# Ash effects during combustion of biomass with additives

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**Abstract.** Biomass combustion has a huge potential to produce heat and power in a sustainable way. However, some biomass fuels, like grass and straw, have problems with ash melting behaviour. This is due to the chemical composition of biomass ash, particularly the presence of potassium, which reacts with other ash forming elements (Si, P and others) and lead to different ash related operational problems. Utilization of additives can abate these problems. This work deals with using of different additives in biomass to abate problems with ash slagging and melting. As additives were used kaolin, talc, limestone, lime, dolomite, bentonite. Additives were added to wood sawdust in amount 2 percent and were pelleted. It was tested effect of additives on abrasion resistance, total heating value, ash content, ash melting temperature and sinter degree in ash of made wood pellets. Based on the obtained results positive effect on ash melting behaviour was showed with using of all used additives except bentonite.

**Keywords:** ash sintering, ash melting, additives, biomass, wood pellets
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## INTRODUCTION

Solid fuels, including biomass, consist of combustible, ash and water. Combustible substance is the part of fuel which releases heat by oxidation, i.e. energy is chemically bounded in fuel. Ballast of fuel is ash and water. Ballast is undesirable proportion of the fuel. [3, 4, 6, 7, 19]

Ash in fuel is result of minerals reaction presented in the biomass. [13] Minerals and other different substances which form ash got into biomass during growth. Ash is solid residue resulted from the perfect laboratory combustion of fuel. It is composed of minerals that are present in the fuel. In the published works [13, 23, 24], it was found that the highest concentration of diversity to make up the ash biomass reaches silicon, aluminium and iron. Chemically, the ash from biomass is mainly composed of a mixture of oxides of inorganic elements $K_2O$, $Na_2O$, CaO, MgO, $Fe_2O_3$, $Al_2O_3$, $SiO_2$, $P_2O_5$. Amount of ash depends on the combustion conditions. [5, 7, 8, 10]

The presence of ash forming elements of biomass is the result of chemical processes, intake of minerals from the soil and method of transporting biomass. Some of these elements are necessary for plant growth. Constituent parts of ash biomass are divided into macronutrients (potassium, calcium, magnesium, phosphorus and sulphur) and micronutrients (iron, manganese and chlorine). Silicon, aluminium and sodium are essential for plant growth. [20]

Ash in combustion boilers can cause various problems. It can avoid heat transfer in heat exchangers, which can cause corrosion of heat transfer surfaces. For biofuels is monitored in potassium, sodium, sulphur, chlorine and the various compounds, as the burning they comprise a molten phase in which the particles become sticky ash, thereby adhering to the heat exchange surface.[20] For certain types of plant biomass, such as straw, whole plant cereals and hay combustion chamber temperature is higher than 800 to 900 ° C. Therefore, they must be regarded as technically complicated combustible fuels. Maintaining the temperature in the combustion chamber in temperature under ash melting temperature and avoid creating of sinter deposits and slags are quite complex, but it is possible to control the combustion temperature at least within certain limits, so that the formation of sediments and sinters is significantly limited. [6]

Possible solution problems of low ash melting temperature of biomass may be the addition of additives to the fuel during its production or addition of additives just before combustion of fuel.

The paper presents the results of using kaolin, talc, lime, limestone, dolomite and bentonite as additives to increase the temperature of the melting behaviour of biomass.

## MATERIALS AND METHODS

### Used additives

At present, by Austrian and German quality standards is allowed content of additives in wood pellets up to 2 per cent. In this work was used lignin like additive in amount of 2 per cent. [5, 7,8, 17]

As additive is considered a substance (ingredient) added to some material (product) in order to improve some of its properties. Usually it happens in practice, that with the improving some characteristics are beginning to discover new deficiencies. Because of this is necessary for each used ingredient to analyse its effects to properties of pellets. [5, 7, 8]

Kaolin, talc, lime, limestone, dolomite and bentonite were used as additives in amount 2 per cent in wood sawdust.

Kaolin is white or light-colored unpaved sedimentary rock, formed mostly decomposition of rocks rich in feldspar. The main ingredient is clayey mineral kaolinite - $Si_2Al_2O_5(OH_4)$, which makes up 80% of its capacity.

Talc is white mineral composed of hydrated magnesium silicate with the chemical formula $H2Mg_3(SiO_3)_4$ or $Mg_3Si_4O_{10}(OH)_2$.

Lime or calcium oxide (CaO) is a white, caustic, alkaline crystalline solid at room temperature.

Limestone is a sedimentary rock composed largely of the minerals calcite and aragonite, which are different crystal forms of calcium carbonate ($CaCO_3$).

Dolomite s a carbonate mineral composed of calcium magnesium carbonate $CaMg(CO_3)_2$. The term is also used to describe the sedimentary carbonate rock dolostone.

Bentonite is an absorbent aluminium phyllosilicate, essentially impure clay consisting mostly of montmorillonite. There are different types of bentonite, each named after the respective dominant element, such as potassium (K), sodium (Na), calcium (Ca), and aluminium (Al). In this work was used Al – bentonite.

## Procedure of experimental production of wood pellets

Pellet production is complex process and it is necessary that starting material – wood sawdust must meet certain conditions. [1, 11, 22, 25] It cannot contain undesirable objects. Biggest size of sawdust fraction must be smaller than diameter of holes in the matrix of pellet mill. [2, 25] The humidity of input material should be around 15%. Manufactured pellets must be cooled and stored properly. [11, 12, 16, 18, 25]

In the laboratory of University of Zilina has been designed and partially implemented an experimental device for pelletizing according to the scheme in figure 1. It consists of input material tank (in which is delivered biomass for production of pellets), crusher (which crush material to fractions of size max. 6 mm), crushed material tank (where the crushed material is temporarily stored), dryer (where is possibly wet material dried for optimal humidity), mixing machine with capacity of 50 dm3 (where is dried material mixed with water and additive), pellet mill with capacity of 70 – 100 kg.h-1 (where is prepared biomass material pressed to pellets), cooler and duster with fan (final product - pellets are cooled to room temperature and dusted) and produced pellets tank (where are pellets temporarily stored before packing).

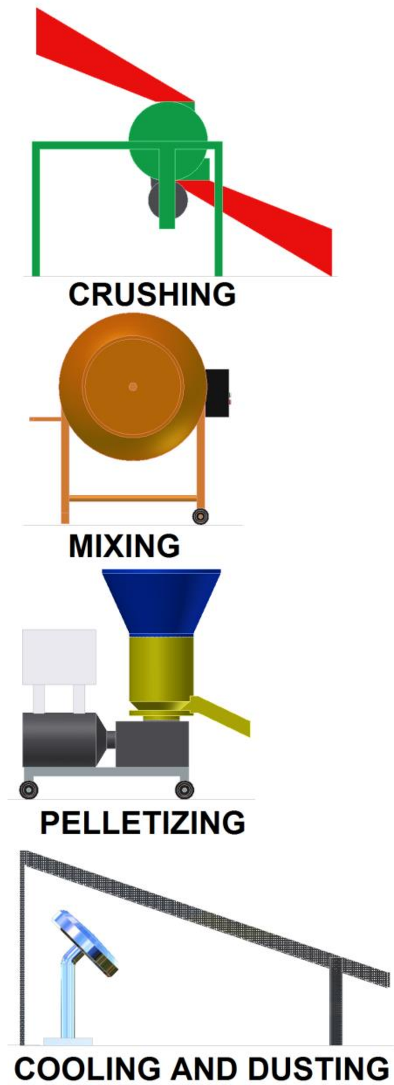


**FIGURE 1.** Experimental device for pelletizing

This experimental device for pelletizing was used for production of experimental samples of wood pellets. For producing of experimental samples was used dendromass - spruce sawdust. [21] Spruce sawdust was delivered by external company and their moisture content was about 8 - 9%. It was necessary to moisten it to the ideal moisture content about 15 to 20 % due to making the process of pelletization uniform. [14, 15, 16] Increasing moisture was carried out in mixing machine, which was also used for mixing the input material with additional additives. About 15 kg of sawdust was milled and compressed into pellets in each experiment.

There were produced one reference sample without additive and samples with 2 per cent addition of kaolin, talc, lime, limestone, dolomite and bentonite.

## Methods of experiment

The following properties of the produces samples were measured:

- Abrasion resistance - it was determined as quality parameter [9] according to STN EN 15210 [27] by using of special device – LignoTester. The samples were placed in stream of air for 30 or 60 seconds, with pressure of air 30 mbar, respectively 70 mbar.
- Total heating value - it was determined according to STN EN 14918 [28] by using of calorimeter LECO AC 500. A sample of wood pellet with weight about 1,0 g was burned in combustion vessel filled with oxygen to a pressure 31,0 bar. Combustion vessel was immersed in 2,0 $dm^3$ of distilled water. During burning of sample was measured temperature increase of water.
- The ash content of produced wood pellets samples was determined on the basis of standard STN EN 14775 [26]. Samples were dried in dryer at temperature 105 °C ± 2 °C. After drying were samples temporarily placed in a desiccator. Then empty corundum plate was weighted after heating on 550 °C ± 10 °C. 5 g of sample were placed to the plate and it was weighted with accuracy 0,1 mg. Plate was placed in the cold furnace which was heated by the following procedure (Fig. 2):

1. Over 30 min steady increase furnace temperature to 250 °C at a rate 7.5 $°C.min^{-1}$.
2. Temperature of 250 °C was kept for 60 minutes due to combustion of the sample released volatiles.
3. For 30 minutes continued uniform temperature increase to 550 °C by 10 $°C.min^{-1}$.
4. Temperature of 250 °C was kept for at least 120 minutes.

Plate with ash was removed from the furnace and it was weighted with accuracy 0,1 mg. Ash content was determined from the equation:

$$A_d = \frac{(m_3-m_1)}{(m_2-m_1)}.100\ [\%] \qquad (1)$$

where $m_1$ is the mass of the empty plate in grams,
$m_2$ is the mass of plate with sample in grams,
$m_3$ is the mass of plate with ash.

- Ash melting temperature of produced wood pellets samples was determined on the basis of standard STN ISO 540 [29]. Meltability of ash is characterized by the physical state of the ash, which occurs during the heating process under well-defined conditions in furnace [7, 8]. During melting of ash were monitored following temperatures:

1. Shrinkage temperature (ST) – is temperature at which first symptoms occur rounded edges or the edges of the test specimen due to melting.
2. Deformation temperature (DT) – is temperature at which the edges of the test specimen completely rounded, without changing the amount.
3. Hemisphere temperature (HT) – is temperature at which test specimen creates hemisphere, the amount of which is equal to about half the base
4. Flow temperature (FT) - is temperature at which the ash pitch on a base in such a layer, the amount of which is approximately one third of the test specimen at the melting temperature

- Sinter degree in ash of wood pellets samples was determined by heating of samples to 1300 °C for 4 hours and keeping on this temperature for 3 hours. Afterwards, ashes were checked for optical and mechanical properties to find a level of sintering in the range between 0 (not sintered 0 %) and 5 (completely sintered 100 %).

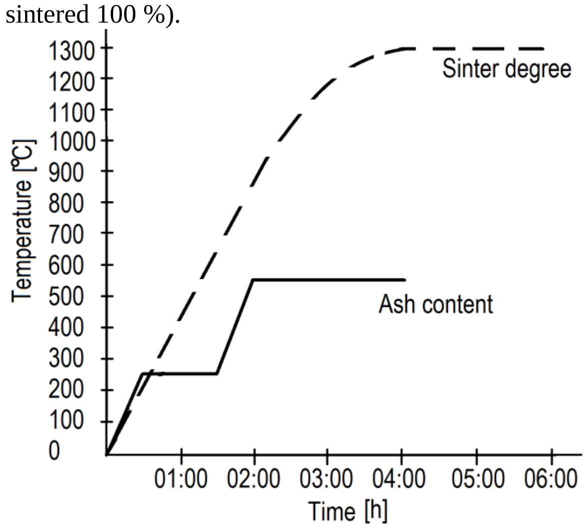


**FIGURE 2.** Temperature program for ash content and sinter degree

## MATERIALS AND METHODS

There were made 6 samples of wood pellets with addition of different additives in amount 2 % and 1 reference sample made from sawdust without additives.

### Effect of additives on abrasion resistance

On fig. 3 are average values of abrasion resistances (AR) of wood pellets samples with additives. From the fig. 3 is visible that addition of bentonite has very negative impact to AR. Addition 2 % of bentonite decreased 60 s AR and hence strength of pellets by 75 % in comparison with reference sample. Measured AR values of other samples were similar to the reference sample.

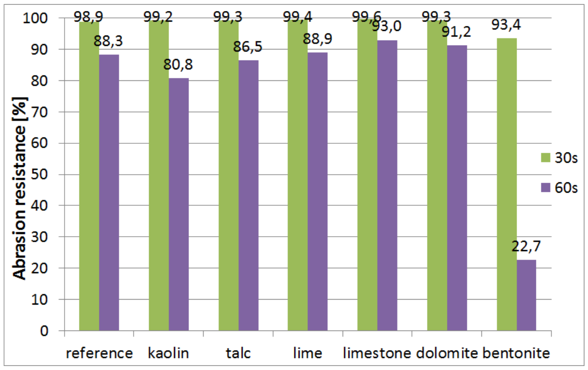


**FIGURE 3.** Abrasion resistance of wood pellets samples with additives

## Effect of additives on total heating value

On fig. 4 are average values of total heating value (THV) of wood pellets samples with additives. From the fig. 4 is visible that addition of bentonite has negative impact to THV. Addition 2 % of bentonite decreased THV of pellets by 12,2 % in comparison with reference sample. Measured AR values of other samples were similar to the reference sample and varied about value 20 $MJ.kg^{-1}$ ± 0,9 $MJ.kg^{-1}$. The results shows, that addition of these additives decrease THV of wood pellets.

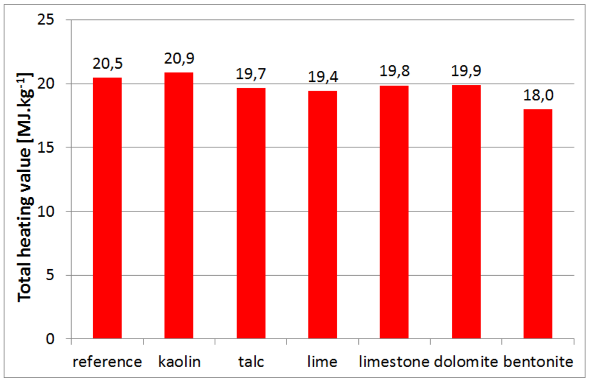


**FIGURE 4.** Total heating value of wood pellets samples with additives

## Effect of additives on ash content

On fig. 5 are average values of ash content (AC) of wood pellets samples with additives. From the fig. 5 is visible that addition of all additives increase AC approximately by 2 % in comparison with reference sample. The highest growth of AC in comparison with reference sample was observed with using of lime as additive.

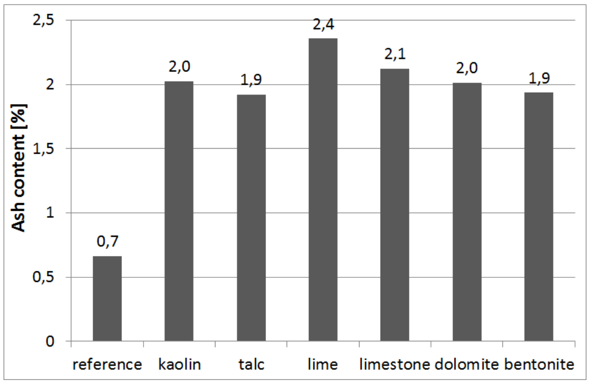


**FIGURE 5.** Abrasion resistance of wood pellets samples with additives

## Effect of additives on ash melting temperature

On fig. 6 are values of ash melting temperatures (AMT) of wood pellets samples with additives. Positive effect was observed with using of all additives except bentonite. Bentonite increased only flow temperature but other AMT were lower than with AMT of reference sample. The highest values of AMT in comparison with reference sample were observed with using 2 % addition of dolomite which increased average AMT by 24,4 %.

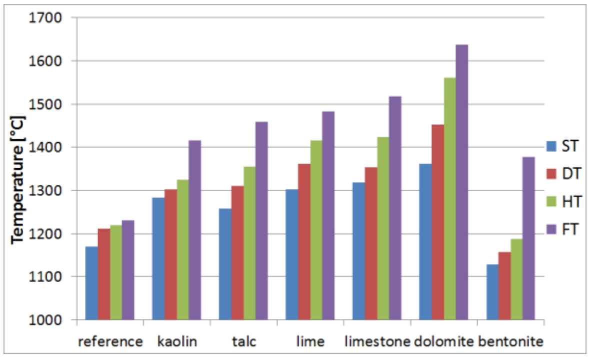


**FIGURE 6.** Ash melting temperature of wood pellets samples with additives

## Effect of additives on sinter degree

On fig. 7 are values of sinter degrees (SD) of wood pellets samples with additives. Similar to AMT positive effect was observed with using of all additives except talc and bentonite. SD of talc and bentonite were very similar to SD of reference sample. At least sinters were in ash of dolomite, where were only approximately 40 % of sinters in the ash.

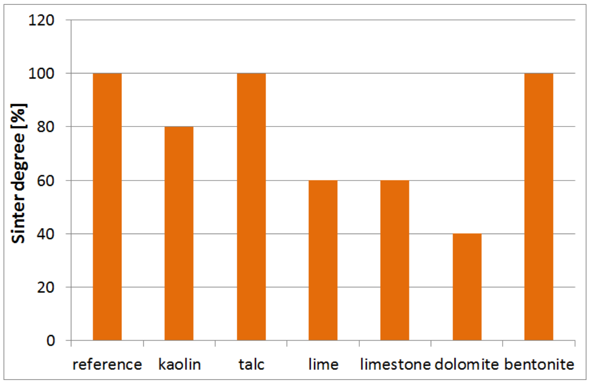


**FIGURE 7.** Sinter degrees of wood pellets samples with additives

## CONCLUSION

Addition of different additives to wood pellets has effect on their properties. Using of kaolin, talc, lime, limestone, dolomite and bentonite had relatively strong effect on abrasion resistance, total heating value, ash content, ash melting temperature and sinter degree of wood pellets.

The main purpose of using additives was increase ash melting temperature and decrease creating of sinters and slags. This was archived by using of dolomite, limestone, lime and kaolin. Dolomite archived the highest improvement of ash related problems and other parameters of wood pellets like abrasion resistance and total heating value were almost same than reference sample. Slightly worse but still positive effects reached lime, limestone and kaolin.

From the obtained results it can be recommended using of dolomite, lime, limestone and kaolin like additives to reduction of ash related problems with biomass combustion.

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## REFERENCES

1. E. Alakangas, P. Paju, 2002: Wood Pellets In Finland – Technology, Economy, And Market. Technical Research Centre Of Finland Jyväskyla
2. L. Dzurenda, J. Slovák, 2001: Energetické vlastnosti peliet vyrobených zo smrekovej piliny. In: Acta Mechanica Slovaca. 5(3), 201 - 206 S.
3. L. Dzurenda, 2005: Spaľovanie dreva a kôry, Vydanie I. Zvolen : Vydavateľstvo Tu Vo Zvolene,
4. M. Carnogurska, M. Prihoda, T. Brestovic, 2011: Modelling of nitrogen oxides formation applying dimensional analysis. Chemical and Process Engineering. 2011, Vol. 32 (3)175-184, ISSN 0208-6425.
5. M. Holubčík, R. Nosek, J. Jandačka, 2012: Optimization of the production process of wood pellets by adding additives, International Journal Of Energy Optimization And Engineering, 20-40, ISSN 2160-9500
6. J. Jandačka, M. Malcho, M. Mikulík, 2007: Biomasa ako zdroj energie, Juraj Štefuň – Georg, ISBN 978-80-969161-3-9
7. J. Jandačka, R. Nosek, Š. Papučík, M. Holubčík, L. Židek, R. Harant, P. Lenhart, 2011, Drevné pelety a aditíva, Juraj Štefuň – Georg, 130p, ISBN 978-80-89401-23-9
8. J. Jandačka, R. Nosek, M. Holubčík, 2011: Vplyv vybraných aditív na vlastnosti drevných peliet a na ich výrobu, Acta Facultatis Xylologiae, Zvolen, ISSN 1336-3824
9. N. Kaliyan, V. Morey, 2009: Factors Affecting strength and durability of densified biomass products, Biomass And Bioenergy, Volume 33, Issue 3, 337-359, ISSN 0961-9534
10. R. Nosek J. Jandačka, M. Holubčík, 2010: Effect of additives to wood pellets properties, Power Control And Optimization, Kuching, Malaysia, ISBN 978-983-44483-32
11. I. Obernberger, G. Thek, 2010: The Pellet Handbook, Earthscan Ltd, London, 593p ISBN: 978-1-84407-631-4
12. J. D. Payne, 2004: Predicting Pellet Quality And Production Efficiency. World Grain, 68-70.
13. R. S. Pedersen, 2003: Residual Ash Formation During Combustion Of Woody Biomass. Copenhagen: Department Of Chemical Engineering, Technical University Of Denmark
14. Pelheat – Biomass Pellet Production Guide (http://www.pelheat.com)
15. R. Samuelsson, H. Larsson, M. Thyrel, A. Lestander, 2012: Moisture Content And Storage Time Influence The Binding Mechanisms In Biofuel Wood Pellets, Applied Energy, Volume 99, 109 – 115, ISSN 0306-2619
16. R. Samuelsson, M. Thyrel, M. Sjöström, A. T. Lestander, 2009: Effect Of Biomaterial Characteristics On Pelletizing Properties And Biofuel Pellet Quality, Fuel Processing Technology, Volume 90, Issue 9, 1129-1134, ISSN 0378-3820
17. D.Tarasov, Ch. Shahi, M. Leitch, 2013: Effect Of Additives On Wood Pellet Physical And Thermal Characteristics: A Review, Isrn Forestry, Volume 2013
18. W. Stelte, J.K. Holm, A.R. Sanadi, S. Barsberg, J.Ahrenfeldt, U.B. Henriksen, 2011: A Study Of Bonding And Failure Mechanisms In Fuel Pellets From Different Biomass Resources, Biomass And Bioenergy, Volume 35, 910-918, ISSN 0961-9534,
19. L. Šooš, M. Koleják, F. Urban, 2012: Biomasa-Obnoviteľný Zdroj Energie. Vert Bratislava, ISBN 978-80-970957-3-4
20. J. Werkelin, B. Skrifvars, M. Hupa, 2005: Ash-Forming Elements In Four Scandinavian Wood Species, Biomass

And Bioenergy, Volume 29, Issue 6, Pages 451–466, Issn: 0961-9534

21. T. Winowiski, 1985: Optimizing Pelleting Temperature. Feed Management. 36:28–33.
22. A. Wolf, A. Vidlund, E. Andersson, 2005: Energy – Efficient Pellet Production In The Forest Industry – A Study Of Obstacles And Succes Factors, Biomass & Bioenergy
23. M. Zevenhoven, 2001: Ash-Forming Matter In Biomass Fuels. Ábo/Turku: Faculty Of Chemical Engineering, Ábo Akademi University;. P. 88.
24. M. Zevenhoven, 2003: Co-Firing in FBC a challenge for fuel characterization and modeling. Proceedings of the international (ASME) conference on fluidized bed combustion
25. L. Židek, 2006: Vykurovanie drevnými peletami, Biomasa, Zdruzenie Pravnickych Osob, Považská Bystrica.
26. STN EN 14775, 2009: Solid biofuels. Determination of ash content
27. STN EN 15210, 2009: Solid Biofuels. Determination Of Mechanical Durability Of Pellets And Briquettes
28. STN EN 14918, 2009: Solid Biofuels. Determination Of Calorific Value
29. STN ISO 540, 2008: Hard coal and coke: Determination of ash fusibility