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Specifics of phytomass combustion in small experimental device

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Abstract. A wood pellet combustion carries out with high efficiency and comfort in modern pellet boilers. These facts help to increase the amount of installed pellet boilers in households. The combustion process quality depends besides the combustion conditions also on the fuel quality. The wood pellets, which don`t contain the bark and branches represent the highest quality. Because of growing pellet demand, an herbal biomass (phytomass), which is usually an agricultural by-product becomes economically attractive for pellet production. Although the phytomass has the net calorific value relatively slightly lower than the wood biomass, it is often significantly worse in view of the combustion process and an emission production. The combustion of phytomass pellets causes various difficulties in small heat sources, mainly due to a sintering of fuel residues. We want to avoid the ash sintering by a lowering of temperature in the combustion chamber below the ash sintering temperature of phytomass via the modification of a burner design. For research of the phytomass combustion process in the small boilers is constructed the experimental combustion device. There will investigate the impact of cooling intensity of the combustion chamber on the combustion process and emissions. Arising specific requirements from the measurement will be the basis for the design of the pellet burner and for the setting of operating parameters to the trouble-free phytomass combustion was guaranteed.

1 Introduction

Biomass is an important renewable energy source with reduced pollutant emissions. It can be considered as the best option and has the largest potential, which meets these requirements and could insure fuel supply in the future. Modernization of biomass technologies, leading to more efficient biomass production and conversion. In the industrialized countries, among main biomass processes, utilized in the future, are expected to be the direct combustion of various residues also [1]. Pellet boilers represent the most advanced technology of continuous biomass combustion in small-scale combustion units. A boiler is created by relative small combustion space. At first step there occurs a pellet gasification very fast and then a char combustion phase continues. On the other hand, a freeboard (an afterburning space) is much larger, usually with a large amount of fireproof boiler lining. It allows keeping high temperature in this space for complete combustion of volatile combustible gases [2]. It is possible to burn wood pellets without some problems, with low emissions and very comfortable. At once, it is possible to carry out high quality combustion process and low production of emissions [3]. However, this arguments are not true for straws, cereals and grass. Nowadays, several principles exist for the phytomass combustion in small-scale boilers. In comparing with boilers for wood pellets, they differ mostly in construction of burner and boiler body.

2 Phytomass combustion matters

Every sort of biomass have their specific energetic properties, which vary between each other considerably. Phytomass pellets can't be generally consider like the fuel with exact defined and homogenous properties, because a chemic composition is very different. A chemic composition depends on sort of biomass and way of growing mainly. Phytomass combustion in small-scale pellet boiler causes a lot of troubles. Disadvantages of straw, cereals and grass are higher amount of ash and forming aggressive compounds during combustion and others. However, the biggest weaknesses are slagging, sintering and melting ash at significantly lower temperature than wood pellets [4, 5]. The most important issue in this problem is the ash deformation temperature, when ash starts to stick together and to stick on boiler parts and walls. After exceeding the ash deformation temperature the ash transforms into the slag, the sinter and other agglomerates. The cumulated ash and agglomerates, which are created in the furnace, restrict the fuel combustion process. It means that combustion is disturbed even it can be stopped. Similarly, we can't ignore much higher emissions from phytomass

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combustion containing also unwanted compounds in comparison with wood pellets [6].

2.1 Low-melting ash issues during the phytomass combustion

The net calorific value of phytomass is only a little less than wood, but the ash content about tenfold higher. The Phytomass contains also much more K, N, Cl in comparing with pure wood. This elements cause not only more unwanted emissions, but also they decrease the ash melting temperature and they participate in a corrosion on boiler walls [6, 7].

The ash melting temperature is only informative fuel attribute. On the other hand, the ash melting temperature is classified among the most important entries for design and operation of boiler for phytomass. It isn't allowed to burn pellets with low-melting ash in common pellet boiler much ash and because agglomerates, sinters or slags are created in the combustion space for a short time. This agglomerates disable a combustion air feeding into basic burning layer, so the combustion process is inhibited. At the end, they can disable the fuel feeding and stop the combustion. Part of ash particles are carried by flue gas and then create a deposits on boiler walls [8]. When the combustion temperature exceeds the ash melting temperature there is created very resistant slags also on a refractory lining and damage it by alkali compounds.

The solution of low-melting ash problem is possible by two ways. First possibility is adding additives into treated phytomass, which raise melting temperature. Such pellets are combusted in ordinary way, without other specifications. The next way is redesign of burner, the combustion chamber and the heat exchanger, so that combustion temperature could be under the ash melting temperature.

2.2 Domestic boiler for phytomass pellets

A lot of producers of small pellet boiler for the phytomass use movable parts of burner for mixing combusted pellets thoroughly. The fuel bed poking into the burner reduces the propensity to the slagging or the sintering of ash. Movable parts in the combustion space are thermal and mechanical loaded markedly. It can lead to troubles during the operation, even to a damage of burner. According to previous analysis [9] underfed burner appears like perspective construction. We decided for concept of the water cooled underfed burner without moving parts. In this way, we intend decrease combustion temperature in the burner under the ash deformation temperature.

2.3 Design of domestic boiler

Chosen underfed burner conception influences the heat exchanger design the most. We decided for the circle boiler conception because of symmetry and possibility of better to utilize available space in comparison with traditional construction. Our intention was to suggest adjustable construction of pellet boiler also for further research. The boiler is created for this reason from three separate parts: a heat exchanger, a furnace, a burner.

As the flue gas heat exchanger as also the boiler body are non-established construction with several flues, which offer larger heat exchanging surface, which is needed because of lower temperature of flue gas. We suggested several constructions, which was compared between each other. So, there was implemented several improving modifications. Part of the heat exchanger creates also cleaning system, which consists of spirals from sheet metal into each flue pipes. Except for cleaning function, the spirals raise flue gas flux and improve heat transfer from gas space into pipes of heat exchanger.

Next key part of boiler is mentioned pellet burner. We decided for the burner construction with underfed fuel inlet without moving parts against agglomerating. Our idea is to protect the fuel bed against the slagging, sintering and agglomerating of ash and other combusted particles by cooling of the burner wall. The agglomerating mechanism of ash residues isn`t completely described, so we decided for study of pellet combustion process in an experimental device.

3 Experimental combustion device

Walls of water cooled burner are in direct contact with burned bed of pellets. So there can occur a problem connected with too low temperature of burner walls. At first, there was necessary to establish cooling possibilities for burning space.

3.1 Construction

We designed a simple experimental device where can be modelled water cooled walls around of burning pellets like in the intended burner.

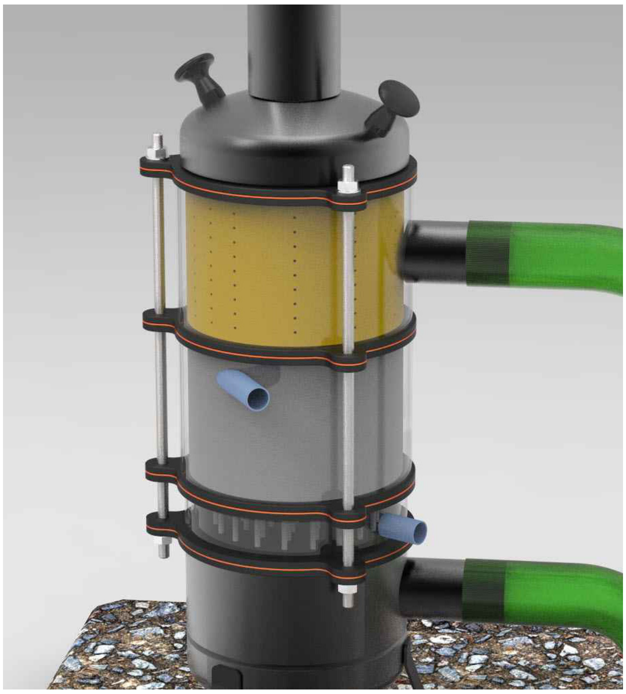

Figure 1. The experimental combustion device for pellets.

The small experimental combustion device, which shows Figure 1 and Figure 2 is intended for study of the pellet combustion process in cooled chamber. The combustion takes place on fixed grade without moveable parts. Inner diameter of the chamber is 150 mm. The design of the combustion reactor is demountable to allow modification of parts. We chose as simple and universal design of the experimental device with the fixed grade. We want to keep the bed temperature below the softening temperature of ash particles to prevent the creation of sintered bodies in the combustion chamber.

Figure 2. The experimental combustion device for pellets in the laboratory, without an insulation around.

3.2 Method of measurement

The requested temperature will be during combustion process control through a water-cooled grate and chamber case. Figure 3 shows the diagram of the measurement system.

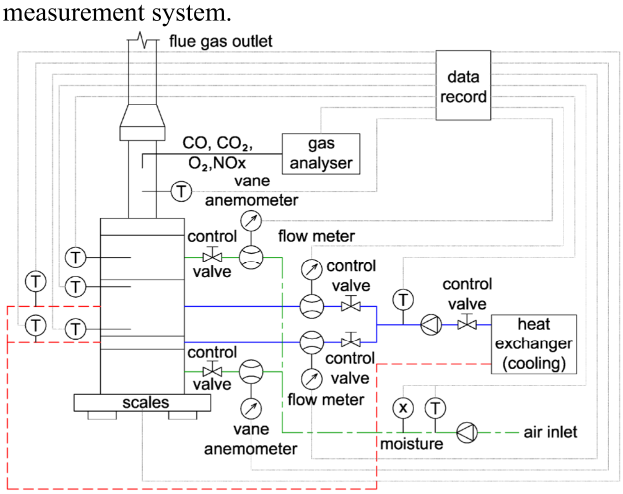

Figure 3. The diagram of the measurement system.

We also want to determine how much the combustion chamber can be cooled, without adverse effect on the combustion conditions. Besides, it will be necessary to find a suitable air-fuel excess ratio and a redistribution ratio of primary and secondary air. They will analyse the quantity and composition of produced emissions at the outflow of the combustion device. After combustion of a batch there will analyse the structure of ash residues and its tendency to agglomerate and sinter. The measured data from the experimental device will serves as background for the design of suitable burner for trouble-free burning phytomass.

3.3 Experimental device setup

Pellet combustion in the chamber of experimental device take place in the bed on fixed grate. The batch consist of exactly defined amount of pellets taken into the chamber before the measurement start. Pellets are evenly distributed on the grate and next are all parts of device assembled together. Then, they heat the cooling water on approximately 70 °C and set the air flow on requested amount. It is necessary to heat water before the ignition, because weight of batch up to 400 g is too low. The ignition of bed is doing by piece of metaldehyde. It is a way of the point ignition source on the bed surface. Several minutes after the ignition, the bed is well stirred.

Next batch could be added manually, but the inlet for pouring pellets is placed on the top of the device. A steel cap covers this hole up during the combustion. If you want to add some pellets during combustion you will uncover the cap. It means that there occurs unwanted infiltration, which influence the combustion conditions markedly. For this reason is better to burn one batch and next batch to add after burning down all pellets.

During combustion are measured this parameters: the water and air flow, the inlet and outlet temperature of water in the grade and chamber case, temperature and moisture of the combustion air. The composition of flue gas was also analysed, especially this species: O_2, CO, CO_2, CH_4, SO_2, NO. Temperature in the combustion chamber was measured in the vertical axis of the device in the height 8, 16, 23 and 29 cm above the grate surface. Pellets was poured in even bed at the start of new measurement, but after added to stirred bed, they were probably heaped. After the experiment, the device was disassembled and the chamber was cleaned. At first, we burnt only wood pellets in order to adjust the fluid flow and other conditions of measurement. Then we combusted pure straw pellets and pellets with additives.

4 Results and discussion

There are several interesting results from experiments under various operating conditions. We chose some results and figures, which represent our assertions.

Figure 4 shows the experiment, when was burnt 200 g wood pellets. The first pick in the Figure 4 represent ignition and metaldehyde burning, which take about 10 minutes. Then pellets start burn and approximately next 10 minutes is the bed well stirred and all pellets are combusted. The temperature T1 is near to grate and it is only several centimetres above bed. Combustible gases don`t have enough time to burn. Hence the highest placed thermocouple gets the highest temperature because of well stirred flame. This situation is similar during every experiment.

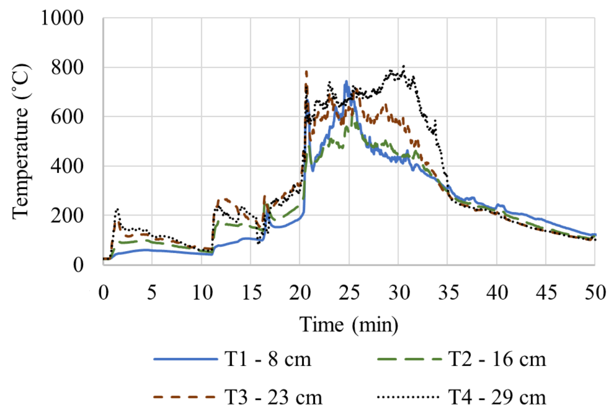

Figure 4. The temperature during 200 g wood pellet combustion

At first, there is adjusted equal water flow to the grate and chamber case. Figure 5 shows that the ratio of water adjustment isn`t good, because the outflow temperature from the grate is very low in comparison with the temperature from the chamber case. Temperatures vary a lot, because the heat exchange surface of the chamber case is 4 times larger than the heat exchange surface of the grate. In this case, the cooling water isn`t heated before the experiment, thus pellets are combusted in the cold chamber. It causes markedly incomplete combustion. Next experiments shows that the appropriate ratio of the water flow to the chamber case and to the grate is around 6.

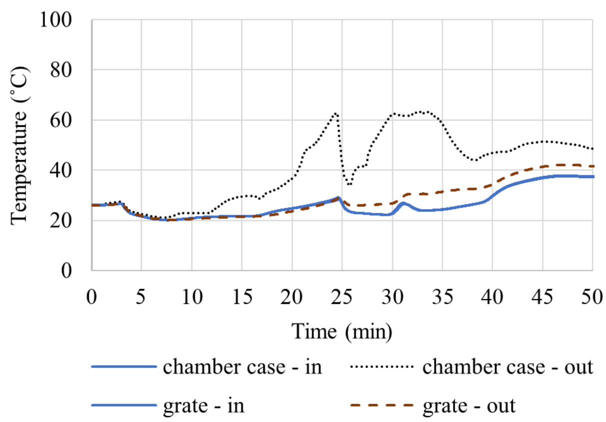

Figure 5. The water temperatures during the combustion of 200 g wood pellets.

In next experiments, there is determined appropriately similar the outflow temperature from both parts, while the flow through the chamber case is 6 times more than through the grate as Figure 6 shows. Onset of temperatures is different because of necessary time for an ignition of whole bed.

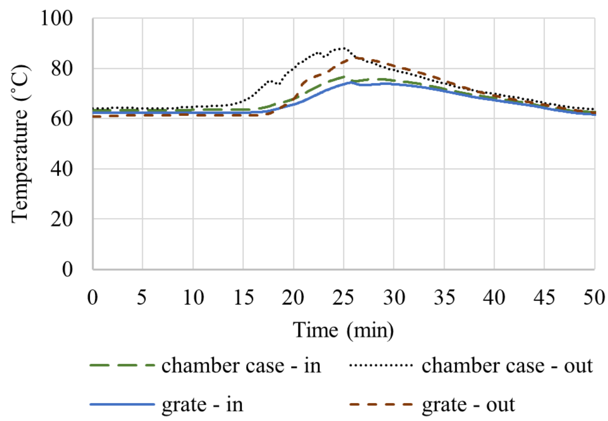

Figure 6. The water temperatures during combustion of 400 g wood pellets.

During combustion of 400 g wood pellets (Figure 6, Figure 7) is mean power approximately 1800 W, but the air flow is unsteady. It influences the temperature fluctuation as it shows Figure 6. Mean temperature during this measurement is around 850 ˚C, but maximum temperature exceeds 1000 ˚C in some moments. The bed temperatures in commercial burners, comparable in dimensions, without cooling, are usually higher, but they work with continuous combustion and with well stirred bed. Temperatures, power and others indicate that the combustion is incomplete, this assumption confirms progression of CO emissions in Figure 8.

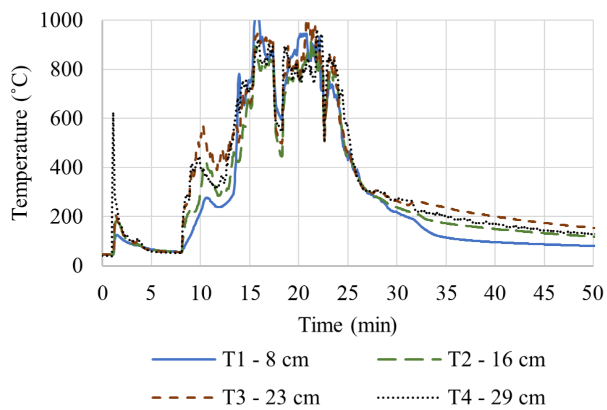

Figure 7. The temperatures in the combustion chamber during combustion of 400 g wood pellets.

We don`t achieve acceptable emission production in any experiment as shows Figure 8, but temperature in combustion chamber is below 800 ˚C as shows Figure 9. There are several reasons, which are described further. The freeboard don`t provide enough space and time to volatile combustion. It would be right to extend the freeboard space to burn all volatiles down. The chimney don`t have installed a draught controlling fan, thereby combustion conditions are very influenced by outdoor conditions. For further experiments, it is necessary to keep constant flue draught.

The experiments show, that 100 – 200 g pellets is very small batch, so bed isn`t well stirred and the combustion is markedly incomplete. Appropriate amount of pellets is 400 g for one batch in this device.

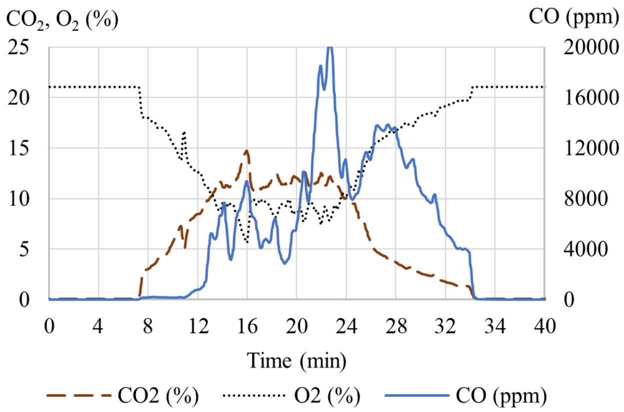

Figure 8. CO_2, CO and O_2 emissions during combustion of 200 g pellets, which are made from miscanthus and lime (2 wt%).

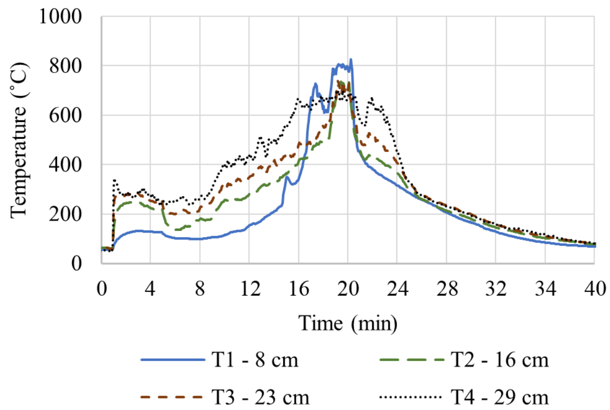

Figure 9. The temperatures in the combustion chamber during combustion of 200 g pellets, which are made from miscanthus and lime (2 wt%).

Other troubles occur because of low temperature of chamber walls. For this reason, gases are rapidly cooled even under the dew point of flue gases and the combustion of volatiles are incomplete. Then, there occurred condensate and tar on chamber walls. In this respect, we were limited by cooling capacity of the cooling system in these experiments. For next experiments is appropriate to raise the water temperature in the cooling circuit as height as possible. We assume that the combustion quality would be better in this device if the height of the cooled chamber part will be lower. Appropriate height might be equal to bed height, but it is need to confirm (e.g. for 500 g is the bed height 45 mm and for 400 g is the bed height 35 mm). Under this conditions, volatiles wouldn`t be cooled on the chamber walls immediately as soon as they leave the bed.

The ash from wood pellets is very fine, but in some cases there remain unburnt residues. It means that combustion conditions is insufficient. It is similar also for phytomass pellets with the additives as shows Figure 10.

During straw combustion without additives is indication of sintering particles on chamber wall and also they develop in bed. The agglomerations are very fragile, but the ash begin to stick together. It means that temperature over 850 °C is high for wheat straw. Amount of ash from straw pellets is higher than from wood, but pellets with additives contain even more ash, what is unwanted.

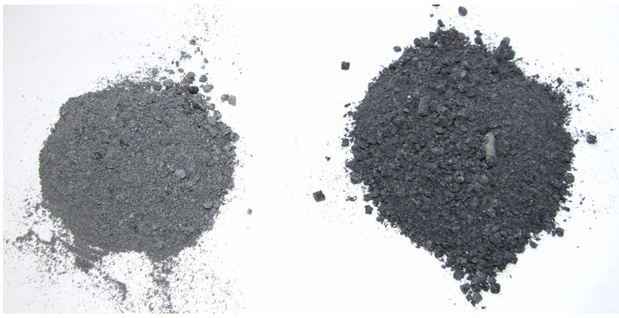

Figure 10. The ash from miscanthus with 2 wt% lime (left) and from wheat straw with 2 wt% china clay (right).

At first, the air flow to combustion chamber was controlled manually according to emissions, what is very difficult. It don`t have positive effect on the combustion, because of fluctuation of other variables. In next experiments is adjusted the constant air and water flow ahead. It appears like well simplification because results are easier comparable.

5 Conclusions

This study presents results from the biomass pellet combustion in the small experimental device with the water-cooled combustion chamber. There is still area to improve the device and experiments. Thus, we want to rebuild part of device according to mentioned suggestions and repeat experiments in future. Our intention is to provide good conditions for complete combustion, so that increase efficiency. The present results confirm that it have significance to deal with the water-cooling burner in the domestic boiler.

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