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Pollutant concentrations from a heat station supplied with cherry stones

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Streszczenie

W kotłowni grzewczej badano stężenia CO, C_xH_y, NO, NO_x i pyłu z kotła o mocy nominalnej 15 kW, zasilanego pestkami wiśni. W palenisku typu narzutowego do peletów drzewnych, mimo obniżenia temperatury, nie udało się uniknąć całkowicie zjawiska mięknienia i zlepiania się popiołu. Uzyskano niższą niż dla peletów drzewnych sprawność cieplną kotła oraz wyższe stężenie tlenku węgla, lecz poniżej dopuszczalnej wartości. Określono wpływ temperatury w komorze spalania i stężenia tlenu na stężenia zanieczyszczeń. Oszacowano wskaźniki emisji.

Abstract

Stężenia zanieczyszczeń z kotłowni zasilanej pestkami wiśni

CO, CxHy, NO, NOx and dust concentrations from a cherry stones supplied boiler with a nominal heat output of 15 kW were researched in a heat station. In the entrained flow furnace designed for firing wood pellets, melting and sintering ash phenomenon could not be successfully avoided. In comparison to wood pellet combustion, the observed boiler heat efficiency was lower. CO concentration was relatively high but did not exceed the permitted value. The impact of temperature in the combustion chamber and oxygen concentration on pollutant concentrations was determined. Pollutant emission indicators were estimated.

1. Introduction

Small solid fuel-fired heating boilers emit a considerable amount of incomplete combustion products per produced energy unit due to relatively low temperature in the combustion chamber, unsatisfactory air distribution and a short time of flue gas flow from the furnace to the heat exchanger. For instance, 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 amount of the total energy obtained is only 1% [1]. In Poland, the ratio per energy unit is probably not lower, as cheap boilers with low heat efficiency are used more frequently. Nowadays, heat stations quite frequently use wood pellets instead of wood logs (in order to decrease CO concentration in the flue gas) and the obtained carbon monoxide concentrations range between 300 and 1200 mg/m^3 (normalized to 10 % oxygen concentration in the flue gas) [2, 3, 4] depending on the quality of pellets, type of furnace and combustion conditions. Sometimes, however, attempts are made in heat stations to use furnaces designed for wood pellets to also fire different kinds of biomass.

Agricultural biomass must be fired at a lower temperature than wood, because of higher K_2O, Na_2O and SiO_2 content, which form eutectics with a melting temperature of 876 and 764 C [2, 3], respectively. Wood ash, on the other hand, usually melts at the temperature of above 1000°C [4], sometimes however if wood pellets are contaminated (with sand or other substances) at a much lower temperature. In order to limit the ash melting and slagging phenomenon, the temperature in the furnace should be brought below the ash melting temperature. The temperature can be reduced e.g. by reducing the stream of fuel while maintaining a constant stream of air for combustion. However, usually it results in a reduced boiler heat output and heat efficiency, with a lower but still increased concentration of carbon monoxide and sometimes hydrocarbons.

Below, experiments of pollutant concentrations from cherry stones combustion in an entrained flow furnace dedicated for firing wood pellets are presented. The aim of study is to verify the possibility of applying cherry stones as fuel in the analyzed model of wood pellet furnace.

2. Material

The study examined cherry stones of approx. 7 mm in diameter. The chemical composition analysis (performed by an accredited laboratory) gave the following result (in wt %): C- 51.58 ±0.298, H-6.45 ±0.044, N-1.4 ±0.081. Moisture 5.0 ±0.2 wt % was determined according to [5]. Lower heating value was determined according to [6]. Ash content was approx. 0.8 wt%, measured in the laboratory of Poznan University of Technology.

3. Experimental set up

The experimental set up is located in the Division of Heating, Air Conditioning and Air Protection of Institute of Environmental Engineering Poznan University of Technology. It comprises a heat station (fig.1), constructed for the purposes of emission and boiler heat efficiency analysis, equipped with two heating boilers of diverse characteristics. The first one is a wood log down-draft boiler with a nominal heat output of 15 kW, in which the fixed grate was replaced with an entrained flow furnace for wood pellets (fig.2). The second one is a wood log boiler with a nominal heat output of 25 kW and with two-stage combustion, including wood gasification and wood gas combustion. The boilers cooperate with a 900 dm^3 water heat storage.

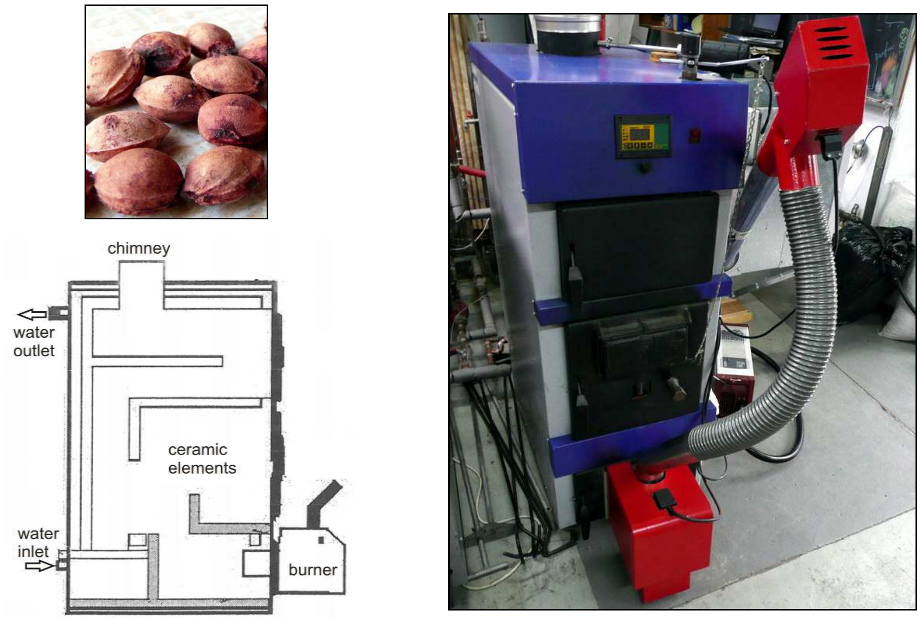


Fig.1. Heat station with two wood log boilers: with a heat output of 15 kW (with a pellet furnace) and 25 kW (with wood gasification); scheme of the boiler with pellet furnace; cherry stones

Fig.2. Furnace view: fixed-speed screw pellet dispenser; fan; air outlets

Cherry stones are supplied from the container by means of a fixed-speed screw feeder. The furnace is also equipped with a fixed-speed screw pellet dispenser, synchronized with the pellet feeder. Fuel stream is changed by fixing the time of screw feeder operation and stand-by. The stream of air used for the burning process (from the fan) is constant. A mixing and piping device, situated between the boiler and the water heat storage, enables water flow in the boiler only after reaching the temperature of 64°C, which guarantees the highest possible temperature of the combustion chamber walls and thus improves the combustion conditions. The flue gas is exhausted through a 8.5 m high insulated acid-resistant steel chimney with a diameter of 200 mm. During the research, heat from the water heat storage is transferred to the atmosphere with a fan cooler located on the roof of the heat station or by means of a heat transfer unit used for central heating and hot water preparation, located in the experimental house.

4. Experimental procedure

In order to reduce the temperature in the combustion chamber and therefore limit the ash melting, sintering and slagging phenomenon that contributes to increased CO and C_xH_y concentrations, the stream of cherry stones was being reduced with constant air supply, while observing the process of cherry stones firing inside the furnace through a sight glass, measuring the temperature in the combustion chamber and monitoring the CO concentration indications of the flue gas analyzer. Pellet screw feeder working mode was set to 10 seconds of operation and 10 seconds of stand-by.

The measurements lasted for 10 uninterrupted hours. For result analysis purposes, the experiment duration time was divided into 10 one hour measurement periods (test runs), as significant variation of measurement parameters was anticipated due to ash melting and slagging. Parameter values were gathered every 10 seconds in the personal computer and mean values were calculated for each one hour measurement period.

Boiler heat output and the quantity of heat transferred to the boiler water were measured with an ultrasonic heat meter. Dust concentration was measured in the chimney 4 times using a gravimetric dust meter with isokinetic aspiration. Fuel (cherry stones) stream was measured several times using a weighing device. For mean parameter values from 10 measurements, uncertainty for a 95% confidence level was calculated.

Pollutant emission indicators could only be estimated, because flue gas velocity in the chimney was not measured. Flue gas and air volume obtained from 1 kg of fuel under stoichiometric conditions was calculated using formulas 1 and 2 [7], depending on lower heating value and in real conditions also on air excess ratio (3):

$$V_{ps}^{t} = 0{,}99 \cdot \frac{Q_i^r}{4186{,}8} + 0{,}126 \tag{1}$$

$$V_{s}^{t} = 0{,}99 \cdot \frac{Q_i^r}{4186{,}8} + 1{,}126 \tag{2}$$

$$V_s = V_s^t + (\lambda - 1) \cdot V_{ps}^t \tag{3}$$

where:

Q_i^r – lower heating value of wood, kJ/kg

V_s^t – flue gas volume under stoichiometric conditions (λ =1) from 1 kg of fuel, m^3_n/kg

V_{ps}^t – air volume under stoichiometric conditions (λ = 1) from 1 kg of fuel, m^3_n/kg

V_s – flue gas volume under real conditions ($\lambda \neq 1$) from 1 kg of fuel, m^3_n/kg

λ – air excess ratio, --

Emission from 1 kg of fuel was calculated as a multiplication of flue gas volume from 1 kg of fuel under normal conditions (for real oxygen concentration value) and the mean pollutant concentration value for the entire measurement period under normal conditions (for real oxygen concentration value).

For the measurements, Vario Plus (MRU) flue gas analyzer was used to register the concentrations of O_2, NO, NO_2 (electrochemical cells), CO and C_xH_y (calculated to CH_4) using infrared procedure and flue gas temperature downstream the boiler. The flue gas analyzer also calculated air excess ratio, chimney loss and NO_x concentration (as a total NO calculated to NO_2 and NO_2). The temperature in the combustion chamber was measured with a radiation shielded thermocouple PtRhPt.

5. Results and discussion

In the attempt to reduce ash melting and CO concentration, fuel stream was decreased until reaching the value of about 3.0 kg/h. Mean parameter values obtained during the experiments were presented in the table 1.

Table 1. Mean parameter values and uncertainty intervals from all 10 one hour measurement periods (test runs) - cherry stones combustion.

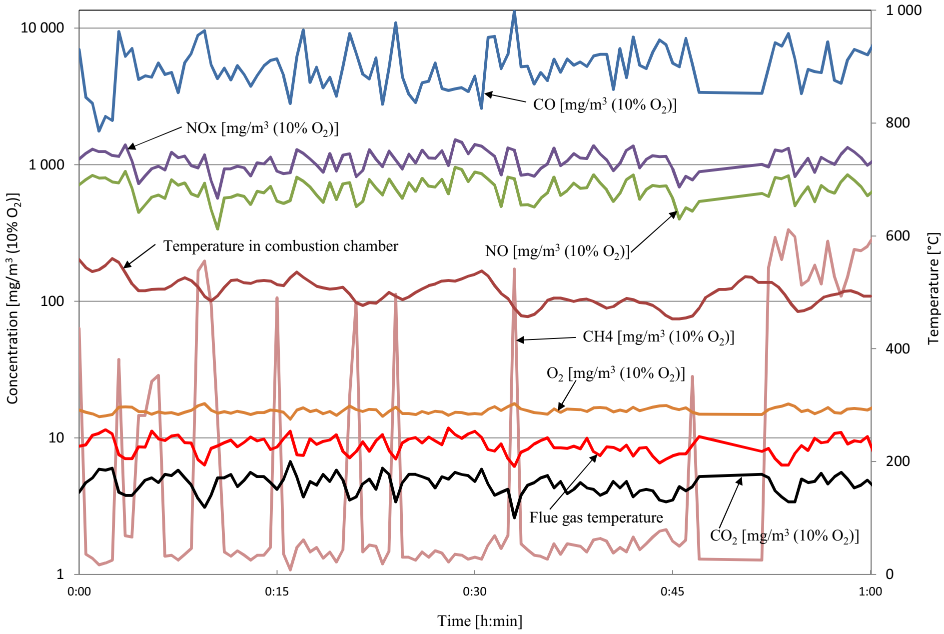
Parameters	cherry stones
O_2 concentration [%]	16,73 ± 0,77
CO_2 concentration [%]	4,01 ± 0,76
Air excess ratio λ [-]	5,22 ± 0,07
Temp in combustion chamber [°C]	528,94 ± 14,47
Flue gas temp. [°C]	236,07 ± 4,11
Boiler heat output [kW]	6,22 ± 0,49
CO concentration [mg/m^3] (10%O_2)	5851,10 ± 425,89
NO concentration [mg/m^3] (10%O_2)	660,48 ± 24,43
NO_X concentration [mg/m^3] (10%O_2)	1073,04 ± 39,69
CH_4 concentration [mg/m^3] (10%O_2)	244,83 ± 59,40
Dust concentration [mg/m^3]	15,16 ± 1,26
CO emission indicator [g/MJ]	2,70917 ± 0,11138
NO emission indicator [g/MJ]	0,52724 ± 0,21959
NO_X emission indicator [g/MJ]	0,49653 ± 0,01743
CH_4 emission indicator [g/MJ]	0,11538 ± 0,01296
Dust emission indicator [g/MJ]	0,00704 ± 0,00042

While firing cherry stones, high CO concentration value of 5851 mg/m^3 was observed, however still below the permitted value which is determined according to boiler nominal heat output and its heat efficiency [8]. Hydrocarbon concentration in the flue gas was not low either (245 mg/m^3). NO_2 concentration was low at all times and was included by the flue gas analyzer in NO_x concentration value. NO_x concentration was very high as compared to wood pellet combustion, because nitrogen content in cherry stones (about 1.4 wt %) is about three times as high as in wood (0.3- 0.4 wt%) [9]. Figure 3 presents parameter value variation during the first hour of measurements (pollutant concentrations, temperature in the combustion chamber, boiler heat output, air excess ratio, oxygen and carbon dioxide concentration, flue gas temperature downstream the boiler).

Figure 4 shows the impact of temperature in the combustion chamber and oxygen concentration on pollutant concentrations for the first hour of measurements. Analyzing the first hour of measurements (test run no. 1) no clear correlation between the concentrations of CO, NO, NO_x, C_xH_y and temperature in the combustion chamber can be seen, due to the fact that temperature was relatively low (below 600°C) and varied within a small range (approx. 100°). Changes in pollutant concentrations related to the increase of oxygen concentration can be only observed in case of CO and, to a lesser extent, in case of C_xH_y. This significant increase of CO concentration correlated with the oxygen concentration appeared during the stand-by of the fixed-speed screw pellet dispenser (working mode: 10 seconds of work/10 seconds of stand-by) when the oxygen concentration increased and the temperature in combustion chamber considerably decreased. Such decrease of the temperature is precisely the cause of CO concentration increase.

Table 2. Minimum, mean and maximum parameter values obtained during the first hour of measurements

Parameters	minimum	mean	maximum
O_2 concentration [%]	13,70	15,82	17,80
CO_2 concentration [%]	2,60	4,65	6,70
Air excess ratio λ [-]	2,90	4,19	6,65
Temp in combustion chamber [°C]	453,00	501,36	560,00
Flue gas temp. [°C]	191,70	228,43	259,60
Boiler heat output [kW]	5,40	7,20	11,40
CO concentration [mg/m^3] (10%O_2)	1762,00	5422,82	13310,00
NO concentration [mg/m^3] (10%O_2)	338,00	664,07	957,00
NO_X concentration [mg/m^3] (10%O_2)	569,00	1076,38	1520,00
CH_4 concentration [mg/m^3] (10%O_2)	1,08	43,56	334,60



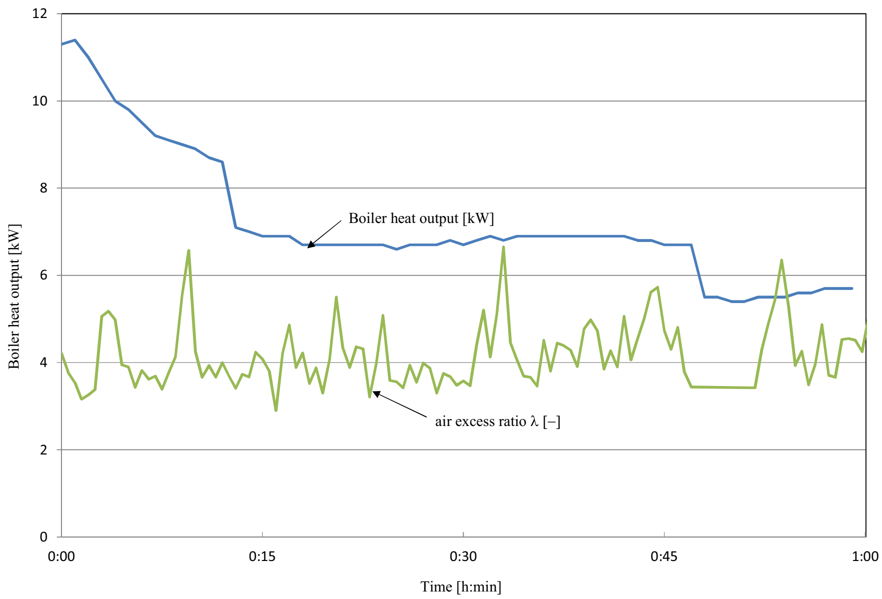
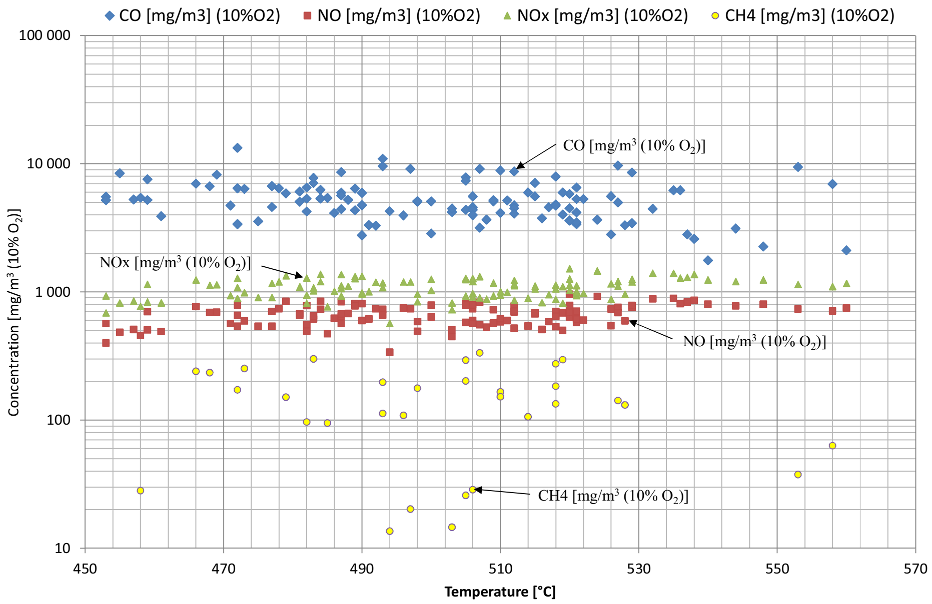


Fig.3. Measurement parameters during the first hour of measurements (test run no. 1, tab.2)



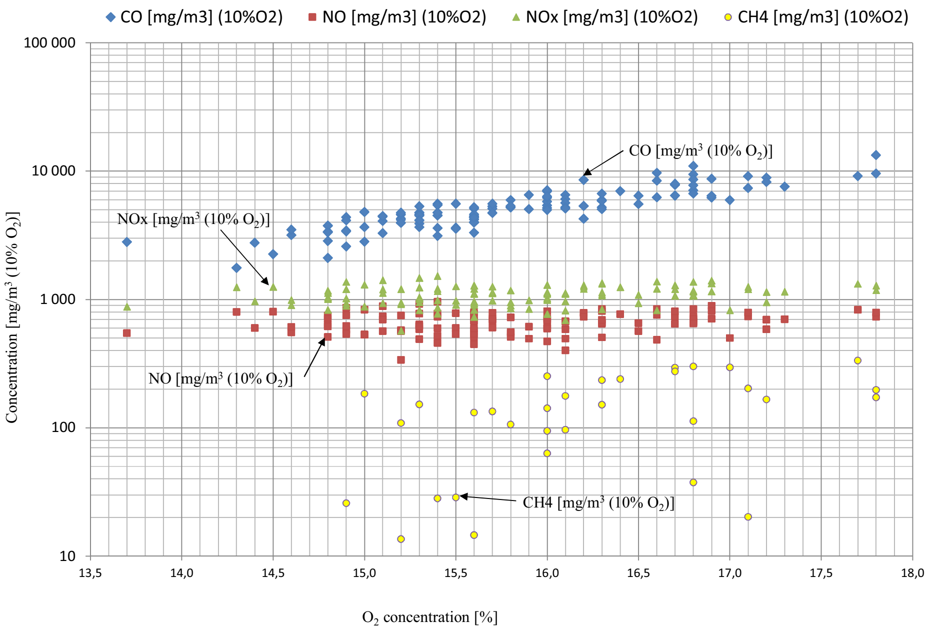
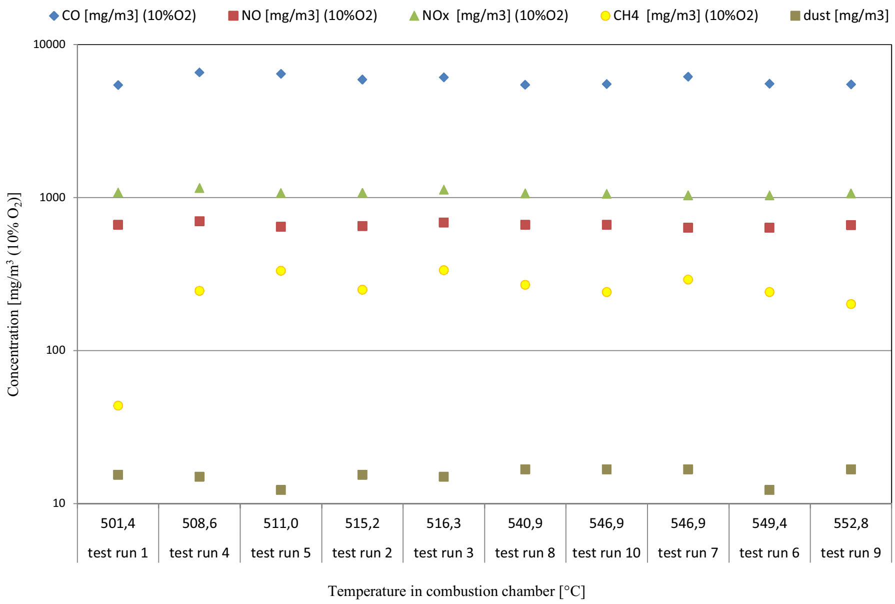


Fig.4. Correlation between pollutant concentrations and temperature in the combustion chamber and oxygen concentration - first hour of measurements (test run no. 1)



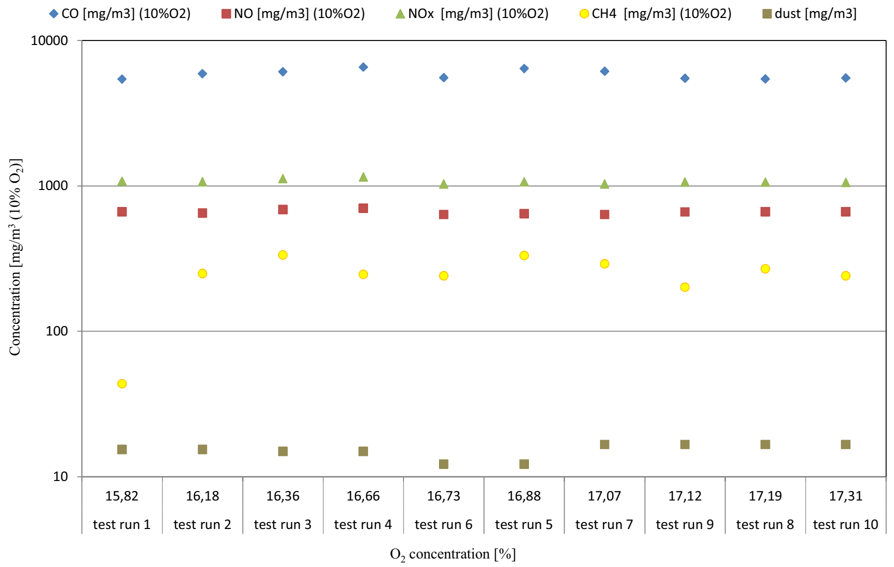


Fig.5. Correlation between pollutant concentrations and temperature in the combustion chamber and oxygen concentration – mean values for the subsequent hours of measurements (test runs).

No increase in NO and NO_x concentrations was observed in correlation with an increase of oxygen concentration and temperature in the combustion chamber, as the temperature was lower than 600°C and its increase was insignificant. Besides, air excess ratio was too high during the whole period of measurements. In these conditions only NO_x concentrations originating from fuel appeared.

Analysis of the mean values obtained during the subsequent measurement hours (test runs-fig.5) indicates a lack of clear correlation between the temperature in the combustion chamber, oxygen concentration and pollutant concentrations. Most probably, it is due to some combustion process disturbances partly caused by the ash melting phenomenon. It can also result from the fact that the oxygen concentration and the temperature in the combustion chamber did not differ significantly from one test run to another.

Boiler heat efficiency during measurements was about 65%.

6. Conclusion

The results have shown that it is possible to fire cherry stones in the presented model of wood pellet entrained flow furnace installed in the 15 kW heating boiler located in the heat station. However, boiler heat efficiency is low, CO concentration is high, but below the permitted value. NO_x concentrations are three times as high as in case of wood pellets.

Therefore, this process can be seen rather as thermal utilization of agricultural residues and can be performed in heat stations of cherry cultivators, especially in a mixture with wood pellets.

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References

[1] Knaus H., Richter S., Unterberger S., Snell U., Maier H., Hein K.R.G., On the application of different turbulence models for the computation of flow and combustion process in small scale wood heaters, Experimental Thermal and Fluid Science 21 (200), p. 99-108,

[2] Werther J., Saenger M., Hartge E. U., Ogada T., Siagi Z., Combustion of agricultural residues, Progress in Energy and Combustion Science 26 (2006), p.1-27,

[3] Rybak W., Spalanie i współspalanie biopaliw stałych, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2006,

[4] Ohman M., Boman C., Hedman H., Nordin A., Bostrom D., Slagging tendencies of wood pellet ash during combustion in residential pellet furnace, Biomass and Bioenergy,27 (2004), p.585-596,

[5] EN 12048, Solid fertilizers and liming materials-Determination of moisture content-Gravimetric method by drying at (105 ±2)°C, December 1999,

[6] PN-81/G-04513 Paliwa stałe. Oznaczanie ciepła spalania i obliczanie wartości opałowej,

[7] Kruczek S., Kotły. Konstrukcje i obliczenia, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2001,

[8] PN-EN 3003-5, Heating boilers, part5. Heating boilers for solid fuels, hand and automatically stocked nominal heat output of up to 300 kW. Terminology, requirements and marking, 2004,

[9] Juszczak M., Investigations of heat station with the boiler utilizing pellet furnace, Archiwum Gospodarki Odpadami i Ochrony Środowiska, vol.8 (2008), p.63-68,

[10] Naskręt M., Badania stężeń zanieczyszczeń ze spalania biomasy w kotle grzewczym. Praca magisterska, Politechnika Poznańska, 2009.