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Moisture content determination in solid biofuels by dielectric and NIR reflection methods

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Abstract

One near infrared (NIR) reflectance and five dielectric moisture meters were tested for their capability of measuring moisture content (MC) in solid biofuels. Ninety-eight samples were tested at up to eight moisture levels covering the MC range from fresh fuel to approximately 10% MC (w.b.). The fuel types ranged from typical solid biofuels such as coniferous and deciduous wood chips over short rotation coppice (SRC) to sunflower seed and olive stones. The most promising calibrations were obtained with the NIR reflection method and two dielectric devices where the sample is placed in a container integrated in the device. The calibration equations developed show that there is a profound influence from both laboratory and fuel type. It is suggested that individual calibrations that are based on the specific fuel types used at the individual heating plant could be applied.

Keywords: Moisture content; Solid biofuel; Fuel chips; On-site measurement; Dielectric measurement; NIR

1. Introduction

Solid biofuels are by nature heterogeneous with respect to moisture content (MC), bulk density and particle size. The fuels range from well-defined upgraded materials such as wood or straw pellets used in domestic burners to wood chips produced from thinnings and residues from logging operations. Pellets typically have a MC below 12% (w.b.), a narrow bulk density range and a uniform size distribution. In contrast, the MC of forest chips varies substantially, from approximately 10% to around 60% (w.b.), it has a wide-range bulk density and a size distribution that largely depends on tree species, raw material and type of chipper used.

The price of the fuel is often based on the MC. Combustion optimisation, storage management and handling properties are influenced by the MC [1–4]. Traditionally, MC is measured as weight loss by convection drying until constant mass in hot air at 103 or 105±2 °C in a drying cabinet. The method is widely accepted and described in a number of standards used for moisture determination of solid biofuels [5–7]. It is considered as being accurate and independent from other parameters such as bulk density or ambient temperature.

However, moisture determination in a drying oven is time and labour consuming. The potential for saving time and obtaining information on the MC prior to incineration is therefore a motivation for using rapid test methods for moisture determination. As reviewed by Nyström and Dahlquist [8], several methods for rapid measurement of MC of solid biofuels exist. Among these, the dielectric- and near infrared (NIR) methods are presently the best alternative to convective drying [9–12]. Common for the devices are that they measure a characteristic of the fuel that which is correlated with the MC.

The dielectric methods are based on electric field changes. The changes are due to the dielectric properties of the material matrix upon radiation with an alternating

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current. The dielectric properties of any material are expressed as the relative permittivity, $\varepsilon = \varepsilon' - \varepsilon''$, where ε' is the dielectric constant of the material which expresses the materials capability to polarise and ε'' is the loss factor of electrical energy within the field due to polarisation of the material. Water has a high dielectric constant ($\varepsilon' \cong 80$) compared to wood ($\varepsilon' \cong 4$–5) [13]. In its simplest version, a moisture meter consists of two plates connected to an alternating voltage supply. The volume between the plates contains the dielectric material e.g. wood chips. When an alternating current passes from one plate (emitter) to the other (receiver), the decrease in the effective electric field compared to a situation with air or vacuum between the plates is a measure of the moisture in the sample. Besides MC, temperature and bulk density also influence dielectric measurements [14–16]. Influence from bulk density and temperature may be reduced by calibrating the moisture meters to fuel types within a suitable bulk density range and by defining the ambient temperature.

If the applied wavelength is within the radio frequency (RF) area (<0.3 GHz), the moisture meter is of the capacitance type. A widespread alternative to radio frequencies are microwaves (0.3–20 GHz). Similar to the capacitance meters, the microwave technique measures the MC by sending a wave of a defined frequency through the material. The waves are either absorbed or reflected by the dipole water molecules, which is measured as a transmission or reflection factor. This technique is particularly attractive since influences from ion conductivity are negligible at high frequencies as compared to the dielectric losses.

The NIR reflectometric method is based on the principle that a material illuminated by monochromatic light of a defined wavelength absorbs, transmits or reflects the light. Water has two distinct absorption bands in the NIR part (800–2500 nm) of the electromagnetic spectrum at around 1475 and 1940 nm. This is used in NIR-reflectometry where monochromatic light of either of the two wavelengths is absorbed by the water molecules of the sample. The absorption difference between the absorbed bands and reference bands using wavelengths that are almost entirely reflected provide a quantitative measure of the functional O–H groups of the material (primarily water). Thygesen [17] found no literature describing influence of bulk density, whereas Fassio and Cozzolino [18] showed that NIR could be sensitive to variances in the colour of the material.

This paper summarises the results of the testing of five rapid moisture meters measuring dielectric properties in the radio and microwaves frequencies and on one optical device based on NIR reflectance. All devices tested are commercially available and two of them are developed particularly for moisture determination of solid biofuels. The study was carried out as a round robin with participants from 11 European laboratories as described in Section 2.3.

2. Materials and methods

2.1. Rapid moisture meters

An overview on the optical and five dielectric moisture meters tested in the study is given in Table 1.

The Pandis and Schaller devices belong to a type where the sample is placed in a container during the measurements (container type). The emitter and receiver are orientated in a way that allows an electrical field to build up within the sample (transmission measurements). Both devices are commercially available only as pre-calibrated versions. The Pandis consists of a cylindrical container (640×500 mm) with a filling volume of approximately 60 l. It is designed to measure MC ranging from 0% to 55% (w.b.) on a mixture of fine and medium chips as described in the ÖNORM M7133 [19]. The sample is compacted during filling by shaking the container twice when it is half full. The Schaller has a cubic sample container ($150 \times 190 \times 400$ mm) which requires a sample size of 1700 ± 10 g. It is designed to measure fine and medium chips [19], at a MC range from 0% to 40% (w.b.) and an optimum measuring range between 10% and 25% (w.b.). With the Schaller, the influence from bulk density is reduced due to the application of a defined sample volume and mass.

ACO, Wile and the microwave type Moist are all hand-held devices. The Wile has a probe (length ≅ 190 mm) that is inserted into the sample, while ACO and Moist have a flat sensor head (ACO, ∅ = 50 mm; Moist, ∅ = 80 mm), that is placed on the surface of the sample during measurements (reflective measurements). The sensor heads of the hand-held devices thus unite emitter and receiver.

Table 1
Description of the tested rapid moisture meters

Method	Principle	Manufacturer: type	Name	Range	MC range (%)[a]
Dielectric	Capacitive	Pandis: FMG 3000	Pandis	<0.3 GHz	0–55
		ACO: MMS-0-1-2-0	ACO		0–80
		Farmcomp: Wile25	Wile		13–85
		Schaller: FS 2002-H	Schaller		0–40
	Microwave	hf sensor: Moist 100	Moist	0.3–20 GHz	0–80
Optical	NIR reflection	Mesa: MM710	Mesa	800–2500 nm	10–40

[a]As recommended by the supplier.