

# Influence of Biomass Combustion Method on Properties of Solid Fuel Residues

*Juraj Trnka<sup>1,\*</sup>, Jozef Jandačka<sup>2</sup>, and Michal Holubčík<sup>1</sup>*

<sup>1</sup>University of Žilina, Department of power Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovakia

**Abstract.** The correct course of the combustion process has a great influence on several output parameters. In addition to the impact on the performance and efficiency of the device, the impact on the formation and properties of gaseous emissions and solid residue is particularly noticeable. The solid combustion residue, in particular in the form of ash, remains trapped as the final product after combustion in the incinerator or may be released to the outside environment. Improperly, combustion can form two negative extremes. The first extreme is the formation of too fine dust particles of ash and solid pollutants escaping into the air as dangerous emission substances for human and other organism's health. The second is the failure to burn larger pieces of fuel or sinter them into clumps, which can subsequently damage the combustion device or reduce the efficiency of combustion. This article aims to examine the various factors influencing the impact of combustion in different types of combustion plants on the properties of the resulting solid fuel residues and further possibilities of their use and effects on the environment.

## 1 Introduction to emissions

Biomass is one of the most widely used renewable energy sources. Combustion of biomass releases thermal energy which we are able to capture and possibly convert into a more noble form of energy such as electricity. However, like any method of obtaining energy, this one also has its disadvantages, which include in particular the generation of waste products which we call emissions. Emissions can have a negative effect on human health, but also on the surrounding environment into which they are released. We divide them into solid, liquid and gaseous.

Gaseous emissions are formed by oxides of combustion elements of fuel or combustion air, which are released directly into the environment and diluted in the atmosphere. They are most often formed by oxides of protozoa such as nitrogen, hydrogen, carbon and sulphur. Each of them has a different degree of negative effect on the environment and some are completely harmless, such as hydrogen, which is converted into pure water vapour during combustion. We can assess their quantity and properties with measuring devices, but we cannot prevent direct release into the environment, so we can assess their impact on the environment only marginally from the observed changes in the environment

---

\* Corresponding author: [juraj.trnka@fstroj.uniza.sk](mailto:juraj.trnka@fstroj.uniza.sk)

around us. Many articles have already paid attention to gaseous emissions, which is why we are turning our attention to other states of emissions [1].

Liquid emissions are largely formed only by pure water which condenses in the flue gas tract under unsuitable combustion conditions, but together with the influence of gaseous emissions of sulphur and nitrogen oxides, these elements dissolve in it and form corrosive acids, dangerous for combustion plants. In addition, when there is a lack of oxygen in the combustion chamber, tars are formed, which are liquid substances composed of aromatic hydrocarbons which also contain dangerous carcinogenic substances such as benzene. These tars are dried under the influence of heat and form a solid layer of settled particles in the combustion paths, which, although it protects against corrosion due to its sticky properties, clogs the chimney.

This leads us to solid emissions, which after combustion usually remain in the combustion plant and thus form a solid fuel residue. The solid residue forms the most chemically diverse mixture of substances that affects the life of the combustion plant and the environment into which it can be released by humans. It can be divided into inorganic ashes and organic soot and solid pollutants. However, both of these components of the solid residue may or may not have a negative impact on the life of the combustion plant as well as on the environment, so it is very important to determine their properties and right reuse in energy, industry or agriculture.

## 2 Theoretical analysis of solid residue formation

The most fundamental factor influencing the properties of the solid residue is the choice of fuel. Many households now switch from clean, almost zero-emission natural gas to solid fuels such as wood, coal, or even burn many illicit materials for economic reasons [2]. This is one of the reasons for the significant increase in emissions of solid residues, which are often contaminated with hazardous substances. By examining the properties of these fuels, we are also able to determine the properties of the solid residue. The chemical composition and mechanical properties of the fuel determine the content of energy contained in the fuel, its combustibility and the content of emissions. For example, the moisture content of fuel determines the efficiency and effectiveness of combustion and significantly affects the entire process. However, the content and properties of ash in the fuel are the most important, because it will determine the amount of solid residue itself and its properties [3]. The following table shows the percentage distribution of the individual basic fuel components.

**Table 1.** Basic distribution of fuel content.

Fuel type	Vlhkost' (%)	Volatile combustible (%)	Solid carbon (%)	Ash (%)
Corn cobs	5,65	74,39	18,59	1,47
Straw	1,51	74,74	18,28	5,47
Needles	6,52	66,84	17,04	7,59
Lawn	5,78	66,22	15,44	12,56
Leafs	6,33	64,71	15,98	12,98
Paper sludge	1,36	55,71	0,93	42,00
Bones	4,14	44,16	2,75	48,95
Asphalt slate	2,06	16,04	3,18	78,72

Combustion in small sources is a very complex and complicated process consisting of several simultaneous processes that best capture mathematical flow models comparable to the results of experimental measurements [4]. The choice of the right combustion method

affects a number of these processes, in particular as regards the flow and redistribution of combustion air to each part of the fuel. Model for small heat sources can be large thermal power plants which produce a solid residue under the most optimal conditions. One wonderful example is the fluidized bed combustion of coal or biomass where finely ground fuel is injected directly into the flame stream whereby we can obtain a uniform production of a solid residue of stable properties [5]. Insufficient supply of combustion air in small heat sources leads to local suffocation of the flame and sub-cooling of the hearth. Such a state can also be called pyrolysis combustion where only volatile combustibles are released or burned, but large unburned particles of solid carbon remain in the ash. In industry, this phenomenon is commonly used to produce coke or coke oven gas, but in the case of small sources it only causes a reduction in combustion efficiency and increases waste disposal costs [6]. Therefore, choosing the right combustion method and setting the combustion conditions to ensure a sufficient supply and redistribution of combustion air is essential [7].

In addition to the combustion air, it is also important to maintain the optimum combustion temperature in the combustion chamber. High combustion temperatures are capable of decomposition and complete oxidation of the fuel, so its absence can cause a number of other problems such as increased gaseous emissions and may lead to imperfect combustion of some parts of the fuel or the formation of hazardous combustion intermediates. On the other hand, exceeding the optimum temperature can seriously damage the material of the combustion chamber and change the properties of the ash, which begins to melt and form ceramic conglomerates on the walls of the combustion chamber.

### 3 Experimental measurements in real conditions

We selected the following four types of combustion methods for our experiment:

- open fire,
- grate combustion in the fireplace insert,
- automatic combustion with bottom fuel supply,
- automatic combustion with side fuel supply.

In the first case, we compared open fire with closed combustion in a fireplace insert. At first glance, it can be seen that the solid residue in the open hearth contained a large amount of unburned particles even in the fire-untouched part of the wood. The ash contained a large amount of carbon, which lost its ignition temperature during combustion and extinguished, especially along the edges of the hearth. The fire kept to the ground with low draft and slow flow rate. The hearth itself was significantly cooled and humidified by the surrounding earth during combustion, which kept the ash moist and heavy on the ground. The temperature gradient was noticeable from the center of the embers towards the edges where sub-cooling took place.



**Fig. 1.** Combustion methods: a) Open fireplace, b) combustion in a closed fireplace insert

In the fireplace insert, the ash contained only a significantly small proportion of unburned particles. The solid residue was formed mainly by light fluffy ash brittle to the touch, which easily disintegrated into smaller particles, which during combustion was manifested mainly by the leakage of solid pollutants and ash into the chimney due to higher flow rates achieved by the chimney effect. After heating, the fireplace insert maintained a uniformly high temperature due to its closed construction, which did not allow any part of the fireplace to cool down. Due to the chimney draft, the embers was sufficiently oxygenated to ensure optimal oxidation of the combustible.



**Fig. 2.** Automatic boiler: a) with Retort pellet burner, b) with Rotary pellet burner

In the second case, we compared the effect of combustion in a retort burner with a bottom fuel supply with a side horizontal rotary burner on the properties of the solid residue. In both cases, the same boiler was used with the possibility of replacing the burner. During the measurements, the same samples of pellets were used, which were supplied to the burner automatically by setting regular dosing. The boiler was cooled by water cooling and a stable temperature was maintained in the combustion chamber. Nevertheless, the temperature directly in the combustion burner reached significantly higher values than in the previous two cases, which caused the ash to sinter into small clumps similar to a meteorite. In addition, the ash from the automatic burners also contained smaller amounts of unburned pellet residues which managed to fall out of the burner during combustion and were extinguished in the ashtray. We analysed the resulting composition of the solid residue for each type of combustion methods and you can see the results in the following figure.



**Fig. 3.** Solid residue in different combustion methods: 1 Open fire, 2 grate combustion in the fireplace insert, 3 automatic combustions with bottom fuel supply, 4 automatic combustions with side fuel supply.

## 4 Conclusions

Comparison of individual types of combustion showed that the largest volume of solid residue occurred in an open hearth where, due to non-compliance with optimal conditions of the combustion process, the embers were quenched and the solid residue contained a lot of unburned solid carbon. The situation was better in the fireplace insert and almost all flammable parts burned. In both cases, the ash was formed by a fine loose consistency of light grey colour.

The use of automatic burners increases the combustion temperature in the burner body, which in both cases caused reaching melting point of ash and the formation of sinters. Whereas in the case of a retort burner, the lumps were held by gravity in the body of the burner and caused it to become clogged, and the molten ash partially adhered to the walls of the burner. As a result, the fire began to choke and the unburned pellets fell over the edge of the burner into the ashtray. The resulting portion of the solid residue was thus largely ash and sinters, but a small proportion of unburned parts of the pellets appeared also. The ash had a slightly darker colour compared to previous types of combustion.

The last case was a rotary burner, which did not clog at all due to the horizontal flame, but due to higher temperatures, ash sinters were also formed, which, however, were easily blown out of the burner due to the reduced effect of gravity. However, this condition also caused the blowing of lighter and smaller combustible pieces of pellets from the burner, which, however, subsequently imperfectly burned in the ashtray, which caused an increase in CO emissions. The ash had the darkest colour due to the higher temperatures in the burner. The resulting ash contained the largest amount of sinter in comparison to the content of pure ash and only a very small amount of unburned residues.

From the point of view of usability, the ash from the solid residue obtained in standard grate combustion in a fireplace insert had the best quality, because it formed a fine and homogeneous fraction, while in the other three cases the ash was contaminated with unburned particles or sinters.

In Industrial use, for example the production of concrete mixtures the ashes would require sieving to remove organic components and break up the sinter formation by grinding [8]. In agriculture, only the content of sinter as a non-natural element with the questionable chemical content would probably be questionable. However, the worst impact on the environment was due to solid pollutants, which, due to their light weight, hardly settled in the combustion chamber at all. However, by optimally shaping the combustion paths, we were able to capture some of them there.

The acknowledgements to the project APVV-15-0790 “Optimization of biomass combustion with low ash melting temperature” and VEGA 1/0233/19 “Construction modification of the burner for combustion of solid fuels in small heat sources”. of which this contribution has been created as part of.

## References

1. J. M. Dasch Environ. Sci. Technol. **16**, 639–645 (1982)
2. M. Vantúch et al., AIP. **1745** (AIP Conference Proceedings 2016)
3. D. Durgun, A. Genc, Energy **34**, 1976-1979 (2009)
4. I. Klaková et al., Mater. Sci. Eng. **776** (IOP Conf. Ser. 2020)
5. L. Armesto, J. L. Merino, Fuel **78**, 613-618 (1999)
6. J. Najser et al. AIP. **1608**, 71 (AIP Conference Proceedings 2014)
7. M. Patsch, P. Pilát, *XXI. International Scientific Conference (AEaNMiFMaE-2018)*

8. J. Brandštetr, J. Havlica, I. Odler, Waste materials used in Concrete manufacturing, 1-52 (1996)