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Bridging properties of biomass fuels

A test procedure for the determination of the flow properties of solid biofuels was developed and tested with international partners. This procedure enables a much wider differentiation compared to other procedures (e. g. the determination of the angle of repose). A multiple regression analysis for wood chips shows the influence of continuously determined image analysis parameters, such as the mean particle size, the particle shape factor, the length-diameter-ratio and the moisture content. The derived mathematical model allows an easier evaluation of the flow properties of wood chips.

Keywords
Wood chips, storage, withdrawal from storage, bridging, pourability, image analysis

Abstract
Landtechnik 65 (2010), no. 4, pp. 280-282, 5 figures, 3 references

The bridging tendency observed in bulk materials such as wood chips or shredded materials often causes problems during emptying of biofuel storage or handling of such material. Despite this, technical characterisation of the physical properties associated with bridging for such fuels has not been possible so far. And there has been no possibility of estimating these parameters based on particular influencing factors. The aim of this work is to find better explanations causing bridging with the apparatus developed for this purpose and its influencing factors.

The test apparatus

Based on a Swedish experiment design from the 1990s (Mattsson [1]), a trial container was developed with a divided floor. The two floor plates are mounted so that they meet in the middle of the container floor and can be slid away from each other on rails enabling a parallel widening of the opening slot. Depending on the material involved, its release in this way results in a certain amount of bridging above the floor opening (see l in **figure 1**). The bulk material is thereby not subject to any frictional forces through movement of the floor. The reason for this is that two PVC mats are laid separating the bulk material from the container floor and which slide down over the rounded edges on the opening. Both floor plates, which are rounded on their touching edges with a radius of 26 mm over 90° (see r in **figure 1**), are moved via crank handle and threaded spindle being slowly parted until 100 % collapse of the material bridge occured. At this point the opening width is measured to a precision of 1 mm and is defined as a standard for the bridging tendency or flowability of the material.

The test bulk container is produced from commercial pressure board (24 mm thick) (interior measurements: length 2.0 m, height 1.0 m, width 1.1 m) and is constructed upon a 1.5 m high steel framework (**figure 2**). The predetermined test volume of 1.65 m³ (i.e. 0.75 m filling height) can in this way be collected in a tipping container positioned under the opening slot. The average of the opening width is calculated from 10 test results for every fuel type (except in the case of pellets and grain where only 5 test results are averaged). A forklift and tipping container are used for filling the bulk container through slow tipping from a uniform height of around 1.4 m above the sidewall.

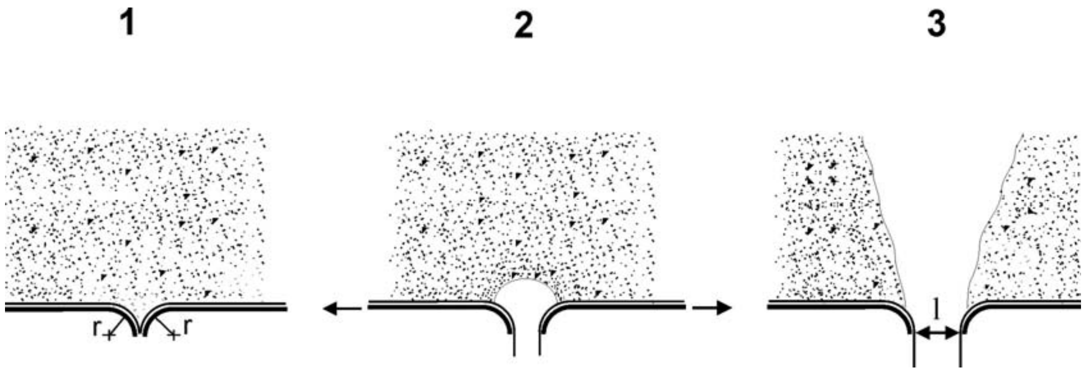
Method and further influence factors

Two identical bridging test apparatus were completed and used by the participating partner research facilities. Thereby a total of 85 separate tests featuring 15 typical types of fuel were conducted, representing the complete breadth of fuels ranging from those with very favourable flow characteristics (pellets, grain) to those with very unfavourable ones (chopped material, hog fuel).

Alongside the actual measurement of the bridging width, further fuel characteristics were determined: moisture content, bulk density and angle of repose according to FEM [2]. With a partial sample of 1 to 3 litres an image analysis determination of further physical characteristics such as average maximum particle length, average length-diameter ratio, average particle shape factor and further measurement values were performed.

For the image analysis the photo-optic classification apparatus Haver CPA4 Conveyor from Haver&Boecker (**figure 3**) was used; this line-scan camera offers a resolution of 4 096 pixels over a breadth of 400 mm, a tech-

Fig. 1



Functional principle of the bridging test apparatus

nology that proved clearly superior to a screening technique for determination of particle length distribution [3].

Bridging width and angle of repose

With a range from 27° to 50° the angle of repose indicated only a limited dynamic reaction to the varying fuel characteristics (**figure 4**). The correlation of the measured bridging width was shown to be limited (R^2 = 0.42). However, measurements with the bridging test apparatus gave an around 4 times higher differentiation in depiction of bulk fuel flow characteristics although, here too, measurement fluctuations (here: variation coefficient) between individual repeat measurements were (depending on material) between 5 % for wood pellets and 20 % for sawdust.

Model setup

The collected measurement parameters for the wood chip samples (in total 51 values) were applied as starting factors for a multiple linear regression analysis considering paired interactions for the deduction of a mathematical model for estimating the opening width (l) (**equation 1**).

$$l = -4.5251 + 7.0553 \cdot PSF + 0.7031 \cdot MP - 0.2832 \cdot M - 6.4037 \cdot LD + 0.2427 \cdot (M \cdot LD) - 0.0058 \cdot (M \cdot MP) \quad \text{(eq. 1)}$$

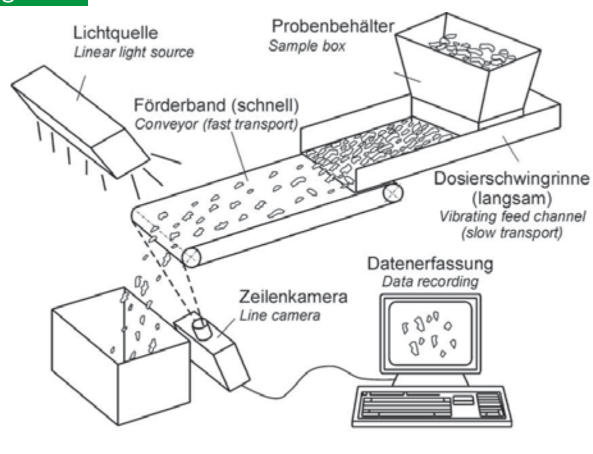
Thereby it was demonstrated that a decisive influence was especially exerted by the parameters mean particle size (MP in mm), moisture content (M as % of total mass), average particle shape factor (PSF, dimensionless) and the average length-diameter ratio (LD, dimensionless). A sensitivity analysis showed that the influence of the just mentioned parameters decreases in the same order. Other parameters (bulk density, interquartile distance of length distribution) proved not to be significant with a 5 % probability of error.

With this model for wood chips a high adjusted R^2 of 0.88 was achieved. The average absolute error between measured and estimated opening width (l) is 32 %, as shown in **figure 5**. As a matter of fact even laboratory comparisons in a round robin featuring a uniform standard chip sample resulted in a variation coefficient of 18 %, the model blur of around 32 % appears to be still acceptable.

Fig. 2

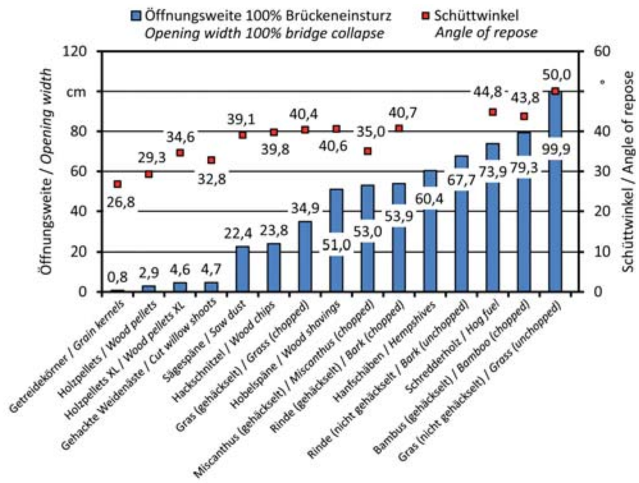
Bridging test apparatus.

Fig. 3



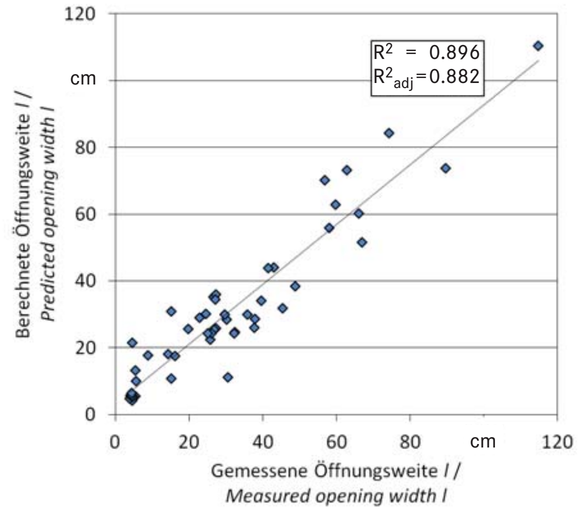
Functioning principle of continuous image analysis

Fig. 4



Angle of repose of selected biomass fuels, sorted in the order of the bridging properties (opening width)

Fig. 5



Model results from equation 1 compared to measured values for bridging of wood chips (n = 51)

Conclusions

The test procedure for the characterisation of flowability described here proved itself to be practicable. Because of the complicated assembly of the test apparatus it appears, however, that in the long term a model estimation using image analysis parameters and moisture content values would be more practical. The assessment based on this and the classification of fuels used in practice means, that it is necessary in advance to identify critical fuel values under varying real utilisation situations involving taking fuel out of storage and moving it.

Literature

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Remark

The results presented here were achieved as part of a European research project: Pre-normative Research on Solid Biofuels for Improved European Standards (BIONORM II). Five further European research institutes from Denmark, Austria, Belgium, Finland and Latvia participated in the data collection.