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Solid biofuels — Bridging behaviour of bulk biofuels

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Contents

Page

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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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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.

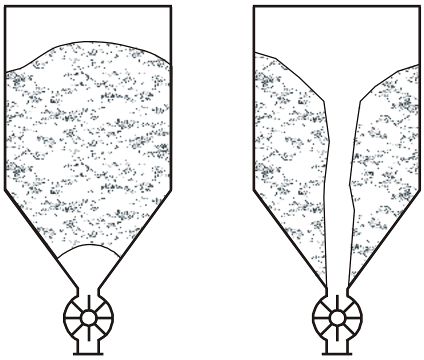


Figure 1 — Unfavourable flowing conditions of bulk fuels can cause the building of a bridge (left) or a channel flow (right)

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

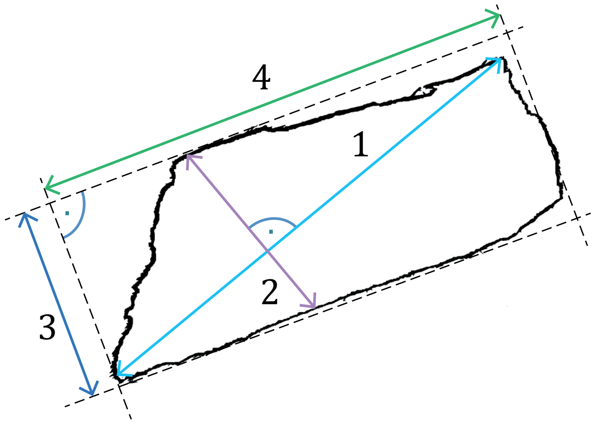
Note 1 to entry: When measured by image analysis, the PSF is the measured circumference of the projection area of a particle divided by the circumference of a circle with the same area as the particle. In the case of a perfect sphere shape (round projection area), the PSF of the particle is PSF = 1,0.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

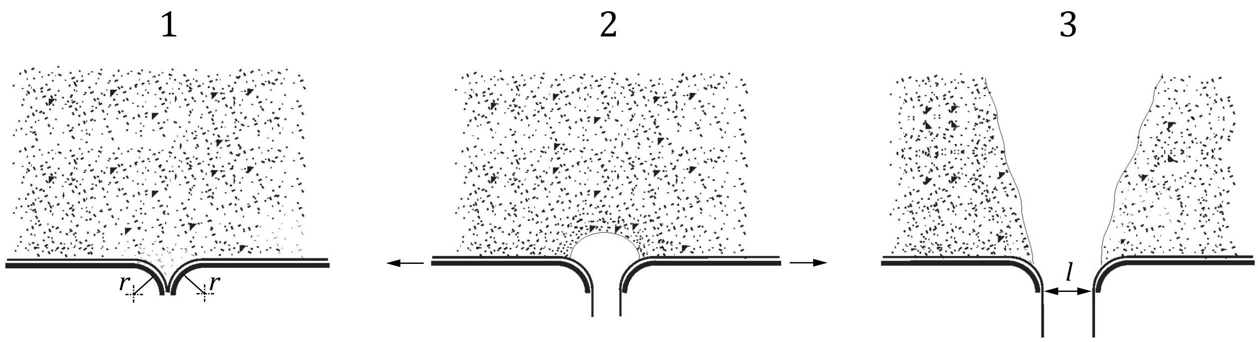
An expandable slot is formed between the two bottom sections of the box. The mat on each of the two bottom sections forms the slot in terms of a quarter of a circular arch with an effective radius of (32 ± 5) mm. The slot is closed when the two bottom sections are pushed together and the two mats meet 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.

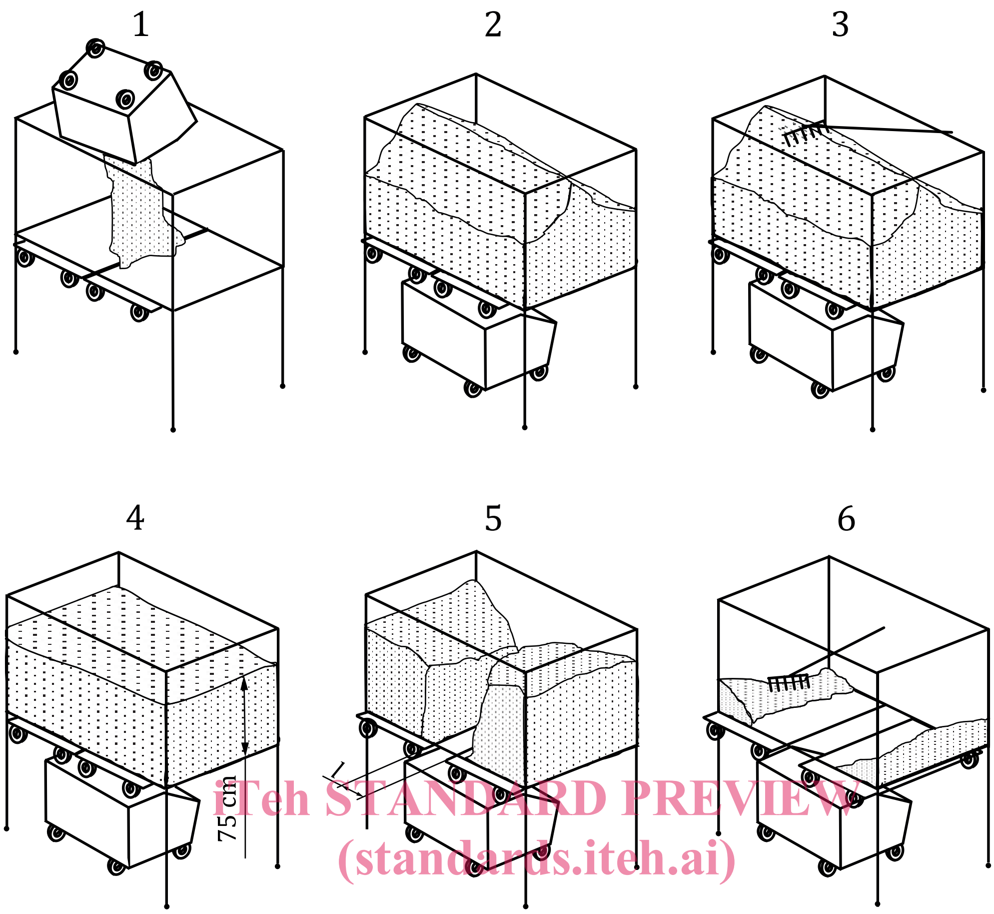
e) The box is reloaded with the unified test portion and the procedure in a) to d) is repeated until ten measurements have been performed per sample. For pellet or grain samples, the total number of repetitions can be reduced to five.

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.

