COMPARISON OF RAPID MOISTURE CONTENT DETERMINATION METHODS FOR WOOD CHIPS

Theresa Mendel, Andreas Überreiter, Daniel Kuptz, Hans Hartmann
Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ),
Schulgasse 18, 94315 Straubing, Germany
Phone: +49-9421-300113, Fax: +49-9421-300211
Email: Theresa.Mendel@tfz.bayern.de

ABSTRACT: Newly developed gravimetric or electric methods may be suitable alternatives to provide a rapid and accurate moisture content determination of wood chips. In total, nine different rapid determination devices were selected for testing including two infrared dryers, four dielectric instruments, two conductivity methods and one time-domain-reflectometry method. Oven drying according to ISO 18134-2 was used as reference. Testing was carried out on different raw materials of wood chips and at different levels of moisture content. On average, the mean measuring deviation from the reference value ranged from -2.6 w-% (± 1.7 w-% SD) to 3.8 w-% (± 4.7 w-% SD). Thereby, best results were obtained with the infrared dryer MA35 for a large range of different moisture contents. In contrast, the electric methods were less accurate but allowed for larger sample sizes. Furthermore, instrument accuracy strongly increased with decreasing moisture content. The high accuracy of the oven drying method could not be reached by any of the tested devices. However, by using a high amount of samples the average moisture content of all measurements approximated the reference value. Therefore, some instruments could be recommended for quality assurance during production.
Keywords: wood chip, moisture content, quality measurements

1 INTRODUCTION

1.1 General

Moisture content (MC in w-%) is the most important fuel quality parameter of wood chips as it influences the net calorific value, fuel combustion behavior and the storability of the biofuels [1]. Moreover, MC directly influences carbon monoxide and particle emissions during combustion. Due to challenging national and international emission thresholds for small- and medium-scale boilers (< 100 kW – 500 kW) [2], boiler manufacturers often define maximal limits for MC of wood chips such as < 15 w-% or < 35 w-%.

Varying MC may present a challenge for wood chip producers, fuel distributors and boiler operators. Hence, correct and on-time MC determination is crucial at many points during production and distribution. However, the standardized method for MC determination, i. e. oven drying according to ISO 18134-2 [3], consumes both time and labor. Moreover, the heterogeneity of wood chips often requires a large number of samples, often exceeding the capacity of drying cabinets. Newly developed gravimetric or electric methods may be suitable alternatives to provide a rapid and accurate MC determination.

1.2 State of knowledge

Common methods to determine MC of solid biofuels can be divided into direct methods such as thermogravimetric measurements and indirect methods such as electric measurements.

Thermogravimetric methods determine MC by weight difference of a medium before and after drying to constant mass. Thus, MC is measured as the loss of water that is removed from the fuel during the drying process [3]. The most common direct method is oven drying according to EN ISO 18134-2. This method uses cabinets for drying of the medium at 105 ± 2 °C [3]. Oven drying is independent of other fuel properties such as bulk density or varying environmental conditions [4]. Another thermogravimetric method facilitates infrared radiation for drying. Such infrared dryers determine MC more rapidly compared to the oven dry method and allow for smaller sample sizes [5].

Indirect methods work nondestructively. In contrast to the thermogravimetric methods, they do not change fuel properties of a medium [5]. In most cases, MC is determined in only a few seconds. Dielectric methods, conductivity methods and TDR (time domain reflectometry) methods are the most common electric methods. Dielectric methods estimate MC by measuring the relative permittivity (ε_r) of a medium. Permittivity is determined by the dielectric constant of water ($\varepsilon_r = 78.2$) in comparison to wood ($\varepsilon_r = 1.5 – 3.0$) [6]. The large gradient between the two dielectric constants show that the permittivity of a medium is strongly affected by the MC. Dielectric methods are sensitive to bulk density of wood chips and air temperature [4, 7]. Therefore, manufacturers usually offer moisture meters with different calibration curves for different raw materials to compensate these effects. Conductivity methods measure on the basis of electrical resistance. Dry solid biofuels are poor electrical conductors. Conductivity increases with increasing MC [5]. Similar to dielectric methods, this method also depends on temperature and wood type. Moreover, MC above the saturation point (> 19 – 25 w-%) causes alternations in electric conductivity [5, 6]. TDR methods measure MC via the propagation velocity of electromagnetic radiation [7]. Materials having a high dielectric constant cause a deceleration of the propagation velocity. This deceleration forms the basis for the estimation of MC [5].

The aim of this study was to determine and compare the accuracy of selected direct and indirect measuring instruments for rapid MC determination of wood chips.

2 MATERIALS & METHODS

2.1 Measuring instruments

In total, nine different measuring instruments were selected for rapid MC testing according to their availability, price, handiness and field of application. The selection included two infrared dryers, four dielectric methods, two conductivity methods and one TDR method (Fig. 1).

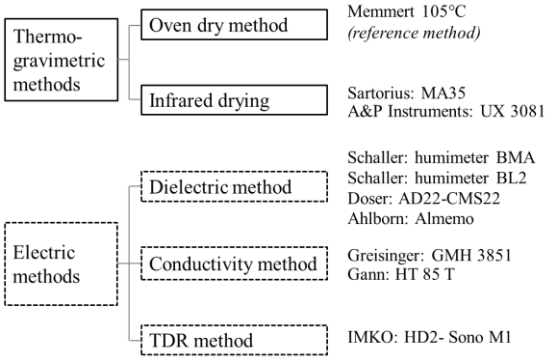

Figure 1: Measuring principles of tested devices

The two infrared dryers were MA35 (Sartorius AG) and UX3081 (A&P Instruments). The sample sizes measured on average 15 g for MA35 and 35 g for UX3081.

The dielectric methods were humimeter BMA (Schaller GmbH), humimeter BL2 (Schaller GmbH), AD22-CMS22 (Doser Messtechnik GmbH Co. KG) and Almemo FH A696-GF1 (Ahlborn Mess- und Regelungstechnik GmbH) (Fig. 1). Schaller GmbH offers the calibration curves 'wood chips', 'coarse chips' and 'industrial wood chips' according to the particle size and the amount of fines (i. e. particle Ø < 3.15 mm) of wood chips. The humimeter BMA also offers the option to measure bulk density. In contrast, Almemo and AD22-CMS22 work with only one calibration curve. However, for AD22-CMS22 a user-defined calibration is possible.

The two conductivity methods were GMH 3851 (Gann Mess- und Regeltechnik GmbH) and Hydromette HT85T (Greisinger electronic GmbH). Both devices work with more than one calibration curve. The calibration of the instrument HT85T categorizes according to wood species. GMH 3851 offers a curve for wood chips in particular.

The only TDR method HD2-Sono M1 (IMKO GmbH) offered three calibration curves: normal, sensitive and less sensitive. These curves were not particularly calibrated for biofuels. This method is mainly used in soil moisture determination, but it also allows for a user-defined calibration curve.

Three instruments, the AD22-CMS22, the Almemo FH A696-GF1 and the HT85T measure MC as wood humidity (i.e. on dry basis). Thus, conversion of the results to MC is required.

2.2 Fuel samples and moisture contents

Testing was carried out on five different types of wood chips (Fig. 2):

Figure 2: Five types of wood chips used for testing (Energy roundwood chips of Norway spruce (1) and European beech (2), Forest residue chips of conifer trees (3) and deciduous trees (4), Short rotation coppice chips of European poplar (5))

- energy round wood chips of Norway spruce (*Picea abies*) (ERC-spruce)
- energy round wood chips of European beech (*Fagus sylvatica*) (ERC-beech)
- forest residue chips of conifer trees (FRC-conifer)
- forest residues chips of deciduous trees (FRC-deciduous)
- short rotation coppice chips of European poplar (*Poplar spp.)* (SRC-poplar)

Based on fuel specifications for wood chips according to ISO 17225-4 [8], testing was done at five different MC levels (Fig. 3), i. e. at the moisture content of fresh material 'as received', at 35 w-%, at 25 w-%, at 15 w-% and at 10 w-%.

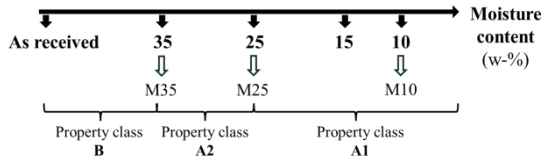

Figure 3: Levels of moisture content, based on ISO 17225-4

At delivery, fresh wood chip types were tested for bulk density according to ISO 17828 [9]. At a MC of 15 w-% chips were analyzed for particle size distribution according to ISO 17827-1 [10].

2.3 Moisture content determination

First MC testing was done at a MC 'as received'. To reach lower MC levels, wood chips were dried naturally by spreading whole samples in wooden boxes on the floor (max. height 10 cm, Fig. 4a). Wood chips were mixed frequently to ensure homogeneous drying. At target MC levels, chips were filled in air-tight plastic bags (Fig. 4b) and stored at 4 °C for a minimum of 24 h. The air-tight storage enabled equilibrium of MC of individual wood particles to the whole sample and, thus, further increased homogeneity.

Figure 4: Measuring procedure: (a) wooden boxes for wood chip drying, (b) air-tight plastic bags, (c) sample preparation: homogenization and mass reduction, (d) barrel used for measurements with lances

After storage and homogenization, sample mass for individual MC measurements was reduced according to EN 14780 [11] (Fig. 4c). For each fuel type and MC level a series of MC measurements was performed with the test devices always following the same procedure. First, rapid testing was carried out with the two infrared dryers. For each infrared dryer three samples were analyzed (n = 3). Then wood chips were transferred into a 220 l cylindrical barrel (Fig. 4d) and condensed following EN 15103 for

bulk density [9]. Measurements with lances were performed by inserting the respective lance into the barrel ten times (n = 10). Afterwards, measurements were performed with humimeter BMA (n = 5). Thereby, a 12 l sample was used. Reference MC was determined by oven drying according to EN ISO 18134-2 directly before and after the series of measurements (n = 8).

3 RESULTS & DISCUSSION

Due to a small fraction of fines and ERC-spruce could be specified as P31S according to ISO 17225-4. All wood chip samples could be classified as P31 according to ISO 17225-1. Therefore, the calibration curve 'wood chips' was valid for all samples tested with both humimeters. Bulk densities (at a constant MC of 15 w-%) varied from 159 kg m^{-3} (SRC-poplar) to 310 kg m^{-3} (FRC-deciduous). MC of samples during testing ranged from 9.5 – 68.0 w-%. Thereby, MC ranges exceeded the ranges for some of the measuring devices according to manufacturer specifications (Tab. I).

Table I: Number of measurements, measuring range and mean deviation (± standard deviation, SD) within the measuring range of instruments

Name of measuring devices	No. of meas. n	Meas. range [w-%]	Mean deviation (± SD) [w-%]
Infrared dryers			
MA35	67	0 – 100	-0.7 (± 2.1)
UX3081	68	0 – 100	-2.6 (± 1.7)
Dielectric methods			
Humimeter BMA	120	5 – 70	-0.5 (± 4.0)
Humimeter BL2	190	10 – 50	3.8 (± 4.7)
AD22-CMS22	220	0 – 50	-0.7 (± 4.0)
Almemo	220	0 – 50	1.5 (± 4.2)
Conductivity methods			
GMH3851	190	5 – 50	0.7 (± 4.9)
HT85T	220	4 – 50	1.9 (± 3.7)
Time domain reflectometry method			
HD2-Sono M1	206	0 – 50	-1.6 (± 5.1)

Both infrared dryers allowed for MC determination between 0 – 100 w-%. Overall, infrared dryers provided the smallest standard deviations and smallest interquartile differences (Fig. 8) despite of the very small sample sizes of 15 g and 35 g. Even at higher moisture content levels (> 25 w-%) interquartile differences were small compared to all electric devices (Fig. 9). MA35 displayed overall best results (Fig. 5, Fig. 9). In contrast, MC measured with UX3081 was constantly lower compared to the reference values (-2.6 w-%, see Table I). This might be due to an incomplete drying of wood chips during the performed study. Drying temperature of UX3081 was 105 °C. By adjusting drying temperatures to > 105 °C measurement accuracy could have been improved. However, with increasing temperatures the risk of losing volatile organic compounds in addition to water increases, leading to higher mass losses and, thus, might bias MC determination [12]. A longer drying time could improve results. At 35 w-% the drying time measured 45 minutes and drying times increased with increasing MC. Hence, it is questionable if these instruments could still be seen as rapid testing methods.

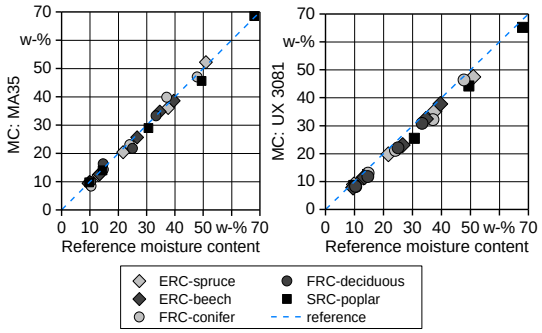

Figure 5: Mean moisture contents (MC) of infrared dryers in comparison to reference MC for five different wood chip samples

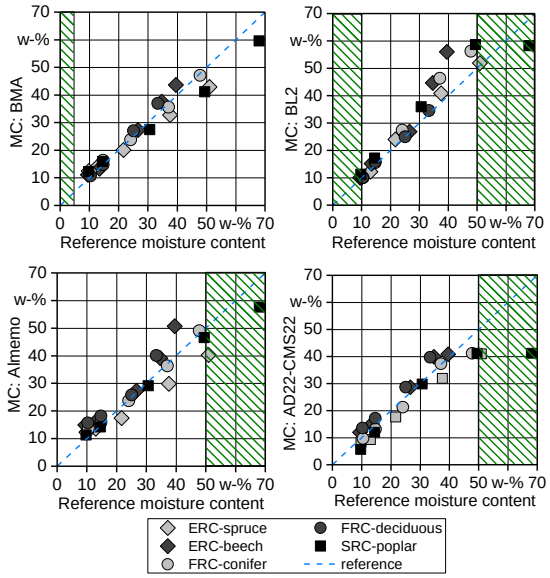

Figure 6: Mean moisture contents (MC) of dielectric methods in comparison to reference MC for five different wood chip samples (hatched areas indicate measurements outside the measuring range of instruments)

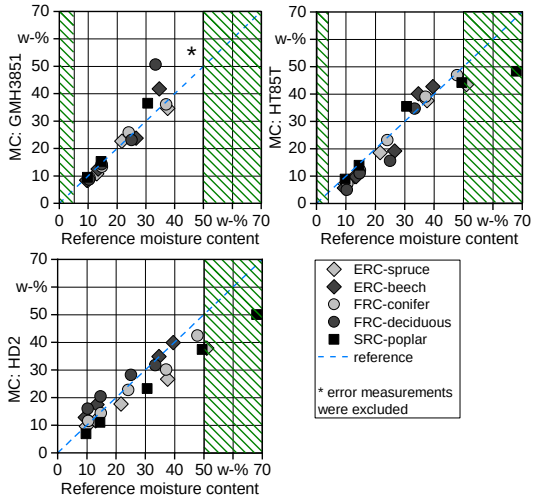

Figure 7: Mean moisture contents (MC) of conductivity and TDR methods in comparison to reference MC for five different wood chip samples (hatched areas indicate measurements outside the measuring range of instruments)

Measuring ranges of dielectric instruments were smaller compared to infrared dryers (Tab. 2). Mean deviations from reference values increased with increasing MC (Fig. 6, Fig. 9, Fig. 10). Among electric devices, humimeter BMA displayed the lowest mean deviations from MC while its measuring range was largest (Tab. I). On average, mean deviations from reference values were highest for humimeter BL2 (-3.8 w-%), especially at higher moisture contents (Fig. 9). Smallest mean deviations at higher moisture contents (> 25 w-%) were given by Almemo (Fig. 9). Manufacturer instructions of AD22-CMS22 specified a maximal measuring range of 50.0 w-%. However, in contrast to reference values, MC according to the instrument never exceeded of 41.2 w-%. Nevertheless, the AD22-CMS22 also provides the electrical raw values allowing for a customized calibration for each wood chip type.

The accuracy of the conductivity methods was similar compared to the dielectric methods. The Hydromette HT85T showed good results at high MC (Fig. 7, Fig. 9). The GMH 3851 displayed error measurements when measuring MC > 38 w-%, although a measuring range up to 50 w-% was stated by manufacturer instructions. However, the mean deviation from reference values was very low when testing was done with wood chips at low MC (Fig. 7, Fig. 10). The TDR method HD2 showed large deviations at high moisture contents. These deviations decreased at lower MC. Customized calibration curves for the HD2 could optimize measuring results.

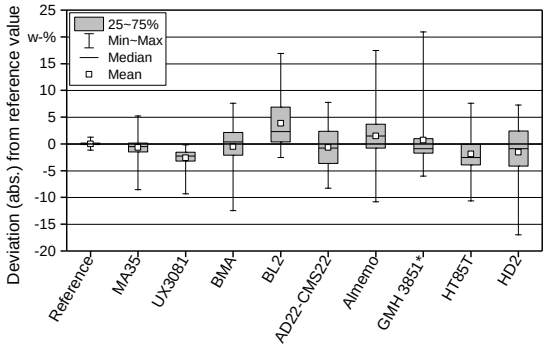

Figure 8: Absolute deviations of rapid moisture content determination methods compared to reference values (* = 'error' measurements were deleted)

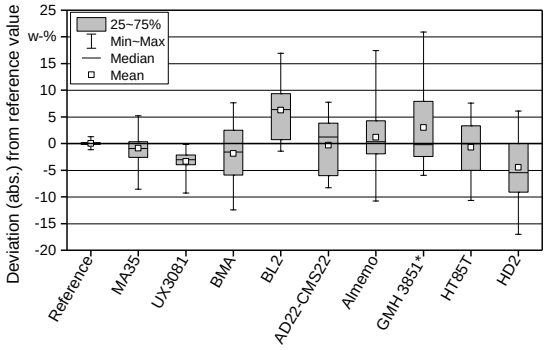

Figure 9: Absolute deviations of rapid moisture content determination methods compared to reference values within a moisture content level of > 25 w-% (* = 'error' measurements were deleted)

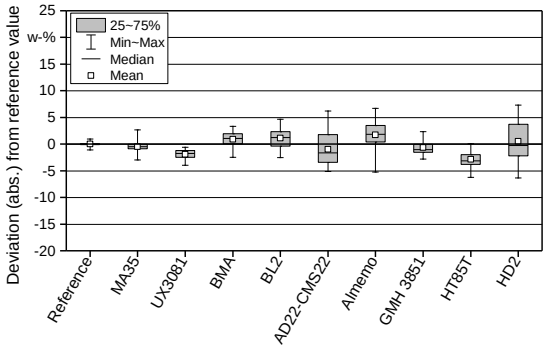

Figure 10: Absolute deviations of rapid moisture content determination methods compared to reference values within a moisture content level of < 25 w-%

On average, all instruments reached best results on forest residues chips of conifer trees. This type of wood chip is with 89 % of wood chips of forest wood the most common in Bavaria [12]. SRC-poplar and ERC-spruce had the smaller bulk densities and FRC-deciduous and ERC-beech higher bulk densities compared to FRC-conifer. A strong correlation (r = 0.94265, $p \leq 0.05$, Pearson correlation) between bulk density and mean deviation was observed for wood chip types. Moisture contents were overestimated for ERC-beech and FRC-deciduous and underestimated for SRC-poplar and ERC-spruce. Hence, customized calibration curves for individual wood chip types should improve measurements.

4 CONCLUSION

The high accuracy of the oven drying method could not be reached by any of the tested devices. On average, the mean deviation of all rapid determination methods was in a range between +5 and -5 w-%. Some instruments can be recommended for quality assurance during production. The tested electric methods allow for a rapid and in most cases instantaneous MC determination of wood chips. The electric methods showed a decreasing accuracy with increasing MC. However, by using a high amount of samples the average moisture content of all measurements approximated the reference value. The infrared-dryers have the advantage of being independent of the type of wood chips and moisture content level. However, drying times can be long. MA35 scored best results despite of a small sample size and a large measuring range. Nevertheless, the heterogeneity of wood chips should not be disregarded. Representative sampling and accurate sample preparation are thereby fundamental for obtaining high-quality results. Thus, sampling may be considered of higher importance compared to instrument precision.

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7 LOGO SPACE