and 12/8 seconds (operation time / stand-by time). A relatively short stand-by time was chosen to prevent the combustion chamber from excessive cooling down. For each setting (15/5 s and 12/8 s), test runs with and without the automatic air flow control system with oxygen sensor were performed (tab. 2-5). Pellet mass stream was adjusted manually before the test runs depending on the scenario. At the beginning, for test runs with the 15/5 s setting with and without air control system, pellet mass stream used was of 2.6 kg/h, whereas for the 12/8 s setting, it was 2.0 kg/h. For the described above test runs without the automatic air flow control system, results were not presented in the tables because the increase in CO concentration in the flue gas was not significant (only between 10 and 15%). Afterwards, pellet mass stream was set to a higher value for test runs without air flow control system (for the 15/5 s setting it was 3.5 kg/h and for the 12/8 s setting, 3.4 kg/h) in order to achieve higher temperature in the combustion chamber and bigger heat output than in cases where air control system was used (tab. 3 and 5). Such diversification of fuel mass stream was necessary to determine if during boiler operation with higher heat output it is possible to obtain comparable or even lover CO concentration values in the flue gas than in case of boiler operation with smaller heat output but using the automatic air flow control system with oxygen sensor.

Every test run had different fan revolutions (tab. 3 and 5) or different oxygen sensor settings (tab. 2 and 4) to observe the correlation between CO concentration (also NO, NO_x) and temperature in the combustion chamber, as well as oxygen concentration.

In order to study the combustion process in detail for both scenarios, with and without the air flow control system, parameter variation in time and correlations between different parameters were juxtaposed in the diagrams (fig. 5-9).

Measuring equipment

Gas pollutant concentrations (CO, NO, NO_x, HC) as well as oxygen concentration in the flue gas downstream the boiler were measured continuously using Vario Plus flue gas analyzer (MRU brand, Germany). Oxygen, NO and NO_2 concentrations were measured with electrochemical cells, whereas CO_2, CO and HC concentrations were measured using the infrared procedure. NO_x concentration was calculated with the gas analyzer by summing up the concentration of NO (transformed to NO_2) and NO_2, and it was presented in form of NO_2 concentration (according to the formula: $NO + ½\ O_2 = NO_2$). The Vario Plus flue gas analyzer transformed pollutant concentration values from ppm to mg/m[3] and presented all of them for 10% O_2 concentration in flue gas in order to be able to compare it with the Polish-European standard [PN-EN 303-5:2012].

The temperature in the combustion chamber was measured with thermocouple PtRhPt that was radiation shielded in order to reduce the negative effect of radiation.

Heat received by the boiler water and boiler heat output were measured with Kamstrup ultrasonic heat meter (Germany), type Multical 66-C. Boiler heat efficiency was calculated as heat transferred to the boiler water (Q_W) divided by fuel mass (m_{fuel}) multiplied by fuel lower heating value (W_d).

$$\eta = \frac{Q_W}{W_d \cdot m_{fuel}} \cdot 100\% \tag{1}$$

At the same time the calculated boiler heat efficiency values were compared with the values visualized by Vario Plus. The obtained values were confronted with estimated heat efficiency values calculated by Vario Plus flue gas analyzer based on chimney loss (correlated with the flue gas temperature downstream the boiler) and other estimated heat losses. This device also calculated and indicated air excess ratio. All the measured parameters were measured continuously, transferred in real time to computer memory, where they were registered every 3 seconds for averaged value calculation. Pellet mass stream was determined with Sartorius weight before each fuel load.

Results and analysis

The results of measurements obtained during test runs with and without the automatic air flow control system, both for 15/5 s and 12/8 s fuel feeding modes, were presented in tables 2-5. In total, 16 test runs, 4 per each setting, were presented. The values of pollutant concentrations (CO, NO and NO_x) and oxygen concentration in the flue gas, temperature in the combustion chamber, as well as other parameters such as boiler heat output and air excess ratio could be thus compared for all the four aforementioned scenarios.

The diagrams (fig. 5-9) were prepared based on two selected characteristic test runs, one for the case with the automatic air flow control system applied (tab. 2, test run no. 1) and one for the case without it (tab. 3, test run no. 5), in order to study various correlations within the combustion process. Only correlations for 15/5 s fuel feeding cycle were compared. All the points visualized in figures 6-9 are values of parameter pairs measured at exactly the same time. Boiler heat efficiencies were: 87% (tab. 2, test run no. 1) and 83% (tab. 3, test run no. 5). The 12/8 s fuel feeding cycle was not taken into account in the diagrams, however, similar conclusions can be drawn based on this scenario as well. Just for comparison, in the 12/8 s cycle, boiler heat efficiencies were: 81% (tab. 4, test run no. 9) and 82% (tab. 5, test run no. 14).

Table 2. Wood pellet combustion using the automatic air flow control system with oxygen sensor for wood pellet mass stream of 2.6 kg/h. Mean parameter values for fuel feeding and stand by time of 15 s and 5 s, respectively

Test run no.	Oxygen sensor settings		Test run duration	Air excess ratio	Heat output	O_2	CO_2	Temperature in the combustion chamber	Pollutant concentrations		
	min O_2	max O_2							CO	NO	NO_X
	[%]	[%]	[s]	[-]	[kW]	[%]	[%]	[°C]	[mg/m^3] (for 10% O_2)		
1	9	11	5400	1.9	11.3	9.8	11.7	629	428	179	287
2	6	8	5400	1.4	9.9	5.4	16.0	657	2055	157	251
3	10	12	5400	2.1	9.6	10.9	10.3	605	328	147	236
4	11	13	5400	2.2	9.9	11.0	10.4	606	811	159	254
Mean value				1.9	10.2	9.3	12.1	623	905	161	257

Table 3. Wood pellet combustion without the automatic air flow control system with oxygen sensor for wood pellet mass stream of 3.5 kg/h. Mean parameter values for fuel feeding and stand by time of 15 s and 5 s, respectively

Test run no.	Fan revolutions	Test run duration	Air excess ratio	Heat output	O_2	CO_2	Temperature in the combustion chamber	Pollutant concentrations		
								CO	NO	NO_X
	[%] max	[s]	[-]	[kW]	[%]	[%]	[°C]	[mg/m^3] (for 10% O_2)		
5	65	5400	1.6	14.5	7.8	13.6	701	500	181	290
6	75	5400	1.7	15.4	8.2	13.2	704	331	189	302
7	80	5400	1.7	15.2	8.8	12.5	691	286	181	290
8	90	5400	1.8	15.6	8.9	12.1	694	295	185	296
Mean value			1.7	15.2	8.4	12.9	698	353	184	295

Table 4. Wood pellet combustion using the automatic air flow control system with oxygen sensor for wood pellet mass stream of 1.8 kg/h. Mean parameter values for fuel feeding and stand by time of 12 s and 8 s, respectively

Test run no.	Oxygen sensor settings		Test run duration	Air excess ratio	Heat output	O_2	CO_2	Temperature in the combustion chamber	Pollutant concentrations		
	min O_2	max O_2							CO	NO	NO_X
	[%]	[%]	[s]	[-]	[kW]	[%]	[%]	[°C]	[mg/m^3] (for 10% O_2)		
9	12	14	5400	2.7	7.3	12.9	8.4	552	461	139	222
10	10	12	5400	2.0	7.0	10.1	11.3	580	408	168	269
11	8	10	5400	1.9	6.5	9.1	12.4	595	811	143	229
12	9	11	5400	1.8	6.2	9.1	12.0	579	686	139	223
Mean value				2.1	6.8	10.3	11.0	577	591	147	236

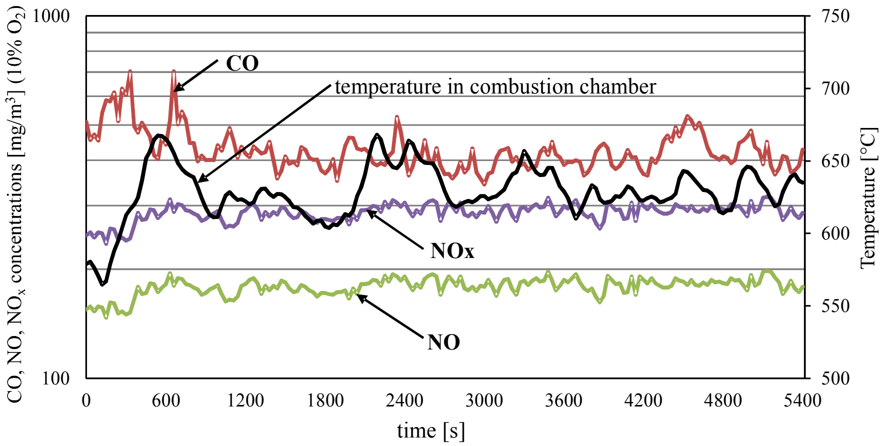
Table 5. Wood pellet combustion without the automatic air flow control system with oxygen sensor for wood pellet mass stream of 3.4 kg/h. Mean parameter values for fuel feeding and stand by time of 12 s and 8 s, respectively

Test run no.	Fan revolutions	Test run duration	Air excess ratio	Heat output	O_2	CO_2	Temperature in the combustion chamber	Pollutant concentrations		
								CO	NO	NO_X
	[%] max	[s]	[-]	[kW]	[%]	[%]	[°C]	[mg/m^3] (for 10% O_2)		
15	65	10800	1.5	13,9	6.9	14.7	693	876	198	317
16	75	10800	1.9	13.0	9.8	11.8	660	328	188	300
13	80	10800	1.9	13.9	9.9	11.6	662	323	176	282
14	90	10800	2.0	13.5	10.6	10.8	652	342	168	268
Mean value			1.8	13.6	9.3	12.2	667	467		292

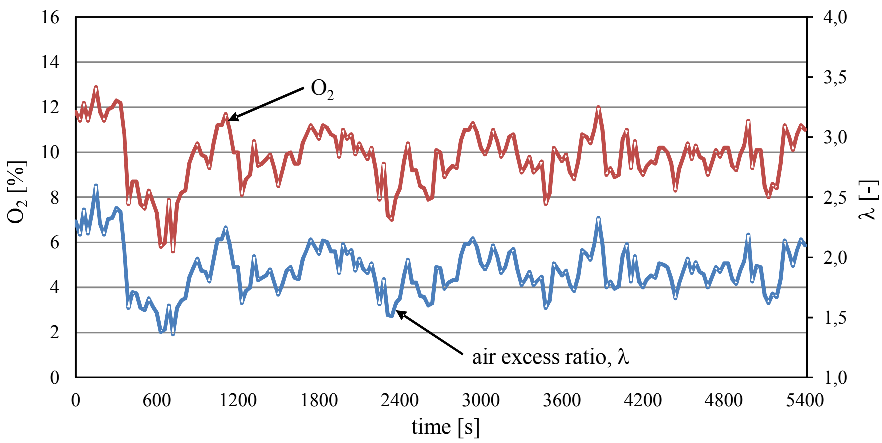
*The temperature in the furnace values presented in the tables and on diagrams were higher in reality, as the thermocouple was placed approx. 0,2 m above the furnace. Based on the measurements performed with a pyrometer it was estimated that in reality the temperature in the furnace was higher by approx. 100ºC.

As presented in tables 2-5, in all the analyzed cases, CO concentrations result much below the permitted value of 3000 mg/m^3, determined by the Polish-European standard for boilers with the lowest heat efficiency (third class boilers) [PN-EN 303-5:2012]. However for highest boiler heat efficiencies (fifth class), CO concentration permitted value is 500 mg/m^3 [PN-EN 303-5:2012], and the highest quality boilers can even reach the Blue Angel Standard which is as low as 100 mg/m^3 [Fiedler 2004]. Some of the highest CO concentration values are: 2055 mg/m^3 (tab. 2, test run no. 2) and 876 mg/m^3 (tab. 5, test run no. 13), which are caused by insufficient oxygen concentration of 5,4% and 6,9, respectively (temperature in the combustion chamber was sufficient in these cases); 811 mg/m^3 (tab. 2, test run no. 4), which is caused by insufficient temperature in the combustion chamber (oxygen concentration was sufficient in this case). Generally, as it can be observed in tables 2-5, the lowest CO concentration values for this type of furnace were obtained when oxygen concentration was about 9-10% (fig. 6) and temperature in the combustion chamber was above 620ºC (fig. 7) – in reality this temperature value in the furnace is about 100ºC higher (see description marked with * below the tables). All the concentrations in this paragraph were presented for 10% O_2 concentration in flue gas.

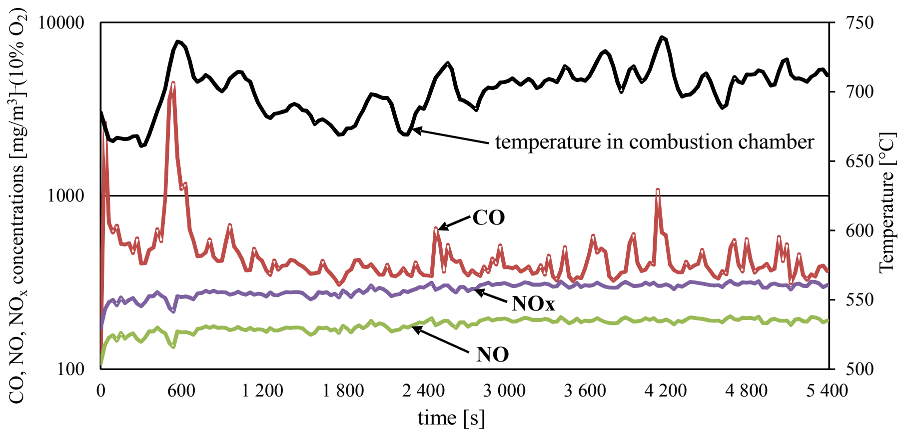
a


CO
temperature in combustion chamber
NOx
NO
CO, NO, NO$_x$ concentrations [mg/m^3] (10% O$_2$)
Temperature [°C]
1000
100
750
700
650
600
550
500
0
600
1200
1800
2400
3000
3600
4200
4800
5400
time [s]

b


O$_2$
air excess ratio, λ
O$_2$ [%]
λ [-]
16
14
12
10
8
6
4
2
0
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0
600
1200
1800
2400
3000
3600
4200
4800
5400
time [s]

c


temperature in combustion chamber
CO
NOx
NO
CO, NO, NO$_x$ concentrations [mg/m^3] (10% O$_2$)
Temperature [°C]
10000
1000
100
750
700
650
600
550
500
0
600
1 200
1 800
2 400
3 000
3 600
4 200
4 800
5 400
time [s]

d

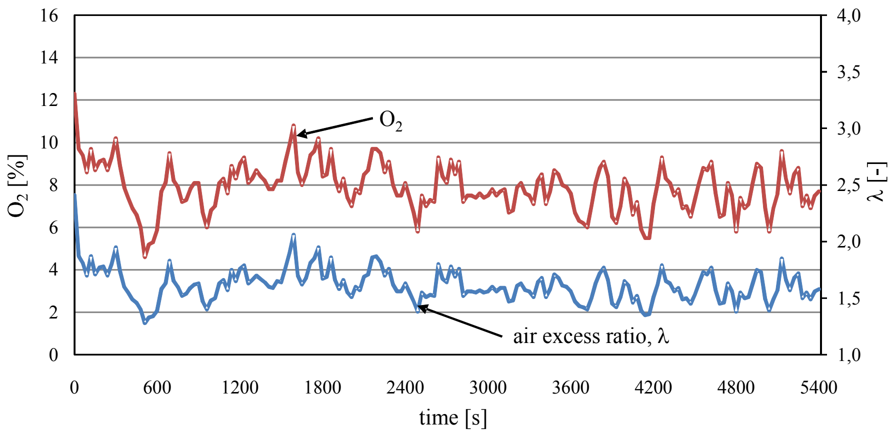


Fig. 5. Comparison of the parameter variation in time (oxygen and pollutant concentrations: CO, NO, NO_x in the flue gas, temperature in combustion chamber, excess air ratio) between the combustion process: a, b – with the automatic air flow control system (test run no. 1, tab. 2); c, d – without it (test run no. 5, tab. 3)

The concentration of NO and nitrogen oxides for boilers with a heat output of up to 0.5 MW is not regulated by Polish law, however it is of common agreement in Poland that it should not exceed 400 mg/m^3 (presented for 10% O_2 concentration in the flue gas) [Kubica 1999], which was the case in this study for all the scenarios (tab. 2-5). As the temperature in the combustion chamber during the experiments was below 1000ºC, NO_2 concentration was negligible. The gas analyzer did not detect any hydrocarbon concentration during the test runs.

Looking at the tables 2-5 we can observe the influence of furnace operation parameters (fan revolutions, oxygen sensor setting) on oxygen concentration and temperature in the combustion chamber. In most examples, as the temperature increases, CO concentration in the flue gas decreases and as oxygen concentration increases, CO concentration decreases.

Based on figure 5, it can be observed that in case of applying the automatic air flow control system (a), variations of temperature in the combustion chamber, as well as of CO concentration, were bigger. Where no air flow control was used (b) sudden increases (peaks) of CO concentration are visible. In both cases, as the oxygen concentration significantly increases the temperature in the combustion chamber decreases and thus CO concentration increases.

Figure 6a shows that with oxygen concentration increase CO concentration gradually decreases until reaching a certain optimum value above which it starts to increase (the automatic air flow control). This provides important information on the oxygen concentration level at which CO concentration presents the lowest values. Finding this optimum value of oxygen concentration is a useful tool in selecting proper configuration of the oxygen sensor. Most commonly this value varies in reality between 7 and 11% [Olsson et al. 2003; Eskilsson et al. 2004; Fiedler 2004; Olsson and Kjallstrand 2004; Kjallstrand and Olsson 2004; Verma et al. 2011b, 2013; Juszczak and Lossy 2012]. The lower the optimum oxygen concentration value, the better the furnace properties. In our case the optimum oxygen level was approx. 9%. In terms of the correlation between CO concentration and the temperature in the combustion chamber (fig. 7), it can be stated that generally CO concentration decreases as the temperature in the combustion chamber increases, both when the automatic air flow control system is applied and without it, however in example described in figure 7b this relation is not so visible.

a

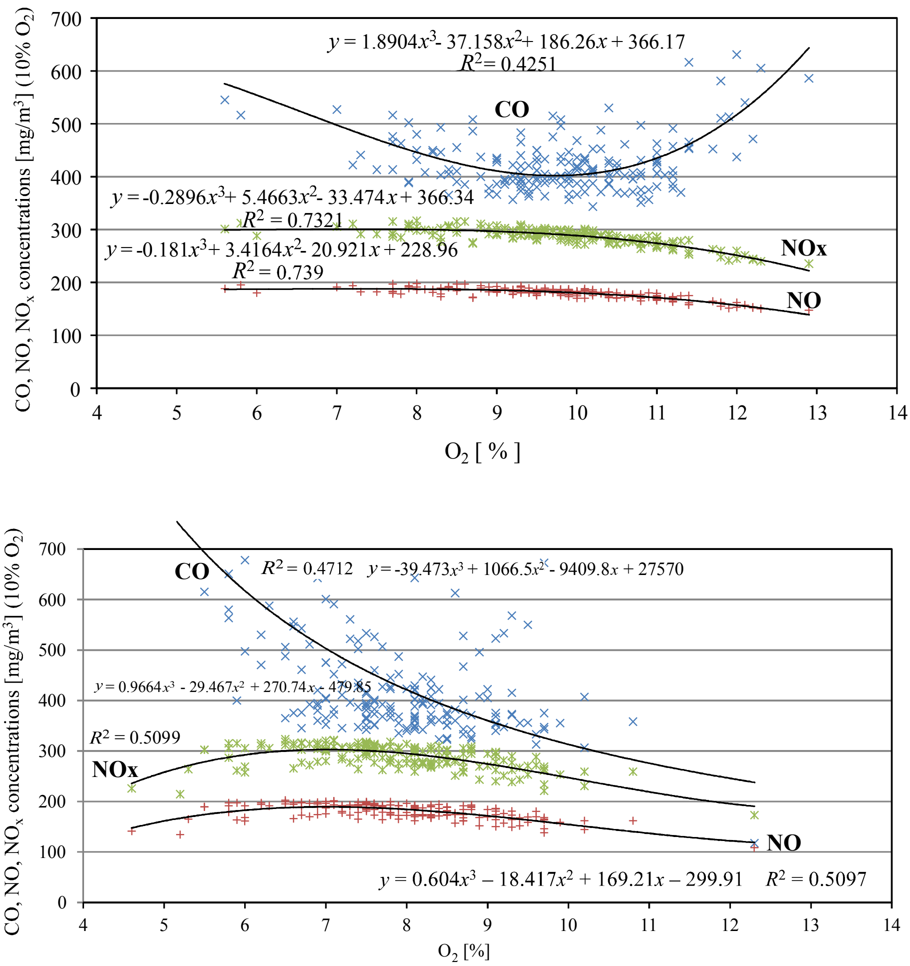


Fig. 6. Pollutant concentrations versus oxygen concentration in the flue gas; comparison between pellet combustion: a – with the automatic air flow control system (test run no. 1, tab. 2) and b – without it (test run no. 5, tab. 3)

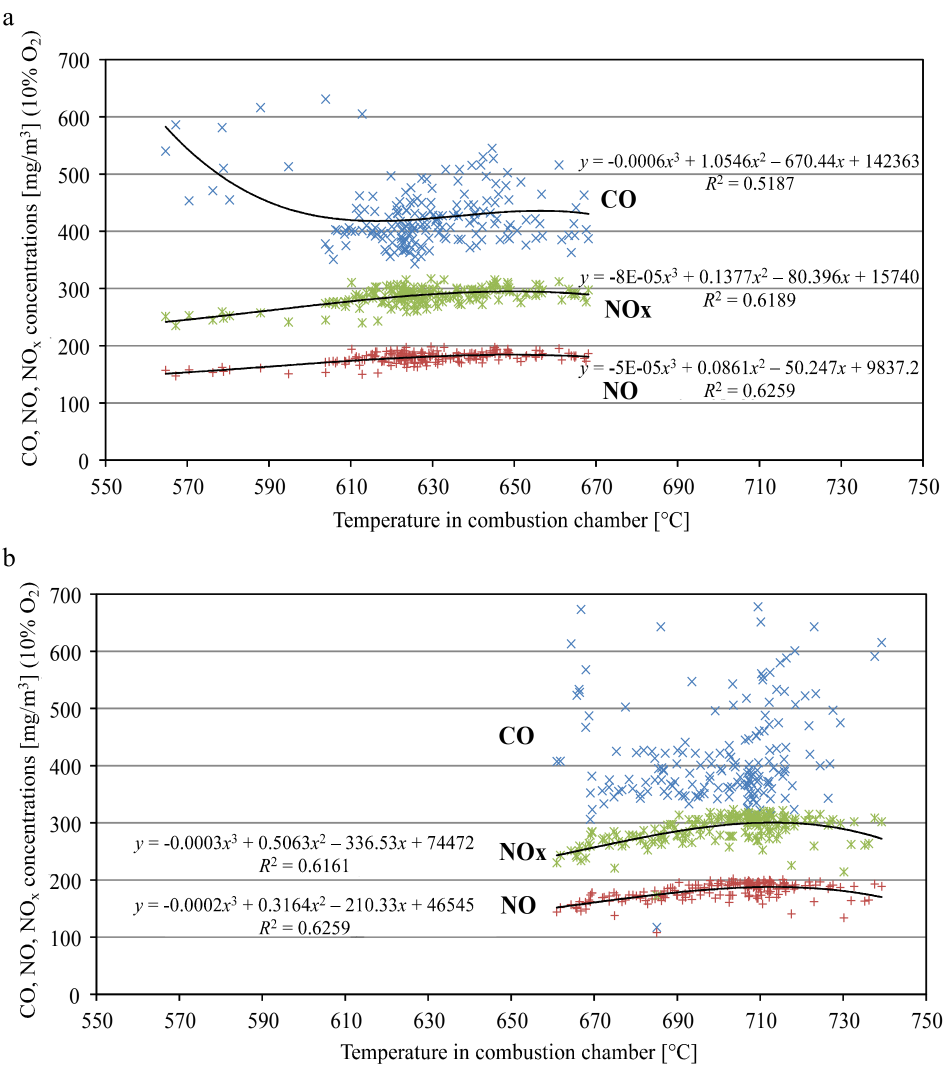
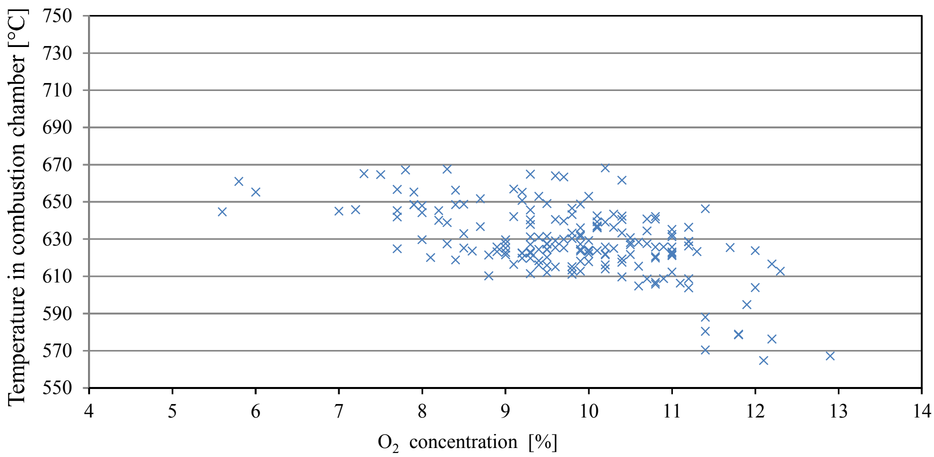


Fig. 7. Pollutant concentrations in the flue gas versus temperature in the combustion chamber; comparison between pellet combustion: a – with the automatic air flow control system (test run no. 1, tab. 2) and b – without it (test run no. 5, tab. 3)

The behavior of NO and NO_x depending on oxygen concentration and temperature in the combustion chamber differs for combustion with and without the automatic air flow control system. With the increase in oxygen concentration, while using air flow control, the concentrations of NO and NO_x decrease (fig. 6a), and with no air flow control they increase at the beginning and afterwards start decreasing (fig. 6b). With an increase in combustion chamber temperature, while using the air flow control, the concentrations of NO

and NO_x increase (fig. 7a), and with no air flow control they slightly increase at the beginning and after that they begin to decrease (fig. 7b).
The described behavior of NO and NO_x concentration in case of constant air flow rate (no automatic air stream control device used) can be explained by the fact that, as commonly known, NO concentration depends both on temperature and oxygen concentration. Usually, an increase in both: oxygen concentration and temperature causes the rise of NO and NO_x concentrations. However, in periodic pellet supply, during stand-by time in fuel feeding, these two factors intervene at the same time in opposite directions: oxygen concentration increases and the temperature in the combustion chamber decreases (fig. 8). Depending on

a



b

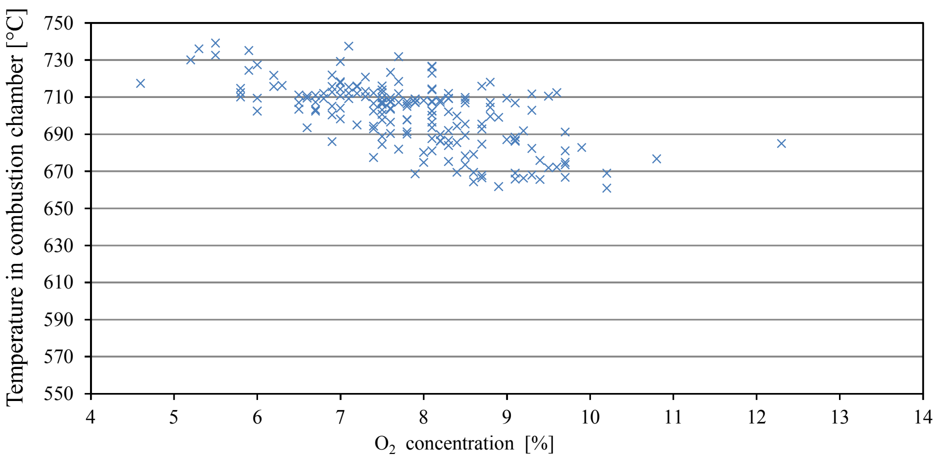
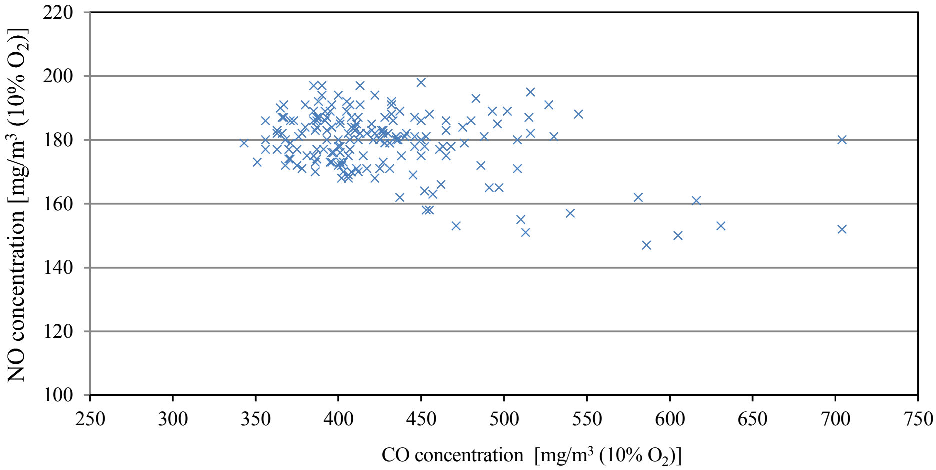


Fig. 8. Temperature in the combustion chamber versus oxygen concentration in the flue gas; comparison between pellet combustion: a – with the automatic air flow control system (test run no. 1, tab. 2) and b – without it (test run no. 5, tab. 3)

a



b

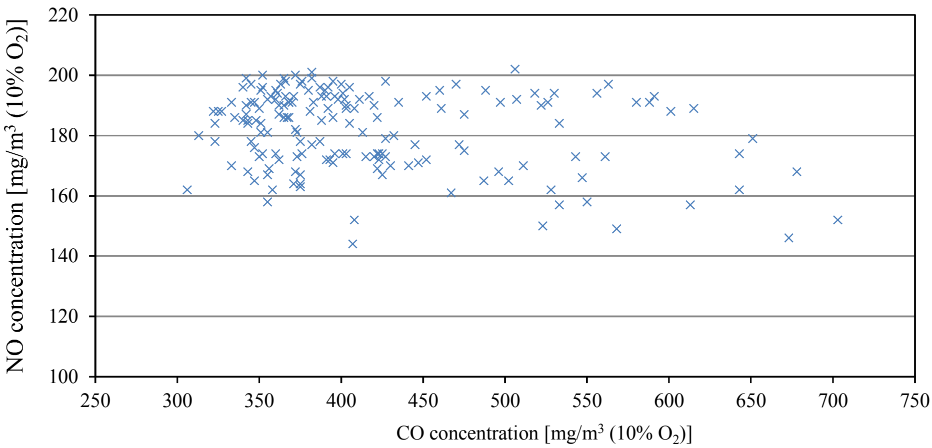


Fig. 9. Nitric oxide (NO) concentration versus carbon monoxide (CO) concentration in the flue gas; comparison between pellet combustion: a – with the automatic air flow control system (test run no. 1, tab. 2) and b – without it (test run no. 5, tab. 3)

the circumstances one factor gets predominant over the other. The reduction of temperature in the combustion chamber with the increase of oxygen concentration in case of using the air flow control system with oxygen sensor is not as visible as in case of constant air flow rate (fig. 8), which affects the fluctuations of NO and NO_x concentrations (fig. 6 and 7).

As far as the correlation between CO and NO concentration is concerned (fig. 9), it can be concluded that NO concentration decreases as CO concentration increases, equally for both scenarios – with and without the automatic air flow control device. The correlations can be then explained by the fact that with the increase of oxygen concentration in the flue gas and temperature in the combustion chamber CO concentration usually decreases and NO concentration increases. Additionally, this correlation may result from the reducing influence of CO on NO, as it can be observed for example in the reburning process. In my previous studies performed for wood log and pellet combustion (not published yet), I have observed that in cases where oxygen concentration exceeds 13% and temperature in the combustion chamber is relatively low, with the increase of CO concentration NO concentration increases as well.

All in all, it can be concluded that in the study described above the use of the automatic air flow control system with oxygen sensor in wood pellet combustion with periodic fuel supply did not caused a significant reduction of CO concentration in the flue gas (or even resulted in higher CO values when oxygen concentration range of the oxygen sensor was set too low) as compared to the scenario with constant air flow and higher boiler heat outputs. The stand-by time in pellet supply was too short for the automatic air flow control system to react properly and adjust (reduce) the air flow according to the current needs. Stand-by time could not be extended however as it would cause the combustion chamber to cool down and, as a consequence, an increase in the CO concentration.

Conclusions

Installing automatic air flow control system with oxygen sensor in case of periodic pellet supply mode (being a commonly used fuel feeding mode) if the boiler combustion chamber is not lined with a ceramic blanket, does not necessarily have to be an effective and beneficial solution. Considering its high price, it is rather recommended to focus on other factors that can reduce CO concentration in flue gas, namely a higher boiler heat output (above 60% of its maximum value) and the use of heat storages of considerable capacity. It is also of extreme importance that high quality pellets, recommended by the boiler producer, are fired.

Automatic air flow control system with oxygen sensor might fulfill its role in case the combustion chamber was lined with a ceramic blanket that would prevent the combustion chamber from cooling down too quickly during stand-up and therefore allow longer fuel supply cycles (e.g. of 40 or even 60 s instead of 20 s).

Using the automatic air flow control system with oxygen sensor seems to be much more effective in boilers with constant pellet supply mode, where the speed of pellet screw conveyor and thus fuel mass stream along with air stream rate can be adjusted according to the current heat demand of the end user.

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