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Solid biofuels — Bridging behaviour of bulk biofuels

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 238, *Solid biofuels*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In all particulate matter that is flowing through an opening, the particles have the tendency to form a solid bridge over that opening. This can cause interruptions or failures, particularly during a vertical transport, with the consequence of clogging of silo outlets, hoppers, down pipes, funnels or screw conveyors. To understand this phenomenon better, a determination test method was developed. The results of these tests can be used to improve the design of handling systems in order to minimize the risk of bridging.

Bridging is a phenomenon that can occur because of the inhomogeneous nature of the biofuel, particularly the variation in particle size, moisture content and number of overlong particles. In addition, biofuels are often not well understood by the designers of handling, storage and conversion systems. Bridging phenomenon can lead to an alternating build-up and collapse of bridges or shafts, often called ratholes (see also Figure 1).

Comprehensive studies referring to the bridging behaviour of solid biomass fuels were first performed by Mattsson[1] and by Mattsson and Kofman[3] in the early 1990s. They considered the basic handling characteristics of solid biofuels, i.e. the angle of repose, the friction of solid biofuels against surfaces and the tendency to build bridges over an opening. As these parameters had until then never been investigated with solid biomass fuels, new measuring principles and devices had to be developed. For determining the bridge building tendency, a test apparatus was constructed consisting of a movable floor which could be gradually opened so that a bridge of fuel could form over the opening until it finally collapsed[1]. Various fuels were tested and the impact of key parameters such as bed depth, moisture content of the fuels and size distribution of the particles were studied.

The test method was further developed as part of the European Project Bionorm 2[15]. The objective was to develop a mechanically improved apparatus to overcome deficiencies related to the inclination of the flexible floor and by assuring constant and reproducible low bending radiuses at the edges of the slot opening. At the same time, a new drive system for a moving floor was also developed, which allows for a more sensitive and dynamic adjustment of the opening speed during measurement[5]. Best practice guidelines[6] for the revised method were also developed and tested, and an international interlaboratory test was performed[7].

The Bionorm 2 project also had the objective of providing detailed descriptions and procedures based on the applied measurement principle. The intention was to establish a useful starting point for any future attempt to develop a harmonized standard method for direct determination of bridging behaviour. In order to document the extensive research and experimental work conducted, this document describes the main outcome.

Bridging behaviour cannot be defined as an absolute value for a particular biofuel since the propensity for bridging varies with moisture content, particle size distribution and content of overlong particles. In existing product specifications of biofuels, bridging characteristics are not normally provided for trade purposes due to variability from sample to sample. However, susceptibility to bridging has been identified as useful for the engineering design of handling and storage facilities, and their relationship to effective transportation of biofuels and safety.

Solid biofuels — Bridging behaviour of bulk biofuels

1 Scope

This document summarizes current knowledge concerning a test method and its technical implementation, and existing knowledge about the bridging performance of biofuels.

The document consists of three parts, as follows:

— Part I: Method for direct determination of bridging behaviour, to make it available for research and development purposes (see Clause 4).

— Part II: Implementing the measurement principle, to assist in the construction of test apparatus and to illustrate the performance of a bridging test (see Clause 5).

— Part III: Experience and results from bridging tests, to provide typical results on bridging for a wide range of biofuels already tested (see Clause 6).

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
bridging
tendency of particles to form a stable arch across an opening and to hinder flow

Note 1 to entry: Bridging is illustrated in Figure 1 (left).

Note 2 to entry: As a consequence of bridging, biofuel conveying can be inhibited or intermittent until the bridge collapses. All particles regardless of size can potentially form an arch. Bridging is caused by a number of phenomena, including mechanical interlocking and interacting adherence forces between particles. Accumulation of material of various sizes and moisture content can create clusters, which causes incoherent flow. Friction between the material and containing walls can cause asymmetrical flow pattern resulting in bridging. The distribution of particles of various sizes when filling a silo tends to concentrate heavier particles at the circumference (rolling down the slope) while finer particles accumulate in the centre of the pile. During the draining of a silo, the material in the centre will have a different flow pattern than the material coming from the circumference of the pile. This can in some cases result in shafts or channels or "ratholes" as illustrated in Figure 1. The phenomena can be avoided by proper design of the handling system.

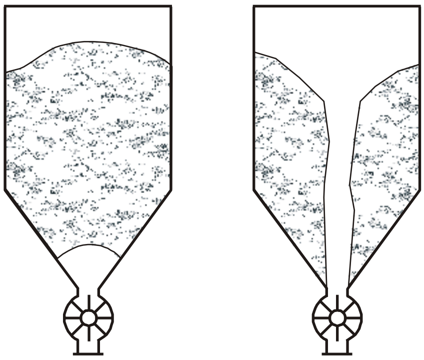


Figure 1 — Unfavourable flowing conditions of bulk fuels can cause the building of a bridge (left) or a channel flow (right)

3.2
angle of repose
steepest angle of descent of a stock pile measured in degrees of the slope of material relative to the horizontal plane when granular material on the slope face is on the verge of sliding

3.3
particle shape factor
PSF
reciprocal of the sphericity, which characterizes the degree of a particle's approximation of an ideal sphere

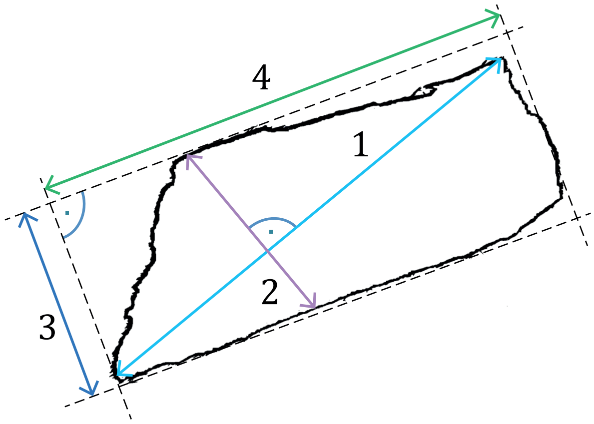
Note 1 to entry: When measured by image analysis, the PSF is the measured circumference of the projection area of a particle divided by the circumference of a circle with the same area as the particle. In the case of a perfect sphere shape (round projection area), the PSF of the particle is PSF = 1,0. A high PSF characterizes a high deviation from a round shape[9].

3.4
length–diameter ratio
LD
ratio of a particle calculated from the maximum length and the minimum *Feret diameter* (3.5)

Note 1 to entry: When measured by image analysis, the LD is calculated from the maximum length as given in Figure 2 and the minimum Feret diameter[14].

3.5
Feret diameter
caliper diameter
distance between two parallel planes restricting a particle

Note 1 to entry: The minimum Feret diameter is the shortest of such distances (see Figure 2).



Key

1 maximum length

2 maximum width

3 minimum Feret diameter

4 length (90° to minimum Feret diameter)

Figure 2 — Important size parameters of a particle determined by image analysis

3.6
mean particle size
MP
size of a particle defined as the maximum length as measured of each particle in a sample

Note 1 to entry: In the calculation of MP, all particles in a sample are considered according to their relative volumetric share in their respective size class; this is done by calculating the weighted average. Mathematically MP is derived as the sum of all multiplications between the mean size class and the relative share of particles in this particular size class. The mean size class is calculated from the defined class boundaries (e.g. the mean size class of the fraction between 8 mm to 16 mm is 12 mm)[9].

Note 2 to entry: In this definition, MP is determined by image analysis.

4 Part I: Proposed method for direct determination of bridging behaviour

4.1 Introduction to the method

Based on prior knowledge, as described in Part II (see Clause 5), a practical research method for direct determination of bridging behaviour was developed through the European Bionorm 2 project. This clause describes the method, which is based on previous research performed in Sweden and Denmark[1][2][3][4]. The method is suitable for all compressed and uncompressed particulate biofuels that either have been reduced in size (such as most wood biofuels, including cut straw) or have a particulate physical form (e.g. olive stones, nut shells, grain).

4.2 Principle

A sample is subjected to a bridging test by placing it over an expandable slot in order to allow the building of a bridge. The opening width of the slot (see slot opening width *l* in Figure 3) is recorded as a measure of the bridge building behaviour of that sample. This requires a frictionless opening of the bottom slot.

4.3 Test equipment

4.3.1 Bridging test apparatus.

A box with a bottom area (inside dimensions) of 1,1 m × 2,0 m and a minimum filling height of 0,75 m (±0,01 m) is used. These dimensions accommodate a required sample volume of 1,65 m^3. The sides of the box are made of low friction coated plywood or similar. The two sections of the bottom of the box are made of flexible mats with low friction surfaces.

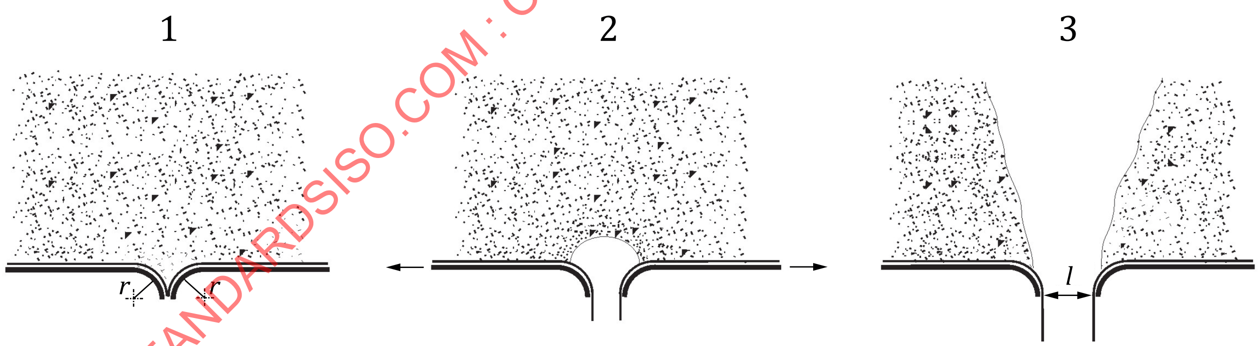
An expandable slot is formed between the two bottom sections of the box. The mat on each of the two bottom sections forms the slot in terms of a quarter of a circular arch with an effective radius of (32 ± 5) mm. The slot is closed when the two bottom sections are pushed together and the two mats meet in the centre of the length of the box. The mats are fully even and horizontal, except at the round edges (see Figure 3). The slot is gradually expandable while the edges remain parallel and the bottom is prevented from becoming inclined during any phase of the opening procedure. The expansion is executed in a way that ensures the mats remain in place, except at the rounded edges where they can slide over a plate and form the rounded edges (see Figure 3). Thus, any friction between the bottom sections and the biofuel sample in the box is avoided when the slot is expanded.

NOTE Alternatively, the mats on the two bottom sections can wind onto rollers under each bottom section. Consequently, the effective radius becomes variable during the opening procedure. In this case, the mat is made of thin material.

The movements of the two bottom sections is synchronized (ganged) and simultaneous during the opening of the slot. The maximum width of the slot is 1,5 m across the bottom of the box. The edges of the slot remain parallel during the opening procedure. A tolerance of 10 mm is acceptable. This tolerance is measured as the difference of the opening width at both ends of the slot and it applies for the full range of the slot opening.

The opening speed is 180 mm/min (±50 mm/min) or lower. The drive mechanism for the movable floor allows for vibration-free, frequent and smooth starts and stops by the operator.

The box is positioned firmly at a height that ensures all sample materials fall freely through the slot without causing any blockages below on the floor (e.g. a height of 1,5 m of the box bottom above the floor).



Key

r effective radius of the round edges at the opening

l opening width of the slot at the expandable base when the bridge collapses

Figure 3 — Functional principle of a bridging test apparatus with expandable slot

4.3.2 Loading device.

For repeated loading and unloading of large sample quantities (>1,65 m^3), a wheel loader or fork lift with suitable bucket volume is required (see 5.2).

4.3.3 Metric ruler or **measuring tape** capable of determining the opening width between the rollers to the nearest millimetre.

4.3.4 Rake, to level out the sample.

4.4 Sampling and sample preparation

The minimum volume of the laboratory sample is 1,65 m^3 loose volume and is sampled in accordance with ISO 18135. If required, the laboratory sample is reduced to the actual test portion of 1,65 m^3 in accordance with ISO 14780. All bridging tests are carried out with this test portion.

4.5 Procedure

a) The box is filled by pouring the test portion from a height of maximum 500 mm above the rim of the box without applying any compaction to the sample. The surface is levelled out with a rake (see Figure 4).

b) A slot is generated under the sample by starting the slot opening procedure. Some particles will immediately fall through the slot but soon a bridge will form over the slot.

NOTE 1 Fine and granulated biofuel samples such as pellets or kernels can require some time to percolate through the slot opening before forming a bridge.

c) As soon as the bridge collapses, the slot opening motion is stopped and the slot width is measured to the nearest mm at the minimum horizontal distance between the two slot edges, as indicated in Figure 3 by the letter "*l*". The measure is recorded. In the case that a single overlong particle prevents the collapse of the entire bridge, the slot opening movement is not continued and a 100 % collapse is recorded.

d) The sample material, which has fallen through the slot and emptied the box completely, is then unified with the remaining sample.

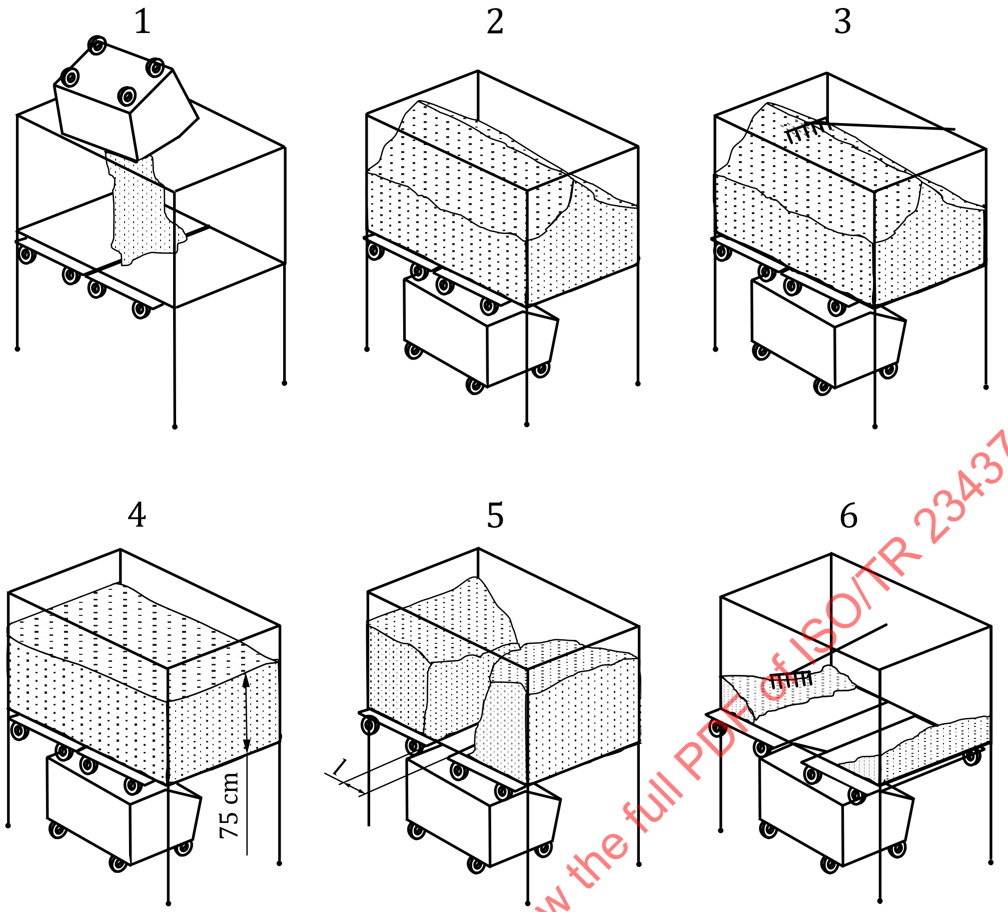
e) The box is reloaded with the unified test portion and the procedure in a) to d) is repeated until ten measurements have been performed per sample. For pellet or grain samples, the total number of repetitions can be reduced to five.

f) Before the start of the bridge determination tests and immediately after completion, a sub-sample of the sample mass is collected and a determination of moisture content is performed in accordance with ISO 18134-2. The moisture content to be reported is the average of the two determinations.

NOTE 2 In many cases, it is useful to provide further information on the tested biofuel, including by:

— collecting a sub-sample of the laboratory sample and performing a particle size classification in accordance with ISO 17827-1;

— performing a determination of the bulk density in accordance with ISO 17828.



Key

1 filling

2 filling completed

3 levelling

4 start of slot opening (at a filling depth of 75 cm)

5 record slot opening width *l* at 100 % bridge collapse

6 remove sample completely before refilling

Figure 4 — Stepwise procedure of a bridging determination test

4.6 Calculation

The measured bridging behaviour for a sample is calculated as the arithmetic mean and standard deviation from the total of ten repeated measurements of the same sample (five for pellets or seeds) of the slot opening width "*l*" as determined in 4.5.

The above average is useful information in order to compare biofuels. For the design of installations, the maximum value for the ten (or five) tests is of importance.

4.7 Precision and bias

Because of the varying nature of solid biofuels covered by this document, it is not possible at this time to give a precision statement (repeatability or reproducibility) for this test method.

Precision of measurement was proven to be highly fuel dependent. This is also evidenced by the results given in 6.1.

4.8 Test reporting

The test report includes at least the following information:

a) an identification of the laboratory performing the test and the date of the test;

b) an identification of product (or sample) tested;

c) a fuel characterization in accordance with ISO 17225-1:—[1)], Table 1 (origin and source), Table 2 (traded form) and the relevant table for that fuel (choose from Tables 3 to 15);

NOTE A detailed fuel description (e.g. type of raw material, method of comminution, storage history, photos with metric ruler) is highly recommended to allow sound data evaluation and interpretation of measured results.

d) a reference to this document, i.e. ISO/TR 23437;

e) the individual results of the bridging test(s) as well as the maximum value, average and standard deviation of the calculated average;

f) the average result from the moisture content determinations;

g) the result of the particle size classification, if performed;

h) the result of the bulk density determination, if performed;

i) any unusual features noted during the determination that could affect the result;

j) any deviation from this document, or operations regarded as optional;

k) the date of the test.

5 Part II: Implementing the measuring principle

5.1 Review of apparatus construction

The idea for the principle was conceived during a research project conducted by Mattsson[1] in the late 1980s. A test bench was designed where the bridging test apparatus had a hanging bottom, sustained by steel cables, and the opening was performed via two hand-operated rollers on which the bottom rubber mat was rolled. This is referred to as "Mark 1 apparatus".

In a later version in the 1990s, the manual operation was replaced by two electrical step motors. These allowed a more gradual opening of the slot as well as automated reading of the width of the slot opening l. Another good feature of this version was that the slot could be opened very quickly after the reading had been completed. This saved a lot of time during the measurement cycle. This machine is referred to as "Mark 2 apparatus".

In the method revision within the Bionorm 2 project, the overall dimensions of previous machine were retained but several changes were introduced. The bottom was kept completely flat, a smooth opening drive was applied and the previously large roller radius, which formed the opening slot, was replaced by a slim deflection edge of only about 32 mm radius at the slot opening (see radius r in Figure 3). This machine is referred to as "Mark 3 apparatus".

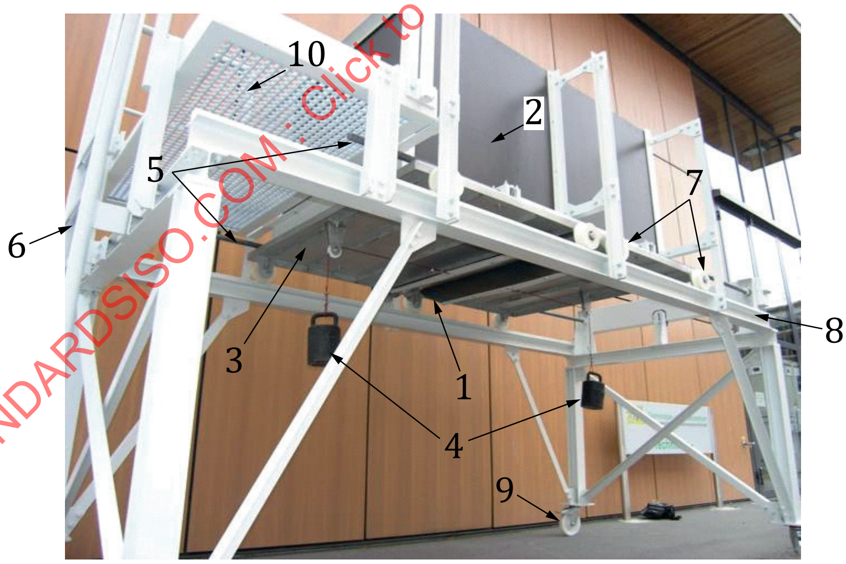
The defined measuring principle as described in Part I was accomplished in an apparatus construction as shown in Figure 5. This equipment implements the required split floor design, which is fully simultaneously movable to both sides. Both halves of the floor are mounted on an undercarriage, which travels on wheels. The opening mechanism ensures a fully parallel movement to both sides. The opening process is propelled by a crank handle. An alternative apparatus version with an electric motor (with

1) Under preparation. Stage at the time of publication: ISO/DIS 17225-1:2020.

adjustable speed) was also successfully tested. It accelerates testing, e.g. by enabling a quick floor closure after testing. In Figure 6, further details of the construction are shown with view from the bottom.

The recommendation is that any future machines are equipped with electric drive. The additional cost of the electrification is easily gained back by the reduced time during testing and a more homogeneous movement between tests is guaranteed.

Figure 5 — Example of a bridging test apparatus in accordance with 4.3.1



Key

1	opening slot	6	ladder
2	bulk container	7	undercarriage
3	movable floor	8	rail
4	weights	9	reels
5	two parallel drive screws	10	walking platform

Figure 6 — Bridging test apparatus — View from below with further details of the construction

The apparatus has a walking platform in order to allow for a comfortable filling and levelling of the sample (see Figure 6). The recommendation for future machines is that the walking platform be on three sides of the box to ease the levelling out of the sample after tipping it into the box.

The technical data of the bridging tester are given in Table 1.

Table 1 — Technical data of the bridging test apparatus

Element	Measurement/description		
Dimensions	**Length** (mm)	**Height** (mm)	**Width** (mm)
Complete testing apparatus	4 155	3 015	1 870
Bulk container (inside)	2 000	1 000	1 100
Bulk container (outside)	2 158	1 000	1 144
Position of bulk container bottom (without reels)		1 500 (above ground)	
Position of bulk container bottom (with reels)		1 741 (above ground)	
Mass	Approximately 850 kg		
Material properties			
Material of the side panels	Film coated plywood		
Material of the movable floor	Steel S235JR, covered with a rope belt		
Material of rope belt	PVC-mat of 1 mm thickness with low friction coating		
Material of the steel frame	Steel S235JR		
Opening properties			
Opening mechanism	By hand crank or by electric motor drive		
Opening distance per rotation	12 mm per rotation (thread pitch Tr 30 × 6)		
Opening speed	15 rotations per minute (i.e. 180 mm/min)		

All dimensions and technical components for reproducing a bridging tester are documented in the technical drawings given in Figures 7, 8, 9 and 10.

Dimensions in millimetres

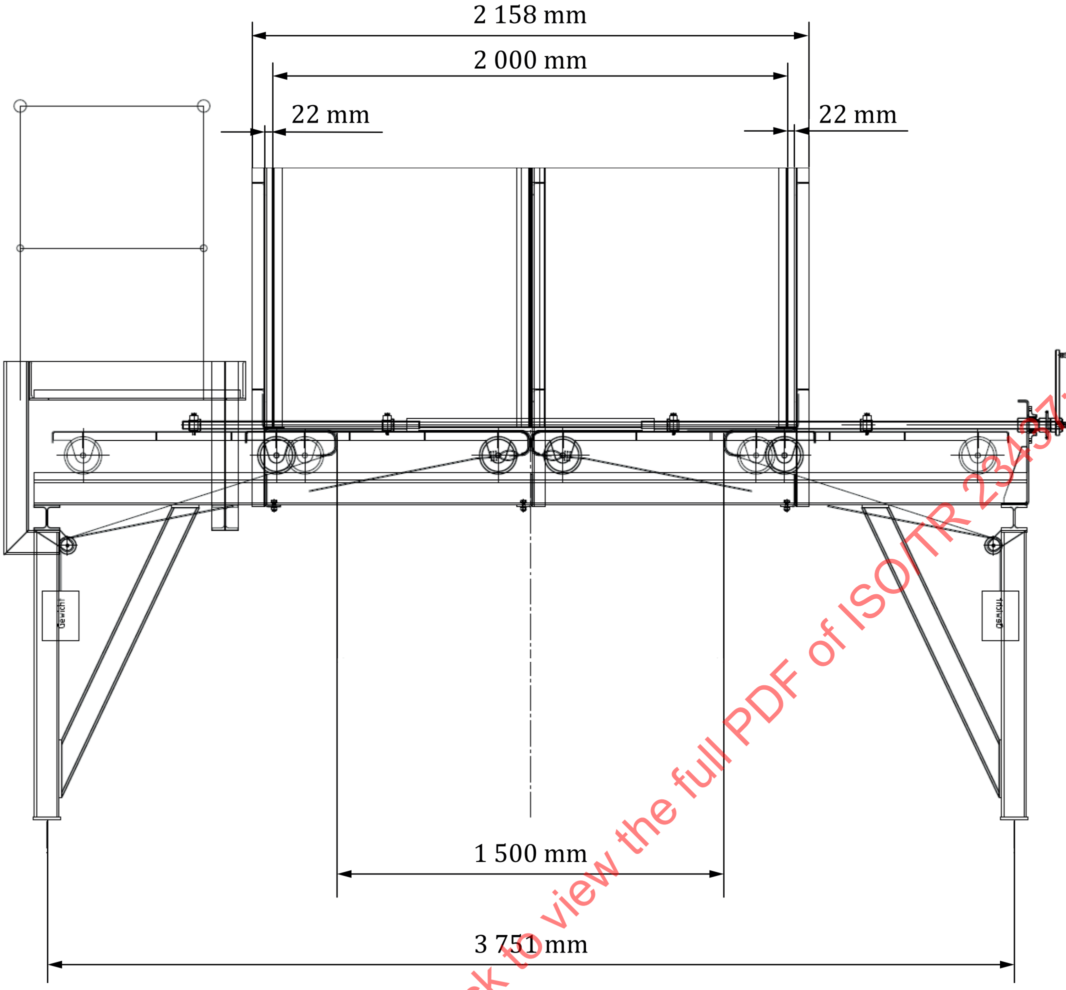


Figure 7 — Front view on the bridging tester

Dimensions in millimetres

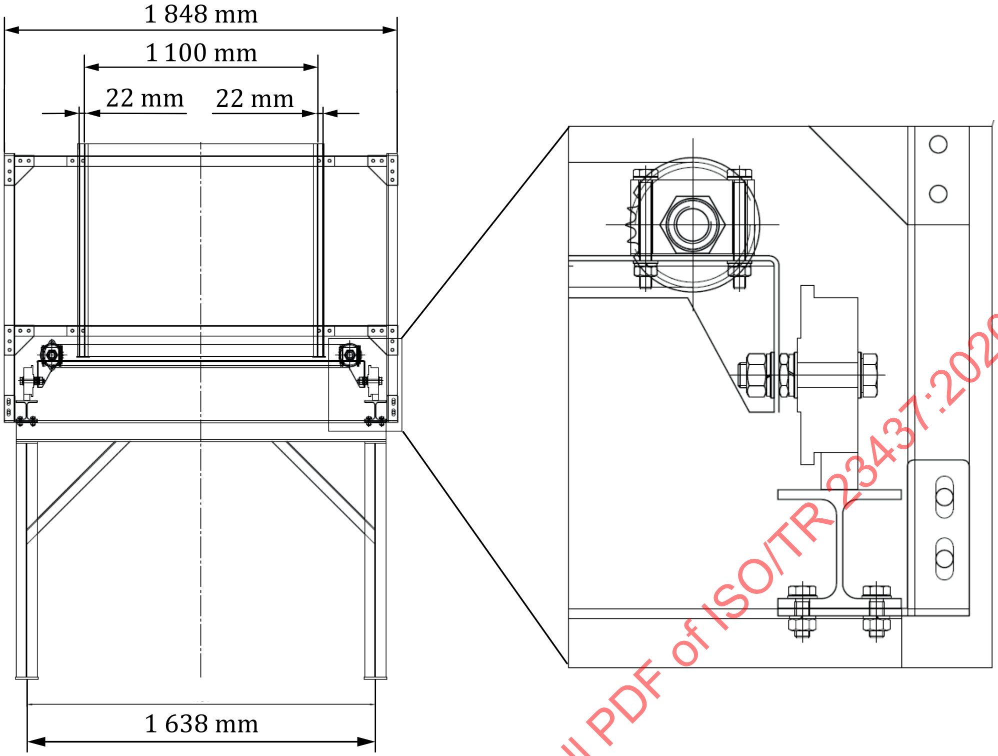


Figure 8 — Side-view (left) with a detailed view on the undercarriage of moving floor (right)

Dimensions in millimetres

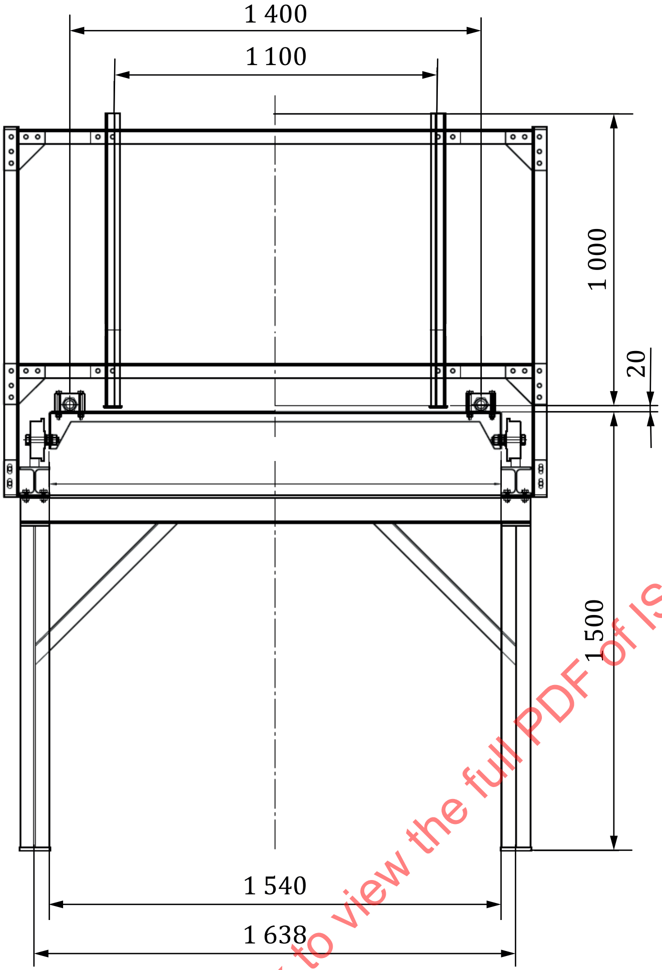
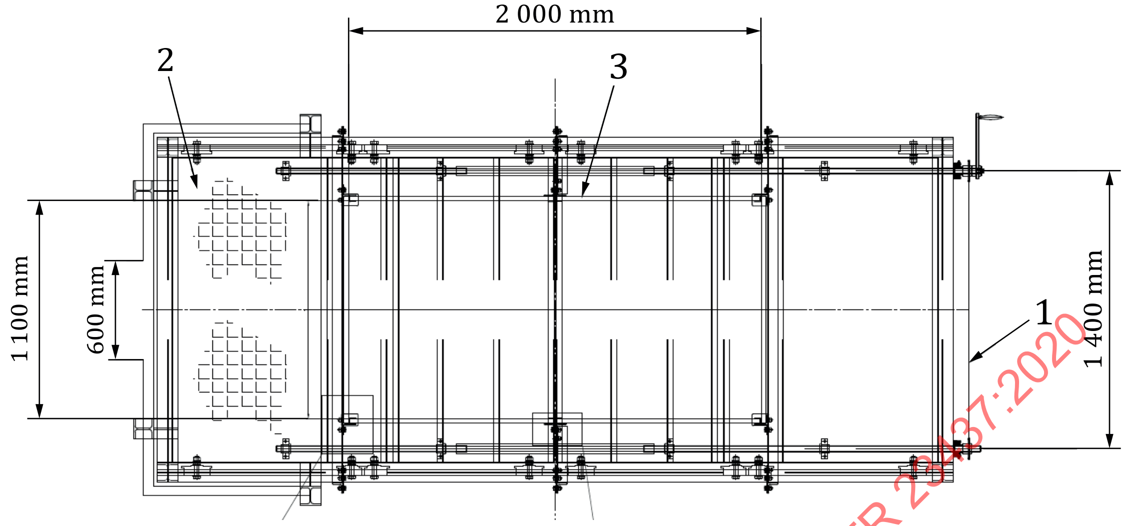


Figure 9 — Side-view on the bridging tester

Dimensions in millimetres



Key

1 chain drive

2 walking platform

3 film coated plywood panel, thickness: 22 mm

Figure 10 — Top view on the bridging tester

The test apparatus in Figure 10 is designed for the required sample volume of 1,65 m^3. The respective filling depth (0,75 m) is marked on the inside walls of the bulk container. The PVC mat, which covers the two movable steel bottom plates of the container, slides over the rounded edges during opening (see Figure 11). However, the loose ends of the mat need to be prevented from blocking any falling sample material while the slot is being expanded. Both loose ends of the PVC mats are clamped by a cable, which is conducted sideways via a roll and kept in tension by a weight hung to each cable end (these two weights can be seen more clearly in Figures 5, 6 and 7).

The reading of the slot opening width l is taken by a metric ruler or, as shown in Figure 12, by an integrated steel tape measure, which is continuously expanded when the slot is opening.

a) View from bottom with closed slot

b) Side-view on roller-suspended bottom plate with edges formed by 32 mm (5/4-inch) tubes

Figure 11 — Opening slot

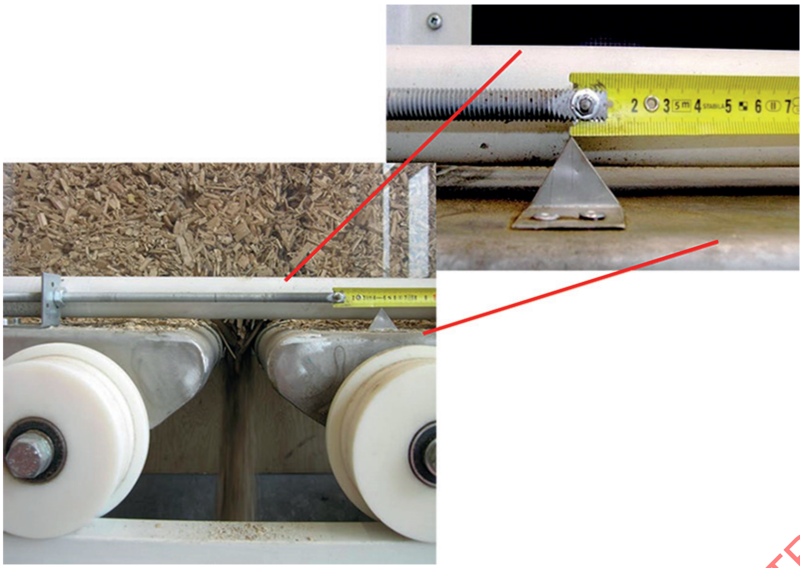


Figure 12 — Measuring unit for the slot opening width *l*

During measurement, the bridging test apparatus is horizontal. To facilitate the adjustment before measurement, a bubble level is fastened to the bed plate of one of the four stilts of the apparatus (see Figure 13).

Figure 13 — Bubble level fastened to the bed plate of one of four stilts of the apparatus

5.2 Other equipment

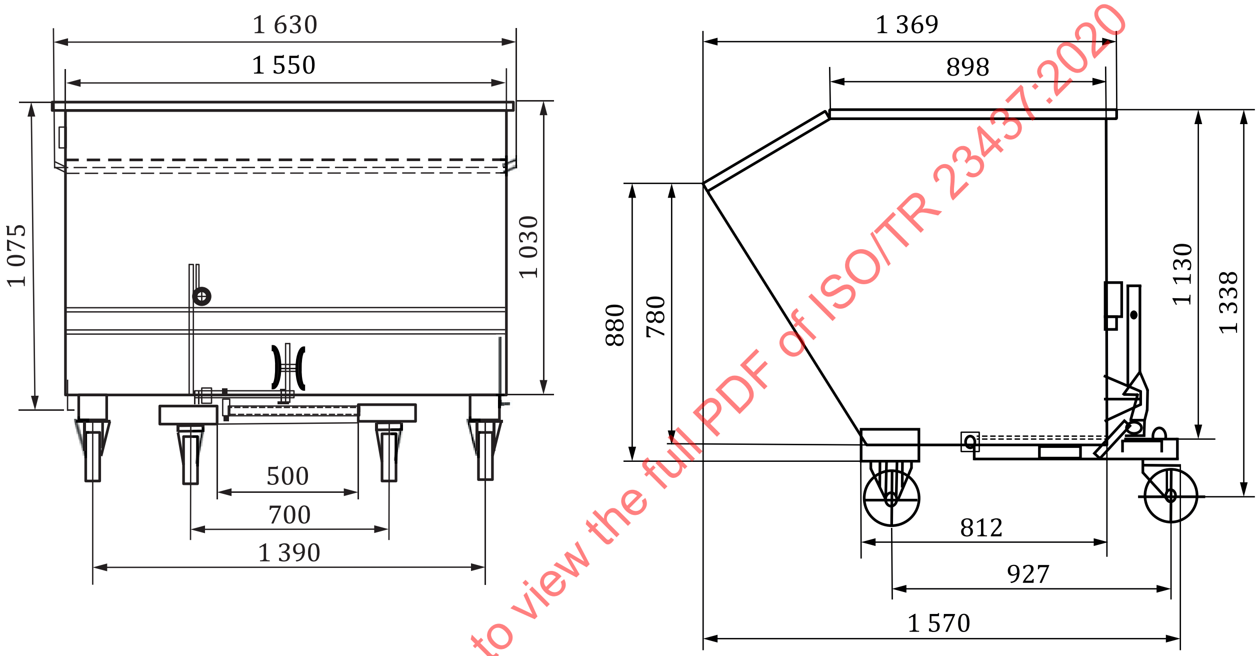
5.2.1 Wheel loader, fork lift or similar equipment, for the handling of a relatively large test portion of > 1,65 m^3. A maximum lifting capacity of 1 200 kg (including the container) is required (e.g. for tests with wood pellets), as well as a lifting height of at least 3,5 m at the bottom of the bucket when it is tipped.

5.2.2 Bucket, as equipment for the loading vehicle, which allows for an easy and gradual unloading into the bridging tester, is large enough to cover the entire width and length of the bridging tester's container, and can capture at least the entire volume of the test portion.

5.2.3 Special tilting container with a hydraulic cylinder, which has been found useful to trigger the unloading in a controlled way.

The construction of such a tilting container is shown in Figure 14. A picture of the container in operation is given in 5.3 (see Figure 15). The tilting container is equipped with a hydraulically driven discharge mechanism, which allows for a controlled and slow increase of the tilting angle when discharging the sample into the box. The tilting container shown in Figure 14 has a capacity of 1,7 m^3. The container's dimensions are suitable to fit below the bottom plates of the bulk container and between the stilts of the bridging tester. Other technical solutions that serve the purpose in the same way are also possible.

Dimensions in millimetres



a) Rear view **b) Side view**

Figure 14 — Tilting container for filling

5.3 Measurement performance

Before starting the measurement, it is ensured that the bridging tester is in a level position. Then, the bridging tester's slot is closed completely and the measuring scale is checked, if available (see Figure 12). If required, it is adjusted to zero.

The loading of the sample into the tester can then be done using a wheel loader or fork lift with a suitable bucket or a tilting container. Gradual sample discharge into the bridging tester is advisable in order to avoid any compaction of sample material in the box. Thus, any variance between the replicated measurements is kept low.

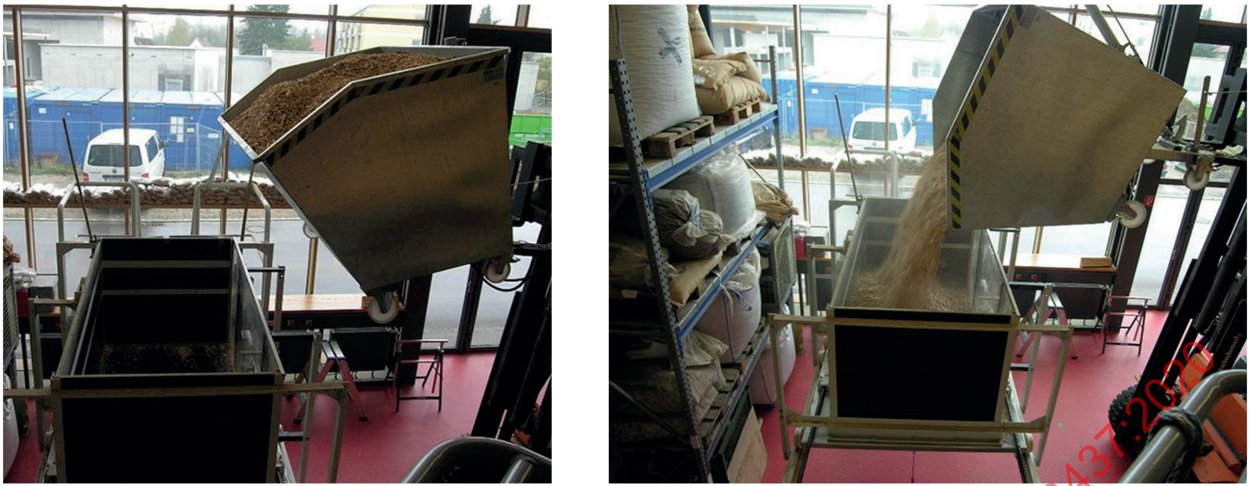


Figure 15 — Loading of the sample into the tester

It is advised to perform the test with two people in order to execute the test procedure properly. One person stands on the walking platform of the tester and the other stands on the ground at the measuring scale. The complete bridge collapse can then be verified by the person on the walking platform without any disturbance caused by climbing upwards. When the apparatus is equipped with an electrical motor for the slot opening, the operation can also be performed by only one person from the walking platform.

The progress of a bridge collapse is illustrated in Figure 16. The procedure to determine the correct slot opening width *l* is described in 4.5. Using an apparatus as described in 5.1, the opening procedure is started by applying an opening speed of about 15 crank rotations per minute (180 mm/min). Jerky motions are avoided. The opening speed is continued until the sample material starts to fall through the slot. If a fuel bridge still exists, the opening process is then continued at the same opening speed and ends at the point of a 100 % bridge collapse.

Figure 16 — Partly (left, middle) and fully (right) collapsed sample bridge during measurement with a wood chip fuel (view from the top)

Sometimes only one or two particles remain to form a bridge over the opening slot (“single particle bridge”), see Figure 17. In this case, the opening procedure can end and the bridge collapse is regarded as “full”.

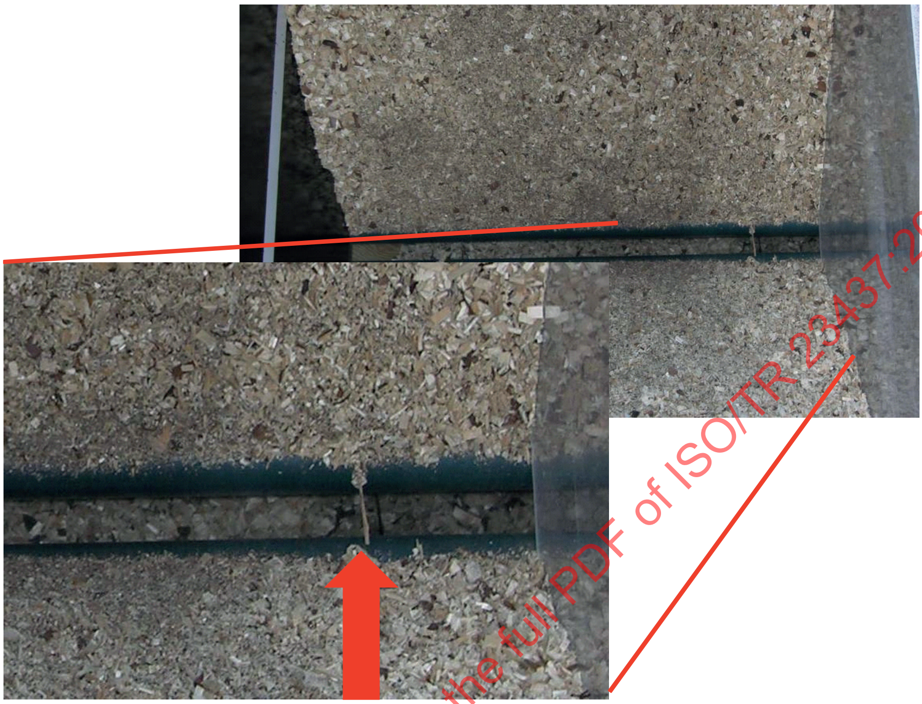


Figure 17 — Example of a single particle bridge

The time requirement for performing a full series of ten measurements is around 2,5 h.

6 Part III: Experience and results from bridging tests

6.1 General

Over the last three decades, three major studies were undertaken on the bridging behaviour of solid biomass. Research first started in Sweden[1][2], where the initial test apparatus was designed. This research was then continued by measurements in Denmark in the early 1990s, where the Mark 1 apparatus was used to test a variety of fuels derived from willow short rotation coppice. The Mark 2 unit was later used to test a large variation of chipped wood fuels, sawdust, wood pellets and hog fuel. The latest test campaign to date was conducted in Germany with the Mark 3 machine. Two Mark 3 bridging testers were used in a European interlaboratory test with six international partners. The basic findings are briefly summarized in 6.2 to 6.5.

Since the method of particle size classification differs between those performed in the first two and the later tests, this clause only refers to the nominal size of the particles. The nominal size is the cut length to which the chipper (or other comminution machine) is adjusted.

6.2 Performance characteristics of bridging test method

6.2.1 General

During the phase of testing and optimizing the bridging method (in the course of the Bionorm 2 project), a series of pre-tests and an international interlaboratory test were performed. The achieved results are summarized in 6.2.2 to 6.2.3.

6.2.2 Sensitivity analysis on testing accuracy

The main conclusions from the sensitivity analysis on testing accuracy were as follows[8]:

— Layer depth: The sample layer depth (filling height) is of significant influence. Thus, it is essential to perform bridging tests with the recommended and required filling height only. Only small variations on the required sample volume are tolerable.

— Fuel moisture: A significant impact of fuel moisture content was determined. Therefore, this parameter is always reported along with the measured slot width.

— Residence time: The bridging tests are best conducted immediately after the filling, and with a time gap of less than a full day between two subsequent replications.

Apart from the Bionorm 2 project, different layer depths of 25 cm, 50 cm and 75 cm were also assessed with the Mark 1 and Mark 2 test apparatus (as described in 6.4)[3][4]. The results confirm the requirement to maintain a defined layer depth when different fuels are compared.

6.2.3 Reproducibility (interlaboratory test results)

By the application of two different standard fuels (fine and coarse wood chips), the reproducibility (variation between laboratories) was determined[7]. Each of two identical bridging test apparatus was successively used within an international group of six test laboratories. The test apparatus and the uniform test fuels went in two loops of three laboratories in each group.

The results are given in Table 2. With the fine wood chip sample material, the reproducibility was significantly higher compared to the coarse wood chip sample: this is indicated by a coefficient of variation (CV) between 5,3 % and 10,8 %. With this fuel, the two apparatuses provided similar bridging results. However, with the coarse fuel, the measuring uncertainty rose to a CV between 16,5 % and 17,2 %. In addition, the mean values of the measured slot opening widths *l* deviated between the two apparatuses by about 100 mm (see Table 2).

For the coarse test sample, the relatively large deviation of measured mean slot width could have been caused by an unsuitable sample division before transport within the laboratory groups. Other impacts on fuel properties during long-distance transport and storage are also possible.

Table 2 — Results from interlaboratory tests with two bridging test apparatuses and two wood chip biofuels[7]

Type[a]	Fine wood chip sample (RR1)		Coarse wood chip sample (RR2)	
	Tester 1[a] (n = 3)	Tester 2[b] (n = 3)	Tester 1[a] (n = 3)	Tester 2[b] (n = 3)
Mean slot opening width l[c] (mm)	44	43	371	266
Standard deviation (mm)	5	2	63	46
Coefficient of variation (%)	10,8	5,3	16,5	17,2

[a] Bridging tester 1 (electric motor drive) was operated by the first group of three laboratories.

[b] Bridging tester 2 (crank handle drive) was operated by the second group of three laboratories.

[c] Measured in ten replications per sample.

6.2.4 Repeatability

Repeatability was tested in the Bionorm 2 project. It can be read from the relative CV in Table 3. Each of the mean values given was calculated from a set of ten measurements for each sample of the respective fuel type. For each individual sample, the relative CV was calculated, and the average of all CVs was reported for the fuel type.

The results from all tested fuel samples (n = 85) gave a global CV of 14,1 %[7]. This global CV was calculated by also including several other biofuels where only one sample could be measured (these results not shown in Table 3).

It was observed that some fuels behave more critically in terms of repeatability. Sawdust and wood chips were proven to be the most problematic fuels in this respect. Thus, they require the highest number of replications for a sound fuel characterization.

Table 3 — Ranking of mean coefficient of variation of a measured slot opening width l [9]

Fuel type	Number of fuel samples tested (each in 10 replications)	Mean relative coefficient of variation %
Wood pellets	7	7,7
Hog fuel	6	12,2
Bark (chopped)	4	12,4
Wood shavings	5	13,4
Wood chips	44	15,8
Sawdust	8	20,0

6.3 Characterization of selected biomass fuels

In the course of the method evaluation in the Bionorm 2 project, a large set of European biomass fuels was tested in order to achieve a fuel inventory concerning the range of physical–mechanical parameters. Table 4 illustrates the bandwidth of results for nine selected fuel types. The determination of the particle shape factor (PSF), length–diameter ratio (LD) and mean particle size (MP) was done by image analysis[9].