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EXPERIMENTAL DEVICE FOR MULTI-STAGE COMBUSTION OF VERY WET BIOMASS

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Abstract: This article describes function and current composition of a multiple-stage combustion water heater for very wet biomass. The combustion can take place in the oxidation setting of a common atmosphere or in an atmosphere enriched by oxygen. This article also presents results from an initial launch of the device. Results contain emission and particle characteristics of combustion in common atmosphere under various working conditions. Another part is about our future plans with this device, including its improvements and experiments.
Keywords: biomass, combustion, multiple-stage, experimental

1. INTRODUCTION
Biomass is one of green sources of energy worth of utilization [1] [2]. Gasification is one way of such utilization [3].

The main goal of the multi-stage combustion device is to effectively produce syngas from very wet waste biomass (stage 1) and consequently burn it (stage 2). As for now, the used fuel is sawdust mixed with woodchips. Woody biomass can be a good source of syngas [4]. The biomasses do not undergo any previous drying or mechanical preparation. The advantage of multi-stage combustion is a better control over the entire process and that after the first stage the produced syngas is a fit fuel for different types of burners, engines, furnaces and water heaters.

To see that the device is working correctly, the initial launch of the device was primarily used as a testing run. From this we were able to check the response of a measurement and a manual control as well as the combustion/gasification ability of the device.

2. DESCRIBTION OF THE DEVICE
The device is fed from a fuel feeder that drives the fuel into a gasifying chamber where it is gasified. The syngas (volatile) then enters a nozzle in which it is combusted and a hot gas (inert) then goes downwind into a water heater where it is cooled down. After this the gas leaves the water heater and is cleansed of particulates in a cyclone separator.

The device is manually operated via a personal computer with a user interface that contains all readings and controls and is programmed in LabVIEW software. To enhance security the programming includes automated sequences for shutting down and cooling.

2.1. Fuel feeder
The fuel feeder is a hatched cylinder container with a worm conveyor. At the bottom is a revolving plate propelled by the worm conveyor drive. The plate is purposed to break up any arched fuel and to ensure a continuous fuel feed in the worm conveyor. The fuel feeder is designed for

weighing by a strain gauge. The stand-by time of the container is about 6 to 8 hours for the nominal power.

2.2. Water heater

This water heater is originally designed for combustion of solid fuels and for our application is modified to combust syngas from the gasifying chamber. It consists of two main parts: the combustion chamber with a fixed water-filled grate and the convective part made of vertical and horizontal heat tubes. All walls are water-filled double walls. Other modification allows placing of three thermocouples and a pressure gauge for the measurement of temperatures and chamber under pressure respectively. Its nominal power output is 110 kW.

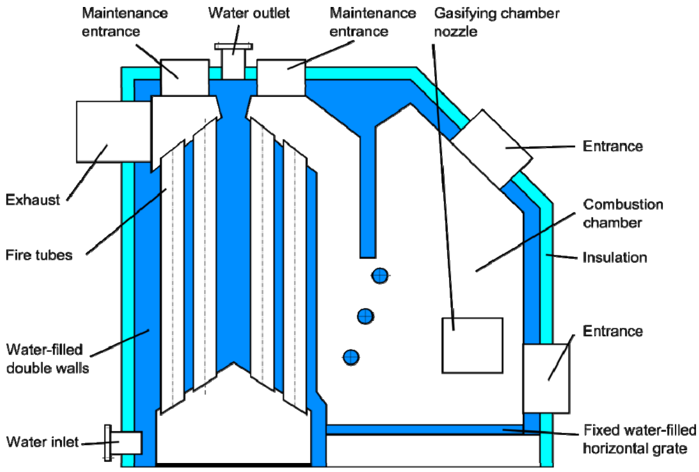

Figure 0.1. Scheme of water heater

2.3. Gasifying chamber

The Gasification chamber is designed for combustion of loose wood, mostly wood chips and other similar biomass material. One of the main characteristic of these fuels is a high content of volatile matter. The construction of the chamber allows gasification of wood and subsequent complete combustion of produced syngas. The gasification takes place on an inclined fixed grate. Downwind the inclined grate there is a horizontal fixed grate. For the research requirements were implemented many changes in the original design, so the measurement of desired units and changes in border conditions for combustion can be done.

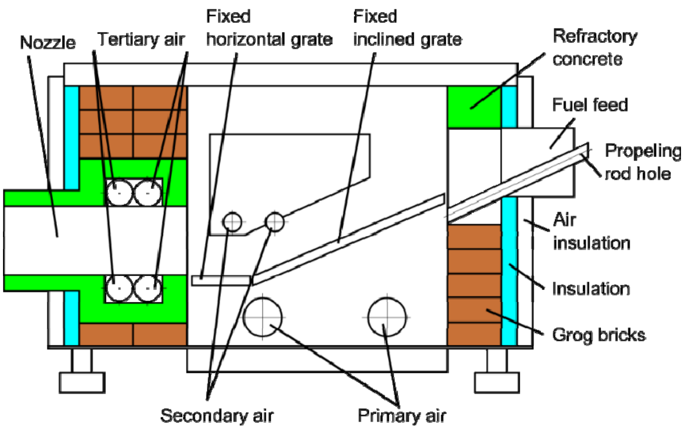

Figure 0.2 Scheme of the gasifying chamber

The fuel is fed into the chamber from back side just above the inclined fixed grate. The primary air inlet is below the inclined grate and secondary air inlet above the inclined grate. The fuel then slides on the grate due to the gravity pull and the newly fed fuel push. At this stage the fuel is heated, dried and finally gasified. After the inclined fixed grate, the fuel reaches the horizontal fixed grate and starts burning, so the nozzle of the chamber enters a flame and syngas. At the beginning of the nozzle is the outlet of the tertiary air and after the mixing of syngas and the air an intense combustion commences.

This configuration provides space for utilization of other methods that can help the gasification of very wet biomass [5].

2.4. Air preheater

The combustion air is divided into three parts: primary, secondary and tertiary. The volume and pressure of air is provided by high-pressure ventilator. Downwind the ventilator the air is divided into three branches, each with its own regulation of flow rate provided by regulation flap with actuator. Each of the three flows is measured by an air flow meter. Heating of each flow is equipped with an independent electrical heater that regulates the temperature between 20 – 200 °C and the temperatures are measured by thermocouples.

3. MEASUREMENT AND RESULTS

To determine the quality of gasification [6] and combustion was used results from two measurements. An on-site measurement of the exhaust gas contents under several working conditions of the primary, secondary and tertiary air and calorific value of ashes from the gasifying chamber and cyclone separator.

3.1. The on-site measurement

This measurement of the exhaust gas was without recording. It was made under conditions of assumed gasification that were set up by primary and secondary air volumes. The measurement was showing insignificant content of carbon monoxide and very high content of oxygen. Using any volume of the tertiary air did not show any significant difference.

3.2. Calorific value of ashes

Ashes in the device had cumulated in the device over the whole testing period in which was tested the functionality of controls and measuring instruments, ranges of operated components and achievable values.

Presuming that the ashes are evenly distributed from the biggest particles at the beginning (Ash from gasifying chamber) to the finest particles at the end of the route (Fly ash from cyclone), we used only these two border samples and fuel for comparison. This should give us an idea of how well is the fuel converted into syngas or/and combusted. Unfortunately, the exact weights of ashes is unknown so the efficiency cannot be determined. The results are shown in Table 3.1.

Table 3.1. Results of ash measurements

Specimen	Moisture content, [%]		Combustion heat, [J/g]		Use of fuel, [%]	
Fuel	13,07		17594		0	
Fly ash	3,7	3,5	3799	3887	78,4	77,9
Ash	1,1	0,7	1557	N/A	91,2	N/A

4. DISCUSSION

Considering the even distribution of ashes, the results of calorific values from Table 3.1 show that the biggest particles (ash) were combusted/gasified with an 8.8 % unused amount of combustion heat while the value for Fly ash is around 21.8 %. Having in mind that the ashes were accumulated over the whole testing session, including the low efficiency warming-up period, the high temperature high efficiency period should feature values lower than those. And we do not know the weight ration of these ashes so we cannot calculate the real efficiency. Nevertheless, even considering the lowered values and that majority of the ashes remain in the gasifying chamber, there is still a big reserve in fuel usage. But this might be connected to the other issue of oxygen content in the exhaust gas.

When the device was operating in supposed gasifying operation set-up by primary and secondary airs, there should have been a high content of carbon monoxide and insignificant content of oxygen and carbon dioxide when the tertiary air inlet was closed and an insignificant amount of carbon monoxide and usual combustion gasses when fully opened. This will proof that when the tertiary air is closed the device is producing syngas from fuel and when the tertiary air is fully opened the syngas is combusted. But the amount of tertiary air had only a little effect on the composition of the exhaust gas, increasing only the amount of oxygen. This was showing that the device was not gasifying the fuel but directly burning it.

After close examination of the device we found out that the primary and secondary air controls were switched. That caused that we did not have optimal control over the device and combustion air distribution and that we were unable to set up the device into gasifying mode. This was the main reason we were combusting the fuel with surplus of oxygen.

All other systems were working as intended.

5. CONCLUSION

The initial run of the device pointed out to us errors in the controls of the primary and secondary air that prevented us to achieve the wanted result of combustion, gasification and fuel utilization. The controls have been fixed and the device is being prepared for another testing run that should provide us with more complex results.

When this is done and the result are satisfactory, the next step will be usage of very wet biomass and utilization of it to achieve optimal gasification and combustion. Another effort to enhance the combustion ability of the device is connection of an oxygen separator that will provide a very volatile combustion atmosphere enriched by oxygen. This can a way to lower emissions and increase utilization of the fuel.

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REFERENCES

[1.] Badea Gabriela; Dzițac Simona; Lolea Marius. Considerations on the Wood Waste Burning in Biomass Plants. Annals Of Faculty Engineering Hunedoara – International Journal Of Engineering, 2007, Tome V, Fascicule 1, Pages 123–128, ISSN: 1584 – 2665.

[2.] Zoran Đukić; Srđan Kovačević; Dragan Adamović; Nemanja Stanisavljević, Utilization of Waste Materials from Biomass as Energy-Generated Product in Technological Process. Annals Of Faculty Engineering Hunedoara – International Journal Of Engineering, 2009, Tome VII, Fascicule 4, Pages 227–230. ISSN: 1584 – 2665.

[3.] Moskalík, J.; Štelcl, O.; Škvařil, J.; Lisý, M.; Baláš, M. Energy Usage Of Contaminated Biomass. Acta metalurgica slovaca, 2011, Volume 2011 (2), Issue 1, Pages 145–152. ISSN: 1338- 1660.

[4.] Yasuaki Ueki; Takashi Torigoe; Hirofumi Ono; Ryo Yoshiie; Joseph H. Kihedu; Ichiro Naruse. Gasification characteristics of woody biomass in the packed bed reactor. Proceedings of the Combustion Institute, 2011, Volume 33, Issue 2, Pages 1795–1800.

[5.] Guangwen Xu; Takahiro Murakami; Toshiyuki Suda; Hidehisa Tani; Yutaka Mito. Efficient gasification of wet biomass residue to produce middle caloric gas. Particuology, October 2008, Volume 6, Issue 5, Pages 376–382.

[6.] Baláš, M.; Štelcl, J.; Lisý, M. The Effect of Temperature on the Gasification Process. Acta Polytechnica, 2012, Volume 52, Issue 4, Pages 7–11. ISSN: 1210 – 2709.

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