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Solid biofuels — Determination of grindability — Hardgrove type method for thermally treated biomass fuels

Biocombustibles solides — Détermination de la broyabilité — Méthode de type Hardgrove pour les combustibles de biomasses traitées thermiquement

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Introduction

Grindability characteristics are of fundamental importance during solid biofuel preparation for energy conversion processes, requiring a predictable particle size distribution. Particles that are too large or too wide in their distribution may result in feeding problems as well as un-burnt fuel passing through the conversion process. Also, in case of processing of biomass for pre-treatment, consistency in particle size determines the yield of such pre-treatment as well as the quality of the final solid biofuel.

The effectiveness of combustion in a pulverized fuel furnace depends strongly on the reactivity and particle size distribution of the pulverized fuel among other factors. For coal, the Hardgrove Grindability Index (HGI) test was developed to characterize the relative grindability of a particular quality of coal relative to a pre-determined standard quality of coal (ASTM D409). The HGI test is an empirical batch method that simulates the continuous grinding and crushing operation of a ball, table or tube type of industrial coal pulverizer, herein also called coal mill. The HGI value is an indication of the degree of grinding required to reach a particular particle size necessary for effective combustion.

Manufacturers of coal pulverizers for preparation of pulverized coal for combustion in coal burning plants provide curves that show the relationships between the HGI for coal, coal mill capacity in terms of tonne/h and coal mill power in kW. This is done as part of the boiler contract and guarantees. It also serves as a first indication as to how to operate a mill when pulverizing different coals with predetermined standard properties. A HGI of 50, which is standard industry convention, implies that 100 % capacity in tonnes per hour (as indicated) can be reached for the coal at a fineness of 70 % less than 75 microns and 99,5 % less than 300 microns. If a coal has a HGI of less than 50 it implies some level of pulverizer capacity loss while on the other hand, a HGI higher than 50 indicates some level of pulverizer capacity gain. The HGI method is internationally accepted and quoted as part of the specification of coal for international trade.

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Grindability may also be applied to thermally pre-treated compressed biomass materials, such as pellets, for pulverization in coal mills. Pre-treatment methods for biomass fuels such as torrefaction, steam treatment or hydro-thermal carbonization (HTC) upgrade the properties of biomass making it more effective as a fuel. With increasing interest in the use of such pre-treated biomass fuels for direct co-firing applications in conventional pulverized coal boilers, this method herein describes a laboratory procedure for determination of the grindability of pre-treated biofuels for powder fuel preparation.

The HGI determination is subject to many limitations, including the fact that measurements can be insensitive to the heterogeneous properties of coal that arise from different mineral contents, maceral constituents and levels of maturity. Three relevant adaptations are applied to the standard HGI method in order to extend its applicability to thermally pre-treated biomass fuels. The adaptations and their justification are as follows:

— Amount of sample used for the test determination.

— Particle size used as basis for defining grindability.

— Reference materials for establishing the calibration curve.

0.1 Amount of the sample used for test determination

Coal pulverizers are volumetric devices but with the densities of coals being fairly similar, the capacity of these devices is expressed in mass units per hour. In contrast different biomass materials have different densities. Therefore, the sample amount was changed to the volume (75 ± 0,5) cm^3 of input material, which approximates the bulk volume of the standard reference coal samples with a particle size between 1,18 mm and 600 µm.

0.2 Particle size used as basis for defining grindability

The standard HGI test for coal uses the mass of particles passing a sieve with an aperture size of 75 µm as criteria for determining the grindability and the resulting HGI value. The furnace volume is designed from the knowledge of coals to be utilized so as to provide an adequate residence time for complete combustion. Combustion efficiency depends in part on fuel particle size especially for pulverized coal

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furnaces. As the combustion efficiency also depends on the reactivity, which is linked to volatile matter content of fuels, the particle size for high-volatile fuels, such as thermally treated biomass, would not necessarily need to meet the strict fineness requirements for coal powders. Therefore, a sieve with an aperture size of 500 µm is used for determination of grindability of thermally treated biomass. This adaptation also has positive implications on the repeatability of the determination.

0.3 Reference materials for establishing the calibration curve

In the standard HGI test for coal, four references coals are needed for calibrating a HGI mill. This enables reproducibility of the results across different labs. For the thermally treated biomass grindability index determination, this is the very first step. The thermally treated biomass grindability index is an index for materials originating from biomass. The sieving behavior of biomass materials differs fundamentally from that of coals due to the difference in the sphericity of the coal particles. Biomass materials, including thermally treated biomass, are more fibrous and have lengthy dust particles compared to coals. Thermal treatment processes, such as torrefaction, modifies the property of biomass by making biomass more like charcoal. Woody charcoal is a product of slow pyrolysis, which degrades the fibrous nature of the biomass. This consequently improves its grindability as well as the sphericity of the pulverized fuel.

The adapted grindability method uses wood pellets (ISO 17225-2:2021 A1 class pellets) and wood based charcoal (ISO 17225-1:2021, Table 14) as calibration reference materials. These biomass reference materials will be given assigned Thermally Treated Biomass Grindability Index (TTBGI) values as a result of the procedures described in Annex A. The materials are available commercially for the determination.

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Solid biofuels — Determination of grindability — Hardgrove type method for thermally treated biomass fuels

1 Scope

This document describes a method for determination of grindability of graded thermally treated and densified biomass fuels such as classified in ISO/TS 17225-8, for the purpose of preparing fuels with a defined particle size distribution for effective combustion in pulverized fuel boilers. The grindability characteristics determined by the test method provide guidance as to the pulverizing mill performance when utilizing such fuels.

Apart from pelletized materials as described in ISO/TS 17225-8, the method can also be applied to non-compressed or non-densified thermally treated biomass as specified in ISO 17225-1:2021, Table 14 and Table 15.

The results created with this method are not relevant for large wood chips, since limitations apply for large pulverizing coal mills, which are typically not used for grinding materials such as chips.

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2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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ISO 3310-1, *Test sieves — Technical requirements and testing — Part 1: Test sieves of metal wire cloth*

ISO 14780, *Solid biofuels — Sample preparation*

ISO 16559, *Solid biofuels – Terminology, definitions and descriptions*

ISO 17827-2, *Solid biofuels — Determination of particle size distribution for uncompressed fuels — Part 2: Vibrating screen method using sieves with aperture of 3,15 mm and below*

ISO 18134-1, *Solid biofuels — Determination of moisture content — Oven dry method — Part 1: Total moisture — Reference method*

ISO 18134-2, *Solid biofuels — Determination of moisture content — Oven dry method — Part 2: Total moisture — Simplified method*

ISO 18135, *Solid Biofuels — Sampling*

ISO 21945, *Solid biofuels — Simplified sampling method for small scale applications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16559 and the following apply.

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

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

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

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3.1
coal mill
industrial pulverizer used for the purpose of size reduction (and including drying) of hard coal with the purpose of creating fine coal powder for combustion in a pulverized fuel fired unit

3.2
HGI mill
stationary grinding device used in the laboratory for the purpose of determining the grindability of coals for industrial coal mill application

3.3
TTBGI
thermally treated biomass grindability index
measure for the tendency of a fixed volume of thermally treated biomass material to produce fine particles after grinding under defined settings and conditions

3.4
reference material
materials used to calibrate instruments and validate a measurement method

4 Principle

The TTBGI for a particular biomass is derived by measuring the tendency of a fixed volume (75 ± 0,5) cm^3 of biomass fuel materials to produce particles below 500 µm sieve aperture size when grinded and crushed in a standard HGI mill under standard conditions (vertical force on balls = 284 N ± 2 N). The TTBGI for biofuels has been developed by three adaptions to the existing Hardgrove Grindability Index (HGI) for standard coals (see ASTM D409) as follows:

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— amount of test sample (75 ± 0,5) cm^3,

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— sieve aperture size (500 µm), and

— reference materials selected for calibration of the grindability method in this document are wood based charcoal (ISO 17225-1:2021, Table 14) and wood pellets (ISO 17225-2:2021, A1) in addition to standard coals as specified in ASTM D409.

5 Apparatus

The following apparatus are required for the determination.

5.1 Standard HGI mill

Standard HGI mill, as per ASTM D409 specification, verified on a periodic basis.

5.2 Sieves

Sieves, with a circular or rectangle sieve area and an effective sieve area of minimum 250 cm^2. The sieves shall have an aperture geometry in accordance with ISO 3310-1 (metal wire cloth). The frame of the sieves shall have a height that enables the sieves to contain the samples and allows a free movement of the sample during the sieving process. Sieves, having aperture sizes of 1,18 mm, 600 µm and 500 µm are required. For the purpose of calibration also a sieve having an aperture size of 75 µm is required.

5.3 Glass measuring cylinder

Glass measuring cylinder, class A, having a filling volume of (75 ± 0,5) cm^3.

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5.4 Sieving machine

Sieving machine, for fine materials (less than 3,15 mm) with a vibrating mechanical agitator for multiple sieves, a collection pan at the bottom and a top cover to avoid any material loss.

5.5 Balance

Balance, capable of reading to the nearest 0,199 g.

5.6 Cutting mill

Cutting mill, fitted with a 1,5 mm screen for pre-grinding of test samples.

6 Sampling and sample preparation

6.1 General

Sampling shall be done in accordance with ISO 18135 or ISO 21945 and sample preparation according to ISO 14780. Two test portions shall be prepared.

6.2 Moisture conditions

Moisture content determination of a test sample shall be done in accordance with ISO 18134-1 or ISO 18134-2. The moisture content shall be below 10 % on a wet basis in order to avoid the impact of moisture on the accuracy of the result. Open air-drying is recommended for samples with higher than 10 % moisture content.

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6.3 Pre-grinding and sieving

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The determination requires duplicate test portions with a defined particle size range between 600 µm and 1,18 mm as is required for the HGI characterization method (see ASTM D409). In the absence of an adequate amount of test portions (minimum of 225 ml) with the required particle size range, pre-grinding to obtain the test portion shall be done in a suitable mill (e.g. cutting mill) equipped with a 1,5 mm screen. This shall be followed by sieving according to ISO 17827-2 using 1,18 mm and 600 µm sieves (Clause 5) in order to obtain the required size fraction between the two sieves.

6.4 Sample size

After pre-grinding and sieving, duplicate portions each of (75 ± 0,5) cm^3 in the described particle size range between 600 µm and 1,18 mm shall be obtained.

Use a class A cylinder to determine the sample volume. Ensure surface is flat but do not vibrate or tap cylinder to prevent the sample from being additionally compacted.

7 Procedure

The test is to be done in duplicate. The procedure is as follows:

a) Weigh a (75 ± 0,5) cm^3 test portion with particle size distribution between 1,18 mm and 0,6 mm to 0,1 g and note it as initial mass (m_0).

b) Place the test portion into the milling cup of a standard HGI mill; grind the test portion for 60 ± 0,25 revolutions (vertical force on balls = 284 N ± 2 N).

c) Sieve the grinded product for 10 min using a sieving machine with a 500 µm sieve (Clause 5).

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d) Collect all particles below the 500 µm sieve on the collector bottom in an appropriate sample container. Then remove all particles, which have remained on the 500 µm sieve. Place them into a holding container for the purpose of sieving again. Then clean the sieve carefully with a brush so that the particles trapped in the apertures are removed and are also collected in the holding container.

e) Repeat the sieving of the materials collected above the 500 µm for 5 min and perform the separation as described in step d; all materials that have passed the 500 µm apertures are unified in the holding container.

f) Repeat step e) a second and a third time if sieving was uncompleted.

NOTE It can be possible that in many cases two re-sieving steps are not necessary. But re-sieving provides the opportunity to control if sieving was completed or some material remained on the sieve, e.g. caused by blocking of the holes. Before re-sieving, all particles sticking in sieve holes need to be removed.

g) Weigh the unified total material collected below the 500 µm sieve to receive mass m_1. Weigh the mass fraction, which remains on the 500 µm sieve to receive mass m_2.

The test results shall fulfil the following requirements:

— the average of the two tests shall meet the repeatability criteria given in Clause 9;

— the sum of m_1 and m_2 shall differ not more than 1 % from the mass of m_0 in each test.

If one of the criteria is not fulfilled, repeat the analysis. If the results from the repeated analysis again do not meet the requirements, state it clearly in the test report.

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8 Calculation

For each of the two test portions of mass m_0 used in the duplicate determination in Clause 7:

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— calculate the total mass m_T as the sum of both fractions (below and above 500 µm) as achieved in g according to Formula (1):

$$m_T = m_1 + m_2 \quad (1)$$

— calculate the relative mass fraction (in %) of the sieving fraction below 500 µm using Formula (2):

$$x = \frac{m_1}{m_T} \times 100 \quad (2)$$

where

x is the relative mass fraction of the sieving fraction below 500 µm in %;

m_0 is the mass of the test portion in g;

m_T is the mass of test portion calculated after sieving according to Formula (1) in g;

m_1 is the total mass of the sieving fraction below 500 µm in g;

m_2 is the total mass of the sieving fraction above 500 µm in g.

Calculate the mean of the duplicate determinations from the results achieved with Formula (2).

To calculate the TTBGI value insert the mean value into the equation of the calibration curve as given in A.3.

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