QUALITY ASSESSMENT OF WOOD PELLETS FOR RESIDENTIAL HEATING SYSTEMS AND COMBUSTION BEHAVIOUR IN A PELLET STOVE

Claudia Schön, Robert Mack, Hans Hartmann
Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ)
Schulgasse 18, D-94315 Straubing, Germany, email: Claudia.schoen@tfz.bayern.de

ABSTRACT: The use of wood pellets is steadily increasing in the European Union. The majority of wood pellets on the German market carry the label EN*plus* indicating a consistent fuel quality. In order to prove this assumption 42 different pellet samples in bags were collected and extensively analyzed. This included combustion properties, physical properties as well as their chemical composition. Eight of the 42 samples did not fulfil the requirements for the standard DIN EN ISO 17225-2. But overall a positive result for wood pellets quality on the German and European market was confirmed. Interestingly, large differences in potassium content (between 280 and 900 mg/kg) which can influence the amount of particle emission were observed. During the combustion of 12 selected pellet samples, no clear dependency between flue gas emission and ash content, potassium content, bulk density or pellet length were found. Therefore, the selection of the fuel can lead to big uncertainties during the combustion in pellet stoves. This has to be further investigated in order to maybe fine the yet unknown pellet parameter influencing the emission behavior in a pellet stove.
Keywords: Wood pellets, fuel characterization, pellet stove combustion, emission.

1 INTRODUCTION

The use of wood pellets is steadily increasing in the European Union. In 2017 about 9.7 million tons of wood pellets were here consumed for residential heating [1]. The highest share was consumed in Italy with about 3.4 million tons. Industrial wood pellets are not included in these numbers. In Germany about 21 % of the produced pellets are sold in bags and almost all of the pellets (99.1 %) carry the label EN*plus* [2]. Previous studies have already shown that the quality of wood pellets can largely differ as it was shown in [3] conducting a Slowenian study. In the present study 42 pellet samples in bags were collected from the European market. 20 samples were from Germany, while the other samples were distributed from all over Europe as well as one sample originating from the USA. Most of the samples (27) carried the EN*plus* label, 22 of the 42 samples carried the DIN*plus* label while only eight samples did not carry any label. The samples were collected from fuel distributers, pellet producers and hardware stores in the year 2014. All pellet samples were extensively investigated including combustion properties, physical properties as well as their chemical composition. All values are compared to DIN ISO EN 17225-2 [4]. After the characterization of all pellet samples, 12 pellet assortments with the EN*plus* label were selected and combusted in a pellet stove with a nominal heat output of 8 kW. Finally, the results of emission measurements after the combustion of 12 pellet samples are shown and discussed.

2 MATERIAL AND METHODS

2.1 Standards of wood pellets

In order to evaluate the obtained results for the fuel characteristics, the physical and chemical requirements of the DIN ISO EN 17225-2 (Solid biofuels – Fuel specification and classes – Part 2: Graded wood pellets) are applied. Pure wood pellets from stem wood or chemically untreated wood residues are therein described by class A1 which serves as a reference in this investigation. Besides the ISO standard, two different labels are present on the market: EN*plus* and DIN*plus*, with slight differences between them as well as to the standard.

2.2 Combustion properties of pellets

The ash content is one of the main parameter to characterize the quality of wood pellets since it can be seen as an indicator for impurities of the fuel. It is determined following DIN EN ISO 18112 [5] and is limited to 0.7 w-% within the standard. The moisture content is determined in accordance to DIN EN ISO 18134-2 [6] and has to be below 10 w-% in order to meet the standard and the label requirement. The determination of the net calorific value is described in DIN EN ISO 18125 [7].

2.3 Physical properties

The bulk density was determined following the procedure described in DIN EN ISO 17828 [8]. The determination of the mechanical durability was done in accordance to DIN EN ISO 17831-1 while the content of fines was investigated based on DIN EN ISO 18846 where the fraction of particles smaller than 3.15 mm was removed using a perforated metal plate sieve [9][10].

The pellet length and diameter may influence the property for fuel transportation, flow properties as well as storage properties. Too long pellets can block the feeding screws or reduce the fuel throughput reducing the heat output of the furnace. Moreover, the fire bed and the emission behavior may be influenced by the pellet length [16]. In contrast to wood chips no average pellet length has been defined yet in any standard, only the diameter and maximal pellet length are defined. In the future, the average pellet length may become more important especially for the emission behavior during pellet combustion in stoves and boilers. For the determination of the pellet length, at least 40 to 50 pellets were used following the procedure of ISO/DIS 17829 [11].

Besides the durability of pellets also the hardness indicates the stability of a pellet and it is defined as the force that is needed to crush a pellet. However, the method for determining hardness of pellets has not been standardized yet and therefore it is briefly explained. The pellet hardness tester by Amandus Kahl was used in this investigation. This tool consists of two screws, a hammer, an ambos and a cylinder containing a spring with a scale for value determination. Five pellets were randomly selected for each pellet assortment. The highest value that could be determined with the mentioned equipment was 700 N because the spring could not be further compressed. Therefore, in case a pellet did not burst at this force, the final value for the evaluation was set to 710 N which was later considered for the determination of average values.

2.4 Chemical composition

The chemical composition influences the combustion behavior as well as the particle emission. Therefore the main component, trace elements and heavy metals are of interest for characterizing wood pellets. All values were determined in an external laboratory (Eurofins Umwelt Ost GmbH) following the existing standards.

2.5 Combustion tests in a pellet stove

For the investigation of different fuel parameters combustion tests on a 8 kW pellet stove without water jacket were performed using 12 pellet assortments from the screening. All fuels fulfilled the EN*plus* label requirements.

The combustion tests were conducted at TFZ in Straubing and the experimental setup for the combustion trials is shown in Figure 1.

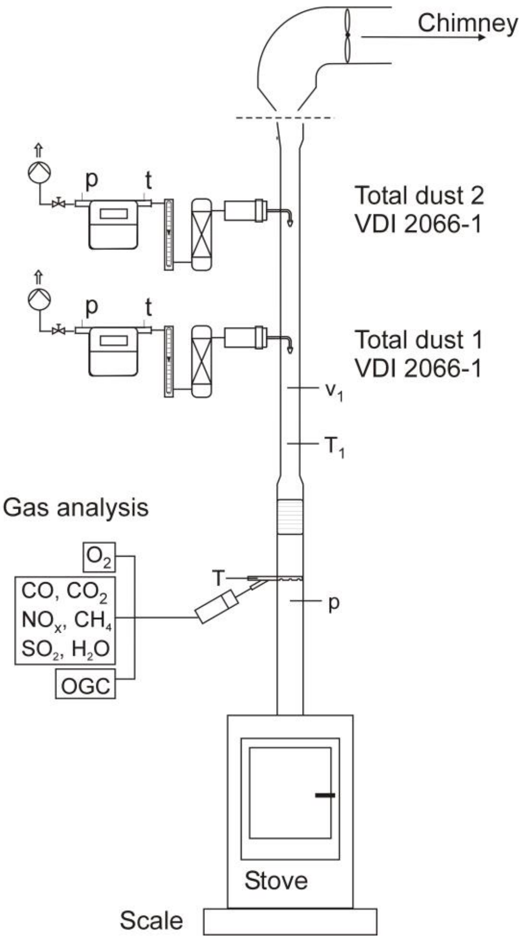

Figure 1: Experimental setup for combustion tests at TFZ

The pellet stove was placed on a scale in order to continuously record the fuel consumption. The flue gas temperature was measured using a thermocouple of type K. The flue gas duct for dust sampling was reduced to an inner diameter of 64 mm in order to increase the flue gas velocity for a reliable isokinetic total particle matter (TPM) sampling.

For every fuel assortment three measurements for gaseous and particle emissions were conducted at stable full load operation. Each measurement lasted for 15 minutes.

The pellet stove was ignited with the first type of pellets and operated until stable conditions were reached at full load. Afterwards three subsequent particle measurements in accordance to VDI 2066 were conducted at a duration of 15 minutes each [12]. The flue gas composition was recorded and evaluated for the same duration. Afterwards, the remaining wood pellets were removed from the fuel storage and replaced by the next type of pellets. The next measurements were conducted after stable operation was achieved again. This procedure was conducted for six pellet types before the pellet stove was shut down. The other six pellet types were combusted on the next day following the same procedure.

3 RESULTS AND DISCUSSION

3.1 Results on combustion properties

The ash content on dry basis of all samples is shown in Figure 2 and is sorted in increasing order. The ash content varies between 0.22 and 0.52 w-% except for sample number 42 having an ash content of 1.0 w-% and exceeding the limiting value of 0.7 w-% as defined in the standard DIN EN ISO 17225-2 for grade A1. The average ash content is 0.35 w-% representing very good results.

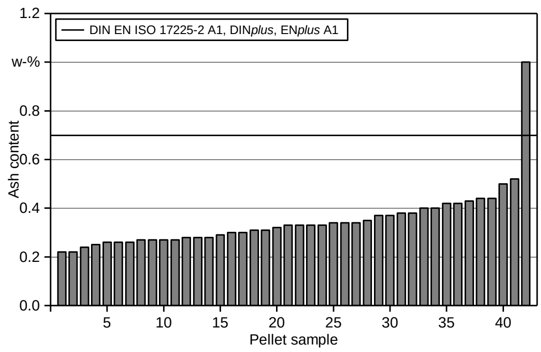

Figure 2: Ash content of pellet samples on dry basis

The moisture content of all samples varied between 3.3 and 10.8 w-% with an average value of 6.9 w-%. The highest value was achieved for sample number 39 and it therefore exceeded the limiting value of 10 w-% given in the standard.

The average value of the net calorific value on dry basis was 18.96 MJ/kg with values between 18.68 and 19.37 MJ/kg.

3.2 Results on physical properties

One of the physical properties determined in this investigation was the bulk density and the results are shown in Figure 3. As it can be seen the bulk density varied between 599 kg/m³ for sample number 21 and 709 kg/m³ for sample number 39. The solid line in

Figure 2 indicates the required bulk density of the pellets in order to fulfil the standard. Only one sample does not meet the requirement of 600 kg/m³.

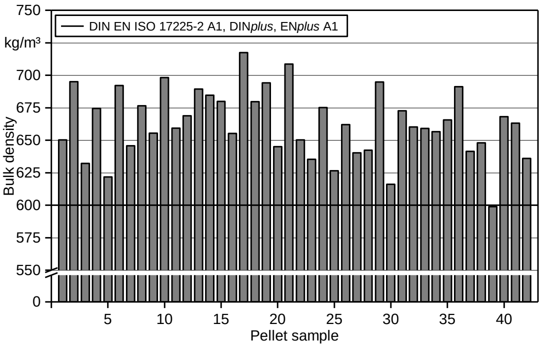

Figure 3: Bulk density of pellet samples

The results for the durability of the pellets are summarized in Figure 4; a minimum value of 97.5 w-% is uniformly required to fulfil the standard and label requirements (indicated by the solid line in the diagram). All samples except for sample number 23 and 39 are in accordance to the standards.

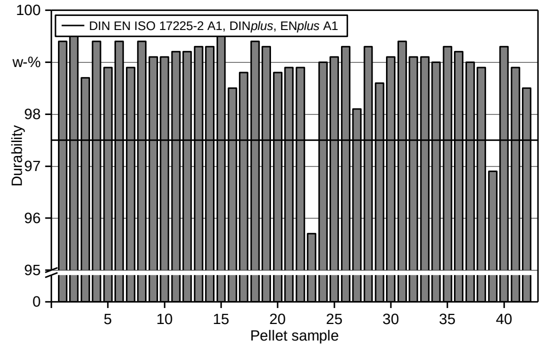

Figure 4: Durability of pellet samples

The share of fines had to be below 1 w-% and only two samples exceeded this threshold, number 30 with 1.1 w-% and 39 with 5.7 w-%. For pellets in bags the limiting value is stricter with 0.5 w-% of fines in the fuel, which is fulfilled for 33 samples in this investigation, Figure 5.

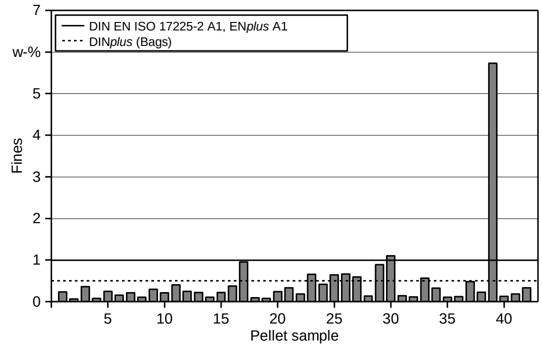

Figure 5: Fines of pellet samples

The results of the pellet length are summarized in Figure 6. The average pellet length was 13.3 mm for all samples but large deviations for each pellet sample were observed. The shortest pellets with an average length of only 7.6 mm were found in sample number 9, while the longest pellets with an average value of 17.1 mm were found in sample number 31. Overall the shortest pellet was only 3.2 mm long while the largest pellet was 39.7 mm. No pellets larger than 40 mm were found and therefore no pellet assortment contained any overlong pellets as defined in DIN EN ISO 17225-2.

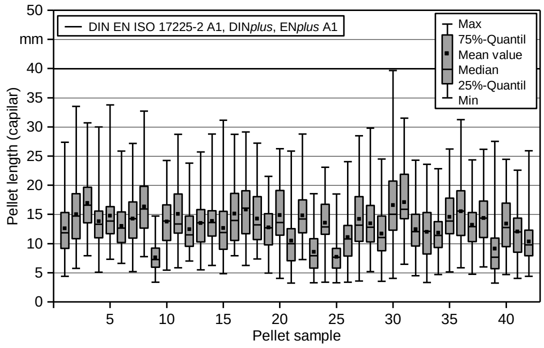

Figure 6: Pellet lengthes determined by using a caliper

All pellet samples had an average diameter of 6±1 mm and fulfilled the requirements of DIN EN ISO 17225-2.

Another physical property was pellet hardness and the obtained results can be seen in Figure 7. The average value for pellet hardness was 560 N. The absolute highest value for hardness could not be determined with the equipment since the highest value was limited to 700 N. The lowest value with only 200 N was determined for sample number 39. Three samples (30, 37 and 38) showed very high hardness with average values above 700 N. In contrast to that, sample 39 and 40 showed the lowest values for hardness with 320 N and 350 N respectively. In general it has to be pointed out that the determination of hardness includes uncertainties since the moment of breaking apart is yet not clearly defined. At the highest values of 700 N, 28 % of all samples showed bruises and cracks but they were not completely broken. It is questionable if the determination of hardness will become an international standard.

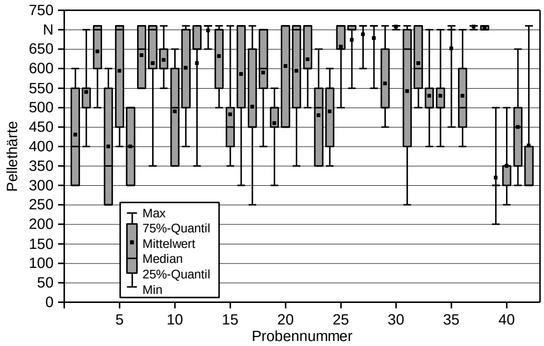

Figure 7: Hardness of pellet samples

3.3 Results on chemical composition

Wood in general consists of carbon (C), hydrogen (H) and oxygen (O). The heat released during the combustion process is caused by oxidation of carbon and hydrogen. The oxygen content in the fuel supports the oxidation process. The investigated wood pellets consisted of 50.8 w-% carbon, 43.0 w-% oxygen and 6.1 w-% hydrogen in average. Only slight variations for C and O were noticed.

Fuel nitrogen is responsible for the formation of nitric oxides during combustion and therefore it is not trapped in the bottom ash. The nitrogen content for untreated wood is generally low and the average value for all pellet samples is 0.1 w-%. The highest value with 0.25 w-% was achieved for samples 17 and 40 but both still were in accordance to all standards and labels.

Sulphur causes the formation of sulphur oxide during combustion which can lead to corrosion problems in a stove or boiler. The sulphur content is lower compared to nitrogen. In 23 of 42 samples no sulphur could be determined since the values were below the detection limit of 0.005 w-%. All pellet samples fulfil the regulations for the European standard, but two samples exceeded the threshold for S for the DIN*plus* and EN*plus* certificate (production year 2014), number 11 and 39 with a sulphur content of 0.032 w-% and 0.037 w-% respectively.

Chlorine is a highly volatile component causing aerosol and dioxin/furan emission. It can also cause corrosion on surfaces e.g. on heat exchangers. Therefore the chlorine content is limited in the European standard to 0.02 w-% which was not fulfilled by samples number 5 and 37 having a chlorine content of 0.025 w-% and 0.03 w-%, respectively. For 24 out of 42 samples the chlorine content was below the detection limit of 0.005 w-%.

Magnesium (Mg), calcium (Ca) and potassium (K) influence the ash melting behavior during combustion and none of these three elements are limited in the European standard. According to most studies potassium decreases the ash melting temperature while calcium increases it. Therefore a high amount of Ca reduces the risk of slagging. A high amount of K may lead to an increased particle emission by aerosol formation. Ca and Mg are not volatile and therefore no additional particle formation is caused and they are mainly found in the bottom ash [13]. The content of Ca, Mg and K is given in Figure 8. In average the element content was about 140 mg/kg for Mg and 826 mg/kg for Ca in the tested pellets. The amount of Mg hardly changes, while the amount of K shows some deviations with values ranging from 280 mg/kg to 900 mg/kg, the average was 528 mg/kg, Figure 8.

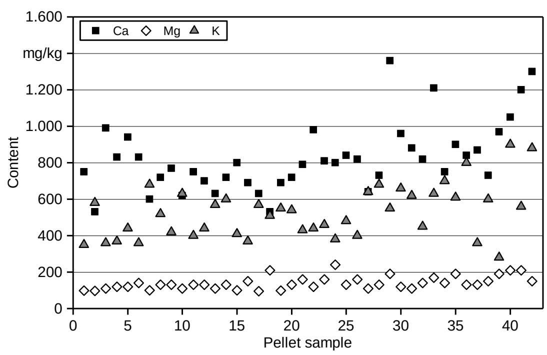

Figure 8: Content of Ca, Mg and K in the pellet samples on dry basis

Silicon (Si) was also determined because it could serve as an indicator for any secondary impurity in case of high ash content and it influences the ash melting behavior negatively. No values for Si could be detected for 18 samples since the detection limit of 100 mg/kg was not exceeded. All other values vary between 112 mg/kg and 553 mg/kg except for sample 42 with a Si content of 1,840 mg/kg.

Heavy metals primarily influence the ash quality. Therefore the content of arsenic (As), lead (Pb), chromium (Cr), cadmium (Cd), copper (Cu), mercury (Hg) and zinc (Zn) is limited in the European standard DIN EN ISO 17225-2. The content of Cr, Cu, Pb and Ni is limited to 10 mg/kg in the European standard. For the majority of samples no value could be determined since the values were below the detection limit of 1 mg/kg. Only pellet sample number 10 exceeded the limiting value with a chromium content of 11 mg/kg. All values for As and Hg were below the detection limit and are therefore in accordance to the European standard.

Finally, all aerosol forming elements (K, S, Cl, Pb, Zn and Na) were summed up and are shown in Figure 9. The highest share of aerosol forming elements is contributed by potassium (K), namely 74 % in average.

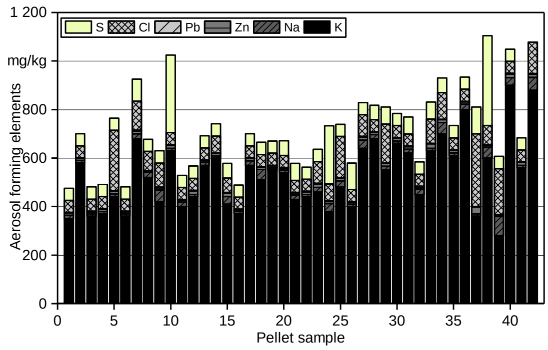

Figure 9: Aerosol forming elements in the pellet samples on dry basis

All single values for the investigated parameters can be found in [14]. In another pellet study with about 250 high quality pellets the potassium content varied between 17 to 1,160 mg/kg having an average value of 557 mg/kg [15].

3.4 Results on combustion tests

For the combustion tests twelve pellet samples from the screening were chosen. These further investigated pellet samples were number 1, 9, 19, 24, 25, 30, 32, 34, 36, 38, 39 and 40, all were carrying the EN*plus* label. In the following figures only the results on carbon monoxide (CO) emissions as well as total particulate matter (TPM) emissions are shown. All values are referred to 13 % oxygen content.

The first parameter of interest was the potassium content in the fuel. For pellet boilers with complete combustion it is well known that with an increasing potassium content the particle emission will also rise. But this observation could not be confirmed for the trials with the selected pellet stove, see Figure 10. The lowest emission was achieved for the pellet sample number 9 having a potassium content of 420 mg/kg and caused only 86 mg/m³ on CO and 45 mg/m³ on TPM while the highest TPM emission (202 mg/m³) was caused by the fuel with a potassium content which was only slightly higher, at 480 mg/kg.

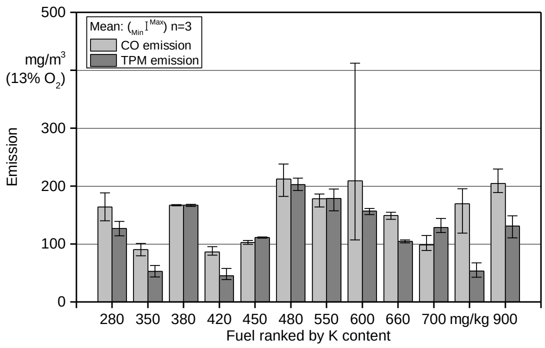

Figure 10: Influence of increasing potassium content on CO and TPM emission during the combustion in a pellet stove with a nominal heat output of 8 kW

Another parameter that may influence the emission behavior can be the bulk density of the fuel since it will influence the amount of fuel per screw rotation transported into the combustion chamber. The results are summarized in Figure 11. The lowest CO and PM emission were caused by the fuel having a bulk density of 655 kg/m³ which almost represents the average value of the pellet assortments in this comparison.

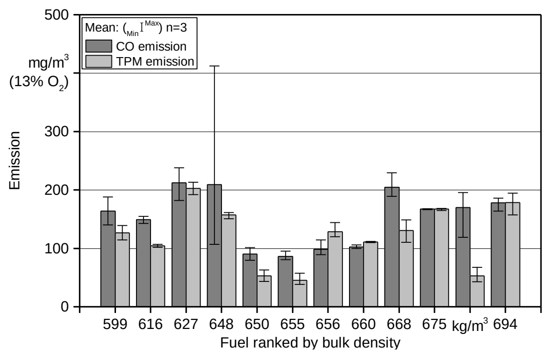

Figure 11: Influence of increasing bulk density on CO and TPM emission during the combustion in a pellet stove with a nominal heat output of 8 kW

The last parameter in this additional evaluation was the average pellet length which varied from between 7.6 and 16.6 mm among the 12 pellet assortment tested, see Figure 12. No clear dependencies between pellet length and flue gas emissions were here detected. However, such an impact had been proven in an earlier study, where the pellet length had been the only variable parameter in a series of trials performed by Woehler et al. [16].

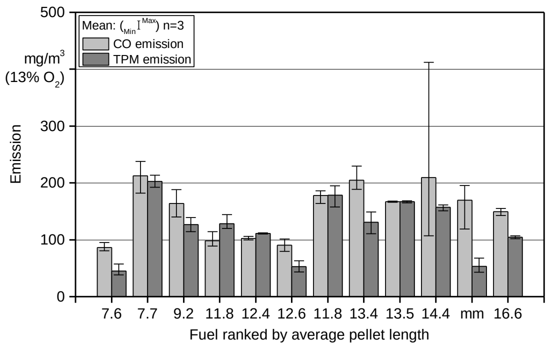

Figure 12: Influence of increasing average pellet length on CO and TPM emission during the combustion in a pellet stove with a nominal heat output of 8 kW

A multiple regression of the obtained data also was performed, but no findings concerning any correlations or interactions between the fuel properties and the emission behavior were made.

4 SUMMARY AND CONCLUSION

A wood pellet screening was conducted including 42 different pellet assortments collected from all over Europe with the main focus on the German market. Almost all pellet samples fulfilled the requirements, but there were some exceptions.

The influence of different fuel parameters of wood pellets was investigated at a typical pellet stove which was believed to be more sensitive towards variable fuel properties compared to a pellet boiler. Although differences for CO and TPM emissions were large and also quite repeatable, they could not be attributed to either of the tested fuel parameters as they are currently specified in the international wood pellet standard ISO 17225-2 or to any of the other parameters which were additionally assessed here. All 12 combusted pellets were in compliance with ISO 17225-2 having A1 quality.

This indicates that simply by screening and a clever choice of the best suitable pellet product, any official type test could be “manipulated” and the stove could pass the test, although with the majority of all other available wood pellets the same stove would in reality perform much worse. Therefore, further research is necessary in order to find a yet unknown fuel parameter which can explain the unexpected differences in combustion behavior of wood pellets in pellet stoves. This is currently the goal in the new research project “FuturePelletSpec” that was launched in March 2019 at TFZ.

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7 LOGO SPACE

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