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Development of a practical and reliable ash melting test for biomass fuels, in particular for wood pellets

Informe

Información del proyecto

ASHMELT

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Sin desperdicio: la potencia de la biomasa

Final Report Summary - ASHMELT (Development of a practical and reliable ash melting test for biomass fuels, in particular for wood pellets)

Executive Summary:
The broadening of the bioenergy fuel resources is a dedicated goal to comply with EU2020 targets. This broadening will also apply for heat production in small scale. However, up to now dedicated methods to assess the fuel quality concerning ash melting is missing. The AshMelT project aimed on the development of methods to provide information about the melting properties and slag formation propensity of biomass fuel ashes. 3 SME AGs (AEBIOM, PPA, DS-TI), 1 boiler manufacturer (Ligno), afuel provider (Schellinger) utility provider (SKELL) cooperated within the AshMelT project to investigate, develop and validate test methods for the ash melting properties.
Basis for this was a broad review on available test methods and assessing them according to defined criteria containing: Implementation aspects for standardisation, economic aspects, handling and safety aspects, accuracy and differentiation and slag predicting capacity. After all, two methods were selected and further optimised: Slag Analyser and PASSA test method. In Round Robin testing, the test methods had to withstand the critical eyes of overall 12 different laboratory institutes and were investigated in terms of reproducibility and repeatability.
To compare the test results with results from practical combustion tests, overall 93 combustion tests in 9 different combustion appliances applying 20 different wooden and non-wooden fuels were conducted. These tests resulted in two criteria: severity and applicability. The severity described the challenge posed by the residues to the combustion systems; the applicability was defined as the impact on the operation of the combustion system. The more severe the residues of fuel combustion were, the less applicable became the fuels in the combustion appliances. Additionally, a fuel classification system was developed, which allows the correlation of fuel properties with the impact on the combustion systems.
Overall project outcome are two draft standards for the Slag Analyser and the PASSA method, which will be proposed to WG5 of TC238. Furthermore, on the basis of the practical relevance a proposal for implementation of threshold values for the slag index within the ENplus label were made. A final comprehensive report on all findings of the project will be released in summer 2015 and will be made available for download from the AshMelT website.
Concluding, the AshMelT project has developed two methods to predict the slag formation.. The research

performed and developments achieved in the project contributes to the deeper understanding of the complex mechanisms of ash chemistry, which occurs when combusting biofuels in small scale combustion appliances. Thus, the findings will definitely help to broaden the applicable fuel resources for heat production.

Project Context and Objectives:
Project Concept
The utilisation of renewable energy sources is a considerable contribution to the EU 2020 targets, and the utilisation of solid biomass for heat production is of great relevance in this regard. The market for solid biofuels is growing rapidly, and the demand for raw materials is increasing. Consequently it is aimed at extending the raw material basis for biofuel production covering also wooden materials of lower quality as well as agricultural raw materials and residues, which often show unfavourable ash melting properties.
The ash fusion test (AFT) is the only standardised method (CEN/TS 15370) currently available to assess the ash melting behaviour of solid biomass. But the significance of this test is frequently criticised, in particular the applicability for low-quality wood or non-wooden biomass. Thus, a respective normative regulation has not been included in the EN 14961 2, which is considered a major drawback for future development of the high quality end consumer market for wood pellets.
A number of alternative test methods have been developed to predict the ash melting properties of biomass fuels, but predictions and test results have scarcely been evaluated regarding their significance with regard to the practical performance of the fuels during combustion.
The objectives of the AshMelT project therefore are to
■ Develop a test method for the assessment of the ash melting characteristics of solid biofuels
■ Specify ash melting classes for solid biofuels
■ Work out a proposal for a European standard for the developed test method
■ Develop a proposal for the implementation of the developed procedure as a testing reference in the ENplus® wood pellets label
3 SME AGs (AEBIOM, PPA, DS-TI), 1 boiler manufacturer (Ligno) a fuel provider (Schellinger) and a utility provider (SKELL)) cooperate within the AshMelT project. RTD work is outsourced to a number of RTD institutions in different European countries: All RTD-partners involved have vast experience in the field of slag formation of biomass fuels in terms of fuel and ash analyses, test methods and experimental work in combustion units (BE2020, DTI, FEU, LTU, TFZ, UmU).
In order to meet the above-described objectives, the project work follows a five-stage approach comprising (1) information gathering, (2) evaluation of methods, (3) method optimisation and (4) validation and (5) dissemination of the project results as shown in Figure 1. The scientific partners contribute with their methodoligical know-how, their competences in the field of ash chemistry and their expertise on combustion technology. The associations and the involved industry partners will evaluate the proposed methods regarding their practical applicability.

State of the art – WP2
The general objective of this WP is to provide a sound summary of the state-of-the-art regarding the topics investigated within the project, and to evaluate available test methods aiming at determining 3-4 methods for practical evaluation in WP 4. Therefore particular objectives are
• to provide an overview about relevant fuel properties and possibilities for fuel classification with regard to ash melting behaviour

• to provide an overview about available methods to determine the slagging behaviour of solid biomass in combustion processes (i.e. melting of the bottom ash)
• to summarise conclusions regarding the applicability of these methods as well as the significance of the respective results
• to summarise results and findings regarding slag formation from investigations in state-of-the-art combustion units

Evaluation of laboratory tests – WP4
In the work package several logistic objectives had to be met: fuel selection and provision for slagging tests and chemical and physical fuel characterisation. But additionally, some profound scientific goals were also defined: They were to gain experience with several laboratory based slagging test methods and to validate their differentiation capacity by results achieved from using the same fuels in long term test bench trials with several boilers. Furthermore, it was also the goal to develop a decision supporting matrix for selecting the best suitable method for further optimisation throughout the course of the project (WP 6).

Method development and evaluation – WP6 and WP7
The objective of WP6 was to further develop and optimise the methods chosen from screening test made in the start of the project. The method were optimised and tested with respect to repeatability and reproducibility. Special focus was set on increasing distinction between different low slagging samples (eg. woody pellets) which has been a significantly weak point for previously developed methods. Finally, these new methods should be constructed and described in a form suitable for a Round Robin test. The accuracy – repeatability and reproducibility - of this methods are evaluated. Based on the description of these methods the developments of first standard drafts are supported.

Analysing the practical relevance – WP5 and WP8
Practical relevance denotes the slagging behaviour of biomass fuels in the final application of the fuel – in small scale combustion appliances. The objective of these work packages was to develop a methodology to investigate the slagging behaviour in various combustion appliances. Finally, the results of the slagging behaviour retrieved under practical conditions are compared with the testing methods developed in the AshMelT project.

Fuel classification system – WP3
In parallel to the method development, the overall aim of WP 3 was to formulate a classification system that gives information of the slagging tendency of a particular fuel in a particular combustion appliance. To achieve this general aim, the specific objectives of this study include:
• to define the nature and the parameters of the test fuels chosen for the project (task 3.1). The selected fuels shall: i) cover a wide range of raw materials/fuels as defined in CEN/TS 14961-1, ii) represent raw materials interesting for the European pellet market, and iii) represent a wide range of the ash forming elements that are important for slag formation.
• to describe the criteria for the assessment of an adequate classification system related to the slagging tendency of a specified fuel (task 3.2)
• to give a detailed description of a fuel classification system relating raw material composition, ash content, concentrations of ash forming elements and type of combustion appliance to slagging tendency and potential operational problems of a fuel (task 3.3-3.4).

Project Results:
State-of-the-art methods to investigate the slag formation propensity

Regarding theoretical methods, both slagging indices and ternary diagrams focus on ratios of Si, P, alkali (Na, K) and alkaline earth (Ca, Mg) contents in the ash. It might be feasible to establish thresholds for these ratios to be considered as relevant parameters for slagging hazard prediction. In addition, multiphase multicomponent equilibrium calculations can provide additional information on melting mechanisms.
Overall 14 different laboratory methods to characterize the slag formation propensity of biomass fuels were reviewed. The Ash Fusion Test (AFT) is still the only standardized methodology (CEN/TS 15370)to assess the slag formation propensity of fuels. Therefore was be considered as a reference method to which compare new methods. However, the standard AFT has been extensively criticized in the literature (e.g. Wall et al., 1995; Coin et al., 1995; Gerald et al., 1981; Huggins et al., 1981, Öhman, 1999, Van Der Drift and Olsen, 1999). One general criticism is the relevance of the ash sample, which is subjected to the test. The ashing temperature used to generate the ash sample is much lower, and the history and atmosphere of the ash are all quite different to what any ash has experienced in combustion situations. Another criticism is that changes in the shape of the sample during heating, due to phase transitions and chemical reaction, can also be interpreted as initial melting (Öhman, 1999, Van Der Drift and Olsen, 1999).
Melt Area Fraction (MAF) has shown promising results). However, there is only one (non-active) user of the method. In addition, hardness and ash weight are not considered.
Thermal analysis and particularly STA methods can be regarded as promising; however, expert assessment is required for interpretation and should be regarded as a promising research tool.
Compression strength method has shown poor performance in some studies, including both under and over-estimations (e.g. Skrivars et al., 1999). Furthermore; some authors (e.g. Llorente et al., 2005) do not consider the method to be able to predict adequately slagging of low-alkali fuels.
Oven tests including laboratory ash granulometry and hardness characterization and Slag Analyzer are promising methods, both requiring further research for potential standardization. In particular, it might be of interest to compare the ash granulometric distribution obtained in oven tests that include ash granulometry and hardness (e.g. CIEMAT method, or variation of rapid test from U. Vigo), with the ash weight, hardness and granulometric distribution from Slag Analyzer and from boiler-scale combustion tests.

The selection of AshMelT method(s) was based on the following aspects:
- Implementation aspects including the availability of the test unit on the market, possible standardisation
- Economic aspects including expected investment costs, expected labour requirement, number of staff during test performance, sample processing time requirement and the costs of any consumables
- Handling and safety aspects including complexity, requirements concerning operating materials, requirements concerning laboratory instrumentation and training and requirement for laboratory staff
- Accuracy and differentiation aspects including sample size, differentiation range, avoidance of error by subjective judgement and expected reproducibility of results
- Slag predicting capacity (“usefulness”) including easy interpretation of the results and expected predictability of slagging in fixed bed combustion

Evaluation of laboratory tests

For the investigation of the slagging behaviour 14 different fuels were selected (Figure 2) and provided to the different project partners for further analysis, laboratory tests as well as combustion tests in up to nine different pellet boilers.
Apart from the direct laboratory test methods to characterize the slagging behaviour, the amount of melted matter as an oxide/silicate was calculated by UMU using chemical equilibrium model calculations which require element concentrations of the selected test fuels as input data. From these calculations a high propensity for slagging tendencies was shown for wheat straw (F11), miscanthus (F10), untreated waste wood (F05) and corn cobs with hay (F13).
For the direct laboratory testing of the slagging behaviour the previously selected three methods (rapid slag test, CIEMAT method and Slag Analyser from DTI) were applied by TFZ, BLT, DTI and FEU. The methods are described in detail and the results are evaluated, while their advantages and disadvantages are also discussed. Combustion tests were conducted in several pellet boilers and the ash/slag residues were sampled and assessed in order to evaluate the slagging tendencies of 14 different fuels for the validation of the laboratory test methods.
It could be shown that the rapid slag test provides only very limited information about the fuel's slagging behaviour, as it only allows to draw a "yes-or-no decision", while no further differentiation between different wood fuels or agricultural fuels was possible. But the CIEMAT method and the Slag Analyser enable a differentiation between different fuel types including wood fuels. Both methods proved high capability for a correct prediction of slagging tendency. But the CIEMAT method is an extremely time consuming method so that it may take several weeks for a final evaluation of one fuel type. On the other hand the Slag analyser provides the results already within a single day. The CIEMAT method underestimated the slagging behaviour for F12 while the Slag analyser over-pre-dicted the slagging tendency for F15 compared to the results of the combustion tests. The Slag Analyser still offers several opportunities for method improvement such as the performance of the sieving with a sieving machine. Moreover, other evaluation strategies of the results obtained by the Slag Analyser can be considered and tested.
An additional method, the "Pellet Slag Sieving method (PSS)" was also tested as an add-on to the work plan. It also provides promising results and may be suggested for practical use.
A direct comparison of the different laboratory slag testing methods with the combustion tests performed in the seven boilers was not straight forward. The different combustion systems showed different slagging behaviour for some fuels, and further difficulty was given by the fact that where samples of the residues were assessed by sieving different sieve sizes were used compared to those applied in the CIEMAT method and with the Slag analyser. All available results from the laboratory methods as well as from the granulometric assessment of the ashes from one of the selected pellet boiler are summarized in Table 1. It shows, for example, that the agreement between the observed slagging severity in a boiler, as indicated e.g. by the green dots of the >1 mm ash particles in the lower graph, is quite accurately reflected by the slagging degree as determined by the Slag analyser (upper graph).

For the evaluation of the investigated methods (AFT, rapid slag test, CIEMAT method and Slag Analyser) an assessment matrix was developed and applied using also manifold technical data which had been generated during the practical method evaluation phase. The assessment matrix was based on five main criteria: Implementation aspects, economic aspects, handling and safety aspects, accuracy and differentiation aspects and slag prediction capacity (Table 2). This matrix ensured that a profound judgement and comparison of the three laboratory methods became possible. The importance of the five

criteria mentioned above was adjusted by individual weighting factors.
Among all compared methods the Slag Analyser achieved the highest ranking and it was therefore selected for further development as is seems to be most promising for a reliable prediction of slagging under real life conditions of a fixed bed combustion. Furthermore, it enables a reasonable differentiation between different wood fuels, too. Since the Slag Analyser is a very complex appliance, it was furthermore decided to develop a laboratory method, which combines the CIEMAT and the Rapid Slag test – called PASSA (Pellets ash and slag sieving assessing) test.

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Figure 2: S&T results, Evaluation of laboratory tests - Fuels for laboratory tests (all pellets) and for boiler tests (pellets in red box) (source: TFZ)
Table 1: S&T results, Evaluation of laboratory tests - Overall comparison of laboratory test methods with results from the combustion tests in one of the selected pellet boilers. All results were normalized to a scale between 0 and 1. Legend: DT = deformation temperature, HT = hemisphere temperature, FT = flow temperature
Table 2: S&T results, Evaluation of laboratory tests - Summary table of assessment matrix for method assessments with final result (score-points) achieved per method and criteria during a common evaluation with all partners involved. Score point definition 1= negative evaluation, 2= medium evaluation or undecided, 3= positive evaluation

Method development
Two methods were developed, tested and optimised in the work of WP6:
• Slag Analyser method
• PASSA (Pellets ash and slag sieving assessing) method.
The reason for the parallel work with two methods was that none of the methods could completely fulfil the set of requirements discovered during the course of the project. The Slag Analyser was found to reveal good sensitivity to distinguish between different low slagging samples and due to a real combustion process provide data that can be compared with real boilers. However, it has a disadvantage of requiring quite large samples (4,5 kg), which are larger than normal set aside samples, and also required a special made equipment for the testing (see figure 3). The PASSA method was thus developed and tested in parallel as a possible alternative method using smaller samples and mainly standard laboratory equipment such as laboratory oven. But, the smaller sample size and the simplified combustion do still raise concerns regarding its comparability with combustion in a real boiler. It is actually this challenge of comparing results in the laboratory with the results from the real boilers that became a major outcome of the results from this work package.

The Slag Analyser was significantly improved from older existing versions. Version V3 was built according to the improvements in the project. The improvements consider several aspects, such as improved automation, stability, slag resistance, tar reduction, user friendliness and especially an improved repeatability of the results. A second unit was constructed at TFZ with some of the earlier drawings of DTI. This unit did also provide a good repeatability, but comparison between of the results between the units did not reveal a reasonable reproducibility (see Table 3). Several reasons are possible, but a significant influence was different combustion temperatures between the two units.
In parallel with the development of the equipment, a great set of tests with improving the evaluation

methods were conducted. While the previous method was based on a hand sieving of the ash and slag samples after each test the new method implemented a machine sieving equal to the method used for evaluation results of the boiler tests (the granulometric sieving test). The implementation of this method enabled a better comparability of results from the boiler tests and the results from the Slag Analyser. Eg. by using the same sieving method the particle size distribution (PSD) of the boiler and the Slag Analyser slag could hereby be directly compared and revealed good correlations between the Slag Analyser and especially the reference boiler B01 from the evaluation of the practical relevance (see figure 4).
However, the implementation of this new sieving method did thus require the development of a new evaluation method and a new slagging index. While the previous slagging index was based on a 5 graded integer scale and subsequently a relative low resolution, the new slag index enabled a linear comparison on a continuous fraction scale more suitable for distinguishing between samples with close but not equal slagging tendencies. Therefore the d80 number was introduced, which describes the point (size) on a linear fitted PSD curve which resembles 80% of the total mass (see Figure 5).
The calculation of d80 enables the comparison of results between test in the old Slag Analyser V2, the new V3 and the one erected at TFZ. The results then reveal the improved repeatability of the V3 Slag Analyser, but also the difference between the DTI and TFZ Slag Analyser (see Table 3).
The formula for the new slag index of the Slag Analyser was thus calculated using the formula:
Slag index SlagAn = 2+ log ((M1+S)*d80)
Where the three parameters:
• M1 … The amount slag particles > 1mm after the sieving with the granulometric method divided by the amount of fuel used for the test (i.e. if diluted the sample size of the fuel tested without the dilution fuel) => Indicates the amount of slag per kg fuel
• S … The amount of slag sticking/fused to the grate after test divided with the amount of fuel => Indicates the stickiness of the formed slag to metal surfaces
• d80 … => The higher the particle size the larger and harder is the slag particles. The d80 is also seen to give similar values to those measured from the full scale boiler tests

The PASSA slag index is based on the input data from the sieving using the accumulated fractions >1 mm and >2 mm and the ash content after fusion test at 1000 °C in a laboratory oven. After optimisation the resulting equation was constructed for calculating a slag index:

Slag index PASSA =2*Ash(% d.b.)/10 + ∑>2mm (% of ash)/100 + 3* ∑>1mm (% of ash)/100

Thus, both methods deliver a slag index within the same fractionated number range and also reveal similar results for most of the fuels investigated in the project (see Table 4). Values between 1 and 2 are no to low slagging, 2-3 moderate slagging, 3 – 4 heavy slagging, and >4 very heavy slagging.

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Figure 3: S&T results, method development – The slag analyser equipment
Figure 4: S&T results, method development – Experimental validation- Particle size distribution of all boilers tested in WP5 compared with the average particle size distribution of the slag analyser using the granulometric sieving
Figure 5: S&T results, method development – illustration of the d80 calculation
Table 3: S&T results, method development - Average values and repeatability of d80 expressed as

standard deviation (STD) and relative standard deviation (Rstd)
Table 4: S&T results, method development – Results of the developed slag index from the Slag analyser and the PASSA method

Round robin testing

The concept and design of the Slag Analyser has been revised. A second analyser was built by TFZ. The results of the two Slag Analysers showed the same tendency comparing the three pellet samples. But there was a systematic difference between the two test apparatus, which is still under investigation. The repeatability of the Slag Analyser results was promising.
In parallel, a lab method based on investigations of FEU was developed. This method is named Pellet Ash and Slag Sieving Assessing Method - PASSA-Test. Eleven laboratories from six different European countries participated in the PASSA-round robin test. There were significant differences between the three analysed test samples. Wooden fuels showed a higher reproducibility concerning the PASSA test results than the investigated straw fuel. Besides that, the information of particle size showed a significantly decreased repeatability and reproducibility in comparison to for example ash content information.

Practical relevance of AshMelT methods

In total 93 combustion tests (55 in WP5 and 38 in WP8) were conducted. 20 different wooden and non-wooden pelletised fuels were surveyed in nine different combustion technologies (see Figure 6). The fuels covered a broad range of ash melting behaviour and include pellets from different wood species, which are presented in Table 5.

Each combustion tests followed a certain 24h procedure. An assessment method describing the fuel specific severity of the residues with respect to the combustion system and the applicability in a certain technology was developed. Depending on the influence of the fuel on the performance of the combustion system, the grate cleaning 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. After the combustion tests, the residues were assessed to their ash melting behaviour. A visual and a granulometric classification was performed to gain information on hardness and mass of formed agglomerates. In combination with the ash content these criteria describe the severity of the ash related challenge to the combustion system.

Combustion of high quality fuels result in low severe residues. The lowest severity was, however, found for fuel F08, which was a mixture of short rotation coppice and spruce. Despite the addition of low-quality wooden fuels, the residues of this fuels were characterised in almost all combustion systems with a low severity. Only the combustion in boiler B09 resulted in a significantly higher severity than in all other boilers. Similar results were found for the severity of F02 residues, which was the highest when combusted in boiler B09 and B05. Despite the high quality (ENplus A1) of this fuel, there were significant differences when combusted in the various combustion systems. The severity for F02 was found to vary by 64% of its average value. Lower fuel quality also resulted in an increase in severity and to a more narrow spectrum of severities for the various combustion appliances. The standard deviation for F15 and F18 was found to be

5-9%, whereas for F05 the residues from combustion were varying by 19% in their severity. Concluding, combusting low quality fuel results in a quite defined severity of the residues, whereas the residues of high quality fuel seem strongly vary when combusted in various combustion systems.

Each combustion appliance is reacting differently, when processing the residues of a fuel. Additionally the combustion system influences the severity of the fuel, because of the variation of combustion conditions on the grate. Figure 7 presents the correlation of severity and applicability for all surveyed combustion appliances and fuels. The chart also contains regression lines for each combustion appliance. Combustion appliances with a steep regression line are more prone to fuels with increasing severity.

The results of the combustion tests are finally compared with the results obtained in laboratory test. 3 different methods were assessed for their ability to predict the ash melting behaviour in small scale combustion systems:
• Ash fusion test according to CEN/TS 15370-1 (see Figure 8)
• Slag Analyser method (see Figure 8)
• PASSA method (see Figure 10)
The comparison of these 3 prediction methods for ash melting behaviour showed significant accordance with the slagging behaviour in real combustion appliances. All three of them allowed a differentiation of severe slagging behaviour and low – to no slagging behaviour of the fuels. However, in the AshMelT is dedicated to the slagging behaviour in particular of wooden fuels, which need a reliable method to quantify the ash melting in small scale combustion appliances. Concerning this, the ash fusion test method was lacking of information depth of its result. All wooden fuels were found having a deformation temperature exceeding 1500°C, which allowed no differentiation between their ash melting behaviour. The PASSA and the Slag Analyser methods, on the other hand, allowed also a statement on the quality of the different wood fuels. Thus, these two methods are promising an information also to differentiate different ash melting behaviours amongst wood fuels.

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Figure 6: S&T results, practical relevance of AshMelT methods - Boiler technologies
Table 5: S&T results, practical relevance of AshMelT methods - Test fuels for the combustion tests
Figure 7: S&T results, practical relevance of AshMelT methods - Severity versus Applicability
Figure 8: S&T results, practical relevance of AshMelT methods – Severity versus shrinkage starting temperature (SST)
Figure 9: S&T results, practical relevance of AshMelT methods – Severity versus Slag analyser results
Figure 10: S&T results, practical relevance of AshMelT methods – Severity versus PASSA test results

Fuel classification system.

The aim of the fuel classification system is to be able to give recommendations of the user friendliness of a certain fuel in a specific combustion appliance. The classification system should be able to define different fuels according to the following question; "What degree of slag related problems can be expected for a certain fuel combusted in a certain appliance?" The classification system will finally be presented as a matrix from which the recommendations can be deduced.
A first estimation of a qualitative fuel classification system for phosphorus poor pelletized biofuels relating

fuel ash composition and type of combustion appliance to slagging tendency and potential operational problems were thereafter formulated in task 3.3-3.4 based on:

• the outcome of a parameter study with Projection to Latent Structures (PLS) done with experimental data from WP 5 including 14 fuels combusted in 9 different combustion appliances resulting in 49 different combustion tests (see WP 5 for further details).

• additional data that have previously been produced in similar way as in WP5 with 36 different biomass fuels in the same type of under feed burner (B08) as used in WP 5. (Näzelius et al, Energy & Fuels 2015 http://dx.doi.org/ 10.1021/ef502531m).

The hypothesis pronounced in the beginning of this project, i.e. that

F(x) = problem = A*xash content + B*x conc. of important ash forming elements + C*xburner type

where A, B and C are specific constants; A) the ash content determine how much slag that is formed, B) the concentration of important ash forming elements describe stickiness and fraction of melted ash formed, and C) the burner type determine both how much slag that is formed and in what way the slag (and ash) can be removed.

The data collected in WP 5 had unfortunately varying bases which means that the predictability of the PLS analysis was quit poor implying that a quantitative model could not be presented from the data produced in WP 5. Despite that fact, the PLS modeling verifies that the hypothesis discussed in the beginning of this project seems to be true i.e. SiO_2-, ash-, K_2O-, CaO-content are the most important fuel parameters in slag formation of P-poor fuels, also affected by the burner technology (i.e. burner/grate design and operation). Hence a conceptual/qualitative classification system will be presented here.

In order to be able to present an outcome of the fuel classification system and to assess if the predicted slag formation potential is problematic or not the Y-variables “time” and “>3.15 mm” from the combustion experiments in WP 5 were used, as suggested by the parameter study performed by PLS. The parameter “time” can, however, be questioned from different aspects, e.g. that it is partly artificial as the burners are manually shut down at 24 h. This means that the results “24 h” can imply either that the combustion experiment was still running or could have proceeded, or that potential slagging caused a shutdown at this time. However as there was a lack of trustworthy data from the combustion experiment in the project Y=time was used as it was despite its origin actually give a clue of the magnitude of the potential combustion problem.

The hypotheses were described as to explain “time” or “>3.15 mm”. From the combustion experiments performed in WP5 it is clear that short (< 24 h) combustion time implies problem for the burner. For that reason the Y-parameter “time” will be denoted “problem” as the work in WP 3 aimed to answer the question: "What degree of slag related problems can be expected for a certain fuel combusted in a certain appliance?" In addition, the parameter study performed by PLS showed that the most significant parameters to explain the changes in time were SiO_2, B09 (moving grate) and CaO followed by ash content, B06 (stoker burner), B07 (auger burner) and K_2O. This occurrence allows the constants for SiO_2, B09 and CaO to be denoted with capitals to state that a change in e.g. SiO_2 will affect the outcome more than a change in e.g. K_2O. The function can be generally expressed as;

F(problem) = A*SiO_2 + b*K_2O – C*CaO + d*ash content + E*burner type (1)

There are different burner types that are significant in function (1) and according to the PLS analysis burner 09 is the most significant. Thus this burner would potentially have a higher constant than e.g. burner 07 that did not turn out to be as significant. Once more it is clear that the results of the combustion experiments from WP5 are not enough to state numerical constants. However, the results clearly show that the time for the combustion experiments are well extended when using especially burner 09, 07 and 06 making it fair to suggest a capital constant for this parameter. In addition, SiO_2 and CaO are also suggested to have capital constants but it is important to state that the constant of SiO_2 will probably be of greater value as this is the very most significant parameter.

The Y-variable > 3.15 mm used in the evaluation of the combustion results in WP 5 denotes how much of the residual ash that is larger than 3.15 mm, i.e. how much slag that is produced by each experiment (according to the slag description above). Thus, for this reason the function describes "amount of slag" rather than ">3.15 mm". The parameter study of that Y-variable show that the most important variables out of the significant ones are SiO_2, B05 (TwinHeat, stoker burner) and ash content followed by B06 (TwinHeat, stoker burner), B04 (Windhager, top feed), K_2O and CaO. This implies that changes in the SiO_2 and certain burner techniques will affect the most. Hence, the function may for that reason be expressed as;

$$F(\text{amount of slag}) = A*SiO_2 + b*K_2O - c*CaO + D*\text{ash content} + E*\text{burner} \quad (2)$$

where A, D and E are capitals to denote their higher importance in the studied experimental domain i.e. in combustion of wood derived and straw fuels. The significant burner techniques, revealed by PLS, are two kinds of stoker burners (feed from side) if to increase the amount of slag produced and a boiler with a burner cup to decrease it.

The proposed qualitative classification system as previously described as functions e.g. equations 1 and 2 have also been semi-validated with the combustion results from WP 5. In Table 7 the system of Y = >3.15 mm (amount of slag) is shown. It displays the fuel abbreviation, the fuel name, which burner that has been used and the case number. The next 4 columns display the most significant parameters of slag formation together with notation of weather the parameter will influence the slag formation negative (−), positive (+) or have no significant effect (0). The notation is based on the information in Table 6 in comparison with the normalized data of the parameters mentioned there. The next 9 columns show the different burners based on the information given in the hypothesis of Y = > 3.15 mm. The last column show the absolute results of Y = > 3.15 mm. Table 8 is built in the same way but where the hypothesis of Y = time is utilized and the last column show the absolute results of Y = time.
According to the results shown in Table 3 and 4 both classification functions seem to fairly predict the outcome. When it comes to the more troublesome fuels the burner technique will play a more crucial role there. Based on the classification system it seems as the combustibility of the more troublesome fuels (e.g. wheat straw) are more dependent on a burner type with either a moving grate or some kind of automatic ash handling system. Solutions with a burner cup is, however, not included here. This means that a fuel that is considered to be "problematic" based on its fuel composition may be possible to use in a burner that is able to mechanically push/convey away the ash from the combustion zone. In this project, technology solutions such as used for the burners B05/B06, B07 and B09 represents this category.Furthermore fuels having a rather high CaO share (e.g. stem wood without bark) in comparison to

the SiO_2 do not seem to be as sensitive of the burner type.

Please see attachment for:
Table 6: S&T results, fuel classification system - Limits for the fuel parameters that is used in the conceptual/qualitative classification system presented in this report. Data is approximated from Näzelius et al, Energy Fuels 2015 http://dx.doi.org/ 10.1021/ef502531m
Table 7: S&T results, fuel classification system - Semi-validation set of the proposed qualitative classification system/function for predicting the amount of slag formed i.e. fraction of the bottom ash from the combustion experiments with a particle size >3.15 mm (by sieving).
Table 8: S&T results, fuel classification system - Semi-validation set of the proposed qualitative classification system/function for predicting the problem arised from slag formation i.e. a matrix of the elapsed time from the combustion experiments

Potential Impact:
Classifying fuels for small scale combustion systems

This project presents a first estimation of a qualitative fuel classification system for pelletized biofuels relating fuel ash composition and type of combustion appliance to slagging tendency and potential operational problems. This classification system allows for the ability to qualitatively assess the occurrence of slag problems in fixed bed combustion of pelletized biomass fuels based on the knowledge of a fuel composition and the combustion technology used.

Assessment method for slag formation propensity of biomass fuels

In the scope of the project two methods were developed and optimized.
- Slag Analyser: A robust technical system, which operates close to operation characteristics of a combustion system. Thus allowing very similar formation conditions for slag.
- PASSA test: a quick and easy laboratory method, which allows the prediction of slag formation propensity of biomass fuels.

Determination of fuel applicability in a combustion system

Not directly in the objective of the project, but it was necessary to fulfill them – an assessment method of the applicability of a dedicated fuel quality in small scale combustion systems was developed. This method allowed the definition of an applicability of a dedicated fuel quality in a combustion appliance. The first time a ranking of combustion technologies for slagging fuels was made possible. In future, this method will be further developed by incorporating impacts of corrosion and deposit formation on the operation of the combustion system, allowing a statement on the overall applicability of a certain fuel quality in a specific combustion system.

Draft standards

The fully elaborated method guidelines for at least two of the test methods, the "PASSA-method" (or rapid slag test method) and the "Slag Analyser method" shall serve as a template for standardisation groups

(ISO TC 238), to who the methods shall be suggested for becoming full ISO standards. Currently the WG5 of TC 238 is preparing a new work item proposal for the CEN/TS 15370-1 Solid biofuels – Method for the determination of ash melting behaviour. This technical specification currently contains part 1: Characteristic temperatures method, which is the ash fusion testing method. The elaborated draft standards will be proposed to this work group as a possible extension of CEN/TS 15370 Part 2 and Part 3. As soon as, the AshMelT test is accepted as a standard method, it is aimed to integrate it as a reference method into EN 14961-2 (and possibly EN 14961-6). Participants of the AshMelT project from Austria, Denmark, Germany and Sweden will try to speed the implementation via suggestion of national supplements of the mentioned standards. The full implementation could be possible in the upcoming years. Thus, a useful alternative for low cost assessment of fuels for use in fixed bed combustion shall be enabled.

ENplus proposal

In the course of the project, a proposal for implementation of a slag index in the ENplus quality label was elaborated. This proposal will be provided to the European Pellet Council, which is able to implement the modifications with the next review of the ENplus handbook. ENplus is spreading quickly since its first introduction in Germany in 2010. In 2014 pellet producers from 28 countries are producing ENplus pellets. More than 6 million tons of actual production is certified in 2013 – this covers around 60% of the pellets used for heating in Europe! Thus, implementing thresholds for slagging propensity for ENplus labelled pellets will help to define future pellets quality market. This will have in particular two effects:
• quality assurance for end-user the end user will benefit from constant quality fuel.
• possibility to adapt combustion appliances according to their slagging behaviour future fuel market might broaden up and diversifies in their quality.

Benefit for SMEs

Two SME partners were directly involved in the AshMelT project. Schellinger KG is a pellets producer in lower Germany. Ligno Heiztechnik is an innovative boiler manufacturer, who just developed his auger burner. Both partners benefit from the R&D work conducted in the AshMelT project. Schellinger is conducting continuous quality measurements of their pellets production. For test reasons they applied an adapted PASSA test method in their quality control tests, which increases the quality assurance of their production. Ligno conducted combustion tests in the field with their auger burner applying corn cobs as fuel to the combustion system. The auger burner was further optimised by deploying the experience from combustion tests made at premises of BE2020. Therefore, Ligno is short before market introduction of their new auger burner product.
Besides the direct effects to the beneficiaries of the AshMelT project, the members of AEBIOM, ProPellets Austria and DS-TI get detailed information on the project outcome. This multiplication effect will apply to pellets producers and boiler manufacturers, allowing them to produce fuels with defined slagging qualities on the one hand and combustion appliances engineered for dedicated fuel qualities. By these means, future fuel market might be broadened up and becomes more sustainable when making more resources applicable for use in small scale applications.

Dissemination activities

The results of the AshMelT project were disseminated in 3 international workshops at premises of biomass conferences and exhibitions. Besides that, the elaborated draft standards will be proposed to WG5 of TC238 as extension of the technical specification CEN/TS15370. Furthermore, the consortium has agreed to develop a comprehensive final report, which will be a summary of all deliverables. The chemistry of slag formation and prediction in small scale combustion appliances is a very complex issue. Therefore, every lesson learned shall be communicated to the scientific community. The comprehensive final report will be available for download at the AshMelT website in summer 2015. The website will be hosted at least until 2017.

Conclusions

By disseminating the results of AshMelT to the stakeholders involved along the value chain and above all to boiler manufacturers and pellets producers a better understanding for the links between the quality of pellets and the slagging behaviour of pellets in a boiler is established. This novel understanding triggers both, increased awareness for the quality of produced and distributed pellets as well as a new thinking for developing new boiler technologies that can also handle fuels of increased slagging propensity. The AshMelT project has therefore contributed to a better understanding for the challenges of introducing new fuels into the existing pellets market. By the development of novel tools AshMelT also offers supporting measures to the development of new and tailor made pellets boilers for new pellets qualities.

Following this, the results of the AshMelt project has also inspired to future R&D where the connection of characterisation methods in the lab should be closer connected to measurements and observation in real boilers. It clearly reveals the challenge of reproducing the complex event occurring in a relatively chaotic environment such as the ash formation and liberation in a combustion zone of a biomass boiler with some controlled methods in a laboratory. Thus, any developed laboratory method will have this challenge and should be developed in close connection to tests in real boilers.

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Documentos relacionados

final1-finalreport_v1_figures.pdf

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Permalink: https://cordis.europa.eu/project/id/287062/reporting/es