APPLICABILITY AND SLAG FORMATION SURVEY OF DIFFERENT BIOMASS FUEL QUALITIES IN SMALL SCALE COMBUSTION– A SUBSTUDY IN THE EU FP7-SME PROJECT ASHMELT

Manuel Schwabl*,+; Sabine Feldmeier*; Klaus Nagelhofer*; Elisabeth Wopienka*; Walter Haslinger*;
* BIOENERGY2020+ GmbH, Gewerbepark Haag 3, 3250 Wieselburg, AUSTRIA
+ Vienna University of Technology, Institute of Chemical Engineering, Getreidemarkt 9/166, 1060 Vienna, AUSTRIA

ABSTRACT: In the future pellet market, different fuel qualities like agricultural biomass (e.g. miscanthus, straw) but also different wooden biofuels (e.g. short rotation coppice, wood thinning and waste wood) will be introduced. For the application in small scale combustion systems one major issue is the slag formation tendency of the respective fuel. At the moment a majority of the combustion systems allow the use of DIN+ or ÖNORM pellets exclusively, without losing the warranty of the boiler manufacturer. But even those standards do not reflect the slagging tendency of a fuel. The purpose of the presented work is therefore a survey of the slagging tendency and the applicability of different biomass fuel qualities in a commercially available combustion system. Combustion tests with 14 different fuels of wooden and agricultural biomass in a 15 kW boiler system using a horizontally moving grate were conducted. The applicability and the slagging tendency of the fuels were determined by evaluating the impact on the combustion system (limitations to power output, emission release, test duration until operational problems,…) and the severity of slag formation (share of slag, hardness,…). A correlation analysis of severity and applicability of the fuels allows a prediction, which fuel quality can be applied reliably to the combustion system. The considered combustion systems showed to be significantly influenced by fuels, forming sintered ashes. The results of this work will allow a correlation of the practical slag forming tendency and the respective applicability curve for a certain combustion system with results of an upcoming laboratory test for slag formation tendency within the EU FP7-SME project AshMelT.

Keywords: combustion, small scale application, biomass, pellet, ashes

1 INTRODUCTION

The EU climate and energy strategy for 2020 is summarized in the 20-20-20 targets. Until 2020 the greenhouse gas emissions shall be cut by at least 20 % of 1990 levels, the use of renewable energy sources shall be increased to 20 % of total energy production and the energy consumption shall be cut by 20 % of projected 2020 level[1]. Apart from energy savings and increased energy efficiency the use of energy from renewable sources is of significant importance in order to reduce greenhouse gas emissions. Moreover, those factors have an important part to play in promoting the security of energy supply, promoting technological development and innovation and providing opportunities for employment and regional development which are clear objectives of the European Union.

The heating sector plays a major role on the energy market. Currently about 50% of the primary energy production are used for heat production, and 50% of the final energy consumption in the EU are heat. Thus, the utilisation of biomass for heat production has the potential for considerable contributions to the EU 2020 targets.

The broad variety of properties of solid biofuels poses a big challenge in particular to combustion technologies. Apart from emissions and corrosion related problems, ash melting and slag formation in the grate section of combustion units is an issue of main relevance in the field of biomass combustion.

The presented work is part of the AshMelT project, which targets for a reliable testing method to overcome operational problems in small scale biomass combustion due to ash related issues, in particular because of the ash melting behaviour. This work surveyed the practical ash melting behaviour of 14 different solid biofuels and determined the impact on a small scale combustion system. This information will allow the development of a laboratory method in the AshMelT project (www.ashmelt.eu) to predict the ash melting behaviour and therefore will support the utilisation of sustainable resources.

Differences of the ash melting properties related to variations in elemental composition have already been documented for coal ashes. Bryers [2] for example categorizes coal ashes dependent on their relation of silica/alumina concentration. The influence of the elemental composition is even more relevant for biomass fuels due to the broad variety of raw materials and their respective properties. In recent investigations categories like "silica-rich" or "phosphorous-rich" are frequently used. Silicon rich fuels, i.e. fuel ash dominated by silicate-alkali chemistry (e.g. straw fuels), generally show relatively high slagging tendencies. Exceptions to these general trends exists i.e. fuels with high Si/K-ratios. Wood derived fuels with relatively low inherent silicon content normally show low or relatively moderate slagging tendencies. [3] However, severe contamination of sand material to woody biomass fuels may significantly enhance the slagging tendencies. [4]

2 METHODS AND MATERIALS

14 different pelletized fuels (6 mm diameter) were combusted in a 15 kW biomass boiler with horizontally moving grate. The fuels covered a broad range of ash melting behavior and included pellets from different wood species, stalk material and other raw materials. The fuels are presented in table 1, where also the ash content (obtained from ashing at 550°C) and the inorganic constituents of the fuel are displayed. The fuels cover in particular the previously mentioned groups classified in terms of ash chemistry, namely silicon lean, silicon rich and phosphorus rich. Also exotic fuels like distillers dried grains and solubles (DDGS), which is normally utilized as nutriment for cattle and is an extraordinary fuel in respect of combustion behavior, since it is rich in silicon and in phosphorus.

The combustion tests followed a certain 24h procedure. Depending on the influence of the fuel on the performance of the combustion system, the grate cleaning

Table 1: Overview on applied fuels and their inorganic constituents.

Nr.	Fuel	Type	a	Cl	S	K	Na	Mg	Al	Ca	P	Si
			[w % $_{d.b.}$]				[mg/kg $_{d.b.}$]					
1	Spruce/Pine mixture	Wood	0,5%	31	68	626	5,0	170	21	1210	68	32
2	Spruce/Pine mixture	Wood	0,4%	23	56	499	30	136	77	904	48	308
3	Beech	Wood	0,8%	24	110	1020	10	336	24	2020	78	116
4	Softwood, bark rich	Wood	0,4%	22	65	474	11	175	39	1050	39	176
5	Waste wood	Other	4,8%	1010	718	1140	1050	673	1020	4590	170	10500
6	Softwood / SRC mixture #1	Wood	0,6%	161	136	937	15	175	18	1430	234	110
7	Softwood / SRC mixture #2	Wood	0,8%	34	159	1060	17	195	47	1650	301	294
8	Softwood / SRC mixture #3	Wood	1,0%	40	234	1460	21	254	50	2310	493	285
9	Miscanthus	Stalk	3,2%	239	343	2780	87	480	233	1110	298	10100
10	Wheat straw	Stalk	9,0%	3510	1390	14600	214	1130	701	5110	882	22100
11	Vineyard prunings	Wood	2,7%	131	393	3310	62	945	371	6020	676	1770
12	Corn cobs & hay	Stalk	3,1%	2190	729	7520	112	679	315	1370	873	5290
13	DDGS	Other	6,2%	1950	12000	12800	5390	3320	26	1130	9240	1610
14	Rape seed cake	Other	7,5%	3890	6840	13200	2990	4850	38	8480	11600	373

interval and/or the thermal power output was reduced. These criteria in combination with criteria assessing the operation condition (grate temperature, emission release and test duration) describe the influence of the fuel on the combustion system and thus the applicability. The applicability reflects how the combustion system is reacting on the fuel and will show a deviation in its standard behavior, if ash-melting or clogging of the grate due to another ash related parameter occurs.
After the combustion tests the residues were assessed against their ash melting behavior. A visual classification (visual) according to Öhman et.al [5] and a granulometric classification (d80) were performed to gain information on hardness and mass of formed agglomerates. The visual classification mainly gives information on the hardness of the residues, whereas the granulometric classification

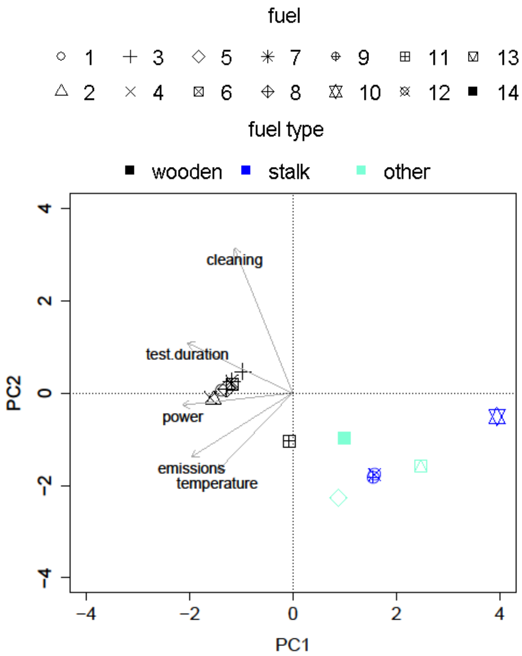

Figure 1: Principal component analysis of applicability criteria.

gives quantitative and qualitative information. Due to the energy input by the automated sieving device, the residues break up and will show a distinguishable size distribution. The quantitative information is then received in form of the total mass of agglomerated residues. In combination with the ash content (a) these criteria describe the severity of the ash related challenge to the combustion system.

3 Results & discussion

Figure 1 shows a principal component analysis of the applicability criteria. The wooden fuels influenced in particular the emission release and showed different behavior in the combustion temperature. However, a decrease in cleaning interval or thermal power output was not necessary to maintain a constant operation. Only vineyard prunings needed an adaption in the operation condition of the combustion system. The stalk material and the other raw materials needed certain adaption of the combustion system to be operated and the tests were frequently also aborted. In particular straw showed the highest impact on the combustion system, which is due to

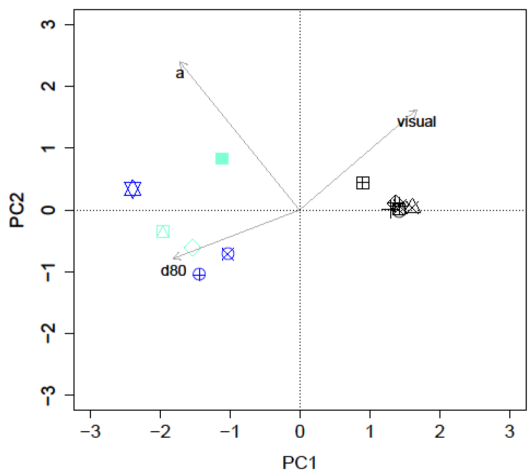

Figure 2: Principal component analysis of severity criteria.

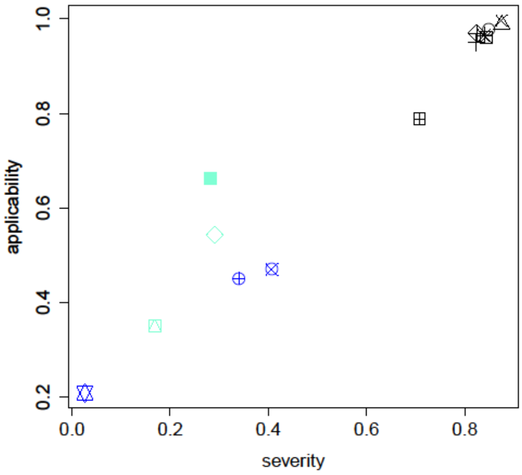

Figure 3: Severity of ash related challenge versus applicability in the concerned combustion system

the adaption of operating conditions (reduction of fuel load and increase of cleaning interval) but also the impact on the operation conditions (high emissions, high variance in grate temperature and short test duration). This impact on the operating conditions of the combustion systems originated in the severity of the formed residues.

Figure 2 shows the distribution of the severity criteria for the surveyed fuels. The wooden fuels show only limited variance in their severity character. Vineyard prunings are identified by higher ash content in comparison to the other wooden fuels. The other wooden fuels only vary slightly in their d_{80} and their ash content. The visual classification of the surveyed wooden fuels resulted all in the same value (2a according to Öhman et.al [5]). Nevertheless the variance in the severity character of wood fuels is low, one have to keep in mind that this survey is referring to the most sever fuel, which was found to be straw. Hence, the small variance is significant and is reflecting a different behavior in the ash related severity to the combustion system.

The variance of stalk and other materials in their severe character is much higher. In particular the ash content, but also the visual and granulometric classification result in a broad variation of their challenging character to combustion systems. As already mentioned, straw was found to be the most severe fuel; its residues were characterized with high ash content, high d80 diameter and low visual classification. The residues of combustion of waste wood, DDGS, miscanthus and corncobs/hay also showed a high amount of formed slag, but were significantly lower in the ash content. The residues of rape seed cake on the other hand were characterized by a high ash content, but lower amount of formed slag in comparison to the other stalk and other materials.

Both groups of assessment criteria (impact on combustion system and characterization of residues) were concluded in two final values for applicability and severity. This conclusion was done by normalization of each measured value and implementing a weighted average according to the importance of each criteria towards the impact on the combustion system. An applicability of 1 is defined as absolutely no impact on the combustion system, whereas severity of 1 means totally not severe or better said 0 means absolutely severe residues. The correlation of the resulting applicability and severity is shown in Figure 3. As can be seen, the applicability of the fuel in the respective combustion system is decreasing with decreasing severity, which means the more severe the residues, the higher the impact on the combustion system. Overall the correlation achieves a correlation efficient of 0.97. Furthermore the correlation also reflects that different wood qualities and thus different severity of the residues influence the combustion system in a distinguishable manner.

4 CONCLUSIONS

A method to determine the impact of slag forming fuel on a combustion system was elaborated and applied. The results show a direct correlation of the applicability of and the severity of the residues. The applicability includes the impact on the power output and cleaning interval, as well as on emissions, temperatures and testing duration. The severity of the residues is characterized in terms of slag formation tendency, hardness of formed slag and ash content of the fuel. In particular the valorization of the impact on combustion systems is promising, in particular in terms of comparison to other combustion systems. Depending on the combustion technology a different applicability to severity curve is expected, which is also topic of the ongoing research in the AshMelT project.

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