Paper submitted for WSED next 2015: Young researcher: Biomass

Development of a novel wood pellet durability tester for small samples

Christoph Schilling*[a, b], Marius Wöhler*[▲, a], Fahimeh Yazdanpanah[b], Xiaotao Bi[b], Anthony Lau[b], C. Jim Lim[b], Shahab Sokhansanj[b,c], Stefan Pelz[a,]

* Joint first authors

▲ Corresponding author: woehler@hs-rottenburg.de, phone: +49 7472 951 269, fax: +49 7472 951 200

a University of Applied Forest Sciences Rottenburg, Schadenweilerhof, D-72108 Rottenburg am Neckar, Germany

b Chemical and Biological Engineering Department, University of British Columbia, Vancouver, BC, V6T 1Z4 Canada

c Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37381, USA

Introduction and Objectives

The EU climate and energy strategy for 2020 relies on an increase in the percentage of biomass used for household heating purposes. Small-scale biomass heating systems such as biomass fired room heating appliances and biomass boilers will play an increasing role in Europe. However, such heating systems differ among each other in efficiency and emissions which is mainly correlated to the used type of fuel such as pellet or firewood (Schmidl et al. 2011). The fact that wood pellet fired combustion systems provide the highest efficiency with the lowest emissions compared with other biomass heating systems will lead to an increasing market for wood pellets.

In the last twenty years, the mainly locally oriented wood pellet market has developed into an international fuel business with stakeholders around the world (Döring 2011). At the same time, research activities in the field of wood pellets have also been extended worldwide. One important part of this research is the study of the pelletability of feedstock. The investigation of the initial biomass properties, the pelletization behaviour and the properties of the produced pellet provides fundamental data about the feedstock suitability for pellet production. Single pellet press (SPP) units are used in several studies for pelletization (Stelte et al. 2011, Carone et al. 2011, Rhén et al. 2005, Wöhler 2011, Nielsen et al. 2010) and are useful to study the pelletization process itself (Stelte et al. 2011, Mani et al. 2006, Nielsen et al. 2009) or to verify models of pressure and friction during the densification process (Holm et al. 2006). One advantage of a SPP is the small amount of feedstock required for pelletization experiments. This is an advantage for material requiring complex pre-treatment processes such as steam treatment or torrefaction (Lam et al. 2013).

After the densification process several properties are measured to verify the pellet quality. To accurately compare research results with industrial wood pellets, often quality related parameters from pellet standards (e.g. EN*plus* based on EN 14961-2) are used. To measure parameters such as diameter, length, water content, ash content and chemical composition, the methods defined in the pellet standards are used. One key parameter for wood pellet quality is the mechanical durability, which is defined as the ability of wood pellets to remain intact during exposure abrasion and shocks caused by handling and transport (Obernberger, Thek 2010). According to the common mechanical durability measurement method (EN 15210-1:2009) samples of 500 g (± 10 g) wood pellets are stirred in a special durability-testing unit with a rotating tumbler. In this process, the pellets are mechanically stressed by collisions against the tumbler casing and against other pellets.

However, this durability test method is unsuitable for pellet research with small sample sizes (i.e. using a SPP). The production of 500 grams of wood pellets with an SPP is generally not possible within the time and budget constraints of research.

Various studies have measured the durability parameters with small samples. Oveisi (Oveisi 2011) used a dural tester, which consists of a rotating impeller in a canister similar to a household grinder. Extensive tests with different settings showed consistent results with an optimum sample size of 200 g. In addition, Oveisi et al. studied the mechanical durability of wood pellets by drop tests, which required samples of 300 g (Oveisi et al. 2013). One other

common method to determine the pellet durability is the measurement of the internal strength by compression tests of a single pellet (Nielsen et al. 2009, Stelte et al. 2011, Wöhler 2011, Lam et al. 2013). During these types of tests, a pellet is placed on its side between two anvils in a compression tester. The top anvil is moveable and attached to a load cell. The pellet is compressed by the top anvil using a defined velocity while force and displacement are recorded. The maximum force the pellet can withstand before crushing defines the pellet strength. We found that strength measured using this method varies widely. For example testing 100 wood pellets for hardness averaged 78 N with standard deviation of 139 and a coefficient variation of 50% (Cannayen et al. 2009). One drawback of pellet-strength measurements is the inability to compare the measure strength values with the results from the tumbler testing method, or durability during transport.
The aim of this study is the development of a novel pellet durability test, which fulfils the following requirements:

- Practicable with a small sample size of a few pellets
- Mechanical stress similar to the tumbler method
- Reliable and reproducible

Material and Methods

For the development of a new wood pellet durability test, a novel shaker was developed. To evaluate the new system a parametric study using various configurations (i.e. samples size, test duration) were performed. Tumbler test according to DIN EN 15210-1 (EN 15210-1:2009) were carried out to verify the shaker results. The small shaker concept was proposed by Sokhansanj and was designed and tested by the senior author during his study exchange at the University of British Columbia.

Shaker construction & operation

The shaker consists of stainless steel box with inner dimensions of 60 x 60 x 60 mm. The thickness of the walls is 3.175 mm. The upper housing section includes a removable lid for sample loading and unloading. The box is sealed with this precisely machined lid which allows operation without sample loss (see Figure 1). One side of the box is attached to a 100 mm extension arm, which is connected to a wrist action shaker (model "*Wrist Action SHAKER Model 75*" from *Burrell Scientific LLC*). The wrist action shaker is originally used for shaking laboratory flasks. It provides a rotation speed of 416 rpm and was set to its maximum shaking angle of 18 degree. Figure 2 shows the movement of the shaker box on the wrist action shaker and Figure 3 shows the entire unit.

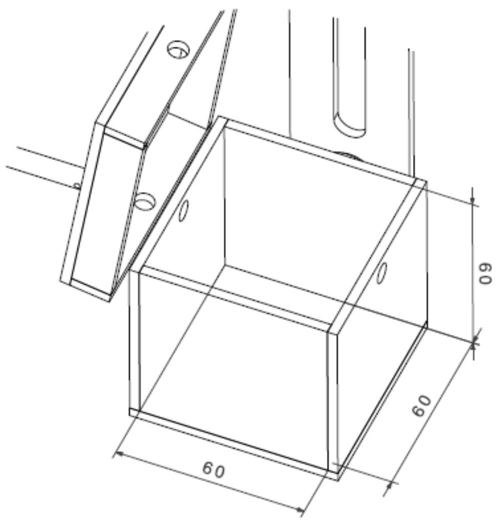

Figure 1 Technical drawing of shaker box

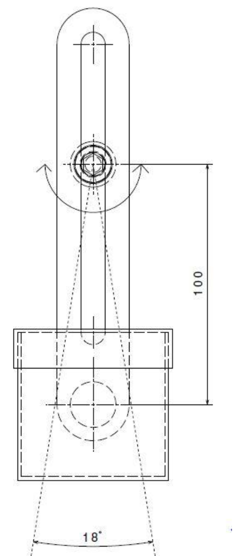

Figure 2 Movement of shaker box

While operating, the wood pellets are mechanically stressed by smashing against the box walls or against each other. To increase the mechanical abrasion an artificial pellet made of tool steel (ISO 1.2767) is placed in the box. The steel pellet has a diameter of 6.35 mm and mass of 0.5 g (± 0.05 g).

Figure 3 Picture of wrist action shaker with attached durability shaker box

During these durability tests, one test portion of pellets is weighed and placed in the shaker box. The amount of sample and duration of the test depends on the chosen test setup. After shaking, the remaining pellets and particles are poured on a 3.15 mm sieve and strained through using a 20 mm antistatic brush. Particles retained on the sieve and in the collecting pan are weighed. For disintegration tests over time, both fractions are filled in the shaker box again and the durability test is restarted. For calculating of the pellet durability equation according to EN 15210-1 (EN 15210-1:2009) is used.

$$D_u = \frac{m_A}{m_E} * 100 \quad (1)$$

D_u durability [%]
m_A mass of pellets before shaking
m_E mass of pellet after treatment

Equation 1 Calculation of mechanical durability (according EN 15210-1:2009)

Tumbler tests

The mechanical durability of all samples is tested using the tumbler tester method according to EN 15210-1. A batch of 500 grams of wood pellets is placed into the testing chamber and the tumbler is operated for 10 minutes with 50 rpm. The entire content of the tumbler is then sieved according to the method described above. For disintegration tests over time, both fractions after screening are filled into the testing chamber again and tests are repeated six times. Results are calculated according to Equation 1.

Samples

Three samples are used to provide different quality parameters for testing. Sample #1 consists of commercially produced wood pellets made of 90% Douglas fir (*Pseudotsuga menziesii*) and 10% lodgepole pine (*Pinus contorta*). The pellets are provided by *Pinnacle Renewable Energy Group.* Sample #2 consists of bagged pellets purchased at a local store in Vancouver, BC. The pellets are commonly used for combustion units in private residences. The composition of the wood pellets is unknown. Sample #3 consists of wood pellets produced by a bench scaled ring die pellet mill (*California Pellet Mill (CPM)*) at the *Chemical and Biological Engineering Department* of the *University of British Columbia.* The CPM made pellets were made of 100% Douglas fir sawdust provided by *Pinnacle Renewable Energy Group*. The purpose of the production of Sample #3 is to provide a pellet sample with low density and mechanical durability (compared to wood pellet standards). For all samples the moisture content is measured according to EN 14774-2 (EN 14774-2:2009); a 300 g sample is dried for 24 hours at 105°C in an oven. Based on the sample mass before and after heating the moisture content is calculated according to Equation 2.

$$M_{ar} = \frac{(m_1 - m_3) + m_4}{(m_2 - m_1) + m_4} * 100 \quad (2)$$

M_{ar} Mass as received in gram
m_1 mass in gram of the empty drying container
m_2 mass in gram of the drying container and sample before drying
m_3 mass in gram of the drying container and sample after drying
m_4 mass in gram of the moisture associated with the packing

Equation 2 Calculation of moisture content (according EN 14774-2:2009)

The pellet particle density is measured using the uplift measurement method. The pellet weight is measured in air and water and the specific density is calculated according to Equation 3.

$$\rho_u = \frac{m_u}{m_u - m_w)} * \rho_w \quad (3)$$

ρ_u pellet density
m_u mass of pellet in air
m_w mass in gram of the drying container and sample after drying
m_4 mass in gram of the moisture associated with the packing

Equation 3 Calculation particle density

In general, all pellets are sampled according to EN 14778:2011. Samples down to a mass of 300 g are divided using a riffle divider. For smaller samples, single pellets are picked randomly from a bag of a representative sample of 500 g. All weight measurements in this study up to 120 g are carried out using an analytical balance with an accuracy of 0.1 mg (model “*Practum124-1S*” from *Sartorius AG*). Samples over 120 g are measured using a scale with an accuracy of 0.1 g (model “*AG EJ-1500*” from *A&D Company, Limited*).
Table 1 shows a description of the pellet samples including the determined moisture content und density.

Sample number	**#1**	**#2**	**#3**
Description	Commercial pellets no EN*plus* certification	Commercial pellets no EN*plus* certification	Lab produced pellets no EN*plus* certification
Feedstock	90% Douglas fir 10% lodgepole pine	100% hardwood	100% Douglas fir
Moisture content	4.7% wb	6.8% wb	9.4% wb
Density	1.26 g cm^{-3}	1.28 g cm^{-3}	1.21 g cm^{-3}

Table 1 Description of used pellet samples

Test procedure

Pre-tests

5 g (±0.5 g) pellets of sample #1 were used in the shaker for a total of 100 minutes. Every 10 minutes the shaker was stopped and the fractions were determined using the 3.15 mm screen. The test was repeated ten times and the mass loss was calculated. Pre-tests were carried out to gain general information about the disintegration of the pellet samples compared with the common tumbler method.

Parametric study

Test runs to verify the correlation between the pellet mass and disintegration behaviour as well as the dependency of the number of pellets used per test run was investigated. For mass correlation tests single pellets of fractions <0.25 g, 0.25–0.5 g, 0.5-0.75 g, >0.75 g with ten repetitions were performed (see Figure 4). To measure the sample-size influence additional test runs with 3 and 5 pellets at a time of <0.25 g and >0.75 g were performed for 10 and 60 minutes with 5 repetitions.

Verification tests

Based on the results of the parametric study a best case configuration for the shaker test run was defined. Using this configuration, verification tests using >0.75 g pellets from sample #1, #2 and #3 for 10 and 60 minutes were performed with 5 repetitions

Figure 4 Example of pellet samples for parametric study

Results and discussion

Tumbler durability

Figure 5 shows the results of the tumbler pellet durability over time for sample #1 according to EN 15210-1. The results are characterized by a good reproducibility and varying less than 0.2% for all test runs. Table 2 shows the tumbler results for all samples for 10 and 60 minutes. The lab produced sample #3 shows the desired reduced durability values.

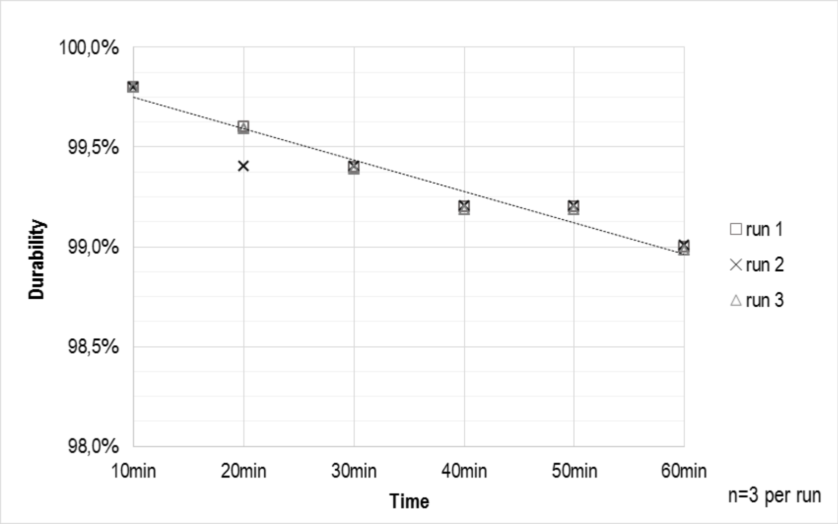

Figure 5 Tumbler durability of sample #1

Sample	10 min	60 min
#1	99.60%	99.00%
#2	99.80%	99.20%
#3	93.76%	87.72%

Table 2 Tumbler durability of sample #1, #2, #3

Pre-tests

Figure 6 presents the pellet durability of sample #1 based on 10 repetitions with the shaker. The sample mass was 5 g (±0.5 g). The pre-test results show successful disintegration of the pellets over time. With increasing test duration, an increasing variance of values can be observed. Compared to tumbler results the results are characterized by decreased individual values and an increased gradient between individual tests.

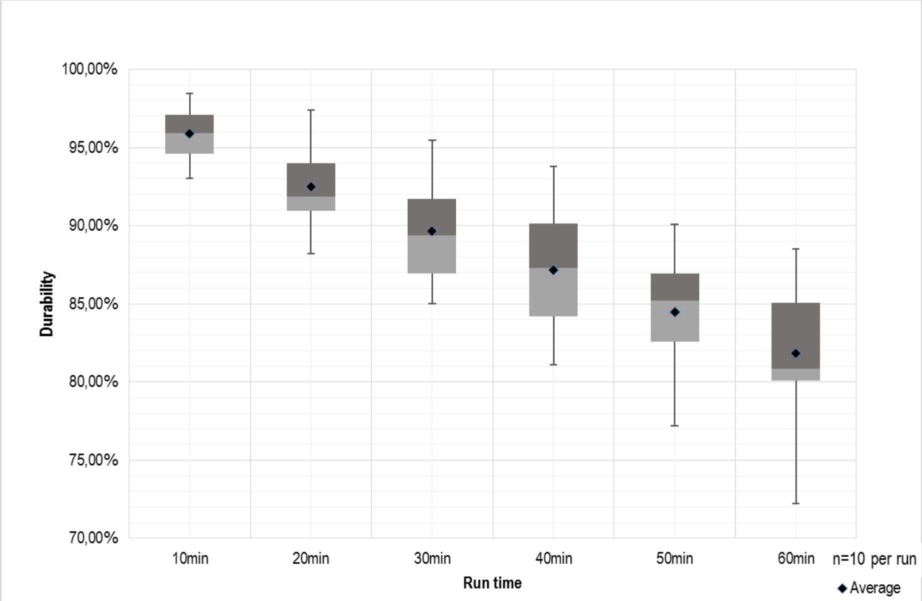

Figure 6 Shaker durability of sample #1

Parametric study

For better understanding of the disintegration affecting factors, test runs with single pellets in a defined mass range were conducted. Figure 7 shows the pellet disintegration of sample #1 based on 10 repetitions with the shaker, each with an operation time of 10 minutes. Increasing pellet weight (i.e. longer pellets due to constant diameter of 6 mm) leads to an increased reproducibility. The similar test with an operation time of 60 minutes revealed similar results (see Figure 8).

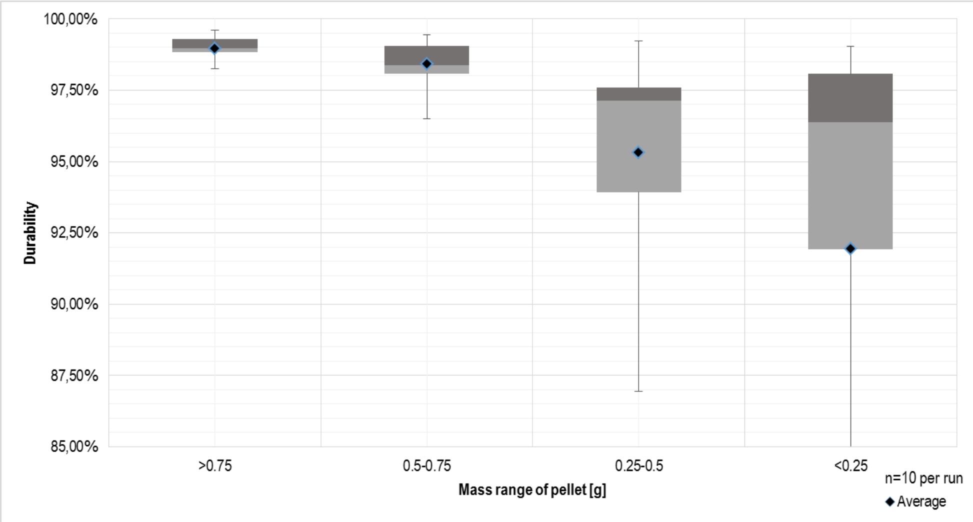

Figure 7 Pellet mass correlation of 10 minutes shaker test

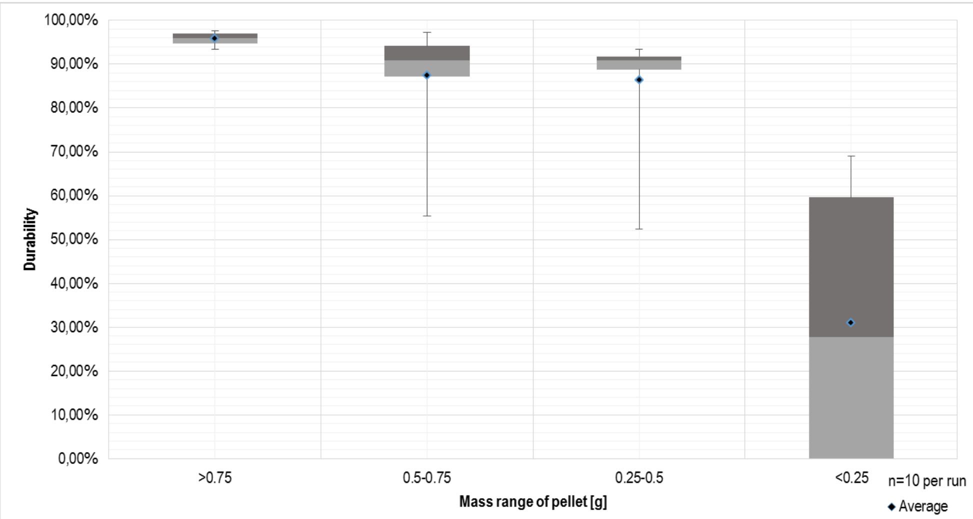

Figure 8 Pellet mass correlation of 60 minutes shaker test

Beside the influence of pellet mass (and thus length), tests in order to study the influence of the number of pellets on the durability per test run were performed. Figure 9 shows the test results for 1, 3 and 5 pellets >0.75 g per test run for 10 and 60 minutes.

In the 10 minutes test, which were repeated 10 times, the standard deviation changed from 0.41% for 1 pellet to 0.47% for 3 pellets to 0.20% for 5 pellets. The same test using pellets <0.25 g showed a standard deviation of 11.20% for 1 pellet, 7.17% for 3 pellets and 10.84% for 5 pellets. In total, all tests showed no significant trend based on the number of pellets. There was a slight trend showing better overall results when using 5 pellets, but tests using 5 pellets or even more are in conflict with the initial method development idea of small samples.

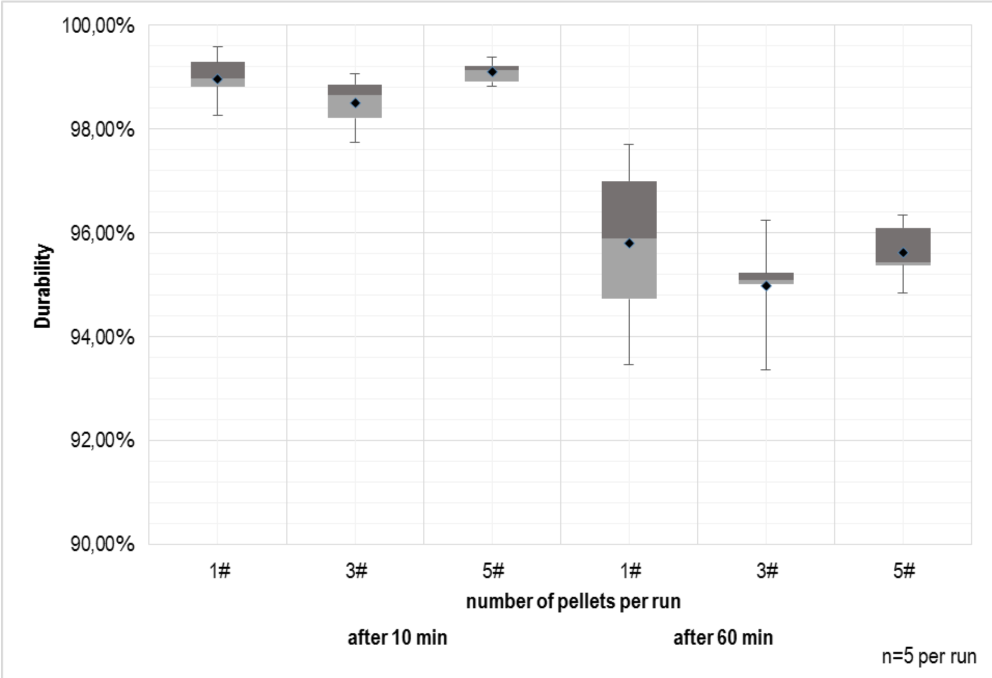

Figure 9 Number of pellet correlation of sample #1 >0.75 g

<u>Verification tests</u>

Test runs were performed using sample #1, #2 and #3 in best case configuration. Based on previous results, best case was defined as one pellet per test run with a mass >0.75 g. Figure 10 shows the test results. The 10 minutes tests show a standard deviation of 0.41% for sample #1, 0.51 % for sample #2 and 1.97 % for sample #3. For 60 min tests the standard deviation of sample #1 is 1.40% for sample #2 1.95 % and for sample #3 2.36 %. The standard deviation was calculated based on 10 repetitions of each sample. Overall, the results of the shaker tests are characterized by a high reproducibility, indicated by the low standard deviation. However, the shaker results differ from the tumbler results.

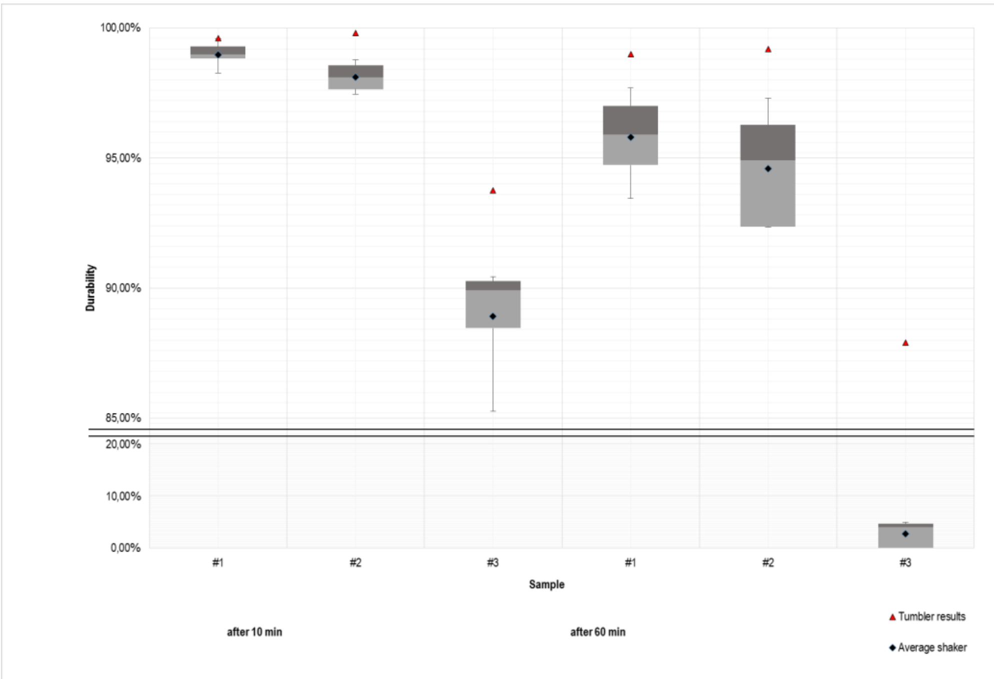

Figure 10 Results verification tests and tumbler results

In conclusion the development of a new pellet durability tester showed promising results. The pre-tests showed a successful disintegration of the samples. The requirement of applicability of small samples was confirmed during the parametric study. In addition, pellets of at least 0.75 g had the best results. In general, the newly developed durability test can be regarded as highly reproducible.
The disintegration process is based on mechanical stress by smashing the pellets against the box walls or against the artificial steel pellet. This process is similar to the process in a tumbler.
However, the shaker and tumbler differ in terms of values for durability and the rate of pellet disintegration over time. To verify and understand these differences an extensive data base of tests results with different wood pellet samples is necessary. This will be done in further studies.

Summary

In this study a novel pellet durability test was developed which allows the measurement of small samples. A stainless steel box with inner dimension of 60 x 60 x 60 mm was attached to a specially designed and constructed laboratory wrist action shaker and moved at 416 rpm with an 18 degree angle. For test purposes, samples between one and five pellets were placed in the shaker box with an artificial steel pellet. Extensive test runs with varying pellet numbers and pellet weights per test run were performed. The results showed a best case configuration of one pellet per test run with a weight of at least 0.75 g. Finally, tests in the best case configuration were performed and compared with the common tumbler durability test. The new shaker showed successful pellet disintegration with a high reproducibility.
The comparison of tumbler and shaker results showed differences in terms of durability values and pellet disintegration over time. Further studies will be conducted to gain an extensive data base of test results. This will help to understand the differences between tumbler and shaker results.

Acknowledgement

This study was completed in cooperation with the UBC Biomass and Bioenergy Research Group and the University of Forestry Sciences Rottenburg. We want to thank all members of the BBRG for their support during these studies. Also special thanks go to the workshop of the Chemical and Biological Engineering Department at the University of British Columbia for building the shaker unit. We want to thank BioFuelNet Canada for their financial support.

Publication bibliography

EN 14774-2:2009: Bestimmung des Wassergehaltes - Ofentrocknung – Teil 2: Gesamtgehalt an Wasser - Vereinfachtes Verfahren.

EN 15210-1:2009: Feste Biobrennstoffe – Bestimmung der mechanischen Festigkeit von Pellets und Briketts – Teil 1: Pellets;

EN 14961-2:2011: Feste Biobrennstoffe – Brennstoffspezifikationen und -klassen – Teil 2: Holzpellets für nichtindustrielle Verwendung.

EN 14778:2011: Feste Biobrennstoffe –Probenahme.

Carone, Maria Teresa; Pantaleo, Antonio; Pellerano, Achille (2011): Influence of process parameters and biomass characteristics on the durability of pellets from the pruning residues of Olea europaea L. In *Biomass and Bioenergy* 35 (1), pp. 402–410. DOI: 10.1016/j.biombioe.2010.08.052.

Döring, Stefan (2011): Pellets als Energieträger. Technologie und Anwendung. Berlin, Heidelberg: Springer.

Cannayen, Igathanathane,; Sokhansanj, Shahab (2009) Variability of wood pellet hardness test using static compression method. BBRG Internal Report. University of British Columbia, Vancouver, BC, Canada.

Holm, Jens K.; Henriksen, Ulrik B.; Hustad, Johan E.; Sørensen, Lasse H. (2006): Toward an Understanding of Controlling Parameters in Softwood and Hardwood Pellets Production. In *Energy Fuels* 20 (6), pp. 2686–2694. DOI: 10.1021/ef0503360.

Lam, Pak Sui; Lam, Pak Yiu; Sokhansanj, Shahab; Bi, Xiaotao T.; Lim, C. J. (2013): Mechanical and compositional characteristics of steam-treated Douglas fir (Pseudotsuga menziesii L.) during pelletization. In *Biomass and Bioenergy* 56, pp. 116–126. DOI: 10.1016/j.biombioe.2013.05.001.

Mani, Sudhagar; Tabil, Lope G.; Sokhansanj, Shahab (2006): Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. In *Biomass and Bioenergy* 30 (7), pp. 648–654. DOI: 10.1016/j.biombioe.2005.01.004.

Nielsen, Niels Peter K.; Gardner, Douglas J.; Felby, Claus (2010): Effect of extractives and storage on the pelletizing process of sawdust. In *Fuel* 89 (1), pp. 94–98. DOI: 10.1016/j.fuel.2009.06.025.

Nielsen, Niels Peter K.; Holm, Jens Kai; Felby, Claus (2009): Effect of Fiber Orientation on Compression and Frictional Properties of Sawdust Particles in Fuel Pellet Production. In *Energy Fuels* 23 (6), pp. 3211–3216. DOI: 10.1021/ef800923v.

Obernberger, Ingwald; Thek, Gerold (2010): The pellet handbook. The production and thermal utilisation of pellets. London, UK, Washington, DC: Earthscan.

Oveisi, Ehsan (2011): Durability Of Wood Pellets. Master Thesis. The University of British Columbia, Vancouver. Chemical and Biological Engineering.

Oveisi, Ehsan; Lau, Anthony; Sokhansanj, Shahab; Lim, C. Jim; Bi, Xiaotao; Larsson, Sylvia H.; Melin, Staffan (2013): Breakage behavior of wood pellets due to free fall. In *Powder Technology* 235, pp. 493–499. DOI: 10.1016/j.powtec.2012.10.022.

Rhén, Christofer; Gref, Rolf; Sjöström, Michael; Wästerlund, Iwan (2005): Effects of raw material moisture content, densification pressure and temperature on some properties of Norway spruce pellets. In *Fuel Processing Technology* 87 (1), pp. 11–16. DOI: 10.1016/j.fuproc.2005.03.003.

Schmidl, Christoph; Luisser, Markus; Padouvas, Emmanuel; Lasselsberger, Leopold; Rzaca, Magdalena; Ramirez-Santa Cruz, Carlos et al. (2011): Particulate and gaseous emissions from manually and automatically fired small scale combustion systems. In *Atmospheric Environment* 45 (39), pp. 7443–7454. DOI: 10.1016/j.atmosenv.2011.05.006.

Stelte, Wolfgang; Holm, Jens K.; Sanadi, Anand R.; Barsberg, Søren; Ahrenfeldt, Jesper; Henriksen, Ulrik B. (2011): A study of bonding and failure mechanisms in fuel pellets from different biomass resources. In *Biomass and Bioenergy* 35 (2), pp. 910–918. DOI: 10.1016/j.biombioe.2010.11.003.

Wöhler, Marius (2011): Investigation of pretreatment and pelletization of Douglas-fir and SRC willow. Master Thesis. University of Applied Forest Sciences Rottenburg, Rottenburg am Neckar.