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POLLUTANT CONCENTRATIONS FROM A 15 kW HEATING BOILER SUPPLIED WITH SUNFLOWER HUSK PELLETS

Sunflower husk pellets were fired in a channel type furnace originally designed for wood pellets. The furnace was installed in a 15 kW heating boiler. CO, C_xH_y, NO, NO_2 and dust concentrations were measured. Despite reducing the temperature in the furnace down to ca. 700 °C by fuel stream reduction, ash melting and sintering phenomenon could not be completely avoided. CO concentration of ca. 6500 mg/m^3 (10% O_2) was observed, boiler heat efficiency being 63%. A test for sunflower husk and wood pellet mixture showed a reduction of CO concentration down to 2153, 1683 and 966 mg/m^3, respectively (10% O_2), wood pellet volume proportion being 25, 50 and 75%, respectively, and hydrocarbon concentration almost down to zero. The impact of temperature in the combustion chamber and oxygen concentration on pollutant concentrations was determined.

1. INTRODUCTION

Solid fuel fired heating boilers with low heat output emit a considerable amount of incomplete combustion products per produced energy unit due to low furnace temperature, 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 in energy production is about 1%, while their contribution to the emission of incomplete combustion products is between 16% and 40% [1]. In Poland, the ratio per energy unit is probably not lower, as cheap boilers with low heat efficiency are used more frequently.

Nowadays, central heating stations quite frequently use wood pellets and the obtained carbon monoxide concentrations range between 300 and 1200 mg/m^3 (normalized to 10% oxygen concentration) [2, 3, 4], depending on the quality of pellets and type of furnace. Interesting information about pollutants emitted from combustion biomass and other fuels can be found in [5,6]. Sometimes however, attempts are made

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in heating stations to use furnace designed for wood pellets to fire also different kinds of agricultural biomass pellets.

Agricultural biomass, including sunflower husk, must be fired at lower temperature than wood, as excessive temperature in the furnace causes ash melting and sintering, originating problems with furnace exploitation, incrementing carbon monoxide and hydrocarbon emissions and diminishing boiler heat efficiency. This phenomenon is due to increased K_2O and Na_2O content in comparison with wood. These substances in combination with SiO_2 in ash form eutectics with a melting temperature of 874 and 764°C, respectively [7, 6]. Wood ash, on the other hand, melts at the temperature of above 1000°C [4, 8].

In order to limit the ash melting phenomenon, the temperature in the furnace should be brought below the ash melting temperature, e.g. by reducing the stream of fuel while maintaining a constant stream of air for combustion. However, usually it results in reduced boiler heat output and heat efficiency, with slightly lower but still increased emissions of carbon monoxide and sometimes hydrocarbons.

Below, experiments of pollutant concentrations from sunflower husk pellet combustion in a channel type furnace dedicated for firing wood pellets are presented. The aim of study is to verify the possibility of applying sunflower husk pellets as fuel in the discussed model of furnace designed for wood pellet combustion.

2. EXPERIMENTAL

Material. Sunflower husk pellets have been examined, 8 mm in diameter and 15–40 mm long. The analysis of chemical composition (performed by an accredited laboratory) gave the following results: C – 49.56 ±0.041%, H – 5.98 ±0.041%, N – 0.86 ±0.014%, S – 0.04±0.061%. Moisture 7.9 ±0.3% was determined according to [9]. The higher heating value 22 968 kJ/kg and lower heating value 22 470 kJ/kg were determined according to [10]. Ash content was ca. 1.9%.

Experimental set up. The experimental set up was located in the Division of Heating, Air Conditioning and Air Protection, Poznan University of Technology. It comprised a heating station, equipped with 3 heating boilers of diverse characteristics. In order to perform the experiments in question, a wood log down-draft boiler with the nominal heat output of 15 kW was used, in which the fixed grate was replaced with a channel type furnace for wood pellets. The remaining boilers were: a wood log boiler with a nominal heat output of 25 kW with two-stage thermal wood conversion including wood gasification and wood gas combustion, and a boiler with the nominal heat output of 20 kW equipped with a retort furnace for wood pellets. The boilers cooperated with a 900 dm^3 water heat storage.

Sunflower husk pellets were supplied from the storage by means of a fixed-speed screw feeder. The furnace was also equipped with a fixed speed screw pellet dispenser, synchronized with the pellet feeder. Fuel stream was regulated by fixing the time of screw feeder operation and stand by. The stream of air for combustion from the fan was constant. A mixing and pumping device, located between the boiler and the water heat storage, enabled water flow in the boiler only after reaching the temperature of 64 °C, which guaranteed the highest possible temperature of the combustion chamber walls and thus improved the combustion conditions. The flue gas was exhausted through a 8.5 m high insulated acid-resistant steel chimney with the diameter of 200 mm. Heat was transferred to the atmosphere with a fan cooler located on the roof of the heating station or by means of a heat transfer unit located at the place of experiment.

3. RESEARCH PROGRAM AND MEASURING EQUIPMENT

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

For the experiments, Vario Plus (MRU) flue gas analyzer was used recording 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 (sum of NO and NO_2). The temperature in the combustion chamber was measured with a radiation shielded thermocouple PtRhPt.

The experiments lasted for 9 uninterrupted hours. Its duration was divided into 9 one hour measurement periods, as significant variation of measured parameters was anticipated due to ash melting. Parameter values were gathered every 10 s in the computer and mean values were calculated for each one hour measurement period. Boiler heat output and the quantity of heat transferred to water were measured with an ultrasonic heat meter. Dust concentration in the chimney was measured four times using a gravimetric dust meter with isokinetic aspiration. Fuel stream was measured several times using a weighing device. One hour tests were also performed for wood and sunflower husk pellet mixture (Table 1) to examine the possibility of decreasing CO concentration.

4. RESULTS AND DISCUSSION

In the attempt to reduce ash melting and CO concentration, fuel stream was decreased until reaching the value of 2.14 kg/h. Table 1 presents parameter values during the fourth hour of measurements (when ash melting and sintering phenomenon was not significant) and mean values from all 9 one hour measurement periods performed during sunflower husk pellet firing, as well results of the experiments with a mixture of sunflower husk pellets and wood pellets.

Table 1

Parameter values measured after the 4th hour of measurements,
mean values from 9 one hour measurement periods for mixture with wood pellets

Parameters	Measurement 4			Mean value 9 measurements	Volume of wood pellets in the mixtures		
	Min.	Mean	Max.		25%	50%	75%
O_2 concentration, %	6.8	11.1	14.1	1.9 ± 0.9	16.3	16.3	15.1
CO concentration (10% O_2), mg/m^3	3522	5774	9763	6477 ± 933	2153	1683	966
NO concentration (10% O_2), mg/m^3	206	372	483	372 ± 35	156	138	127
NO_X concentration (10% O_2), mg/m^3	317	571	740	571± 53	239	212	195
C_xH_y[a] concentration (10% O_2), mg/m^3	39	123	320	159 ± 62	0	0	0
Dust concentration (10% O_2), mg/m^3		27		37 ± 6	[c]	[c]	[c]
Flue gas temperature, °C	280	314	353	302±28	240	240	256
Temperature in the combustion chamber, °C	639	702	763	686±58	791	788	842
Boiler heat output, kW	9.5	10.2	10.9	8.8 ± 1.4	9.4	9.8	10.3
Air excess ratio	1.5	2.2	3.1	2.7 ± 0.5	4.5[b]	4.5[b]	3.6[b]
Chimney loss, %	17	21	26	23+-3	32	32	27

[a]Calculated as CH_4.

[b]Very high air excess ratio in conditions of high chimney draught at the ambient air temperature of 15 °C (other measurements were performed in the summer at the temperature of ca. 20 °C).

[c]No measurement.

For mean parameter values from 9 measurements, uncertainty for the 95% confidence level was calculated. NO_2 concentration was very low during the experiment and was included by the flue gas analyzer in NO_x concentration value. While firing sunflower husk pellets with no additives, high CO concentration was observed, however still below the permitted value which is determined according to boiler nominal heat output and its heat efficiency [11]. Once a mixture with wood pellets was applied (25, 50 and 75 vol. %), a significant decrease in CO concentrations was achieved, which decreased as wood pellet content in the fuel increased. Significantly lower CO concentrations, below 700 mg/m^3 (10% O_2), at the boiler heat efficiency of 83% [12] were reached in the same furnace during firing of wood pellets. The observed C_xH_y concentrations were low and after applying a mixture of sunflower husk pellets and wood pellets they approached zero.

Figure 1 presents time dependences of the parameters of the process during the fourth hour of measurements (pollutant concentrations, temperature in the combustion chamber, boiler heat output, air excess ratio, oxygen concentration, flue gas temperature downstream the boiler).

Figure 2 shows the impact of temperature in the combustion chamber and oxygen concentration on pollutant concentrations in the fourth hour of measurements (measurement 4, Table 1).

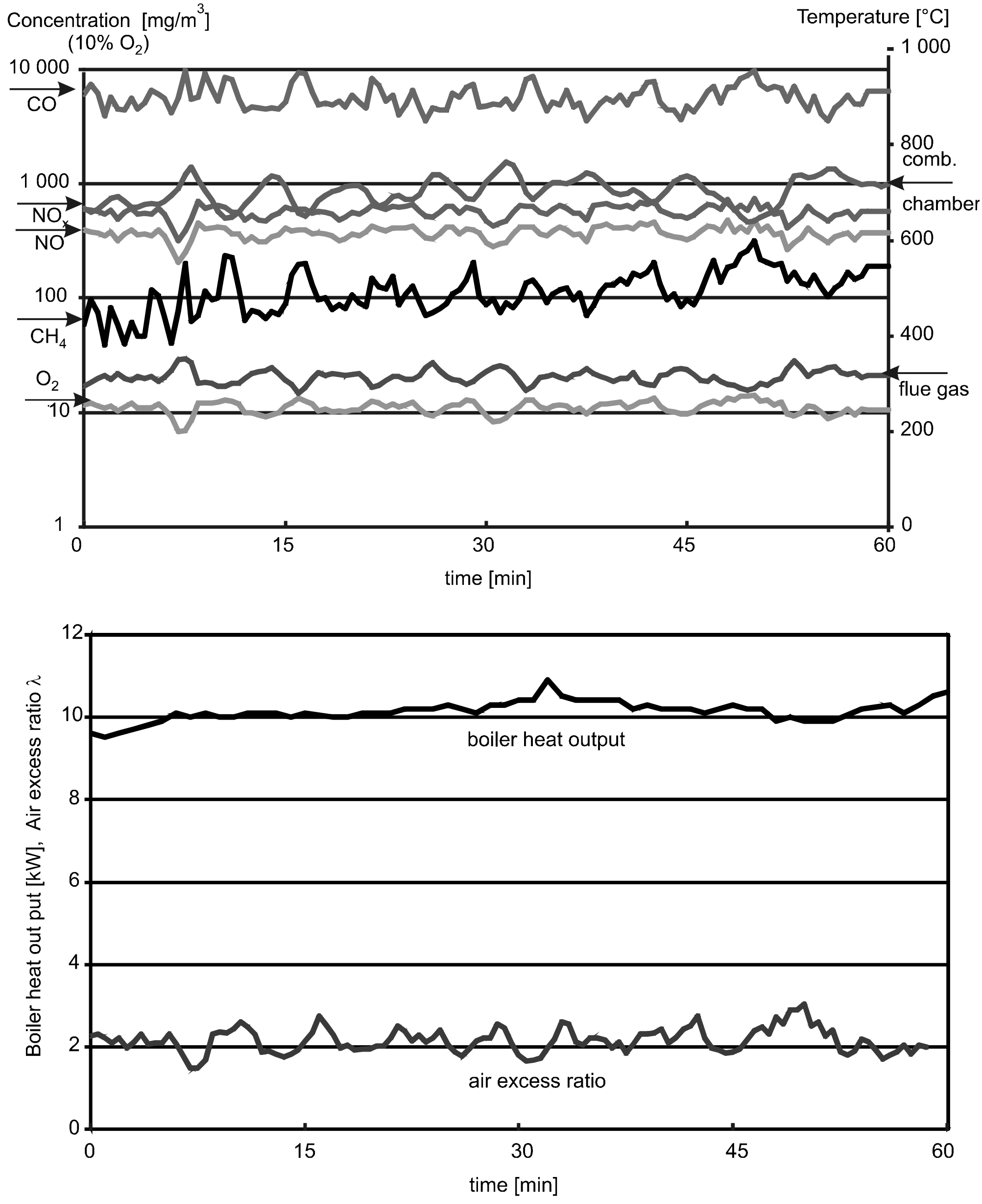
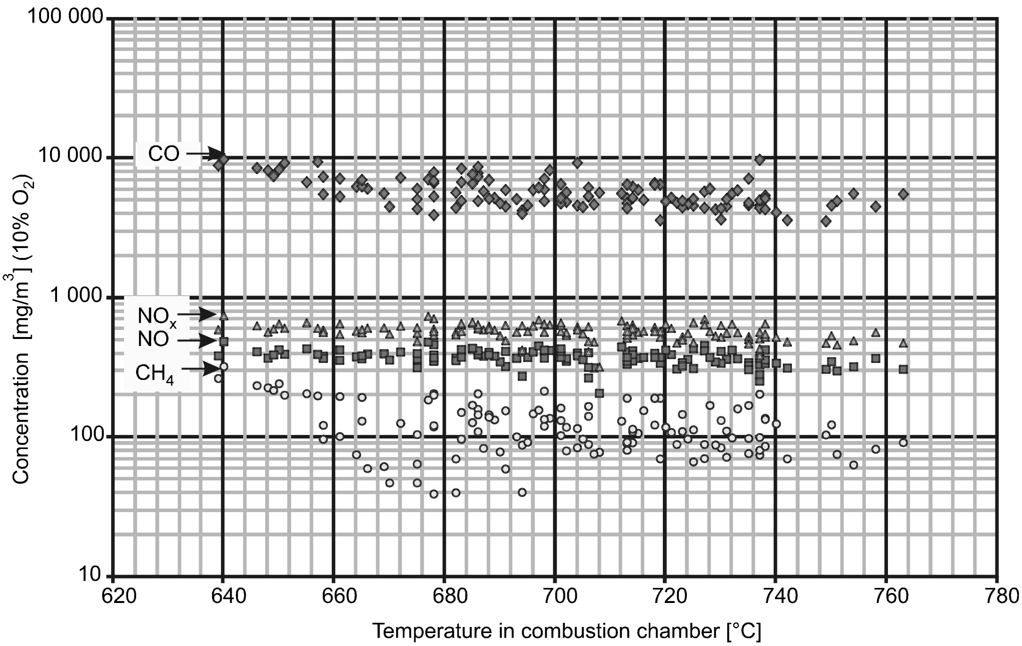


Fig. 1. Measured values of parameters during the fourth hour of measurements (measurement 4, Table 1)



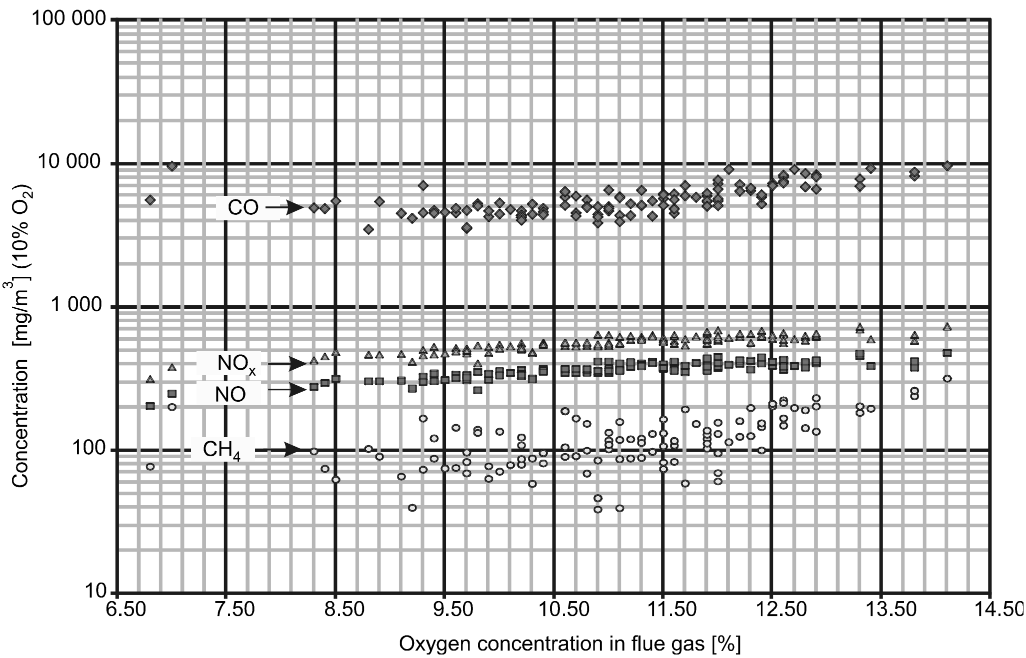


Fig. 2. Dependences of pollutant concentrations on temperature in the combustion chamber and oxygen concentration – fourth hour of measurements (measurement 4)

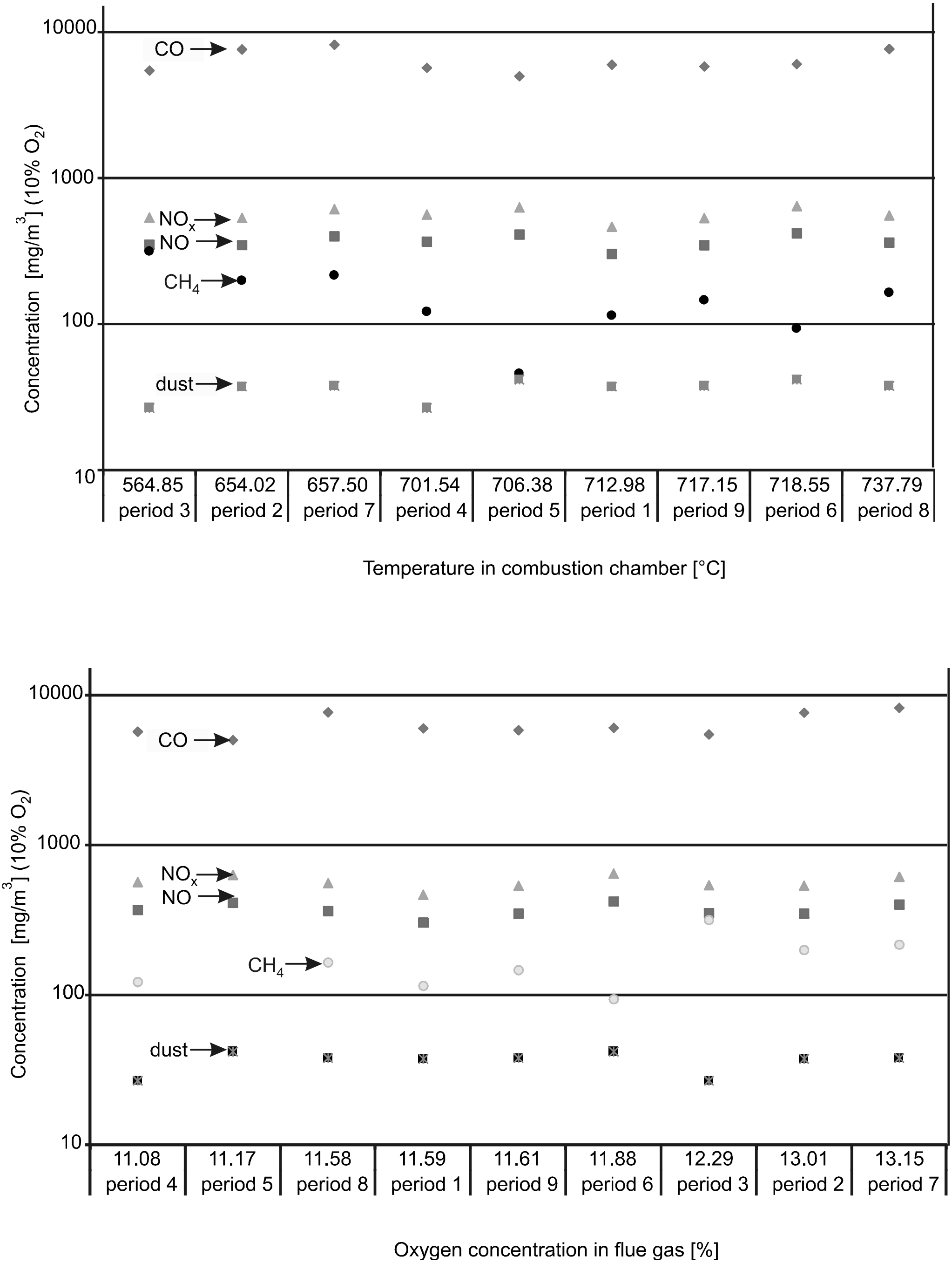


Fig. 3. Dependences of the pollutant concentrations on temperature in the combustion chamber and oxygen concentration – mean values for the subsequent hours of measurement

A decrease in CO and C_xH_y concentrations can be observed as the temperature in the combustion chamber increases. No increase was observed however in the concentration of nitrogen oxides, a slight decrease occurred instead that could originate from the exclusion of part of fuel caused by the ash melting phenomenon. Moreover, the temperature increase was insignificant (ca. 100 °C). On the other hand, an increase of nitrogen concentration was observed with respect to increase of oxygen concentration. The influence of oxygen concentration on CO and C_xH_y concentrations is hardly noticeable.

Analysis of the mean values obtained during subsequent measurements (Fig. 3) indicates a lack of clear correlations between temperature in the combustion chamber, oxygen concentration and pollutant concentrations. Most probably, it is due to some combustion disturbances partly caused by ash melting.

The results (Table 1) have shown that excessive air (no possibility of air stream regulation) caused high chimney losses. Dust concentrations in the chimney were low, however, it could be caused by partial depositing of dust on the horizontal surfaces of the heat exchanger. Also heat efficiency of the boiler was low, only 63%. This value was determined once for the entire measurement period, being the amount of heat transferred to the water divided by the fuel mass and multiplied by the fuel lower heating value.

Pollutant emission indicators were estimated. Flue gas and air volumes obtained from 1 kg of fuel under stoichiometric conditions were calculated from Eqs. (1) and (2) [13], depending on the lower heating value, flue gas volume under real conditions depended also on the air excess ratio (Eq. (3)):

$$V_{ps}^{t} = 0.99\frac{Q_i^r}{4186.8} + 0.126 \tag{1}$$

$$V_{s}^{t} = 0.99\frac{Q_i^r}{4186.8} + 1.126 \tag{2}$$

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

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_n^3/kg, V_{ps}^t – air volume under stoichiometric conditions (λ = 1) from 1 kg of fuel, m_n^3/kg, V_s – flue gas volume under real conditions ($\lambda \neq 1$) from 1 kg of fuel, m_n^3/kg, λ – air excess ratio.

Emission from 1 kg of fuel was calculated as a product of flue gas volume from 1 kg of fuel under normal conditions and the mean pollutant concentration for the entire measurement period under normal conditions, with a real oxygen concentration (11.9%) (Table 1). Pollutant emission indicators for CO, NO, NO_x, C_xH_y and dust were: 5.315; 0.306; 0.469; 0.130; 0.030 g/MJ, respectively.

5. CONCLUSIONS

While firing sunflower husk pellets in a channel type wood pellet furnace, with no air stream regulation, ash melting could not be completely avoided. The boiler heat output and boiler efficiency were low, CO concentration was high, however below the permitted value. Significant reduction of CO and C_xH_y concentrations was achieved when using a mixture with wood pellets.

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