Archives of Waste Management and Environmental Protection
Archiwum Gospodarki Odpadami i Ochrony Środowiska

http://ago.helion.pl ISSN 1733-4381, Vol. 13 nr 1 (2011), p-39-50

Experimental study of CO, CxHy, NO, NOx and dust concentrations from a heat station supplied with rape cakes

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Abstract

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.

Streszczenie

Badania stężeń CO, CxHy, NO, NOx i pyłu z kotłowni zasilanej makuchami rzepakowymi

W kotłowni grzewczej badano stężenia CO, C_xH_y, NO, NO_x i pyłu z kotła o mocy nominalnej 15 kW, zasilanego makuchami rzepakowymi. 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.

1. Introduction

Heat stations with small solid fuel-fired 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. New made heat stations frequently use recently wood pellets instead of wood logs (in order to decrease CO concentration in the flue gas) and the obtain carbon monoxide concentrations range between 300 and 1200 mg/m^3 (normalized to 10 % oxygen concentration in the flue gas) [1,2] depending on the quality of pellets, type of furnace and burning conditions. Sometimes, however, attempts are made in heat stations to use furnaces designed for wood pellets to 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 [1, 3], respectively. Wood ash, on the other hand, usually melts at the temperature of above 1000°C [1,2], 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, experimental study of pollutant concentrations from rape cake burning in an entrained flow furnace dedicated for firing wood pellets is presented. The aim of the study is to verify the possibility of applying rape cakes as fuel in the analyzed model of wood pellet furnace located in the 15 kW wood log boiler situated in the heat station belonging to Poznan University of Technology.

2. Material

The study examined rape cakes presented in the fig.2. The chemical composition analysis (performed by an accredited laboratory [4]) gave the following result (in wt % of dry mass): C- 47.54 ±0.056, H-6.64±0.020, N-5.65±0.035. Moisture 8.1±0.3 wt % was determined according to [5]. Lower heating value 22490 kJ/kg was calculated according to [6]. Ash content was approx. 5.5 wt%, measured in the laboratory of Institute of Environmental Engineering , Poznan University of Technology. For comparison the chemical composition analysis presented in [7] gave the following results(in wt % of dry mass): C-51.0, H-7.38, N-4.97, ash-6.2, K (potassium) -1.6, for wood K- between 0.13(spruce) and 0.22(beech).

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)

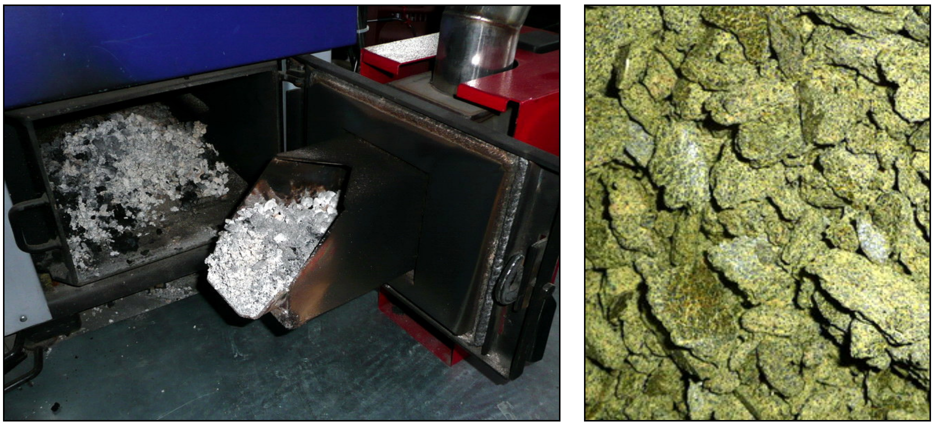


Fig.2. Pellet furnace with ash, rape cakes

Rape cakes 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 from the fan for the burning process 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.

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 rape cakes was being reduced with constant air supply, while observing the process of rape cakes burning inside the furnace through a sight glass, measuring the temperature in the combustion chamber and monitoring the CO and C_xH_y 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. Rape cake mass 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 [8], depending on lower heating value and in real conditions also on air excess ratio (3):

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

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

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

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). Gas analyzer cools flue gas probe during measurement to temperature about 0°C. Pollutant emission indicators were calculated as emission of 1 kg of fuel divided by fuel lower heating value.

5. Measuring equipment

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 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.

6. Results and interpretation

In the attempt to reduce ash melting , rape cake stream was decreased until reaching the value of about 3.6 kg/h. Mean parameter values obtained during the experiments(10 one hour test runs) were presented in the table 1.

While firing rape cakes CO concentration of 2657 mg/m^3 and dust concentration of 118 mg/m^3 were observed, below the permitted value which is determined according to boiler nominal heat output and its heat efficiency [9]. Hydrocarbon concentration in the flue gas was not low either (235 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 727 mg/m^3 as compared to wood pellet combustion, because nitrogen content in rape cakes (5.65 wt %) is more than 10 times as high as in wood (0.3-0.4 wt%) [10]. Figure 3 and table 2 presents a big parameter value variation during the third 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), typical while ash melting and sintering phenomenon appears and combustion process is not stable. In other hours (test runs) parameter variation was similar.

Table 1. Mean parameter values and uncertainty intervals from all 10 one hour measurement periods (test runs) – rape cakes burning

Parameters and indicators	**Rape caces**
O_2 concentration [%]	12.4 ± 1.5
CO_2 concentration [%]	8.5 ± 1.5
Air excess ratio λ [-]	3.3 ± 0.1
Temp in combustion chamber [°C]	440 ± 42
Flue gas temp. [°C]	180 ± 15
Boiler heat output [kW]	6.3 ± 1.4
CO concentration [mg/m^3] (10%O_2)	2657 ± 671
NO concentration [mg/m^3] (10%O_2)	451 ± 98
NO_X concentration [mg/m^3] (10%O_2)	727 ± 175
CH_4 concentration [mg/m^3] (10%O_2)	235 ± 224
Dust concentration [mg/m^3]	118 ± 6
CO emission indicator [g/MJ]	0.639 ± 0.271
NO emission indicator [g/MJ]	0.118 ± 0.019
NO_X emission indicator [g/MJ]	0.191 ± 0.032
CH_4 emission indicator [g/MJ]	0.057 ± 0.024
Dust emission indicator [g/MJ]	0.029 ± 0.002

Table 2. Minimum, mean and maximum parameter values obtained during the third hour (as an example) of rape cake burning

Parameters	minimum	mean	maximum
O_2 concentration [%]	4.1	12.6	18.1
CO_2 concentration [%]	3.1	8.3	15.8
Air excess ratio λ [-]	1.2	3.2	7.4
Temp in combustion chamber [°C]	264	404	595
Flue gas temp. [°C]	89	169	244
Boiler heat output [kW]	3.9	5.6	8.4
CO concentration [mg/m^3] (10%O_2)	178	1779	3861
NO concentration [mg/m^3] (10%O_2)	101	491	921
NO_X concentration [mg/m^3] (10%O_2)	174	828	1540
CH_4 concentration [mg/m^3] (10%O_2)	0.47	62	368

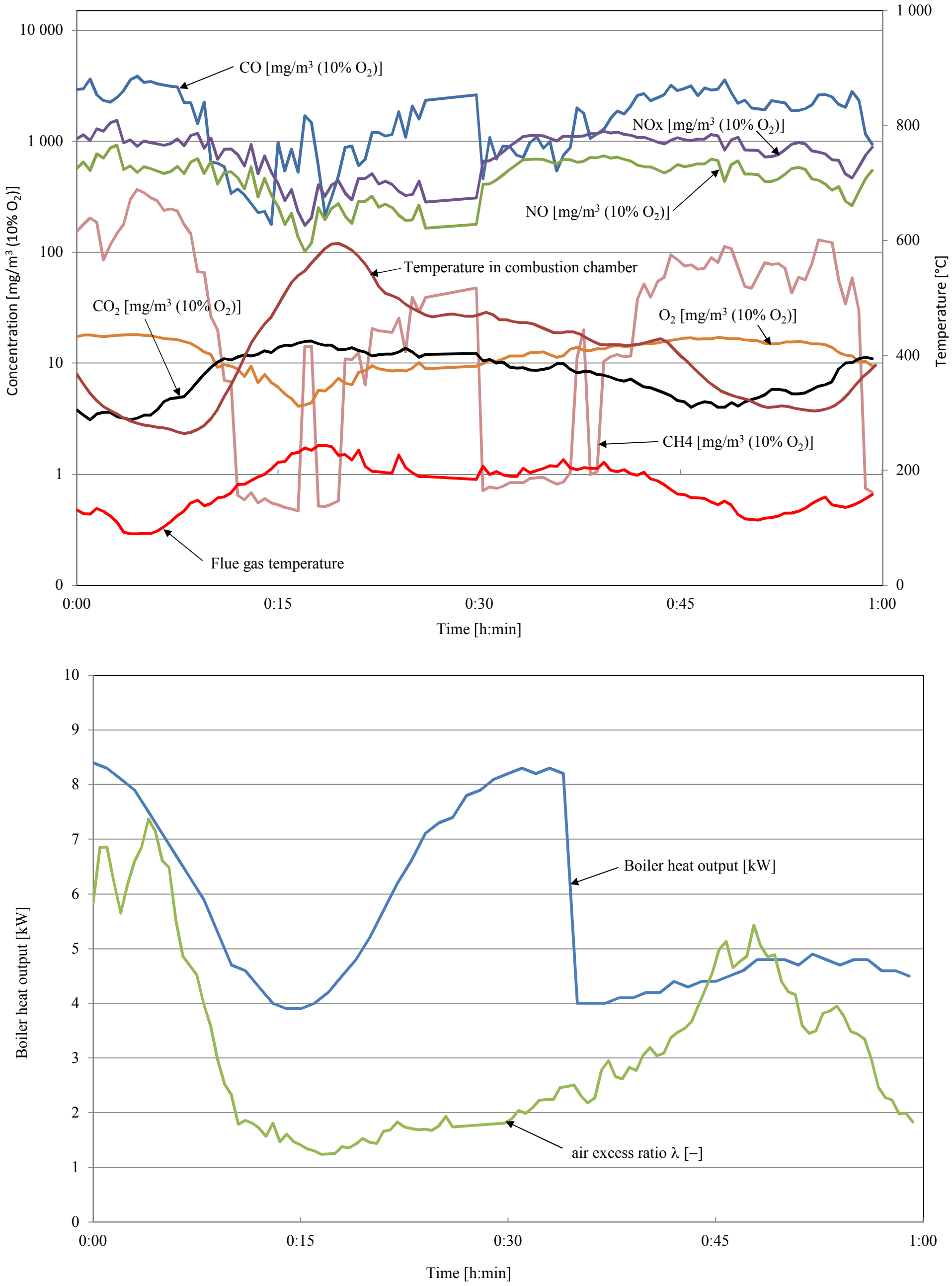
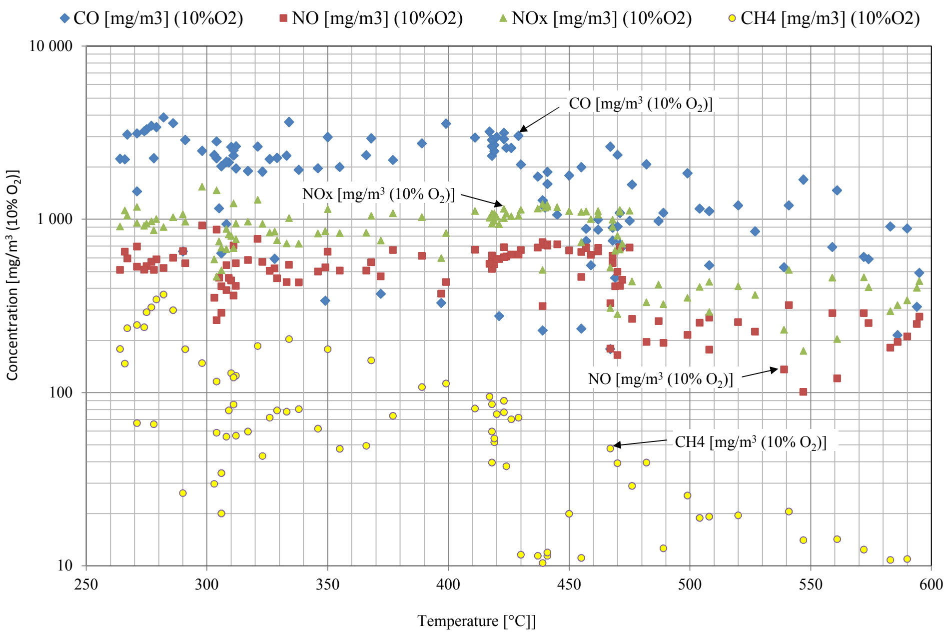


Fig.3. Measurement parameters during the third hour of rape cake burning (test run no. 3, tab.2)



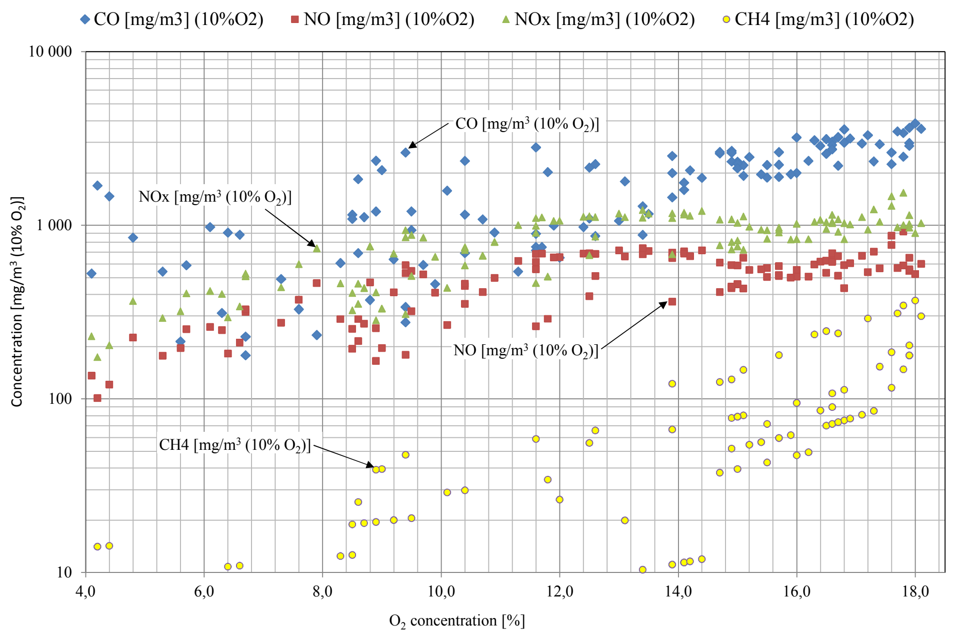
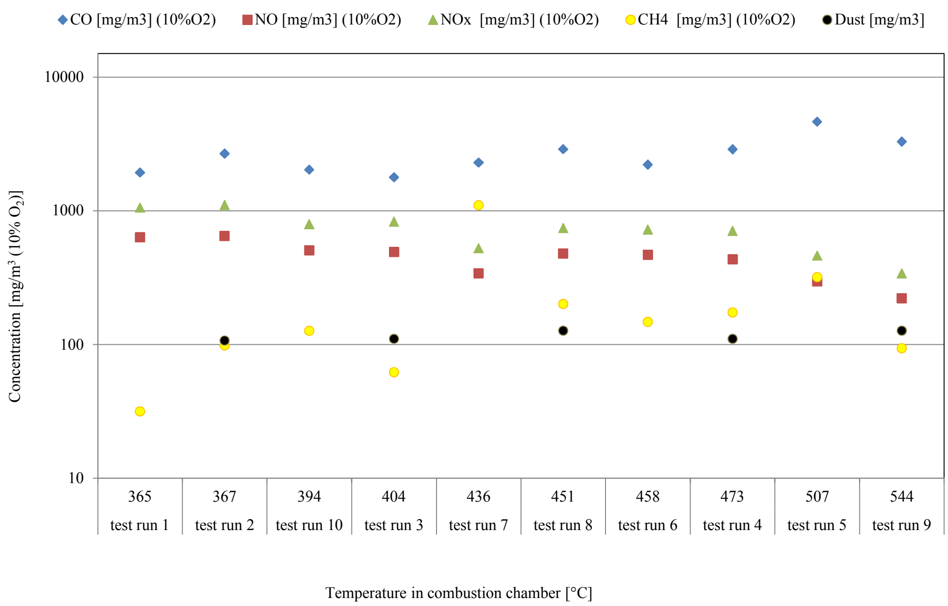


Fig.4. Pollutant concentrations versus temperature in the combustion chamber and oxygen concentration - third hour of measurements (test run no. 3)

Figure 4 shows the impact of temperature in the combustion chamber and oxygen concentration on pollutant concentrations for the third hour of measurements. Analyzing the third hour of measurements (test run no. 3) CO and C_xH_y significant concentration decrease related to the temperature increase in the combustion chamber can be seen. Increase of CO and C_xH_y concentrations related to the oxygen concentration increase was noticed. This significant increase of CO and C_xH_y concentrations correlated with the oxygen concentration increase 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. No significant 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 interval range was insignificant. Besides, air excess ratio was too high during the whole period of measurements. In these conditions almost only NO_x concentrations originating from fuel appeared.

Analysis of the mean values obtained during the subsequent measurement hours (test runs-fig.5) indicates unexpected CO and C_xH_y concentration increase and NO and NO_x concentration decrease related to the temperature increase. Perhaps it was caused by ash melting and sintering phenomenon and bad contact of rape cakes with the air. During oxygen concentration increase, NO and NO_x concentration increase was noticed as it was expected as well as CO an C_xH_y concentration decrease. Boiler heat efficiency during measurements was about 60%.



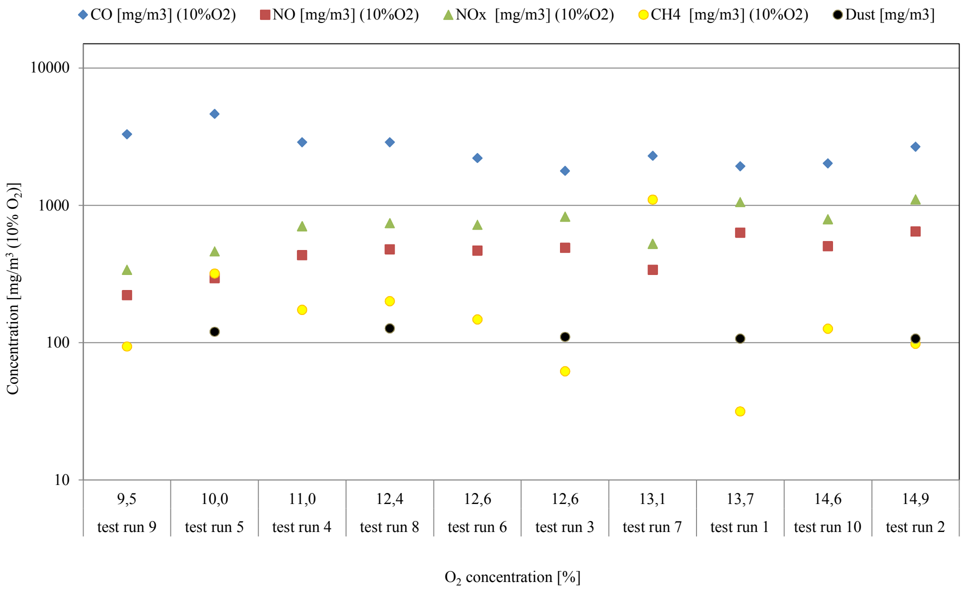


Fig.5. Pollutant concentrations versus temperature in the combustion chamber and oxygen concentration – mean values for the subsequent hours of measurements (test runs).

7. Conclusion

The results have shown that it is possible to fire rape cakes 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 and dust concentrations are high, but below the permitted values. NO_x concentrations are about two and half times as high as in case of wood pellets. C_xH_y concentration is not small. Rape cakes can be considered rather as agricultural residue but not as fuel.

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

Acknowledgements

I would like to thank the technical workers and students of Poznan University of Technology [11] for their help during the research. This work was carried out as a part of the research project PB-13/615/08BW sponsored by Poznan University of Technology.

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