Combustion of pellets from wheat straw

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The alternative energy sources are more and more used for production of heat. Several new combustion devices allow co-firing of different fuels, like dendromass and phytomass. The article analyses combustion of wood and straw pellets in the same boiler. Measurements were realized in two automatic heat sources – one is adapted to burn pellets made from wood or straw and another allows only burning of wood pellets. There are analysed performance and emission parameters of boiler.

***Key words:** wood pellets, straw pellets, energy crops, performance, emission*

Introduction

At present there is high interest in using of agricultural waste from plant production and energy using of energy crops that are deliberately planted on a big fields. Energy crops are plants with non-wood stems grown specifically for energy production. Their energy content is about 15 - 20 $MJ.kg^{-1}$ in the dry state. Growing of energy crops has an indisputable advantage for farmers because they do not compete with food, so this "green energy" can then ensure smooth sales.

In terms of Europe can plant create 1.2 to 1.4 g of dry phytomass from 1 MJ of solar power, plant with C4 type of photosynthesis are more efficient. Creation of 1.4 g dry weight from 1 MJ of solar energy is considered one of the criteria for selection of plants for use in phytoenergetics. (Jandačka et al., 2007)

These energy crops can be directly used for production of heat in combustion devices or they can be improved to pellets or briquettes.

In practice, there are used only a few kinds of plants. In terms of energy is particularly important yield, production costs, product modification for the purpose of heating engineering, logistics, transport of finished biofuel to consumers, etc. Grown plants, bio-treatment, distribution and marketing of agricultural biofuels are aspects for the use of plants. Energy content of agricultural biofuels for energy using is necessary to utilize in combustion devices, and this is the second page of the problem.

Most agricultural biofuels have low temperature point of softening, melting and flow of ash (cereal straw) or a large production of CO (carbon monoxide) (feeding juices and most types of grass) and almost all contain a high content of ash (more than 5 %). These are negative qualities that wood biomass pellets and briquettes from waste wood do not have. One of the ways to eliminate negative properties is making from energy crops and other possible components a mixture of certain proportions. Another option to eliminate negative properties of agricultural biofuel combustion is adjusting of combustion device such another type of burner, shape and size of combustion chamber, rapping and blowing of burner to remove the excessive proportion of ash, or modification of regulatory and management system. (Jandačka et al., 2007).

In many cases, manufacturers of automatic boilers for wood pellets report that in these boilers can be burnt pellets made from energy crops (straw pellets) as well. These small heat sources are produced in most cases, with automatic control using regulation of feeding and standing time. In feeding time is fuel transported by screw conveyor to burner in combustion chamber. However, for each fuel type is this setting various and the biggest problem for manufacturers of boilers is finding usable interval of fuel feeding. It is given by different properties of used fuel. It is also important to note that change of settings which control to lower operating performance (lower time intervals) may not be automatically provided setting to optimum combustion of fuel. It is necessary to do a lot of experiments in order to find usable time intervals for combustion of various types of fuel in one heat source.

Related work

Verma et al. (2011) tested wood pellets from the Belgium, peat pellets and reed canary grass pellets (RCG) from Finland, pellets made of apple juice industrial waste from Poland, pectin pellets made of citrus shell (CPW) from Denmark, sunflower husk pellets (SFH) from Ukraine and two kinds of wheat straw pellets from Belgium (straw-1 with 100% pure straw and straw-2 with 2wt% of hydrated lime $[Ca(OH)_2]$

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as an additive). Pellets were burned in multi-fuel domestic pellet boiler (40 kW) under standard laboratory conditions and in two boilers (35 kW) were tested in real life conditions. Under standard laboratory conditions, wood pellets yielded the highest combustion efficiency (92.4 %) followed by apple pellets (91.3 %). The CO and dust emissions were the highest with peat and sunflower husk pellet, respectively. Straw pellets emitted the highest NO_x and SO_x. For agro-pellets, statistical differences in ash contents were significant. High ash contents and low ash melting temperature made straw pellets less suitable for this type of boilers. Reed canary grass, citrus pectin and apple pellets have advantage over others with reasonable less ash contents and less emissions. In the real life conditions, the boilers had around 90% combustion efficiencies. Comparison with the standard laboratory performance showed that the NO_x emission was higher in real life condition than standard laboratory conditions; however, lowed CO and particle emissions were reported in real life conditions. In the real life condition, dust emissions were 5.0 and 5.8 mg Nm^{-3} with RL-1 and RL-2 boilers, respectively. The FE–SEM examination of the particles revealed that most of the dust particle had a tendency to form small clusters of sub-micron size ranging between 300 μm and 1.2 μm.

Schmidl et al. (2011) tested production of gaseous emissions and particulate matters (PM10) when they burned 8 different types of fuel in 2 automatically and 2 manually fired appliances. Softwood briquettes, beech, oak and spruce logs, wood pellets as well as further biogenic fuels: wood chips, miscanthus (elephant grass) pellets and triticale ("energy crop") pellets were tested. Gaseous emissions were measured continuously while PM10 was sampled with a dilution system and averaged over standard test cycles. Manually fired stoves exhibited highly variable emissions resulting in an uncertainty of 30 % for most measured compounds, determined in a series of replicate experiments. Average PM10 emissions from manually fired appliances were around 130 mg m^{-3} (standard conditions for temperature and pressure (STP), 13 % O_2, dry gas), equivalent to 90 mg MJ^{-1}. Wood pellets and chips combustion under full load operation with automatically fired appliances emit almost one order of magnitude less PM10, respectively: 12–21 mg m^{-3} (STP, 13 % O_2, dry gas), or 8–14 mg MJ^{-1}. Around 30 % of total particle mass from manually fired systems account for elemental carbon and 30–40 % for organic carbon, resulting in carbonaceous fraction content of around 90 %. On average around 5 % of PM10 emitted by manually fired stoves consisted of levoglucosan while this anhydrous sugar was below detection limit in full- and part load operation of automatically fired systems. Generally, emissions from automated systems were relatively constant for the same fuel type predominantly consisting of inorganic constituents. Emissions are mainly influenced by the mode of operation, start-up, full load or part load for a given fuel type. Surprisingly high emissions were observed for triticale pellets: 184 mg m^{-3} (125 mg MJ−1,) PM10 and 466 mg m^{-3} (395 mg MJ^{-1}) NO_x, (under full load operation, STP, 13 % O_2, dry gas), originating from high chlorine and nitrogen contents of the fuel.

Experimental device

Combustion of wood pellets and straw pellets was realized in two automatic heat sources. One of these heat sources was adapted to burn pellets made from wood or straw (boiler "1") and another allowed only burning of wood pellets (boiler "2").

Boiler "1" (fig. 1 left) is low-temperature heat source designed for automatic biomass combustion in the form of wood pellets respectively straw pellets from agricultural biomass and wood chips with tiny fraction less than 20 mm. The boiler has water body made from welded steel plate. Combustion is realized at fixed grid with movable components (fig. 1 right). On the top side of boiler is placed control unit with a display that shows the basic operating parameters of the boiler and keyboard through which these parameters can be set up and individual functions of the boiler can be effectively controlled. Nominal performance of boiler "1" is 25 kW.

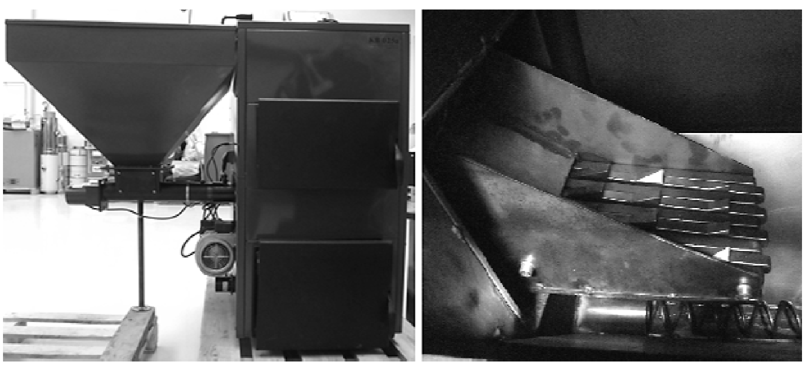

Fig. 1. Left: Boiler "1" for combustion of various pellets, Right: Burner of boiler "1".

Boiler "2" (fig. 2 left) is low-temperature heat source designed for fully wood pellets combustion. It is possible to burn black coal with maximum granularity 25 mm. Nominal performance of this boiler is 18 kW. In the boiler is used retort burner (fig. 2 right). Pellets from the hopper are moved by gravity into the hole of feeder. From there, screw feeders transported it to the retort space. Fan with variable speed spur combustion air to burner. Subsequently pellets are burned in the burning layer. Burned pieces and ash are pushed from the burning layer by new supplied pellets while fall into the ash box.

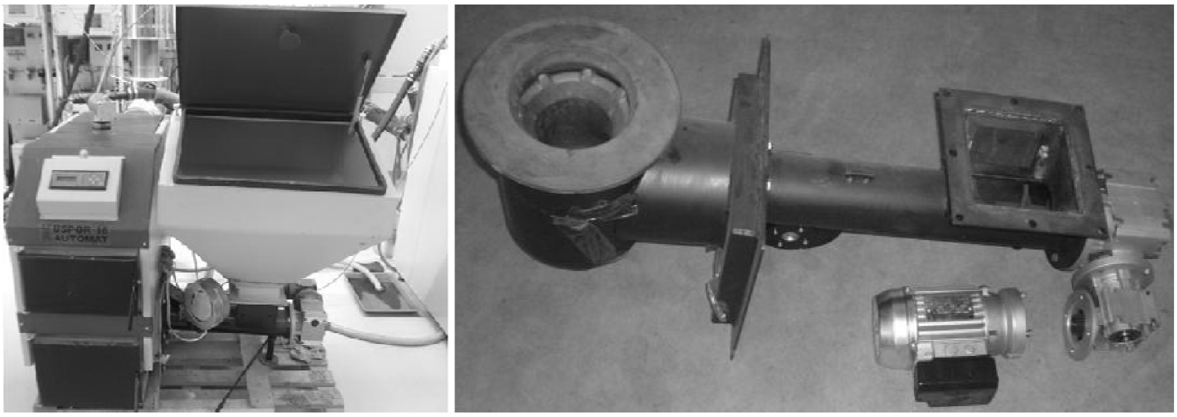

Fig. 2. Left: Boiler "2" for combustion of wood pellets, Right: Burner of boiler "2".

Measurements of performance and emission parameters were performed by standard EN 303-5 "Heating boilers for solid fuels supplied manually and automatically, with nominal performance to 300 kW". To determine thermal performance, boiler efficiency, burning time, temperature of exiting flue gas, emission characteristics boiler must be operated in nominal thermal performance. Testing devices may be connected according to configuration, which is shown in fig. 3. For nominal boiler performance, respectively minimum boiler performance measurements are recorded the following parameters: temperature of boiler output (T_V), inlet temperature to the boiler (T_R) and the mass flow of heat transfer medium ($\dot{m}_v$). Boiler thermal performance is determined by the following calorimetric equation

$$P = \dot{m}_V \,.\, c_W \,.(t_V - t_R) \qquad [W], \tag{1}$$

where c_w is specific heat capacity of the heat transfer medium [$J.kg^{-1}.K^{-1}$], while the mass flow of the heat transfer medium is calculated by the following relationship

$$\dot{m}_V = \dot{V} \cdot \rho \qquad [kg.s^{-1}], \tag{2}$$

where $\dot{V}$ is volume flow rate of heat transfer medium [m^3s^{-1}] and ρ is density of heat transfer medium [$kg.m^{-3}$].

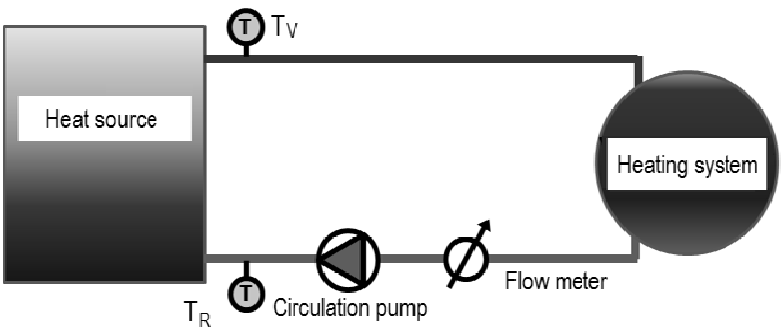

Fig. 3. Scheme of test equipment for measuring parameters of heat sources.

Measured results

On fig. 4 and 5 are shown profiles of measured thermal performance and profiles of measured emissions CO and NO_x according to the time, where wood pellets were burned in boiler "1". The measured concentration of emissions were recalculated to the reference oxygen (O_2ref = 10 %).

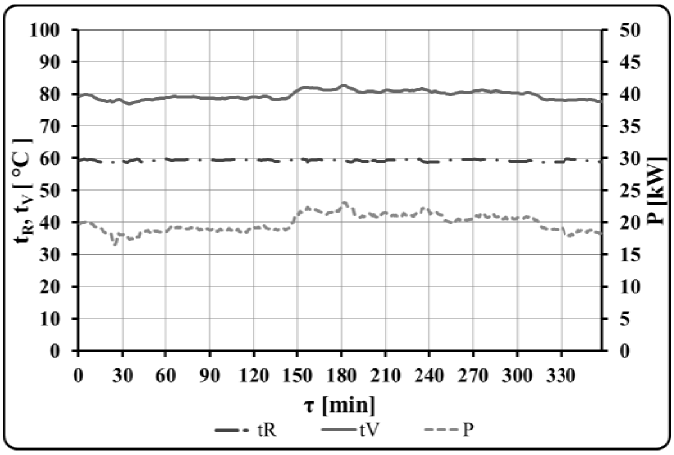

Fig. 4. Profile of thermal performance – boiler "1", wood pellets.

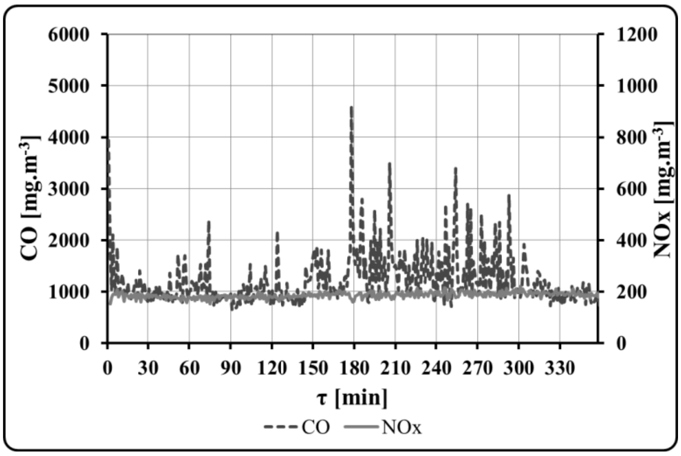

Fig. 5. Profiles of measured emissions CO and NOx – boiler "1", wood pellets.

On fig. 6 and 7 are shown profiles of measured thermal performance and profiles of measured emissions CO and NO_x according to the time, where wood pellets were burned in boiler "1".

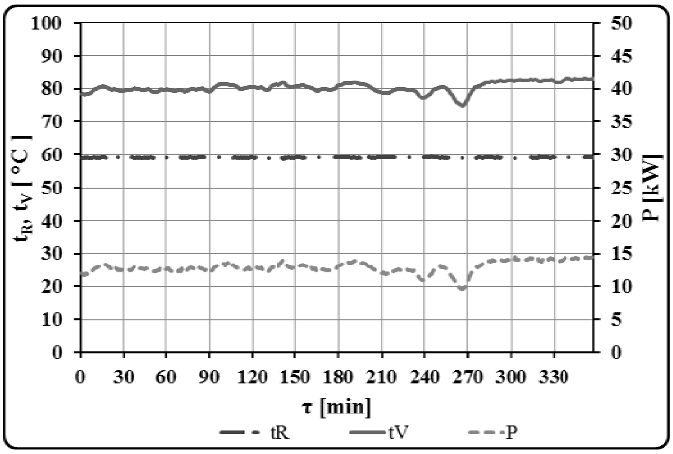

Fig. 6. Profile of thermal performance – boiler "1", straw pellets.

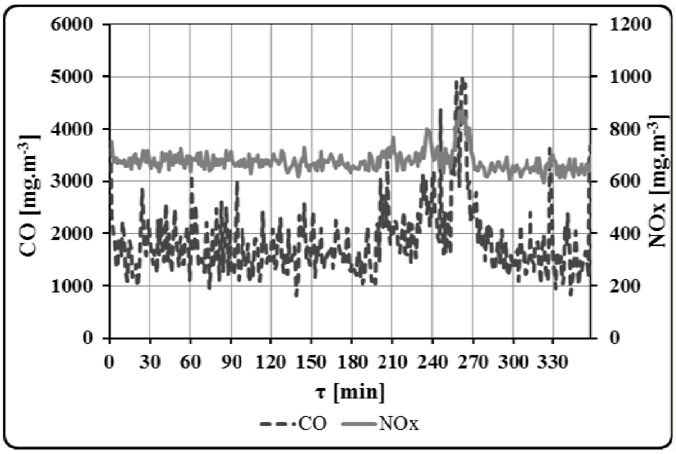

Fig. 7. Profiles of measured emissions CO and NOx – boiler "1", straw pellets.

On fig. 8 and 9 are shown profiles of measured thermal performance and profiles of measured emissions CO and NO_x according to the time, where wood pellets were burned in boiler "2".

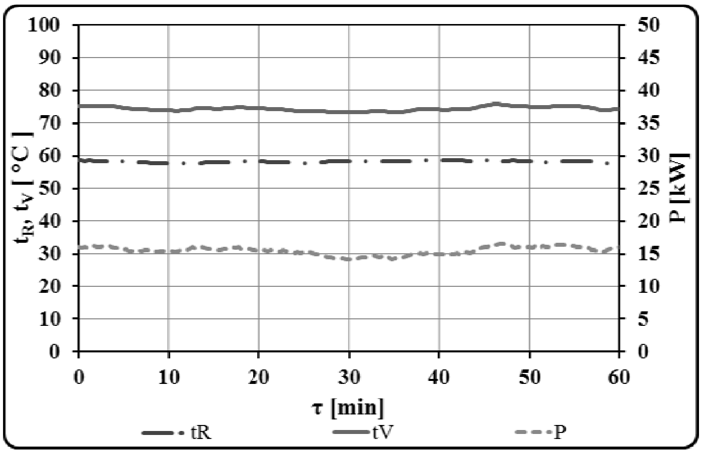

Fig. 8. Profile of thermal performance – boiler "2", wood pellets.

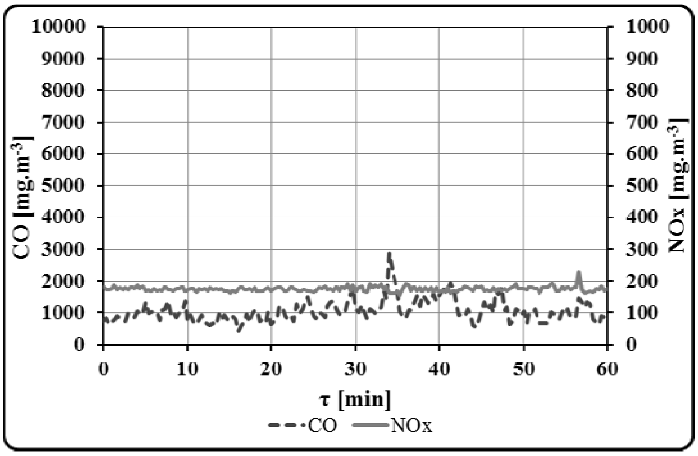

Fig. 9. Profiles of measured emissions CO and NOx – boiler "2", wood pellets.

On fig. 10 and 11 are shown profiles of measured thermal performance and profiles of measured emissions CO and NO_x according to the time, where wood pellets were burned in boiler "2". Boiler "2" is not adapted for burning straw pellets. When passing from the combustion of wood pellets to burn straw pellets suddenly began to fall heat performance of boiler from 17 kW to 10 kW. During the combustion of straw pellets this performance has declined steadily, this is visible on fig. 10. Production of emission CO increased five times and production of emission NO_x increased almost four times. The biggest issue was in using of burner, which is not adapted for burning of agricultural pellets. On the surface of the burner were formed clusters of ash, which caused low flow temperature of ash. These ash clusters prevented proper combustion process.

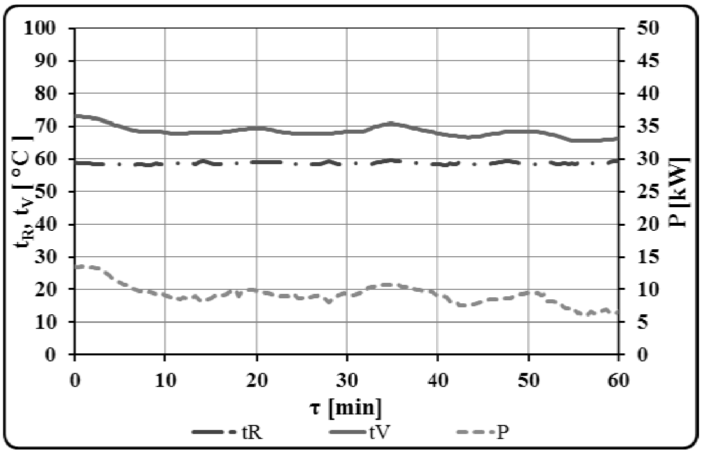

Fig. 10. Profiles of thermal performance – boiler "2", straw pellets.

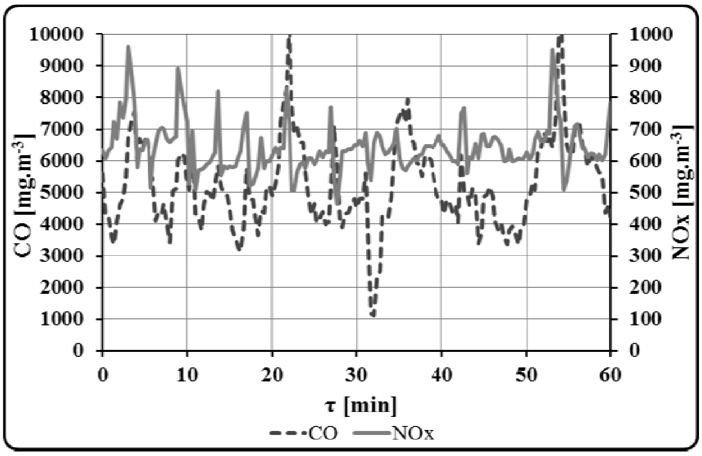

Fig. 11. Profiles of measured emissions CO and NOx – boiler "2", straw pellets.

Conclusion

Average thermal performance of boiler "1" was 19,9 kW. Average measured concentration of CO was 1214 mg.m^{-3} and NO_x 186 mg.m^{-3} in boiler "1". Average measured thermal performance of combustion of straw pellets in boiler "1" was 13,2 kW. Average measured production of emission CO was 1850 mg.m^{-3} and emissions of NO_x 676 mg.m^{-3} of combustion of straw pellets in boiler "1".

Average measured thermal performance of combustion of wood pellets in boiler "2" was 15,7 kW. Average measured production of emission CO was 1034,4 mg.m^{-3} and emissions of NO_x 174,8 mg.m^{-3} of combustion of wood pellets in boiler "2". Average measured thermal performance of combustion of straw pellets in boiler "2" was 8,9 kW. Average measured production of emission CO was 5245,3 mg.m^{-3} and emissions of NO_x 644,3 mg.m^{-3} of combustion of straw pellets in boiler "2". When the measurement continued thermal performance decreased, because clusters of ash limited the combustion of pellets and unburned pellets dropped to ash box. Later, after measuring, clusters of ash extinguished the fire and thermal power decreased sharply.

It is obvious that combustion of straw biomass is complicated and need special burner with cooled grid or burner with movable grid. It has been shown on measurements. Combustion of straw pellets in boiler "1" was more effective than combustion in boiler "2". During combustion of straw pellets was thermal performance significantly lower than in the case of wood pellets. This difference was greater in a boiler "1" designed to burn only wood pellets, namely 43.3 %. The boiler "2" is designed to burn two different types of pellets, this difference was 33.7 %.

The thermal performance of the boiler “2” had a downward trend. The concentration of CO has increased by 52.4 % when burning straw pellets in boiler “2” and NOx increased 3.6 times more in comparision with the combustion of wood pellets. In the case of boiler "1" it was worse. The formation of CO increased more than 5 times in the case of straw pellets and the concentration of NOx was 3.7 times more in comparision with the combustion of wood pellets. Larger amount of NOx in the both boilers is very similar, which is caused by a higher content of nitrogen in the phytomass as in dendromass. The concentration of CO is much higher in the second boiler “2”. This is because the burner of the boiler “2” is designed to burn agri-pellets and during combustion occurs the melting of ash and of clusters of ash. This resulted in imperfect combustion process, lower performance and higher production of CO emissions.

The above measurements have pointed to the fact that the combustion of agro - pellets is quite difficult and requires use of special burners. Measurements also showed that the purchase and burning of cheaper phytomass pellets in boilers designed to burn only wood pellets is inappropriate.

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