Environment Protection Engineering

Vol. 40 2014 No. 2

DOI: 10.5277/epe140205

MAREK JUSZCZAK[1]

# CONCENTRATIONS OF CARBON MONOXIDE AND NITROGEN OXIDES FROM A 15 kW HEATING BOILER SUPPLIED PERIODICALLY WITH A MIXTURE OF SUNFLOWER HUSK AND WOOD PELLETS

The impact of periodic feeding mode on the concentrations of carbon monoxide (CO) and nitrogen oxides (NO, $NO_x$) in the flue gas downstream the boiler was analyzed during firing of a mixture of sunflower husk and wood pellets in an overfeed furnace. The mixtures containing 100, 70 and 50 wt. %, of sunflower husk pellets were supplied to the boiler in two feeding modes: 1 s of operation 4 s of stand-by and 1s of operation 6 s of stand-by. Correlation between pollutant concentrations and the temperature in the combustion chamber was evaluated. The following concentrations of CO for various feeding modes and sunflower husk pellet proportions have been obtained: 1:6, 100% – 6150 mg/m$^3$, 1:6, 70% – 3360 mg/m$^3$, 1:6, 50% – 2600 mg/m$^3$, 1:4, 100% – 4580 mg/m$^3$, 1:4, 70% – 2570 mg/m$^3$, 1:4, 50% – 870 mg/m$^3$ for 10% $O_2$ content in the flue gas. The study indicates the advisability of reducing the stand-by period in the pellet feeding system.

## 1. INTRODUCTION

Limited availability of high quality and cheap wood pellets in Poland (that are currently used in power plants) aroused interest in agricultural biomass pellets as fuel for heating boilers with low heat output. In southern countries such as Italy or Spain, agricultural produce residues, e.g. tomato [1] or grape residues [2], are thermally processed after being dried, however concentrations of carbon monoxide (CO) can reach a few thousand mg/m$^3$ (10% $O_2$ content in the flue gas) and are much higher than emission from wood pellet combustion (in high quality boilers much below 1000, or even 500 mg/m$^3$ [3]). Due to low ash melting temperature, agricultural biomass should be fired at temperatures lower than 700 °C [4, 5], in order to avoid the production of slag that hampers furnace operation and the combustion process [6]. Also chlorine

[1]Poznan University of Technology, Institute of Environmental Engineering, Division of Heating, Air Conditioning and Air Protection, Piotrowo 3A, 60-965 Poznań, Poland, e-mail: marekjuszczak@put.poznan.pl

content is an important factor in biomass combustion as it can form KCl that melts at a low temperature. Therefore, it is recommended to use additives such as $Ca(OH)_2$ or dolomite that react with chlorine and impede KCl formation [7–9].

Presently in Poland almost no furnaces of low heat output are in use, specifically adjusted for firing selected kinds of agricultural biomass pellets. Therefore, attempts are made to fire them in wood pellet furnaces, where combustion temperature may reach up to 900 °C. This generates problems in furnace operation caused by slag that is produced when firing biomass at a high temperature. This results in deterioration of the combustion process and elevated CO concentrations in the flue gas. For this reason, firing biomass in wood pellet furnaces gives much better results when biomass pellets are fired in a mixture with wood pellets [10]. Due to a temperature that is better adjusted to the fuel type, the combustion process can be improved and slagging phenomenon that occurs above 1000 °C (being the wood ash melting point) can be minimized [11].

The majority of wood pellet furnaces with low heat output, even those produced by renowned manufacturers, do not enable regulation of fluent pellet stream. Instead, they use periodic fuel supply, which means that in order to achieve the defined boiler heat output, one needs to set the fuel stream by manually modifying the operation and stand-by time of the fixed-speed screw feeder, as well as the stream of air for combustion. The fact that air stream is not reduced during the stand-by period in pellet feeding causes lowering of the temperature in the combustion chamber and excessive increase of oxygen concentration, and as a result an increase of concentration of CO. This is why fluent pellet feeding system would seem to be more beneficial. In periodic fuel supply during the stand-by period, the concentration of nitrogen oxides (NO, $NO_x$) barely changes, because while the feeder is in stand-by two opposite factors potentially altering nitrogen oxides concentration are having an effect: on one hand the increased oxygen concentration causes nitrogen oxides concentration to raise, on the other, the decreased temperature causes its reduction [4, 12]. Therefore, NO and $NO_x$ concentrations at the temperature in the furnace of below 700 °C mostly depend on nitrogen content in the fuel. Interesting study results in the area of pollutant emission from firing biomass and other fuels can be found in the references [13–15].

In the studies conducted at the Poznan University of Technology, a series of boilers and furnaces have been examined in search for a device that would enable firing wood pellets with low CO emission and the highest possible heat efficiency. The research has also been focusing on devices for firing agricultural biomass pellets in a mixture with wood pellets. The presented study is a continuation of previous studies performed in the same experimental heating station [10]. A boiler with similar nominal heat output and a furnace of similar design and functionality were used. Nonetheless, the previous boiler was characterized by a more outdated design, very low heat efficiency and was mainly used for studies of emission from firing deciduous and coniferous wood logs. The currently used boiler has much higher heat efficiency, the slagging tendency of the furnace is not as significant and the combustion process can be conducted at a slightly higher temperature (yet below 700 °C). It is not necessary to cool down the combustion chamber with as high air stream as it was the case in the previous studies [10].

The aim of the study was to determine the concentrations of CO and nitrogen oxides from firing sunflower husk pellets alone and in a mixture with wood pellets, in a 25 kW heating boiler located in a full scale heat station in conditions resembling the real ones.

## 2. EXPERIMENTAL

Wood and sunflower husk pellets of 8 mm in diameter and 10 to 35 mm long and chemical composition determined by an accredited laboratory (Table 1) were investigated. The weight proportion of sunflower husk pellets in the mixture was: 100, 70 and 50%.

Table 1

Chemical composition of the material [%]

| Fuel type | C | H | N | S | Cl | Ash | Moisture | Lower heating value [MJ/kg] |
|---|---|---|---|---|---|---|---|---|
| Spruce wood | 49.8 | 6.3 | 0.13 | 0.015 | 0.03 | 0.5 | 6.3 | 19.0 |
| Sunflower husk | 49.6 | 6.0 | 0.86 | 0.040 | 0.18 | 1.9 | 7.9 | 18.5 |

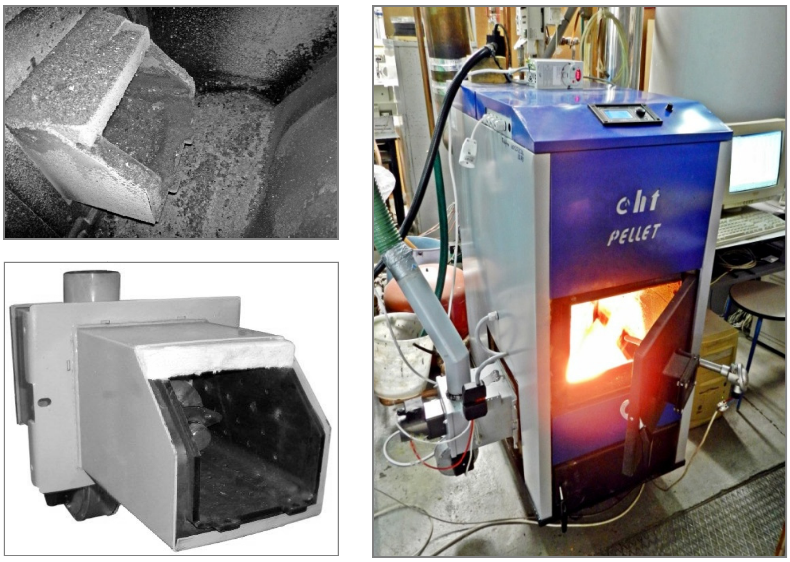


Fig. 1. 25 kW heating boiler with an open combustion chamber to show the position of the thermocouple, overfeed channel furnace located in the combustion chamber

The boiler (Fig. 1) was not equipped with an automatic device for air stream regulation with an oxygen probe, that is usually placed in the flue gas downstream the boiler. An overfeed channel furnace with periodic pellet feeding system and fixed--speed screw feeder was installed in the boiler. During the experiments, the pellet screw feeder was set to two different working modes: 1 s of operation 4 s of stand-by and 1 s of operation 6 s of stand-by. Air stream for combustion was adjusted manually at the beginning of each test (for each mixture and mode separately), while monitoring the indications of the CO analyzer and observing the furnace through a sight glass, in order to obtain the lowest possible values of concentration CO. The experiments were conducted for ca. 5 h for each mixture and pellet feeding mode. As significant variation of measured parameters was anticipated due to ash melting and sintering (based on the previous experience from the study performed with a slightly different boiler and furnace [10]), the measured values were averaged within 30 min measurement cycles.

Concentrations of gas pollutant in the flue gas downstream the boiler were measured using a Vario Plus (MRU) flue gas analyzer: concentrations of oxygen and nitrogen oxides were measured with electrochemical cells while concentrations of CO and hydrocarbon using the infrared procedure. Parameter values were collected every 2 s, recorded in the computer, and mean values were calculated for each 30 min measurement period. The flue gas analyzer calculated the $NO_x$ concentration as a total of the concentrations of NO (calculated to $NO_2$) and $NO_2$. The temperature in the combustion chamber was measured ca. 0.3 m above the furnace with a radiation shielded thermocouple Pt-Rh-Pt and recorded similarly to pollutant concentrations. Dust concentration in the chimney was measured using a gravimetric dust meter with isokinetic aspiration. The boiler heat output and the quantity of heat transferred to the boiler water were measured with an ultrasonic heat meter and recorded continuously. Fuel stream was measured several times using a weighing device (Sartorius scales). The boiler heat efficiency was determined using the direct method as heat absorbed by the boiler water divided by the mass of fuel fired multiplied by fuel lower heating value.

## 3. RESULTS AND DISSCUSION

Table 2 and Figures 2 and 3 show time and temperature dependences of concentration of CO in the combustion chamber, respectively, for 30 min periods during which the slagging phenomenon was insignificant. Dust concentration did not exceed 50 mg/m$^3$, which is much below the permitted values [8]. The tendency of ash to form deposits on heat exchange surfaces was observed. The concentration of hydrocarbons (calculated to $CH_4$) was also negligible as it did not exceed 70 mg/m$^3$ (10% $O_2$).

Table 2

Concentrations of CO and nitrogen oxides from firing the mixture of sunflower husk pellets and wood pellets (all values in the table are mean values calculated for each five-hour period)

| Fuel proportion feeder operation: stand-by time [s] | Concentration | | | | Air excess ratio | Temperature in the combustion chamber[2] [°C] | Boiler heat | | Fuel mass stream [kg/h] |
|---|---|---|---|---|---|---|---|---|---|
| | CO[1] | NO[1] | $NO_x$[1] | $O_2$ [%] | | | Output [kW] | Efficiency [%] | |
| 100% sunflower 1:6 | 6150 | 420 | 640 | 14.4 | 3.3 | 470 | 7.7 | 45 | 3.05 |
| 70% sunflower 30% wood 1:6 | 3560 | 310 | 470 | 13.7 | 2.9 | 520 | 11.5 | 54 | 4.10 |
| 50% sunflower 50% wood 1:6 | 2600 | 300 | 460 | 12.9 | 2.6 | 630 | 9.2 | 46 | 3.80 |
| 100% sunflower 1:4 | 4580 | 550 | 840 | 11.4 | 2.2 | 560 | 11.2 | 42 | 5.10 |
| 70% sunflower 30% wood 1:4 | 2570 | 470 | 720 | 11.4 | 2.2 | 630 | 11.7 | 43 | 5.20 |
| 50% sunflower 50% wood 1:4 | 870 | 350 | 535 | 9.0 | 1.8 | 690 | 14.6 | 51 | 5.50 |

[1]Concentration mg/m$^3$ presented for 10% $O_2$ content in the flue gas.
[2]Approximately 0.3 m above the furnace.

In view of the sufficient amount of air delivered to the furnace (air excess ratio was ca. 1.8–3.3), the value of CO concentration was mainly influenced by the temperature in the combustion chamber (Table 2). During the experiments, the temperature in the furnace was below 700 °C and ash melting and sintering were not significant. On the other hand, during firing in such low temperatures concentrations of CO were high, as only at above ca. 650 °C efficient oxidation to carbon dioxide occurs [12]. The CO concentration was lower in the case of the fuel feeding mode with a shorter stand-by period.

The concentration of nitrogen oxides in the flue gas was high, reaching 700 mg/m$^3$ (Table 2). Polish environmental legislation [16] does not define permitted values for $NO_x$ concentrations, although in order to obtain the Polish ecological certificate the values below 400 mg/m$^3$ are required (all concentrations are normalised to a reference oxygen content in a flue gas of 10%) [17]. In the case of periodic fuel supply with constant air stream, during the stand-by period in fuel feeding the temperature in the combustion chamber decreases, however oxygen concentration increases. These factors, that usually influence nitrogen oxide emission compensated mutually to a big extent. Therefore, the concentration of NO and $NO_x$ mainly depended on the stream of nitrogen supplied to the furnace in the fuel as temperature in the furnace was relatively low. The main supplier of nitrogen to the furnace were sunflower husk pellets due to the fact that they contain much more (0.86%) nitrogen than wood pellets (0.13%).

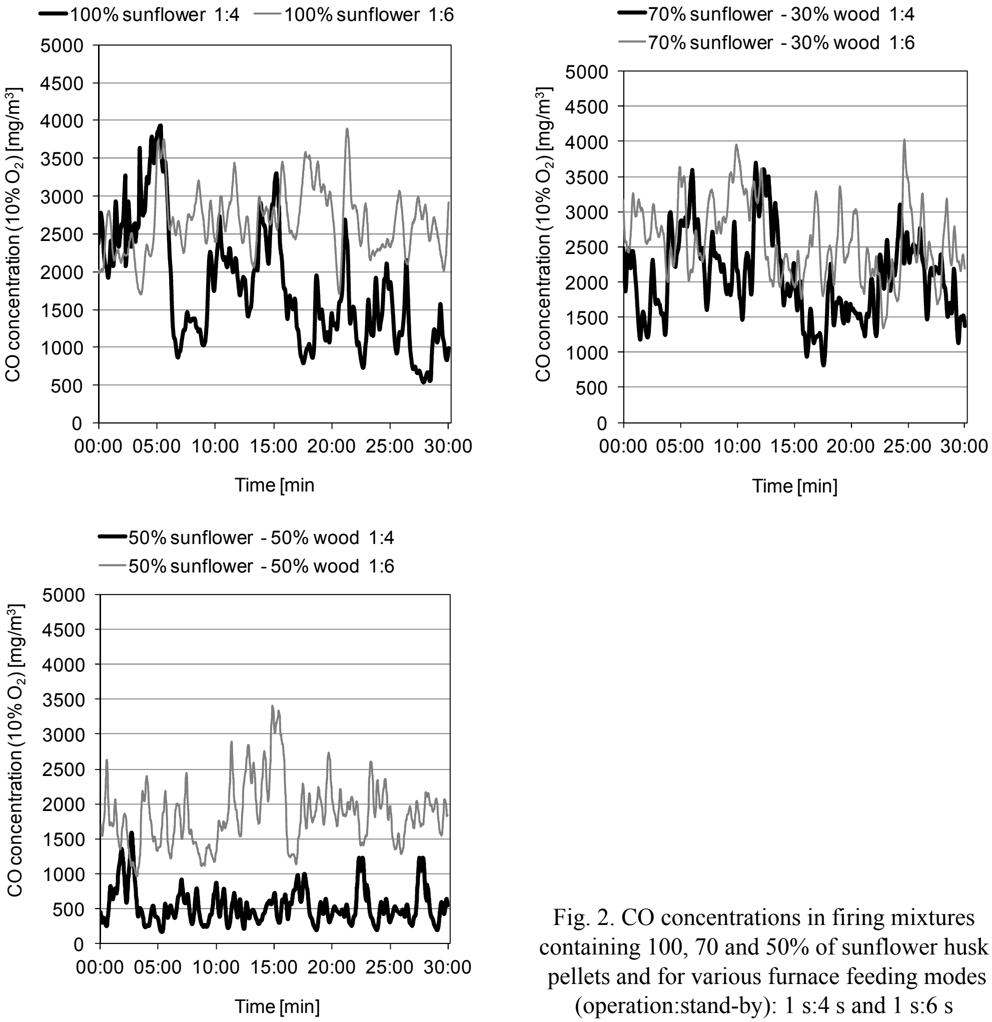


Fig. 2. CO concentrations in firing mixtures containing 100, 70 and 50% of sunflower husk pellets and for various furnace feeding modes (operation:stand-by): 1 s:4 s and 1 s:6 s

Supplying the furnace with sunflower husk pellets alone, without combining them with wood pellets, for both feeding modes resulted in exceeding the permitted CO concentration determined for furnaces with automatic biomass supply, which is 3000 mg/m$^3$ (concentration refers to 10% $O_2$ content in flue gas) [16].

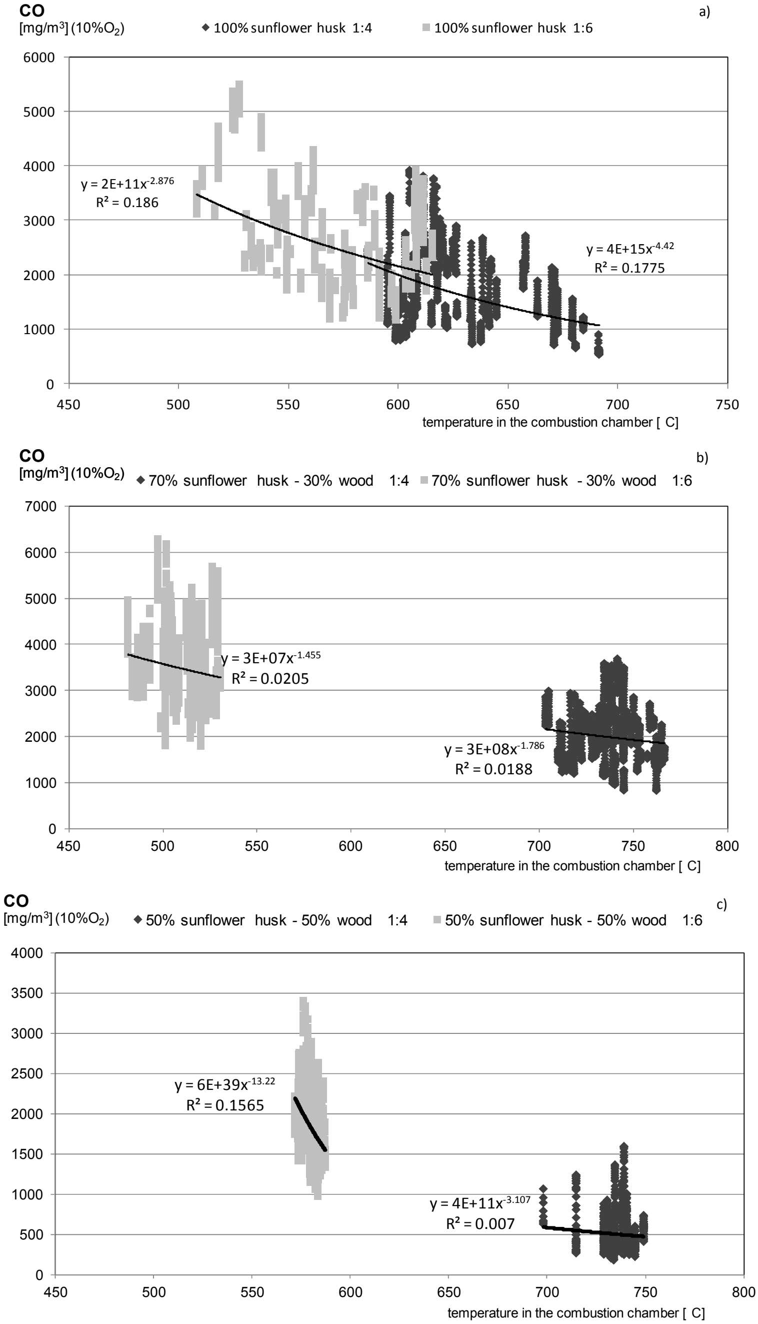


Fig. 3. Temperature dependence of CO concentration in the combustion chamber: a) 100% sunflower, b) 70% sunflower, 30% wood, c) 50% sunflower, 50% wood

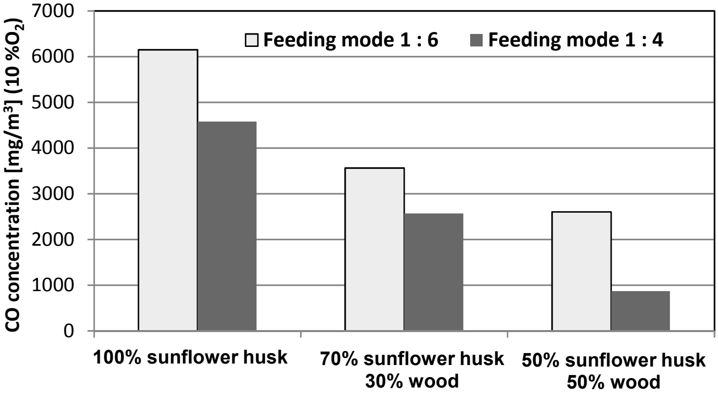


Fig. 4. Dependences of the CO concentrations onthe fuel feeding mode as well as on the proportion of sunflower husk pellets and wood pellets in the mixture presented in Table 2

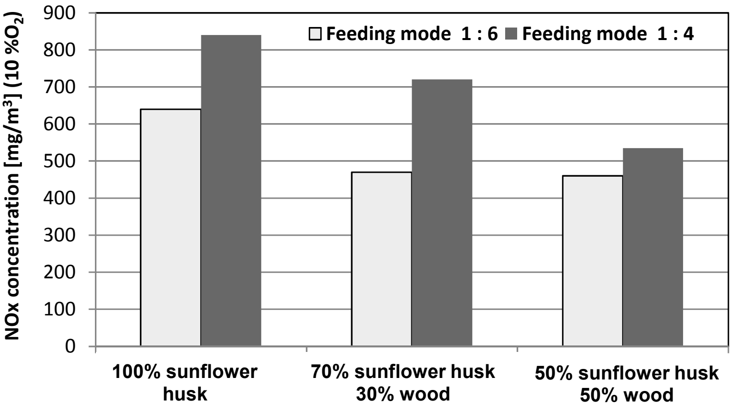


Fig. 5. Dependence of the fuel feeding mode as well as the proportion of sunflower husk pellets and wood pellets in the mixture and $NO_x$ concentration presented in the Table 2

## 4. CONCLUSIONS

Using sunflower husk pellets in the boiler and furnace of the studied type requires mixing them with wood pellets, so that CO concentration is maintained below the permitted value. Based on the results of the study, it was concluded that the weight proportion of sunflower husk pellets in the mixture should be lower than 70%. In order to reduce the CO concentration, one should aim at maintaining the temperature in the combustion chamber at the highest possible level, yet not exceeding 700 °C, to avoid forming significant amounts of slag. For this purpose, the stand-by period in fuel supply should be shortened as much as possible. The best solution seems to be applying uninterrupted pellet supply with fluent regulation of the rotational speed of the fixed speed screw feeder. Due to the tendency of ash to form deposits on the heat exchange surfaces, it is suggested that periodical cleaning of the mentioned surfaces be performed.

ACKNOWLEDGEMENTS

This work was carried out as a part of the research project PB-13/615/08BW sponsored by the Poznan University of Technology. The author gratefully acknowledges the support from technical workers and students of the Poznan University of Technology during the course of the research as well as from Małgorzata Juszczak for providing the English translation of the manuscript.

REFERENCES

[1] GONZALES J.F., GONZALES-GARCIA C.M., RAMIRO A., GONZALES J., SABIO E., GANAN J., RODRIGUEZ M.A., *Combustion optimisation of biomass residue pellets for domestic heating with a mural boiler*, Biomass Bioenerg., 2004, 27, 145.
[2] MEDIAVILLA I., FERNANDEZ M. J., ESTEBAN L.S., *Optimization of pelletization and combustion in a boiler of 17.5 kWth for vine shoots and industrial cork residua*, Fuel Process. Technol., 2009, 90, 621.
[3] KJALLSTRAND J., OLSSON M., *Chimney emission from small-scale burning of pellets and fuelwoods. Examples referring to different combustion appliances*. Biomass Bioenerg., 2006, 27, 557.
[4] RYBAK W., *Bio-fuels combustion and co-combustion*, Ofic. Wyd. PWr., Wrocław 2006 (In Polish).
[5] WERTHER J., SAENGER M., HARTGE E. U., OGADA T., SIAGI Z., *Combustion of agricultural residues*, Prog. Energ. Combust. Sci., 2006, 26 (1), 1.
[6] GIBLE C., OHMAN M., LINDSTROM E., BOSTROM D., BACKMAN R., SAMUELSSON R., BURVALL J., *Slaggig characteristics during residential combustion of biomass pellets*, Energ. Fuel, 2008, 22, 3536.
[7] POSKROBKO S., ŁACH J., KRÓL D., *Experimental investigation of hydrogen chloride bonding with calcium hydroxide in the furnace of a stoker-fired boiler*, Energ. Fuel, 2010, 24, 1948.
[8] POSKROBKO S., ŁACH J., KRÓL D., *Experimental investigation of hydrogen chlorine bonding with limestone and dolomite in the furnace of a stoker-fired boiler*, Energ. Fuel, 2010, 24, 5851.
[9] POSKROBKO S., ŁACH J., KRÓL D., *Hydrogen chloride bonding with calcium hydroxide in combustion and two-stage combustion of fuels from wast*e, Energ. Fuel, 2012, 26, 842.
[10] JUSZCZAK M., *Pollutant concentrations from a 15 kW heating boiler supplied with sunflower husk pellets*, Environ. Prot. Eng., 2012, 1, 36.
[11] OHMAN M., BOMAN C., HEDMAN H., NORDIN A., BOSTROM B., *Slagging tendencies of wood pellet ash during combustion in residential pellet burners*, Biomass Bioenerg., 2004, 27, 585.
[12] KORDYLEWSKI W., *Combustion and Fuels*, Ofic. Wyd. PWr., Wrocław 2000 (in Polish).
[13] MUSIALIK-PIOTROWSKA A., KORDYLEWSKI W., CIOŁEK J., MOŚCICKI K., *Characteristics of fair pollutants emitted from biomass combustion in small retort boiler*, Environ. Prot. Eng., 2010, 2, 123.
[14] MUSIALIK-PIOTROWSKA A., KOLANEK C., *Emission of volatile organic compounds from diesel engine fuelled with oil-water emulsion*, Environ. Prot. Eng., 2011, 1, 31.
[15] HARDY T., MUSIALIK-PIOTROWSKA A., CIOŁEK J., MOŚCICKI K., KORDYLEWSKI W., *Negative effects of biomass combustion and co-combustion in boilers*, Environ. Prot. Eng., 2012, 1, 25.

[16] PN-EN 303-5, *Heating boilers*. Part 5. *Heating boilers for solid fuels, hand and automatically stocked nominal heat output of up to 300 kW. Terminology, requirements and marking*, 2004, (in Polish).
[17] KUBICA K., *Efficiency and environmental safety criteria for low thermal output solid fuel-fired heating boilers for municipal use*. *Environmental Safety Mark Standards of Certification*, Institute for Chemical Processing of Coal, Zabrze 1999 (in Polish).