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Pollutant concentrations from a heat station fuelled with a wood pellet and coffee husk pellet mixture

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Abstract

CO, CxHy, NO, NOx and dust concentrations from a heat station with a boiler of 15 kW nominal heat output supplied with a wood pellet and coffee husk pellet mixture were researched . In the entrained flow furnace designed for firing wood pellet burning, melting and sintering ash phenomenon was 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.

Keywords: wood pellets, coffee pellets, heat station.

Streszczenie

Stężenia zanieczyszczeń z kotłowni zasilanej mieszaniną peletów drzewnych i peletów z łusek kawy

W kotłowni grzewczej badano stężenia CO, CxHy, NO, NOx i pyłu z kotła o mocy nominalnej 15 kW, zasilanego mieszaniną peletów drzewnych i peletów z łusek kawy. W palenisku typu narzutowego dostosowanego 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.

Słowa kluczowe: pelty drzewne, pelety z łusek kawy, ciepłownia.

1. Approach

The aim of study is to verify the possibility of applying mixture of wood pellets and coffee husk pellets as fuel in the analyzed model wood pellets furnace located in the heat station belonging to Institute of Environmental Engineering Poznan University of Technology.

Heat stations with small solid fuel 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) to obtain 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 fire also 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 maintained 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 high concentration of carbon monoxide and sometimes hydrocarbons.

Below, experiments of pollutant concentrations measurement from combustion of wood pellets and coffee husk pellets mixture in an over-fed pellet furnace dedicated for firing wood pellets are presented.

2. Materials

The study examined pellets of approx. 7 mm in diameter and length between 10 and 18 mm. The chemical composition analysis (performed by an accredited laboratory) gave the following result (in wt %): wood pellets: C - 50.3, H - 6.5, N - 0.1 and ash content - 0.9; moisture content (8.5 wt %) was determined according to [5]; coffee (mbuni) husk*: C - 43.8, H - 4.9, N - 1.5, moisture content - 11.2 and ash content - 4.5 wt %. Lower heating value of tested fuels was determined according to [6] in laboratory of Poznan University of Technology: wood pellets - 19 100 kJ/kg, coffee (mbuni) husk pellets- 16 388 kJ/kg.

*coffee (mbuni) husk- residue obtained during dry processing of coffee berries

3. Experimental set up

Experimental set up 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 over-fed pellet 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 hot water heat tank.

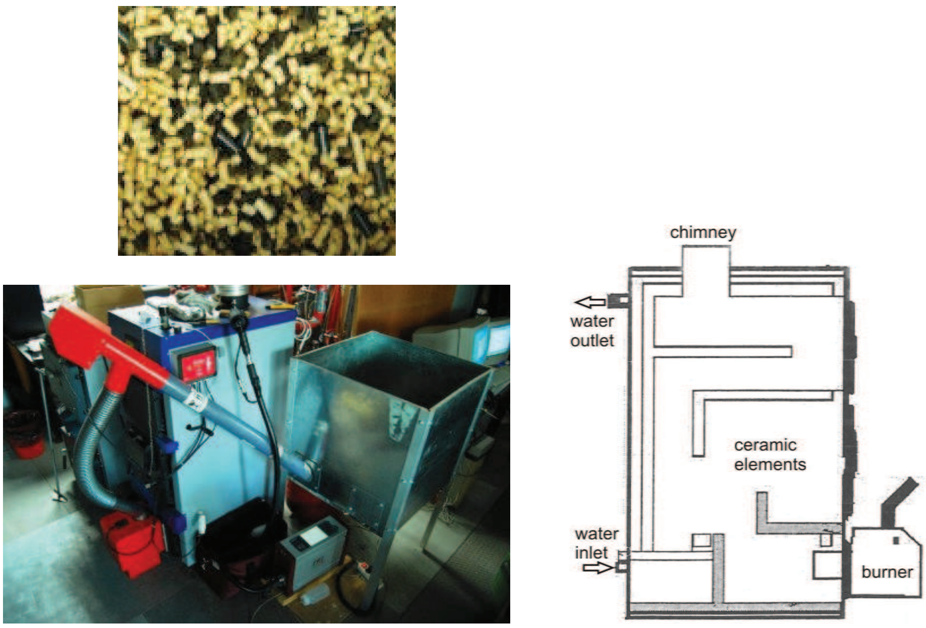

Fig. 1. Heat station with two wood log boilers: with a heat output of 15 kW (with a pellets furnace) and 25 kW (with wood gasification); scheme of the boiler with pellets furnace; mixture of wood pellets and coffee (mbuni) husk pellets: 3:1 (volumetric)

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

Wood pellets and coffee husk pellets mixture (3:1, volumetric) is supplied from the container by means of a fixed-speed screw feeder. The furnace is also equipped with a fixed-speed screw pellets dispenser, synchronized with the fixed-speed screw 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 hot water tank, 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 experiments heat from the hot water tank is transferred to the atmosphere with a heat exchanger 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

The measurements lasted for 10 uninterrupted hours. For results 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 2 seconds in the personal computer and mean values were calculated for each one hour measurement period.

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 wood pellets and coffee husk pellets mixture was being reduced with constant air supply, while observing the process of wood pellets and coffee husk pellets mixture 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. Screw pellets dispenser working mode was set to 5 seconds of operation and 5 seconds of stand-by.

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 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. Discussion of results

For reduction of ash melting in the furnace and CO concentration in flue gas, fuel stream was decreased until reaching the value of about 3.3 kg/h. Mean parameter values obtained during the experiments were presented in the table 1.

While firing mixture of wood pellets and coffee husk pellets, high CO concentration value of 8538 mg/m^3 was observed, but below the permitted value which is determined according to boiler nominal heat output and its heat efficiency [8]. Heat efficiency was low, below 70%, caused old inefficient construction of the boiler heat exchanger. Hydrocarbons concentration in the flue gas was not low either (182 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 high (413 mg/m^3) as compared to wood pellets combustion, because nitrogen content in coffee husk (about 1.5 wt %) is about three times as high as in wood (0.3- 0.4 wt%) [9]. Figure 3 presents for example of relatively good combustion, parameter value variation during the seventh 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). Most probably, parameter variation is due to some combustion process disturbances partly caused by the ash melting phenomenon.

Table 1. Research parameters from combustion of wood pellets and coffee (mbuni) husk pellets mixture (mean values and uncertainty intervals from all 10 one hour measurement periods - test runs)

Parameters		Wood pellets and coffee (mbuni) husk pellets 3:1
O_2 concentration	%	9.9 ± 2.0
CO_2 concentration	%	9.7 ± 1.7
Air excess ratio λ	-	2.2 ± 1.2
Temp. in combustion chamber	°C	679 ± 70
Flue gas temp.	°C	274 ± 23
Boiler heat output	kW	9.4 ± 2.5
CO concentration	mg/m^3 (10%O_2)	8538 ± 3020
NO concentration	mg/m^3 (10%O_2)	269 ± 62
NO_X concentration	mg/m^3 (10%O_2)	413 ± 95
CH_4 concentration	mg/m^3 (10%O_2)	182 ± 98
Dust concentration	[mg/m^3	101± 35
CO emission indicator	g/MJ	1.626 ± 0.606
NO emission indicator	g/MJ	0.057 ± 0.013
NO_X emission indicator	g/MJ	0,087 ± 0.019
CH_4 emission indicator	g/MJ	0.034± 0.019
Dust emission indicator	g/MJ	0.010 ± 0.003

Table 2. Parameter values obtained during the seventh hour of measurements - relatively good combustion

Parameters		minimum	mean	maximum
O_2 concentration	%	6.8	10.0	17.5
CO_2 concentration	%	3.1	10.1	12.3
Air excess ratio λ	-	1.5	2.0	6.1
Temp. in combustion chamber	°C	560	705	757
Flue gas temp.	°C	193	275	309
Boiler heat output	kW		9.7	
CO concentration	mg/m^3 (10%O_2)	1107	3934	25287
NO concentration	mg/m^3 (10%O_2)	118	284	512
NO_X concentration	mg/m^3 (10%O_2)	180	435	786
CH_4 concentration	mg/m^3 (10%O_2)	0	705	757

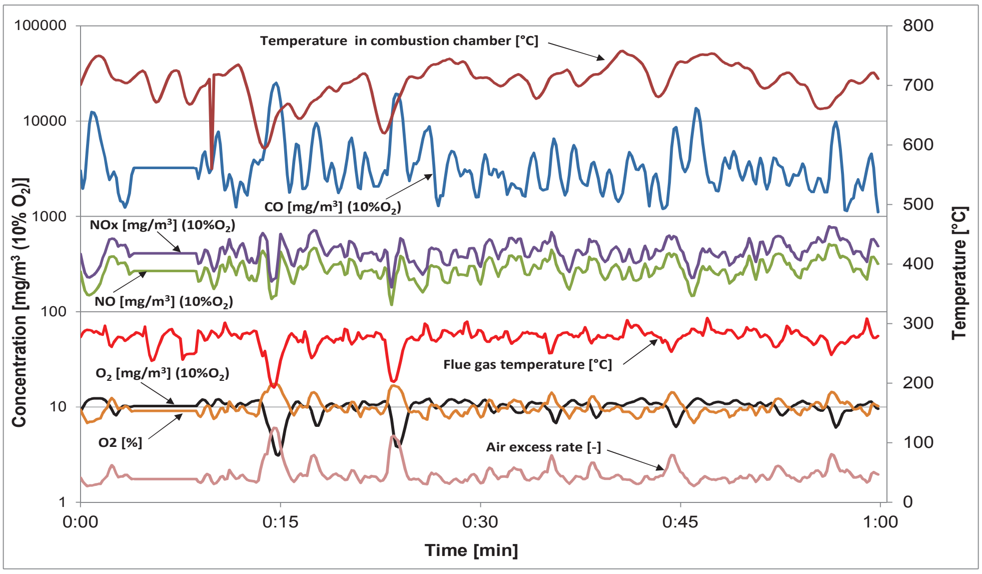

Fig. 3. Parameter values during the seventh hour of measurements (test run no. 7, tab.2)

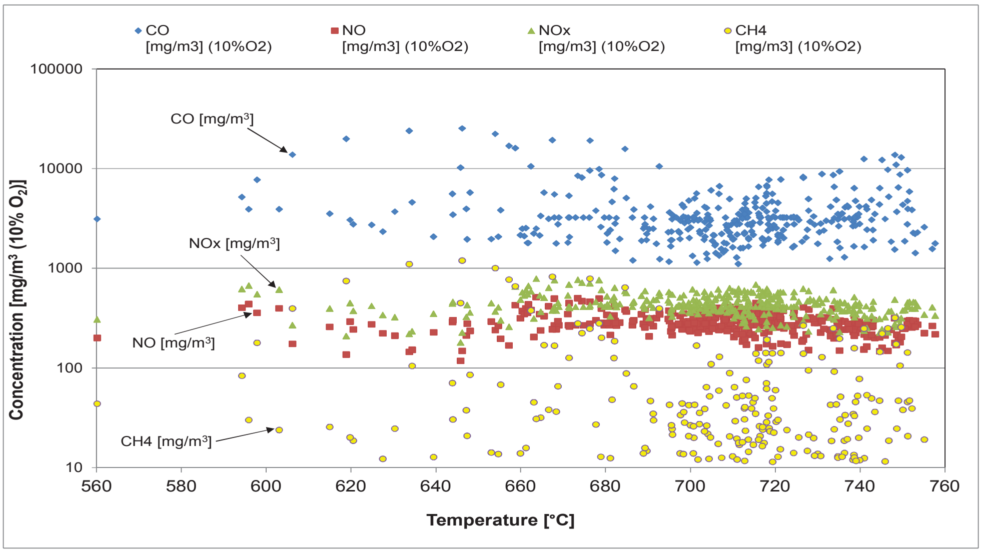

Fig. 4. Pollutant concentrations versus temperature in the combustion chamber - seventh hour of measurements (test run no. 7)

Figure 4 shows the impact of temperature in the combustion chamber on pollutant concentrations for the seventh hour of measurements. Analyzing the seventh hour of measurements (test run no. 7) 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 760°C) and varied within a small range (approx. 250°). In these conditions only NO_x concentrations originating from fuel appeared.

Analysis of the mean pollutant concentration values obtained during the subsequent measurement hours (test runs - fig.5) indicates a lack of clear correlation between the temperature in the combustion chamber and pollutant concentrations. Looking at the fig.6 we can noticed that carbon monoxide concentration decreases and nitrogen oxides concentration increase a little if oxygen concentration increases. 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 70%.

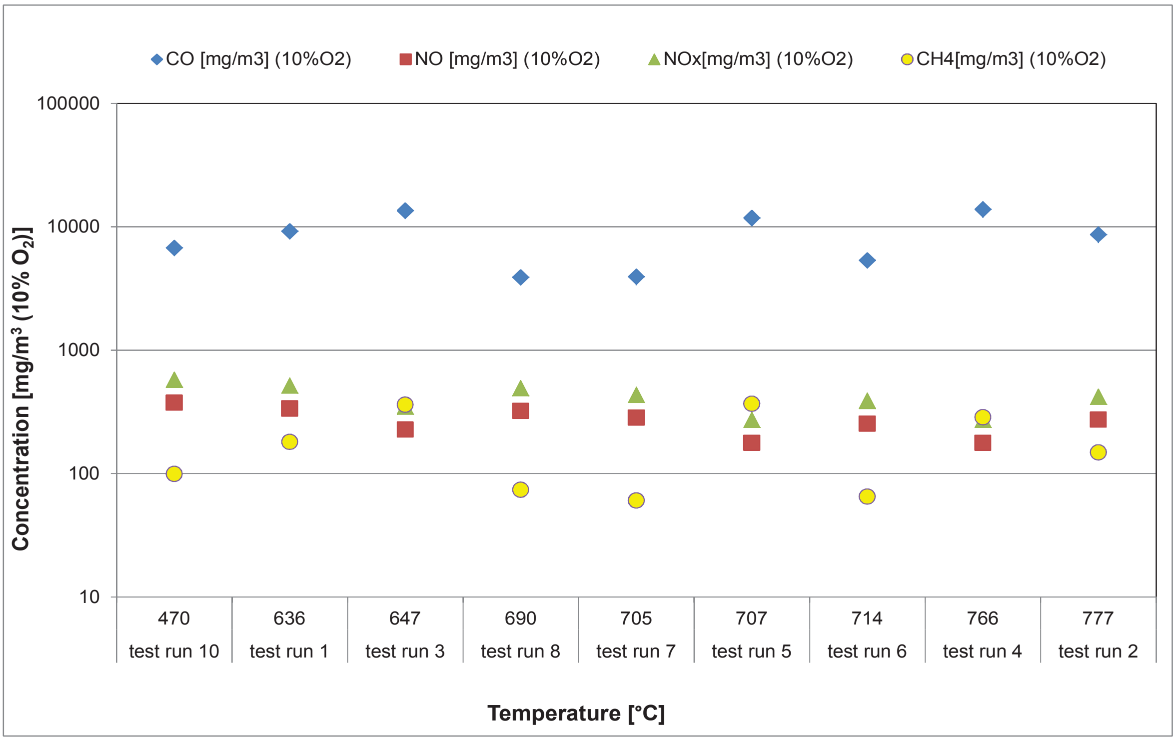

Fig. 5. Pollutant concentrations versus temperature in the combustion chamber – mean values for the subsequent hours of measurements (test runs)

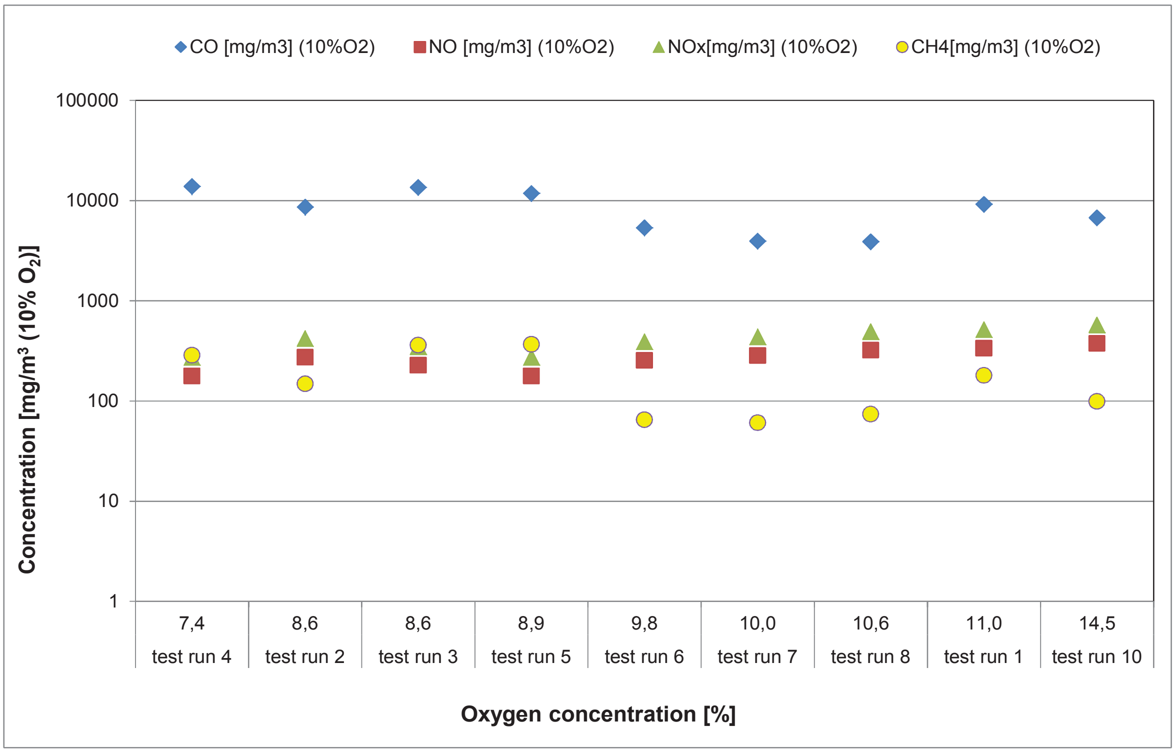

Fig. 6. Pollutant concentrations versus oxygen concentration – mean values for the subsequent hours of measurements (test runs)

6. Conclusions

It is possible to fire coffee (mbuni) husk pellets in the mixture with wood pellets in volumetric proportion 1:3, in the presented model of wood pellets over-fed pellet furnace, installed in the 15 kW heating boiler located in the heat station. Previous experiments indicated that it is impossible to fire coffee husk alone in this furnace type because of ash melting and sintering phenomenon. However, boiler heat efficiency is low, CO concentration is high, but below the permitted value. NO_x concentrations are almost 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 only in heat stations belonging to coffee producers.

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