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POLLUTANT CONCENTRATIONS FROM DECIDUOUS WOOD FUELLED HEAT STATION

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CO, NO, NO_2 and dust concentrations from combustion of deciduous wood (birch, beech, lime-tree) logs and pellets in two heating boilers (15 and 25 KW), situated in a heat station were investigated. Time dependences of pollutant concentrations as well as the impact of temperature in the combustion chamber and oxygen concentration on pollutant concentrations were presented. Pollutant emission indices have been estimated.

Keywords: heat station, wood, combustion, emission

1. INTRODUCTION

Waste wood and wood waste can be burnt in Poland in heat generating and industrial boilers as well as in domestic heating boilers if only it does not contain any chemical components, especially organic chlorine compounds, wood protection substances or heavy metals. Waste wood and wood waste free from chemical components can be called biomass and considered fuel (Regulation, 2003). In case of small wood fueled boilers, only the emission of incomplete combustion products is significant due to the fact that the flame temperature is frequently relatively low and air distribution in the combustion region is often dissatisfactory. Emission of nitrogen oxides is not high as the typical nitrogen content in wood is below 0.6 % and furnace temperature in most cases does not exceed 1000 ºC. Sulfur content is very low, therefore SO_2 emission is negligible. Dust emission from furnaces is usually low compared to the emission obtained during i.e. coal combustion, because ash content in wood is about 1% and in coal mostly between 6 and 12%. Unfortunately, sometimes wood waste contains much more ash originating mostly from contamination in the form of sand received during logging, handling or storage of raw material. On the other hand, if the flue gas coming from the furnace immediately touches the cold surface of the boiler heat exchanger, soot can appear, causing sometimes a significant increase in dust concentration in flue gases.

It is estimated that in Germany the share of small scale wood combustion systems contributing to the emissions of CO, hydrocarbons and soot is between 16% and 40%, although the total energy amount obtained this way is only 1% (Knaus et al., 2000). In Poland the numbers are similar or even the contribution of incomplete combustion pollutant emission is higher, because customers (especially in rural areas) frequently use the cheapest small wood heating boilers, of simple and old design, that operate without any automatic device for air supply (or with devices that are appropriate for pollutant emission control). Fortunately, in the last few years a new design of small wood boilers appeared on the European market and emission of incomplete combustion products has been significantly reduced and their heat efficiency has increased (Hartmann et al., 2006). The optimization of combustion

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performance is associated with pollutant emission reduction and improvement of boiler heat efficiency (Nussbaumer, 2003). Unfortunately, the number of these new wood boilers used in Poland is not high, as they are relatively expensive (especially small heating boilers with pellet furnaces).

2. PREVIOUS EXPERIMENTS CONCERNING POLLUTANT EMISSIONS FROM SMALL DECIDUOUS WOOD SUPPLIED BOILERS

Incomplete combustion product emissions depend on combustion conditions and boiler design. The emission levels for old and modern boiler designs differ significantly as it has been shown in various research studies. Carbon monoxide concentration in the flue gas from wood log combustion in an old boiler was found to be 4100 mg/m^3 (Kjallstrand et al., 2006), CO concentration from old downdraft boiler was between 4800 and 5200 mg/m^3 (Johansson et al., 2004). In case of boiler furnace with two stage combustion (gasification and wood gas combustion), CO concentration value of 1520 mg/m^3 was obtained (Saravanakumar et al., 2007). For an old boiler working with pellet furnaces, CO concentration of 470 and 610 mg/m^3 was obtained (Kjallstrand et al., 2006). A boiler of new design, working with water heat storage during log combustion obtained CO concentrations of 507, 770 and 1300 mg/m^3 (Johansson et al., 2004). Carbon monoxide concentration in flue gas obtained in wood combustion obtained in a new type of boiler (year 2001) was 190 mg/m^3 (Kjallstrand et al., 2006). During pellet combustion in a new type of pellet furnaces 36 mg/m^3 of CO concentration was obtained (Johansson et al., 2004). Low CO concentration values such as 11 and 101 mg/m^3 can also be obtained during wood chip combustion in a boiler of new design (Lundgren et al., 2004). All the concentration values mentioned above were normalized to 10% oxygen in the flue gas.

Previously, in the heat station belonging to Poznan University of Technology, measurements of pollutant concentrations in the flue gas of the boilers in unstable conditions were performed. Boilers adapted to operate with insufficient heat output, combustion chambers were not completely filled with fuel and the temperature in the combustion region was therefore low causing incomplete combustion and a very high CO concentration in the flue gas, sometimes even above 25 g/m^3 (Juszczak, 2008). Other measurements of CO, NO, NO_x (as NO_2) and dust concentrations were performed with a full fuel load and low heat demand of central heating installation. For this purpose, a water cooler with fan simulated the central heating installation. As water was not cooled and reached too high temperature in the boiler, the fan supplying air to combustion frequently stopped . As a result, CO concentrations were also elevated, even above 10000 mg/m^3 (normalized to 10 % oxygen concentrations in the flue gas) (Juszczak, 2007).

3. POLISH – EUROPEAN REGULATIONS REGARDING POLLUTANT EMISSION LEVELS

The admissible pollutant concentration values are established separately for different ways of solid fuel supply (hand or automatically stoked) and fossil fuel or biomass. Boilers, nominal heat output of up to 300kW, are divided into three classes according to heat efficiency declared by the boiler producer. After the boiler producer declares boiler heat efficiency and nominal heat output values, it is possible to determine the boiler class and the admissible pollutant concentration values based on Table 1 (PN-EN-303-5:2002). Heat efficiency limit for these classes (PN-EN-303-5:2002) is calculated in relation to boiler nominal heat output, using the formulas presented in Table 1.

For heating boilers of heat output equal or below 300 kW, the admissible values imposed by Polish regulations (PN-EN-303-5:2002) are set for carbon monoxide, total organic carbon and dust concentrations in the flue gases (Tab. 1). During operation of small heating boilers of less than 300 kW heat output, CO presence in the flue gases should not be ignored, especially for manually supplied solid fuel boilers. However, for these small heating boilers, the admissible, values for NO_x concentration in the flue gas are not determined in Polish regulations (PN-EN-303-5:2002), probably because it is usually low. Nevertheless, in order to obtain an ecological certificate in Poland, which facilitates boiler commercialization, producers of small heating boilers must comply with NO_x concentration levels in the flue gas of below 400 mg/m^3, normalized to 10% oxygen concentration in flue gas (Kubica, 1999).

Table 1. Admissible values for carbon monoxide, total organic carbon and dust concentrations* for hand stocked biomass boilers, nominal heat output of up to 50 kW (PN-EN-303-5:2002)

Boiler class	Heat efficiency, η %	Carbon monoxide concentration, mg/m^3	Total organic carbon concentration, mg/m^3	Dust concentration, mg/m^3
1	η > 67+6logQ_k	5000	150	150
2	η > 57+6logQ_k	8000	300	180
3	η > 47+6logQ_k	25000	2000	200

*normalized to 10% oxygen concentration, dry gas; Q_k – boiler nominal heat output, kW

4. EXPERIMENTAL SET-UP

The heat station (Fig. 1) located in a laboratory belonging to Poznan University of Technology, Institute of Environmental Engineering, was constructed in 2003 for measurements of flow and thermal boiler parameters, as well as pollutant concentrations in the flue gas produced during the combustion of wood, wood waste and other biomass types. It is also designed for observation of boiler cooperation with water heat storage and mixing device.

The heat station (Fig. 1) consists of two different heating boilers burning wood logs and one of them also pellets. They are of old design, probably one of the cheapest in the Polish market and work without a proper automatic device equipped with oxygen probe (lambda sensor) located downstream the boiler for combustion air stream regulation. The boilers work alternately and are connected to a water heat storage of 900 dm^3 with a special mixing device (a pump and three valves located in one body, Fig. 1). Due to this device, during the first minutes of boiler operation, the water is heated in the boiler without flow and once it reaches the temperature of 64 ºC, it begins to flow in a short circuit (through the boiler and the mixing device only). After reaching the temperature of 72 ºC, a part of the boiler water begins to flow also through the water heat storage. Such operation of the mixing and piping device helps to maintain the highest possible temperature in the combustion chamber, because temperature of the water that enters the boiler is always above 64 ºC. In wood and wood waste combustion process, this is crucial for minimizing soot formation by keeping the combustion chamber walls hot.

During the experiments, boiler water was cooled in the air-cooled heat exchanger, located on the roof of the heat station, loosing heat to the atmosphere. However, boiler water from the heat station can be also directed through the insulated underground pipelines (36 mm of inner diameter, about 35 m. long) to the heat transfer unit located in a small detached house (wooden structure, living area of approx. 100 m^2). In this way, heat produced in the heat station can be also used for heating and hot water preparation.

The flue gas produced in the boiler is conducted to an insulated steel chimney (200 mm of inner diameter and 8.5 m high). Two sight glasses have been placed in the front wall of each boiler combustion chamber for observation (Fig. 2). In the gasification sector flame should not appear on incandescent wood or wood waste and if that happens, it indicates an excess of air supplied to the gasification region.

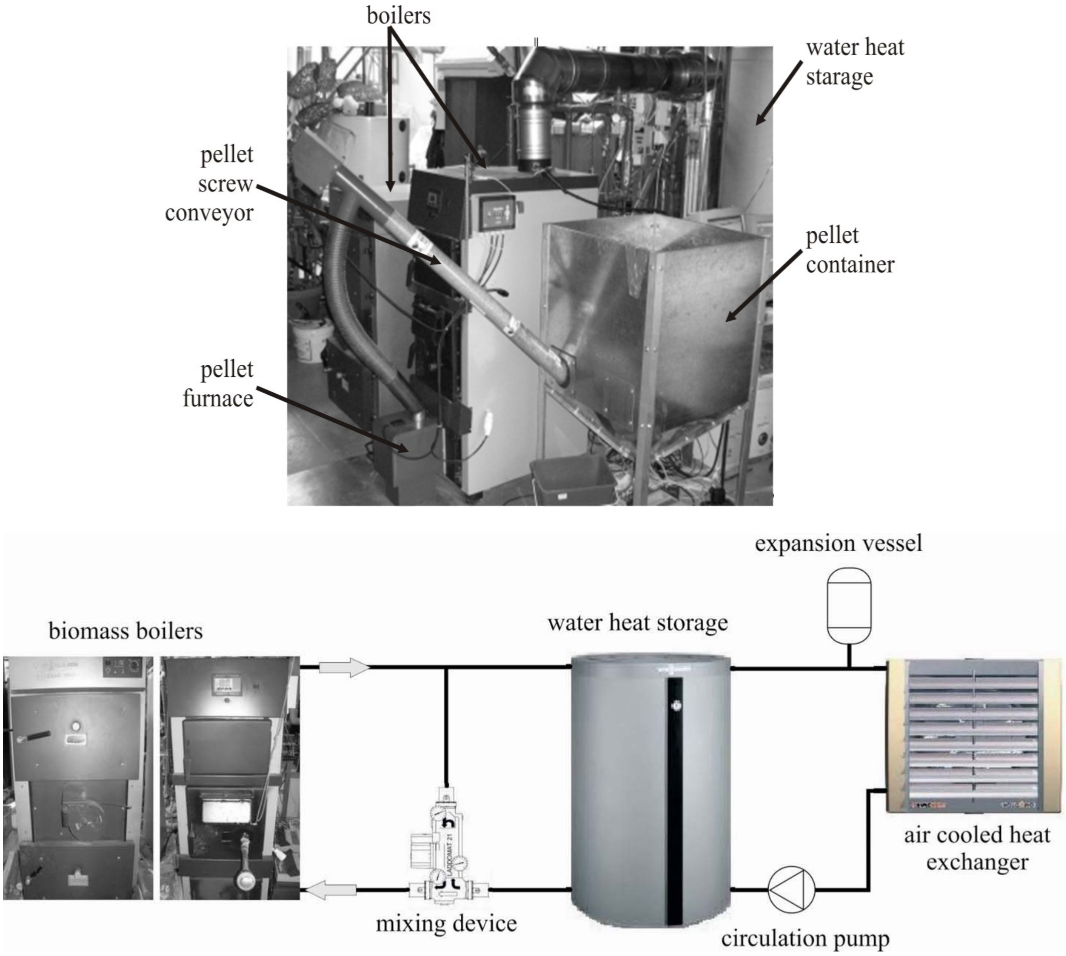


Fig. 1. Heat station (view and scheme) equipped with two residential boilers: boilers, water heat storage, mixing device, air cooled heat exchanger

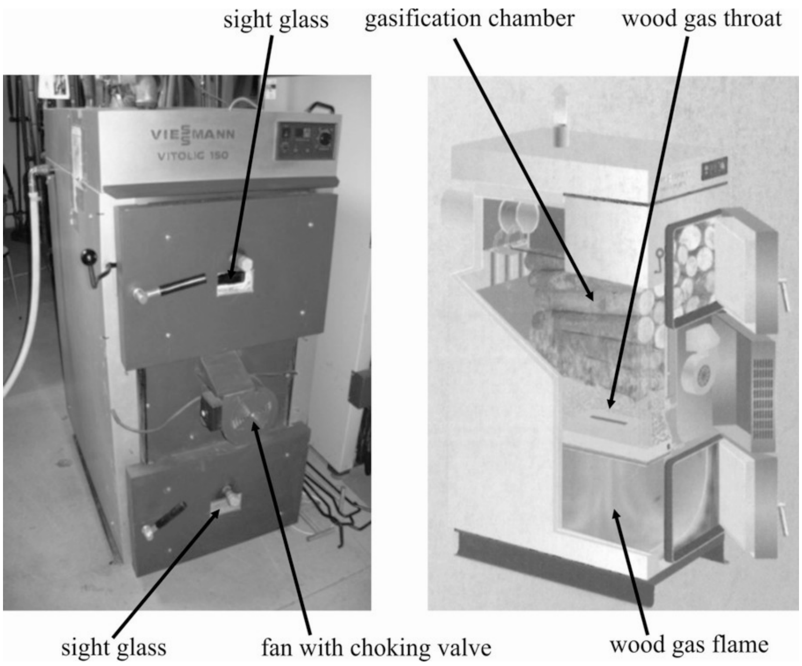


Fig. 2. Wood log boiler with a nominal heat output of 25 kW and two stage combustion (gasification and wood gas firing): view and scheme

The first one of the two boilers (Fig. 2) is a typical wood log boiler with a nominal heat output of 25 kW. Here the combustion process is performed in two steps: wood gasification in the gasification chamber and wood gas combustion in the throat located at the bottom of the gasification chamber. Air needed for both steps of the process is supplied with one fan. Air enters the throat through four pipes each ended with one round outlet. Air stream can be modified manually by a choking valve situated in front of the fan. However, during the experiments, setting of the choking valve was not changed considering the fact that it is not regulated in domestic practice either. The fan stops when the water temperature reaches its maximum value of 85 ºC and it reinitiates after a temperature decrease of 5 ºC.

The second boiler (Fig. 3) is a typical small downdraft boiler with fixed grate. It is fueled with wood logs. Primary air moves to the upper part of the combustion chamber due to natural draft of the chimney through a rectangular door (Fig. 3), which automatically opens wider when water temperature decreases. Secondary air also flows under gravity through a round inlet, situated in the lower part of the combustion chamber back wall. Outside the boiler, the inlet is equipped with a round door for manual regulation of secondary air stream (changing door position).

For wood pellet combustion in the same boiler, the grate (used for log wood combustion) is removed and substituted with a Danish pellet furnace (Fig. 4) placed at the front door of the boiler (Fig. 3). The pellet furnace has its own electrically heated automatic ignition device (Fig. 4).

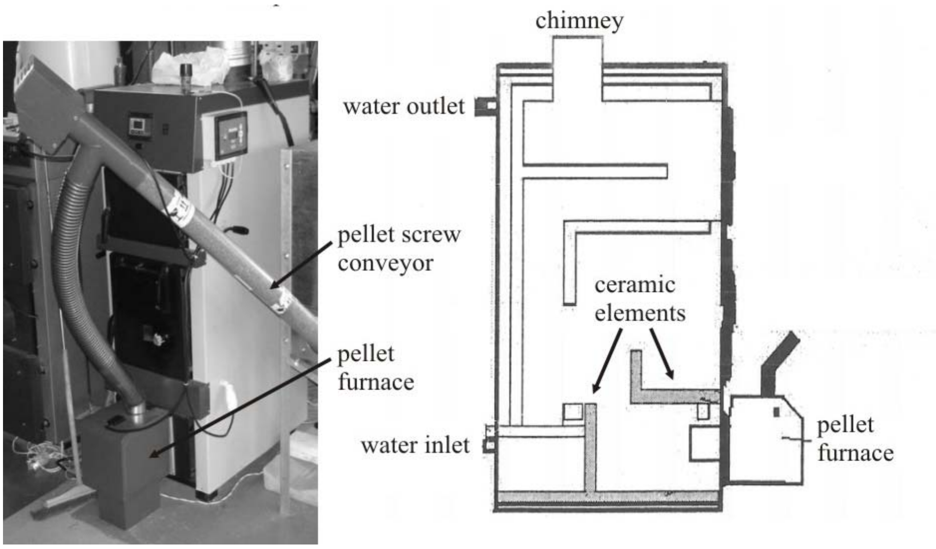


Fig. 3. Downdraft wood log boiler with a nominal heat output of 15 kW with pellet furnace instead of fixed grate (natural draft): view and scheme

The furnace stops when boiler water temperature reaches 85 ºC (maximum value). Pellets are loaded from the pellet storage with a screw conveyor (Fig. 1) and then they fall onto the furnace. Another horizontal screw conveyer (Fig. 4) of the furnace introduces pellets to the burning region. Both conveyors are synchronized (they always work simultaneously). Air is supplied to the burning zone by a fan located in the furnace (Fig. 4). Neither air stream nor the velocities of both screw conveyors can be changed. Fuel mass stream can only be controlled by a manual modification of conveyor work/break time in order to obtain good combustion conditions (low CO concentration in flue gas) and boiler heat output.

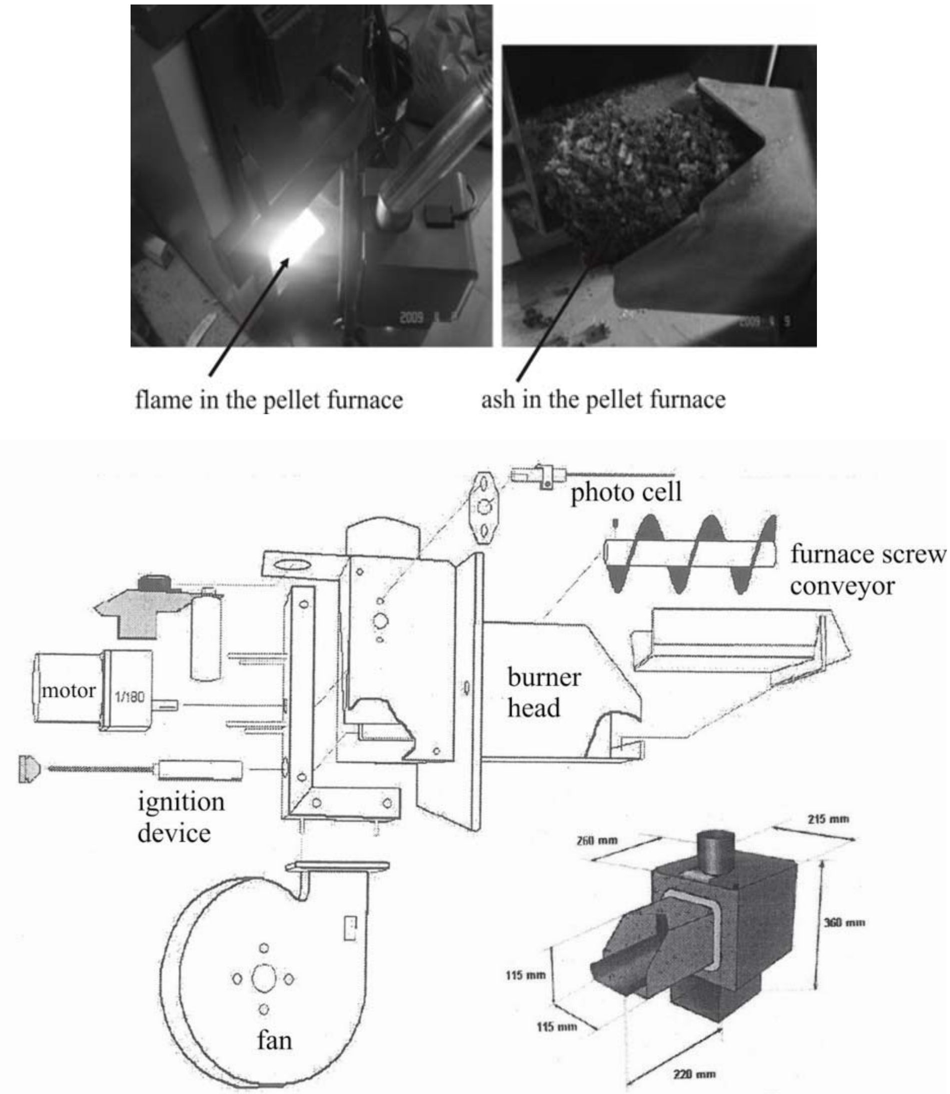


Fig. 4. Pellet furnace: views and scheme

5. WOOD LOGS AND PELLETS USED FOR COMBUSTION

Three following species of deciduous trees commonly found in Poland: birch, beech and lime-tree, were chosen for the experiments. Wood of deciduous trees is preferred for combustion over coniferous trees as it burns longer and not so intensively due to a lesser content of resins. Wood log dimensions for the 25kW boiler with two stage combustion were: max. length 500 mm, max. diameter 70 mm and for the 15kW downdraft boiler: max. length 300 mm, max. diameter 70 mm. Pellets were 10-15 mm long and 6 mm in diameter. Wood log and pellet moisture was measured in the laboratory of Poznan University of Technology, according to European regulations (EN 12048:1999). Dry wood lower heating value for logs was measured in the laboratory of Poznan University of Technology and as a result a value of 19000kJ/kg was taken for further estimation of pollutant emission indices (Table 3). For pellets, dry wood lower heating value was given by the pellet producer. An ultimate analysis of wood logs and pellets used for the experiments is presented in Table 2.

Table 2. Ultimate analysis of wood (performed by an accredited laboratory)

Wood type	chemical element, wt%			
	N	C	H	O
Birch	0.56 ± 0.03 SD	49.48 ± 0.06 SD	7.21 ± 0.01 SD	39.52
Beech	0.30 ± 0.02 SD	47.05 ± 0.58 SD	7.01 ± 0.11 SD	41.99
Lime-tree	0.53 ± 0.06 SD	48.85 ± 0.55 SD	7.07 ± 0.73 SD	40.67
Pellet	0.35 ± 0.05 SD	51.50 ± 0.25 SD	7.58 ± 0.11 SD	40.00

SD- standard deviation.

Ash content was measured in the laboratory of Poznan University of Technology and was always below 1 wt%.

6. METHODS AND MEASUREMENT EQUIPMENT

The conditions created for research purposes were favorable for CO emission reduction. Full fuel load in the combustion chamber was guaranteed in order to keep temperature in the combustion zone high enough and therefore avoid CO concentration increase in the flue gas. The logs were supplied manually, about every 2 or 3 hours (Tab. 1), one load after another, filling the combustion chamber completely. After wood gets almost burnt out, the temperature in the combustion chamber of the boilers decreases and oxygen concentration increases significantly, a new load of fuel is supplied to the combustion chamber. Before starting the first daily test run, the boiler was preheated by burning a small amount of wood. It was necessary to reach the temperature sufficient for drying and gasification process.

The experiments lasted several days. Boilers were operating only during daytime and the daily working time did not exceed 12 hours. During each measurement, only one of the boilers was operating. In the last part of the experiments, the fixed grate of the downdraft boiler was replaced by a pellet furnace and wood pellets were burnt.

For wood log combustion, a few (mostly three) test runs were performed daily. A test run was defined by the period between the successive fuel loads. Test runs were repeated approx. 10 times for each wood type in order to ensure repeatability (Tab. 1). For pellet combustion, test runs were carried out continuously without switching off the furnace and the operation time was divided into measurement cycles (test runs) of 1.5 hour for calculations of mean parameter values and for comparisons. Three series of measurements for pellets were performed. The first and the third one consisted of 8 test runs, the second one comprised 18 test runs (Tab. 1).

All the obtained data were continuously stored in the computer memory . For each test run, data were collected every 15 seconds, averaged and then mean parameter values were calculated. This time interval of data gathering was optimal as the measured values were not changing very quickly. The medium values of about 10 consecutive test runs were taken to obtain an overall mean value for each experiment type (see Tab. 3). Uncertainty intervals of all the measurement results for the probability of 0.95 were calculated (Tab. 1).

The following parameters were measured: CO, NO, NO_2 and O_2 concentrations and flue gas temperature (in the flue gas downstream the boiler), dust concentration (in the chimney), flame temperature (in the combustion chamber), boiler heat output, heat quantity obtained by boiler water. Fuel mass was also weighed. Subsequently, emission indices were estimated. Because flue gas velocity was not measured, Rosin formulas (Orlowski and Dobrzanski, 1976) were used for gas volume calculation. Heat efficiency was calculated once a day as heat transferred to the water during one day of measurements divided by fuel mass multiplied by wet wood lower heating value.

The measurements were performed using the following measurement devices:

- O_2, NO and NO_2 concentration were measured with electrochemical cells and CO concentration with an infrared equipment. Gas analyzer measured also flue gas temperature with a thermocouple and calculated excess air number. Gas analyzer calculated NOx concentration as sum of NO (transformed to NO_2) and NO_2 concentration.
- Heat received by boiler water and boiler heat output were measured with an ultrasonic heat meter.
- Temperature in the combustion chamber was measured by means of a radiation shielded thermocouple PtRhPt, located in the combustion chamber, connected additionally to the temperature meter (for data comparison); the obtained data were transmitted to a personal computer via data acquisition system.
- The concentration of dust in the flue gas was measured in the chimney with a dust meter equipped with isokinetic probe sampling.

7. RESULTS AND DISCUSSION

The amount of air used for log combustion was excessive due to lack of proper automatic devices for air stream regulation, which also decreased boiler heat efficiency, especially in case of the downdraft boiler. Also for this reason probably, the correlation between CO concentration in the flue gas and the temperature in combustion chamber could not be clearly seen (especially in case of the downdraft boiler). During pellet combustion, soot formation in dust was sometimes observed because the flue gas touched the cold heat exchanger wall in a short time. The examined boiler was not adapted to proper pellet combustion, meaning that no additional ceramic elements were installed inside the furnace. Similar situations were described in some other laboratory studies (Wiinikka et al., 2006).

The results obtained during the measurements performed in the heat station are presented below. They include mean values and uncertainty intervals (Table 3) obtained during combustion of beech, birch and lime-tree logs in two different boilers and pellets in the furnace, variation of selected parameters in time (Figs. 5-7) and influence of temperature in combustion chamber and oxygen concentration on pollutant concentrations (Figs. 8-10).

The values shown are mean values with the uncertainty interval indicated. For pellet combustion, the lowest CO concentration in flue gas was observed in the second test run series that comprised 18 test runs. This resulted from the highest temperature in combustion chamber in comparison to other experiment series and excess air number of 2.2 turned out to be optimal for this furnace type. The best combustion performance (lowest CO concentrations in flue gas) was observed in case of lime-tree log firing, for both boilers. During log combustion, regardless of wood and boiler type, fuel sometimes got stuck instead of falling onto the bottom of the combustion chamber after each fuel portion has been burned down. This was caused by loading the logs too tightly in the combustion chamber. As a result, combustion parameters were not satisfactory: temperature in combustion chamber decreased, CO concentration and excess air number increased. In such case, it was necessary to open sometimes the combustion chamber and push the logs down manually which had unfavorable effects such as cooling of the combustion chamber and falling of some unfired log pieces out of the combustion chamber. All these occurrences caused a considerable decrease in the boiler heat efficiency. These kinds of problems, however, need to be dealt with in practice as well.

Table 3. Measurement results obtained during wood log (birch, beech, lime-tree) and pellet combustion in a 25 kW water boiler (two stage combustion with gasification) and a 15kW downdraft water boiler (also working with pellet furnace)

boiler type/ measurement parameters	downdraft 15 kW			gasification and wood gas comb. 25 kW			downdraft 15 kW with burner		
wood type	birch	beech	lime-tree	birch	beech	lime-tree	pellet	pellet	pellet
number of test runs	10	10	10	10	9	8	8	18	8
fuel mass, kg	12.98	11.59	7.22	22.15	28.24	22.60	4.63	4.80	4.37
time, h	2.46	1.73	1.83	2.92	2.61	2.59	1.50	1.50	1.50
dry wood lower heating value, KJ/kg	19 000	19 000	19 000	19 000	19 000	19 000	18 677	18 850	18 677
moisture, %	22.0	27.5	22.7	22.0	27.5	22.7	6.1	5.2	6.1
wet wood lower heating value, KJ/kg	15 063	13 829	14 906	15 063	13 829	14 906	17 499	17 839	17 499
boiler heat output, kW	14.2	19.1	9.9	22.6	32.5	26.7	13.2	12.5	11.3
flue gas temp., °C	170.0	145.8	124.5	135.5	165.0	163.4	180.0	238.0	180.0
boiler heat efficiency, %	64.3	74.2	60.6	71.2	78.2	73.9	87.8	78.8	79.8
temp. in comb. chamber, °C	471.4	664.3	469.1	773.5	913.3	921.5	596.0	645.0	538.0
O_2 conc., %	13.9	11.4	12.8	14.7	9.0	8.4	8.2	11.3	12.5
excess air number, -	3.1	2.3	2.6	3.7	1.8	1.7	1.7	2.2	2.7
CO conc., mg/m^3*	5091.1 ±591.4	2648.8 ±208.4	3708.6 ±273	3540.6 ±208.4	1804.6 ±760.6	1285.1 ±896.1	667.0 ±131.0	436.0 ±53.0	1049 ±311.0
NO conc., mg/m^3*	85.6 ±27.0	147.3 ±27.7	118.8 ±19.2	78.8 ±17.9	134.5 ±18.2	135.4 ±14.0	128.0 ±16.9	122.0 ±27.0	115.0 ±18.0
NO_x conc., mg/m^3*	137.8 ±43.5	237.6 ±44.6	191.7 ±30.9	126.9 ±28.8	216.9 ±29.3	217.6 ±22.5	208.0 ±27.1	197.0 ±44.0	185.0 ±29.0
dust conc., mg/m^3*	116.6 ±76.6	51.7 ±17.7	61.7 ±25.3	120.7 ±86.8	18.7 ±14.3	18.9 ±13.6	33.0 ±14.4	8.5 ±2.1	31.0 ±14.0
CO emission index , g/MJ	7.403 ±1.144	2.807 ±0.344	4.109 ±0.357	5.618 ±0.677	1.600 ±0.677	1.057 ±0.740	0.547 ±0.112	0.489 ±0.060	1.329 ±0.186
NO emission index , g/MJ	0.124 ±0.41	0.156 ±0.053	0.132 ±0.020	0.125 ±0.035	0.119 ±0.062	0.111 ±0.014	0.105 ±0.015	0.137 ±0.030	0.146 ±0.014
NOx emission index, g/MJ	0.200 ±0.066	0.251 ±0.085	0.212 ±0.032	0.201 ±0.056	0.192 ±0.100	0.179 ±0.220	0.169 ±0.026	0.221 ±0.050	0.235 ±0.023
dust emission index, g/MJ	0.170 ±0.112	0.055 ±0.007	0.068 ±0.025	0.191 ±0.141	0.017 ±0.013	0.016 ±0.011	0.027 ±0.012	0.010 ±0.002	0.039 ±0.008

*normalized to 10 % oxygen concentration in flue gas

Typical test runs for both boilers and boiler with a pellet furnace are presented in Figures 5-7.

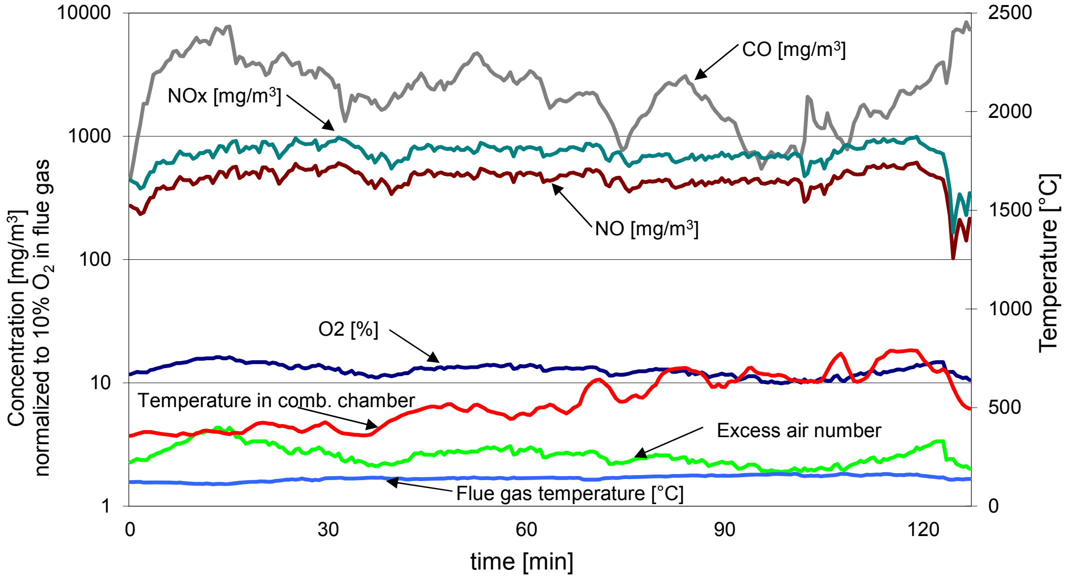


Fig. 5. Variation of selected parameters obtained during a test run of the 15kW downdraft boiler (beech logs)

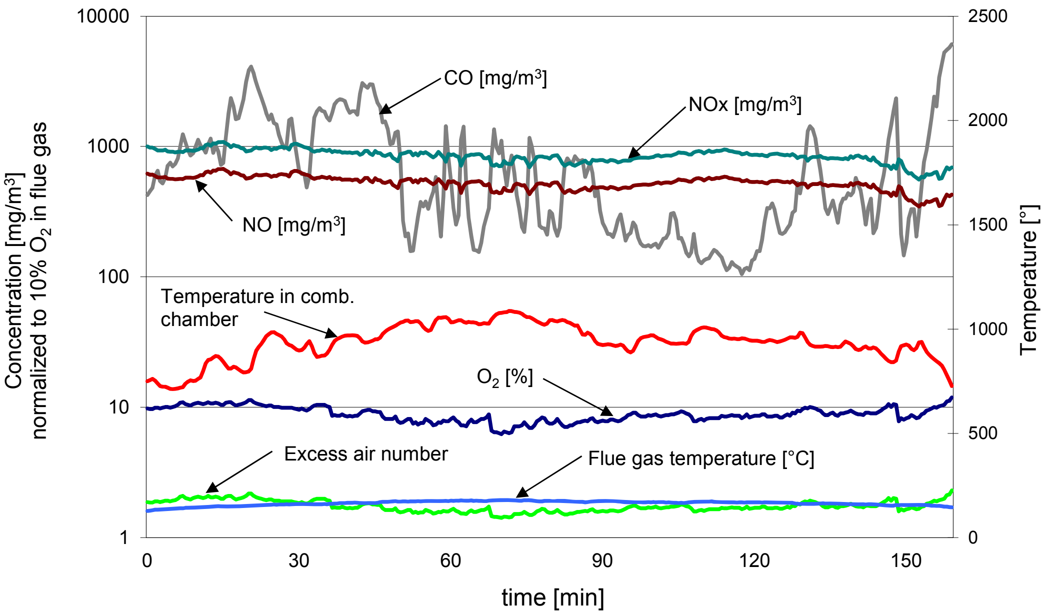


Fig. 6. Variation of selected parameters obtained during a test run of the 25 kW two stage combustion boiler (beech logs)

In the first minutes after wood logs were supplied to the boiler, a CO concentration boost could be observed (Figs. 5, 6). CO concentration decreased however, after the temperature in combustion chamber increased. CO concentration in the flue gas increased again when the wood was almost burnt out, temperature in combustion chamber went down and oxygen concentration increased. The curves representing these parameters are obviously different for the 25 kW boiler with two stage combustion with a fan used for air supply and the 15 kW boiler where combustion air was delivered by natural draft. Some unexpected increase or even peaks of carbon monoxide concentration were noticed. It can be explained by occasional wood log position change in the gasification or combustion region . During pellet combustion in the furnace, variation of the described parameters is significantly smaller (Fig. 7). In all the three combustion devices, variation of NO, NO_x concentration values, throughout the whole combustion period, was small (Figs. 5-7). Variations of selected parameters obtained during birch and lime-tree logs combustion in both boilers were similar to those obtained during beech logs firing presented in Figs. 5, 6.

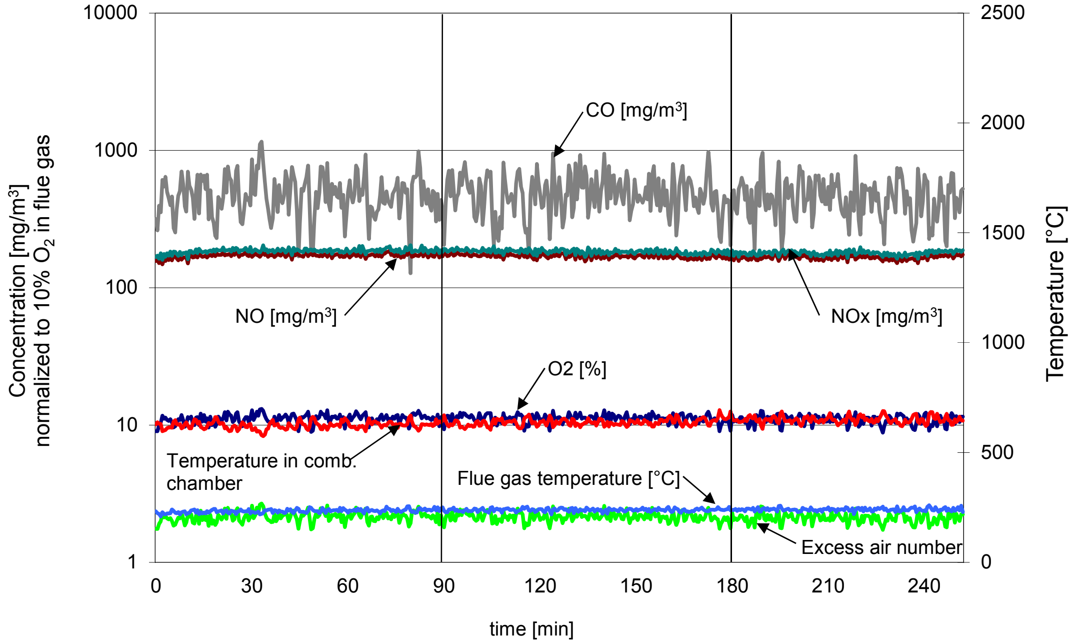


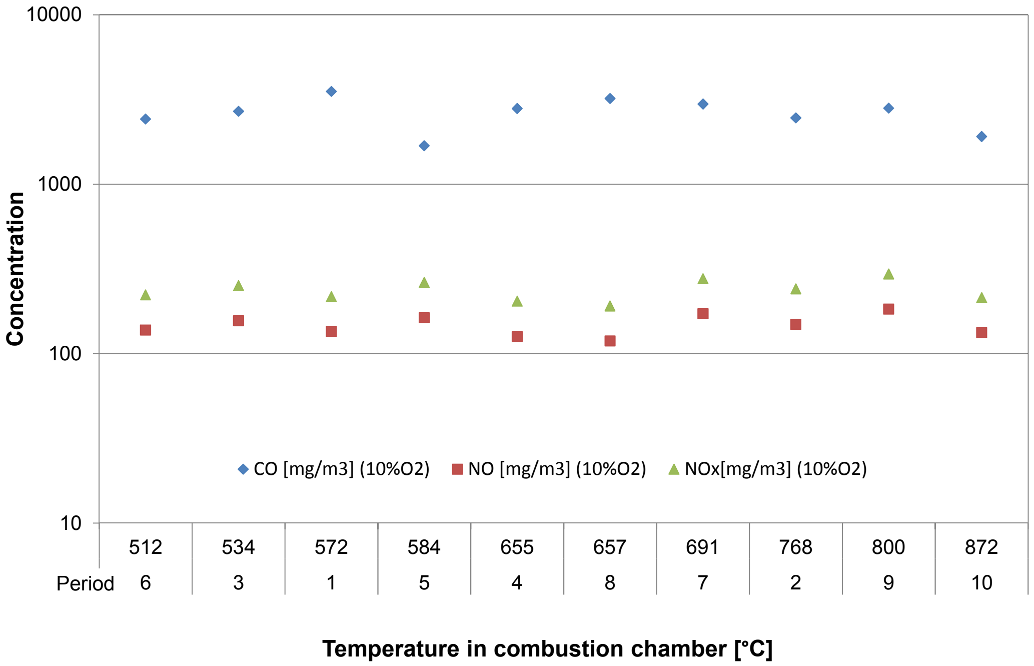
Fig. 7. Variation of selected parameters obtained during three test runs of a 15 kW boiler with pellet furnace

The influence of temperature in combustion chamber and oxygen concentration on CO, NO, NO_x concentrations in the flue gas during beach logs combustion in the two boilers and pellets in the furnace are presented in Figs. 8-10.

A small influence of the temperature in combustion chamber on CO concentration was noticed in case of the 25 kW boiler and during pellet combustion (Figs. 9, 10). In general terms, CO concentration was decreasing when temperature in combustion chamber was increasing. In case of log combustion in the downdraft boiler (Fig. 8), such clear correlation was not observed. The correlation was not observed for all the test runs as there were probably other factors influencing CO concentrations, such as movement of logs in furnace during operation. A significant effect of oxygen concentration on NO, NO_x concentrations was observed only during pellet combustion. When oxygen concentration increased above 11% an increase of NO, NO_x was noticed.

NO and NO_x concentrations were low in case of all combustion devices. NO and NO_x concentration in the flue gas depended mainly on nitrogen content in the wood and also not much on temperature in combustion chamber (because it was low, below 1000ºC and variation of mean temperature value in combustion chamber between test runs was not large). Dust concentration was not changing much either during log combustion, although dust deposits appeared on boiler heat exchanger surfaces.

a)



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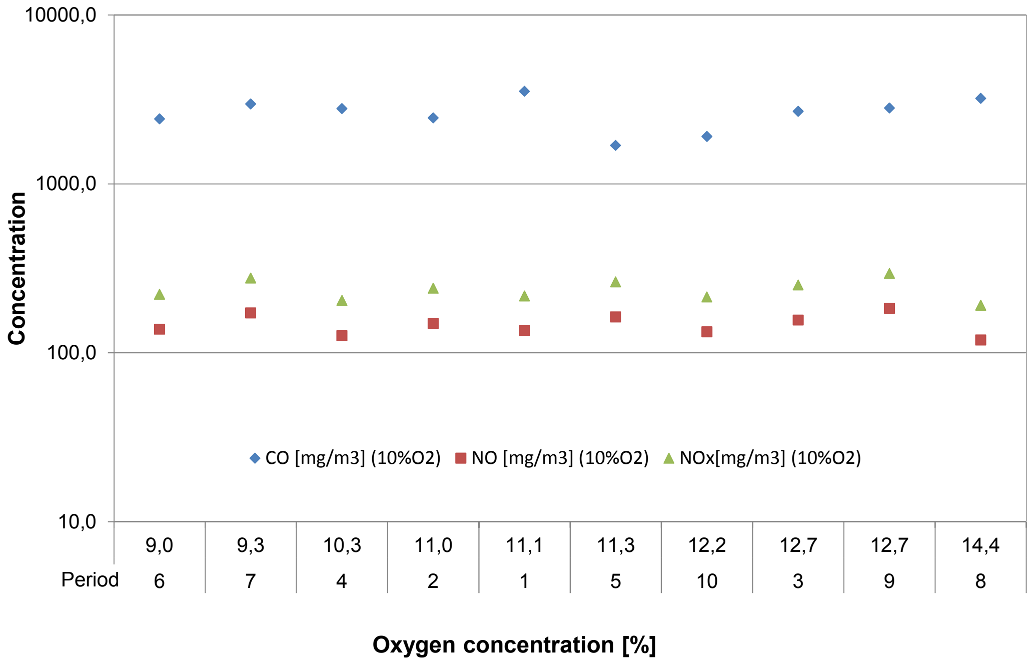
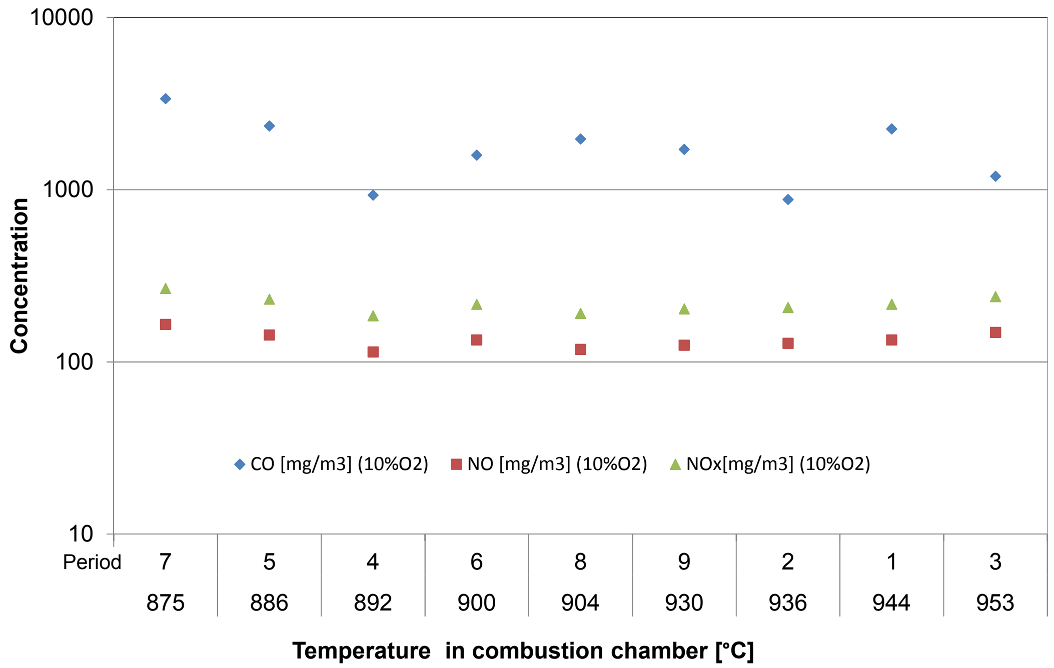


Fig. 8. 15 kW downdraft boiler (beech logs). Relation between CO, NO, NOx and dust concentrations in the flue gas, a) flame temperature, b) oxygen concentration

a)



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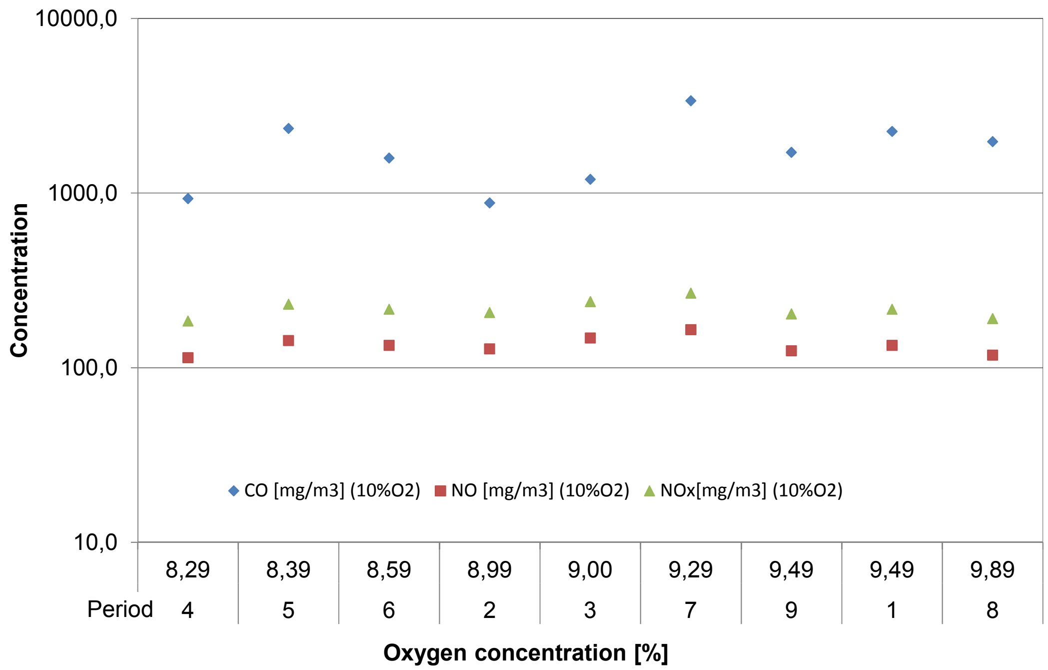

Fig. 9. 25 kW two stage combustion boiler (beech logs). Relation between CO, NO, NOx and dust concentrations in the flue gas, a) temperature in combustion chamber, b) oxygen concentration

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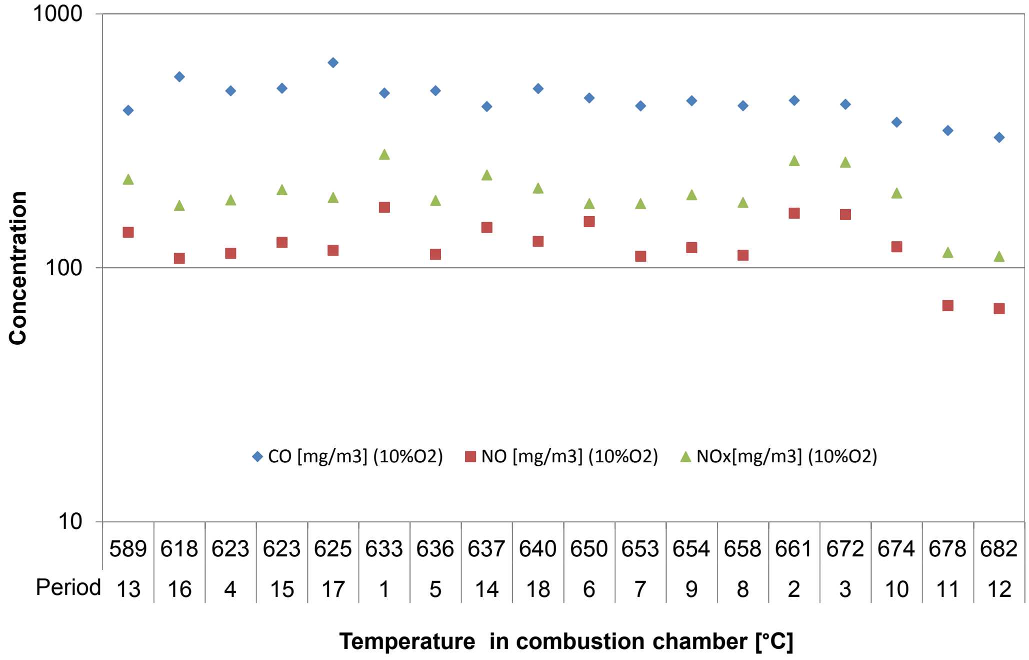


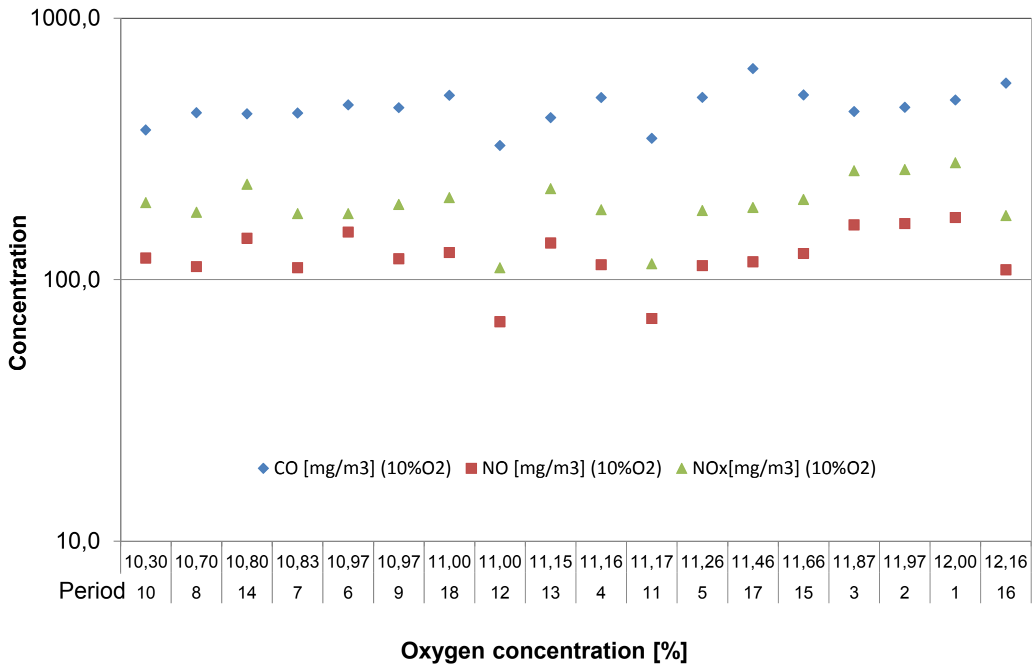
b)


Fig. 10. Pellet furnace located in 15 kW downdraft boiler (wood pellets). Relation between CO, NO, NOx and dust concentrations in the flue gas, a) temperature in combustion chamber, b) oxygen concentration

5. CONCLUSIONS

During the experiments, real values of CO, NO, NO_x and dust concentrations were measured during combustion of wood, typical in Poland. The conditions resembled the ones existing during wood combustion in domestic boilers frequently used in Poland. It was concluded that CO concentrations in the flue gas were relatively high (the highest in the downdraft boiler-below 5100 mg/m^3, in 25 kW boiler-below 3600 mg/m^3, the smallest during pellet burning - below 1100 mg/m^3). However, they remained below the admissible values established in Polish and European regulations

(PN-EN-303-5:2002). Dust concentration values were not high, below 125 mg/m^3 during logs combustion, below 15 mg/m^3 for pellets firing, although dust deposits could be observed on boiler heat exchange surfaces. NO_x concentrations were moderate and did not exceed 240 mg/m^3 (all concentrations normalized to 10% oxygen concentration in flue gas).

To improve boiler heat efficiency and decrease CO concentration the following could be recommended: proper arrangement of logs in the combustion chamber that is not excessively tight, elimination of irregularly-shaped logs, proper gravitational movement of logs to the bottom of the combustion chamber.

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