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Research article

Industrial stress-test of a magnetic resonance moisture meter for woody biomass in southern European conditions

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ABSTRACT

Moisture content (MC) is the most important quality parameter for energy wood. Unfortunately, checking MC under operational conditions is difficult, because the standard method for MC measurement requires up to 48 h. The bioenergy industry needs alternative methods allowing fast and reliable MC determination, but most of the commercial devices require biomass-specific calibration models. This is an important limitation, particularly in Mediterranean areas, where mixed forest dominate and feedstock loads can include multiple species. In this study a moisture meters based on Magnetic Resonance (MR) was tested for assessing its reliability as an alternative to oven drying. For this purpose, a stress-test was performed at the premises of an energy facility in Southern Italy, using a commercial MR analyzer. Thanks to the non-destructive action on the biomass of MR technology, the MC of 350 samples was measured with both MR and standard gravimetric techniques. Results confirm the validity of the MR analyzer as an alternative to oven drying. Accuracy and precision of the machine are both satisfactory, with over 95% of values within ± 2.5% of deviation and a Standard Error of Performance of 1.2%. Furthermore, the analyzer processes over 15 samples per hour, coping with frequent deliveries.

1. Introduction

In bioenergy systems, moisture content (MC) is among the most important quality parameter for lignocellulosic fuels, such as wood chips [1]. A high moisture content in biomass fuel has detrimental effects on the whole forest-energy supply chain, from transportation to energy conversion. In biomass logistics operations a high MC increases the density of the feedstock, reducing the effective payload of trucks and increasing transportation costs [2]. Once the biomass has been delivered to the industrial users, loose wood chips must be stored at the woodyard, in order to build large enough buffers for securing a steady flow of fuel to the furnace. Storage may last weeks or months, and under these conditions a high MC will favor microbial development, leading to important biomass losses [3–5], with a clear and immediate value loss and an undesired proliferation of fungal spores in the biomass piles [6]. In some cases, this process can even lead to self-ignition [7], causing destruction of the stored fuel. High MC strongly reduces the heating value of the fuel [8], leading to higher costs for biomass supply. Furthermore, feeding the boiler with biomass with MC higher than the tolerance limits of the plant reduces the grate temperature, decreasing combustion efficiency while increasing pollutant emissions in the flue gases [9]. A similar behavior has been observed in wood gasification and pyrolysis technologies, where high MC negatively impacts gas yields and quality [10], and decreases the efficiency and durability of the generator.

Considering these problems, plant managers must devote important efforts to make sure that the biomass delivered fulfils all set quality specifications, including MC thresholds. Supply contracts generally define the maximum allowed moisture content of fuel. Exceeding this threshold theoretically leads to rejecting the load, which is returned to the producer before unloading. Furthermore, as an incentive for delivering dryer biomass, several buyers have established price lists for the fuel, with monetary values inversely proportional to MC. In practice, these guidelines are difficult to apply due to the time required for analyzing MC. In fact, while the official gravimetric system for biomass moisture evaluation requires up to 48 h of oven drying (ISO 18134-1:2015), the decision to reject a load must be taken on the spot. Similarly, invoicing the contractors according to set price lists based on biomass MC requires that MC is measured before the empty truck leaves the plant. For these reasons, the bioenergy industry badly needs new MC meters coupling fast measurement and reliable results.

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Nomenclature and acronyms

MC	moisture content, %	SEP	Standard Error of Performance, dimensionless
MR	magnetic resonance	SS	Wood chips sub-samples of regular mass according to ISO 18134-1:2015, moisture measured with gravimetric method, %
NIR	Near Infra-Red (spectroscopy)	SV	Wood chips sub-samples previously measured by the Valmet MR (smaller mass), moisture measured with gravimetric method, %
RF	Radio Frequency	δ_{SS}	Dataset of deviation values between moisture measured on SS sub-samples with gravimetric and magnetic resonance method, %
GLM	General Linear Model	δ_{SV}	Dataset of deviation values between moisture measured on SV samples with gravimetric and SV sub-samples with magnetic resonance method, %
KPI	key performance indicator		

As a response, in the last two decades several manufacturers have introduced in the market a number of moisture meters based on diverse technologies and types of sensors. Nystrom and Dahlquist [11] compared several alternative technologies with the standard gravimetric method, concluding that Near Infra-Red (NIR) and Radio Frequency (RF, also known as dielectric) technologies were the best suited for moisture content measurement in flow and bulk fuels, respectively. The same technologies were tested more recently by Pan et al. [12] with encouraging results, but the authors identified the same drawback as the former authors: the performance of these technologies is strictly linked to fuel-specific calibration models to be installed on the device prior to the analysis. This drawback has been highlighted also in the research by Daugbjerg-Jensen et al. [13], where bulk density, fuel type and moisture range have been identified as the main parameters involved in developing the fuel-specific calibration model. Even if NIR can be potentially deployed also for assessing other quality parameters (at constant MC value) [14–16], the necessity of fuel-specific calibration models poses a challenge for users, particularly if operating with highly variable feedstock types. In these conditions the reliability of the moisture meter may be weakened by a mismatch between the biomass characteristics and the calibration model applied. This issue may be negligible in boreal areas, where a relatively homogeneous forest biomass is processed from very few tree species, and most variability is related to the production process (e.g. sawmill residues, logging residues, etc.). In temperate and warm-temperate climates, such as in the Mediterranean region, natural variability is generally much higher [17]. For instance, in mountain areas of the Mediterranean basin, within a radius of 70 km (typical catching range of most plants) one may find forests dominated by several species of conifers and broadleaves, evergreen and deciduous, with a dramatic increase in the number of potential feedstock types. This variability is amplified by the large variation in work systems and machine types deployed on the different forest resources (e.g. high vs coppice forest) leading to a very heterogeneous wood chips feedstock [8,18].

Under these conditions, plant managers can hardly cope with the necessity to identify each incoming biomass load and match it with the appropriate calibration model for the analysis, which reduces the reliability of NIR and dielectric systems. Unfortunately, it is exactly in these areas that the problems related to a high MC are magnified. In fact, the relatively high winter temperatures allow for a full microbial development even during the cold season, with dry matter losses in the stored biomass that can get close to 50% [19] - much higher than what may be recorded in North European conditions [4].

A new opportunity for fast and reliable MC determination may be offered by the application of Magnetic Resonance (MR) technology applied to biofuels [20]. While MR technology did not result among the best performing systems in the comparative study by Nyström & Dahlquist [11], the latest technology developments seem to hold much promise. In a recent study performed under Nordic conditions (Sweden and Canada), a new Magnetic Resonance MC analyzer was tested by Fridh [21] on different types of biomass (debarked sawmill residues, logging residues, roundwood) with variable MC classes obtained by artificial drying. Results suggest that the analyzer is accurate and reliable, and it does not require fuel-specific calibration models. However, tests were performed under laboratory conditions with trees belonging to very similar species (*Picea abies* and *P. mariana*), representative of Nordic forests: therefore, test results were not general enough to cover the conditions of industrial users in areas with high floristic variability.

Within this context, the aim of the present study was to test whether MR technology provides the necessary reliability to be considered as an alternative to the gravimetric method under the challenging industrial conditions of commercial power facilities installed in the Mediterranean region and fuelled with a large variety of tree species and biomass types.

2. Materials and methods

The Valmet MR, formerly known as Metso MR, is a stationary Magnetic Resonance moisture meter specifically designed for solid biofuels. It determines the moisture content of biomass by exposing the sample to a dynamic electromagnetic field and recording the returning voltage. Different materials, such as wood and water, feature a specific “reaction time” between irradiation and voltage return. Therefore, it is possible to filter out interferences by measuring the voltage in a specific time after the excitation. The result is a voltage reading that is linearly correlated with the water mass and is automatically related to the weight of the sample in order to calculate MC. The unique external input required by the analyzer is the temperature of the sample. The machine deploys cylindrical standard plastic (HDPE) containers with snap-on locks and a nominal capacity of 0.8 l. This system facilitates collection and handling of the sample: loose biomass is transferred into the container which is closed and placed on the internal scale (surrounded by the magnet) for performing the analysis. A more detailed description of the analyzer is provided by Fridh et al. [21], while Järvinen [20] provides details regarding the theory of Magnetic Resonance technology applied to biomass moisture measurement.

An important advantage of the machine is the calibration method: this is performed by running the machine sequentially with a container full of water with known temperature and an empty container. The whole cycle takes about 5 min and is independent from the type of fuel. According to the producer, calibration should be done daily, but for the purposes of our study this operation was repeated twice per day, at the beginning of each measurement shift (morning and afternoon). A total of 7 calibrations were done the during the whole duration of the study.

2.1. Data sampling

The test was conducted at the fuel yard of a biomass power plant located in a mountain region of Southern Italy. Sample collection was performed during the normal business activity of the company in two separate “seasons”: early October and late November. According to the power plant managers, these two periods show the maximum possible MC difference in the incoming biomass in a limited time span. In particular, the early October sampling campaign was meant to catch the last stocks dried during the hot and dry summer, while the late November campaign would capture the wetter biomass harvested during autumn (in Mediterranean climate, most rainfalls are concentrated in this period). For each season 35 incoming truck-loads were sampled, for a total of 70 loads.

The Valmet MR analyzer was installed at the receiving station,