Methods to determine the dry matter content of roundwood deliveries

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ABSTRACT: In pulp production, the dry matter content of pulpwood affects debarking and pulping. For pulpwood to be traded due to its dry weight, a prerequisite is that the measurement of dry be done quickly and accurately. No current method fulfils these requirements, although there are different methods that have the potential to determine the dry matter content in wood. These techniques include radar, gamma rays, dichromatic photon absorptiometry, computed tomography, near infrared (NIR), nuclear magnetic resonance (NMR), and radio frequency (RF). A literature review showed that several of the techniques can determine the dry matter content with an acceptable error. Several of the methods cannot handle frozen or semifrozen samples, which disqualifies them as an acceptable method. NIR, dichromatic photon absorptiometry, and RF techniques might have the potential to meet the requirements of fast measurement with high accuracy.

Application: Several alternative methods have potential for use in determining the dry matter content of wood quickly and accurately.

In Sweden, most pulpwood is currently scaled when it arrives at the pulp mills. The trucks arrive at the measuring station, where the height, length, and width of each pile of wood is measured manually. The solid volume percentages are then visually estimated, and the wood is also graded with respect to species, dimension, and rot. This method may not be the optimal way to determine the quantity and quality of the pulpwood, as the outcome of pulp is closely correlated to the weight of the wood and its dry matter content and has less to do with volume [1]. Several investigations have been performed regarding the possibility of replacing the current pulpwood measuring system with weighing the pulpwood and determining its dry matter [2,3]. One problem with such a change has been lack of a sufficient method to determine the dry matter content. Such a method would be needed to determine the dry matter content with errors of approximately a few percent. Moreover, the method must be fast because it is desirable to get the result while the truck is still at the measuring station.

METHODS TO DETERMINE DRY MATTER CONTENT

This paper gives an overview of different methods that have potential to determine the dry matter content in wood. The techniques presented are the oven dry (o.d.) method, electrical moisture meters, radar, gamma rays, dichromatic photon absorptiometry, computed tomography (CT), near infrared (NIR), microwaves, radio frequency (RF), and nuclear magnetic resonance (NMR). The study was conducted as a literature review.

Oven dry method

The oven dry (o.d.) method is most commonly used to determine the dry matter content in wood. The sample is first weighed and then put in a drying oven that has a temperature of 105 ± 2˚C [4]. The samples are ready when a constant weight is achieved [5]. The samples are then weighed again, and the dry matter content of the samples can be calculated.

Electrical moisture meters

The technique of measuring the dry matter content of wood with help of its electrical properties has been in use for a long time. Two different techniques are used for this purpose. The first is the resistance meter, which measures the dry matter content on the basis of its electrical resistance. When the dry matter content in wood increases, the resistance in the wood increases and the dry matter content can be determined. The dry matter content is measured between two electrodes that are driven into the wood [6]. Sawmills commonly use this method for measuring the dry matter content in sawn and dried lumber.

The other technique uses the dielectric constant and the loss factor (the product of the dissipation factor [D] and the dielectric constant [ε'] of a dielectric material [7]) to measure the dry matter content. Both the dielectric constant and the loss factor decrease with decreasing dry matter content at a given alternating current frequency [6].

Electromagnetic waves

Many of the methods that could be used to determine dry matter content come from the field of electromagnetic waves. The electromagnetic spectrum includes gamma rays, X rays, NIR,

infrared, microwaves, and radio waves. The borders between the different wavelengths are not fixed, and some discrepancies can be found in the literature regarding the distinctions between particular wavelengths. The main principle of a measurement method using electromagnetic waves is that the interaction between the sample and radiation depends on the relationship between the energy of the incident light quantum (photon) and the association energy of the atom/electron that is hit [8].

Gamma rays have the shortest wavelength (0.01–0.001 nm) [8]. A beam with gamma radiation is sent through the sample. The radiation then interacts with the material, which leads to an attenuation of the gamma-ray beam. The attenuation is dependent on several factors, such as chemical composition and the energy of the gamma-ray beam [9]. When measuring dry matter content with gamma rays, a characteristic wavelength is chosen for the gamma-ray beam and the intensity of the radiation is recorded after it passes through the sample. One prerequisite is that the bulk density of the sample must be known [10].

X-ray methods use electromagnetic waves of 0.01–10 nm. There are two types of X rays: dichromatic photon absorptiometry and CT [8]. Dichromatic photon absorptiometry was originally developed for medical purposes, where it is used to determine the calcium content of the skeleton and the fat content in living tissues [11]. The technique uses radiation with two energies or two different wavelengths and is often referred to as dual energy X ray. The sample is radiated simultaneously with the two X-ray beams with different energies (e.g., 40eV and 70eV) [4]. The beams are absorbed by the material, and the quotient between the absorption of the energies is calculated. On the basis of this calculation, conclusions about the composition of the material can be made. The absorption of the beams takes place in the atoms, which makes this method independent of the samples' temperature. This method is relative, which means that it requires calibration against samples where the attenuation coefficients for water and wood are known [11].

Engström [12] performed a study with dichromatic photon absorptiometry on spruce wood chips, using equipment that is under development. During the study, five equal 200-g samples of spruce wood chips were investigated. Every sample was measured 10 times at seven different levels of dry matter content. Engström's results showed that, with a dry matter content of 40%–60%, the accuracy in the measurements gave an absolute error compared with the standard oven method of 4.7%, with a standard deviation of ± 5%. With dry matter content outside this interval, the results were worse. Engström concluded that the mediocre performance in his study resulted from sample sizes that were too small. Because wood is an inhomogeneous material, the variance in wood composition then became too large.

Dissing and Nylinder [13] also attempted to determine the dry matter content of pine chips using dichromatic photon absorptiometry. They concluded that it was possible for chips to determine the dry matter content with an error of 50 g (5%) of water per kg of chips.

Nordell and Vikterlöf [11] studied whether dichromatic photon absorptiometry can obtain faster measurement results. They investigated 10 different biofuels using dual X-ray equipment that was normally used for medical purposes. Their major conclusion was that it was possible to determine dry matter content with an error of only a few percent.

Computed tomography uses ionized radiation to obtain a three-dimensional picture of the sample. CT measures the whole log, making the method nondestructive. A CT scanner consists of an X-ray tube and detectors. The X-ray tube rotates around the sample and scans it. After the sample is scanned, a computer calculates the average linear attenuation coefficient for each volume element (voxel). This value is then normalized with the corresponding linear attenuation coefficient for water. This value is called the CT or Hounsfield number. The Hounsfield number varies with density. The calculated attenuation values are then translated into a grey or color scale and a picture from the cross section of the sample is shown on a screen [14,15]. When measuring the dry matter content with CT, the sample is scanned twice, once when it is wet and once when it has been oven dried. The two images are subtracted from each other. The image needs to be corrected due to shrinkage of the o.d. sample. The difference between the two pictures is due to water [16].

Near infrared waves have a wavelength of 850–2500 nm. Two different techniques are used when employing NIR to determine dry matter content: transmission (NIRT) and reflectance (NIRR). When using the NIRT technique, the transmitter and the detector are located on different sides of the sample. The light that has passed through the sample is recorded and interpreted. With the NIRR technique, the transmitter and the detector are on the same side of the sample. Two different light beams are sent through the sample. One is a reference beam that is not absorbed by the sample and the other penetrates the sample as deep as 10 mm below its surface. The depth of the penetration is dependent on the chemical composition and the density of the sample [17,18]. When the molecules in the sample are hit by and absorb some of the incoming light, the bonds between the molecules begin to oscillate. These oscillations create vibration energy that occurs only at certain wavelengths or energy levels for each particular bond [19]. For water, there are three absorption maxima in the NIR spectra, namely 990 nm, 1450 nm, and 1930–1940 nm. The quotient between the reference beam and what remains of the absorbed beam is inversely proportional to the dry matter content [10].

Several studies have been performed with NIR technology. Berg et al. [19] investigated a broad range of biofuels, such as bark, wood chips, peat, and a mixture of chips, including bark. Their dry matter content varied between 30% and 100% (dried samples). They concluded that the accuracy of the dry matter content determination was as good as the currently used o.d. method. They also concluded that, if the system was

implemented at a specific location (for example, a measuring station), the calibration model could be adjusted to the specific material used at that site and would probably result in even more improved accuracy.

Nyström and Dahlqvist [18] performed a long-term study of online measuring of woodchips with the NIR technique. They concluded that it is possible to determine the absolute moisture content with an error of 0.5%. They also concluded that ice did not seem to affect the result.

When measuring the dry matter content with radar, a radar beam is sent through the sample and is reflected from the bottom of the container where the sample is stored. The radar beam is received by the antenna from which it was transmitted and the time between transmission and reception is calculated. The time it takes for the radar beam to go back and forth is dependent upon factors, such as the material's water content, density, chemical composition, and temperature, with water being the most important. The time it takes for the radar beam to pass through the sample is linearly related to its water content. Because the pass time of the radar beam is calculated, it is very important to measure the depth of the sample carefully to calculate the correct value for the water content. The radar beam is reflected at the bottom of the container, so the bottom of the container must be made of metal or similar material. A high frequency is required to get high resolution in the measurement. However, a consequence of using a frequency that is too high (900–1000 MHz) is a sample that reduces the energy too much and leaves too little energy to reflect [10,20].

Blomqvist et al. [20] performed a study in which they attempted to determine the dry matter content of frozen and unfrozen sawdust, using a subsurface interface radar system. They concluded that if a higher frequency was used (700 MHz), the measuring error would reduce to a maximum of 2%–4% of the dry matter content. They also found it probable that similar results would be observed when the sample is completely frozen. However, a sample that is only partially frozen will give deviant values of dry matter content. The amount of this divergence was not investigated in their study.

Microwaves are defined as electromagnetic waves with a frequency between 300 MHz and 30 GHz [21]. Microwaves show certain similarities to other techniques using electromagnetic waves. In the first stage, microwaves are sent through the material. When water molecules are hit, they start to move, which, in turn, attenuates the microwaves. This attenuation can then be recorded on either the same or opposite side of the sample [8,10]. If only the attenuation is measured, some problems can occur because this method reflects not only the dry matter content but also the density of the sample. To solve this problem, another parameter, phase shift, is measured and must be calibrated.

Johansson [22] studied whether it was possible to predict the dry matter content and density distribution of Scots pine (*P. sylvestris*) with microwave techniques. They investigated seven pieces of wood with cross sections of 125 mm x 25 mm. The pieces were raw and then dried in four steps to a dry matter content of 100%. They concluded that it is possible to predict the dry matter content and the density distribution with high accuracy using microwave techniques.

Lundgren [21] studied whether it was possible to predict density and dry matter content simultaneously on a pixel level for wood. Scots pine samples 25 mm and 50 mm thick were measured at three different dry matter content levels. The microwave sensor generated images that had a pixel size of 8 mm x 8 mm. He concluded that, on a pixel level, it was possible to get accurate measurements of the dry matter content. It was possible to get satisfactory results from average values in homogenous regions but inhomogeneous regions (e.g., knots) would reduce the accuracy.

Nuclear magnetic resonance (NMR) is based on the magnetic spin of nuclei [8,16]. The NMR technique measures the amount of hydrogen in a sample, which requires that the volume of the sample is known. The two main types of NMR are steady state NMR and pulse NMR. Only the pulse NMR technique is described here. The main concept of this method is that, in a sample, the hydrogen atoms are aligned randomly and, when the sample is put into a magnetic field, the nuclei will align [4,23]. The rate of the alignment is dependent on the material. The sample is then irradiated with a pulse of RF energy. The nuclei are then tipped 90° from the aligned direction. Because they are still in the magnetic field, the nuclei start to realign themselves and emit energy that was absorbed by the RF pulse. This energy is then detected by a sensor coil that generates a current [23]. The amplitude of the signal is a measurement of the hydrogen atoms in the sample [16].

Thygesen [16] studied whether it was possible to determine the dry matter content on cylinders from Norway spruce and Scots pine by using pulse NMR. She also tested whether it was possible to determine dry matter content on frozen wood. For the green cylinder, the result showed that it was possible to determine the dry matter content with an absolute root mean squared error of prediction (RMSEP) of 3.1%. For frozen wood, Thygesen concluded that it was impossible to determine the dry matter content with the NMR technique because the signal from the frozen hydrogen cannot be separated from the signal of hydrogen in wood.

Radio frequency waves are electromagnetic waves with wavelengths between 0.3 m and 1000 m and frequencies between 30 KHz and 1 GHz. The RF method is based on the fact that metal surfaces reflect radio waves while wood attenuates the signal [24]. The sample is placed between two antennae. An RF signal is sent out by one antenna and passes through the sample. During this passage, the signal is attenuated and phase shifted. The attenuation and phase shifting of the RF wave is correlated with the dielectric constant and the loss tangent of the material. The spectrum is affected by factors such as density and temperature. The spectrum received is then analyzed using multivariate analysis [10,24].

Dahlquist et al. [17] performed a study on six different biofuels. For wooden chips, three different sample heights were

measured to see how sensitive the method was to changes in sample height. They showed results with an RMSEP less than 2.7% for all biofuels, with the exception of peat. They further concluded that the differences in sample level only affected the results marginally. However, with larger samples, stronger effects could be expected. Their final conclusion was that the RF method could be used to determine the dry matter content instead of the o.d. method.

Nyström [24] tried to determine the dry matter content of sawdust with the RF technique. Samples were collected from municipal power plants and had dry matter contents ranging between 35% and 66%. They concluded that it was possible to determine the dry matter content in sawdust with the RF technique. For a dry matter content below 40%, their calibration model, based on the multivariate analysis method PLS (partial least square), did not work properly.

DISCUSSION

The advantages of the o.d. method are ease of use and high accuracy. Its major drawbacks are that it is very time consuming and it can require much space if many samples are handled at the same time. Therefore, it would be preferable if another method could be developed that has similar accuracy and could also deliver the results while the truck with the pulpwood is still at the measuring station. A third requirement is that the method must be able to handle samples during wintertime.

When discussing electrical moisture meters, two different techniques are used. The first is the resistance meter. This technique has a low accuracy when the moisture content is above the fiber saturation point and is, therefore, not suitable for determining dry matter content in pulpwood [25]. The second technique uses the dielectric constant and the loss factor. The dielectric constant is very similar between frozen samples and samples that have high dry matter content and the results obtained when measuring frozen samples would be too low. In addition, if the moisture on the surface is high, the results are not significant [25]. This method is not suitable for determining the dry matter content in pulpwood.

A relatively limited number of studies have been conducted using radar techniques to determine dry matter content. For unfrozen material, the radar technique has been shown to be a functional method. Unfortunately, radar does not seem to be applicable for semifrozen material.

Gamma rays have the advantage of being able to also measure frozen samples. However, problems occur if a sample contains pollution or needles because such a sample will have a different chemical composition than the original sample. In addition, surface moisture and condensation will decrease the accuracy of the measurement. Moreover, this method requires that the basic density is known for the sample [9,10,25].

Dichromatic photon absorptiometry, often referred to as dual X ray, might be a possible technique to use because its error of estimation of dry matter content is small. Dual X-ray results are indifferent to the temperature of the sample, which is another advantage over some other methods. Unfortunately, this method has not been investigated in detail yet and it requires further development.

Using this CT method, it is possible to determine dry matter content with an accuracy of ± 1% [26]. The real purpose of CT, though, is to obtain detailed information about wood structure, density, and distribution of moisture in the trunk [9]. Considering the sophistication of CT and costs related to its implementation and usage, it could be argued that benefits of using this method are disproportionate to the input required. The CT method is also time consuming because the log has to be measured in both wet and dry stages.

The NIR technique is one of the most interesting possibilities for replacing the standard o.d. method to determine dry matter content. It is fast, and studies conducted so far have shown its potential to be highly accurate. Of note, it is possible to measure additional parameters (for example, density) with the same equipment [8]. Critics of this method claim that it can be sensitive to surface moisture, which can diminish the accuracy, and that the penetration depth is not sufficient.

Microwaves have some potential to determine dry matter content with satisfactory accuracy, but there is still work to be done in this area. Its advantage is that it can measure several parameters at the same time (e.g., dry matter content and density), but its major drawback is that it does not handle ice and has problems if the surface of the sample is wet [8,10].

RF is a relatively new method that has been shown to have the potential to meet commonly used standards. It has the benefit of being able to penetrate larger samples and is not sensitive to surface moisture. One of its disadvantages is that as a recent development it still requires improvements.

NMR makes it possible to determine the dry matter content in a sample very fast and with a satisfactory accuracy. The main drawback of this method is its inability to determine the dry matter content in frozen wood.

Currently, no method fulfils all requirements set for determining the dry matter content of pulpwood in Sweden. A major limiting factor is that many of the methods cannot determine the dry matter content on frozen or semifrozen samples. Methods that have the potential to be used are NIR, dichromatic photon absorptiometry, and RF, but all three techniques need further development before they can be considered as true options.

CONCLUSIONS

Two main conclusions were drawn from this literature review. First, a technique is needed that can determine the dry matter content in wood quickly with high accuracy. This technique must be able to handle frozen or semifrozen samples. Second, NIR, dichromatic photon absorptiometry, and RF methods are three different techniques that, after further development, will be able to determine the dry matter content in pulpwood. **TJ**

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This work was undertaken to look at the progress being made toward finding fast and accurate alternative methods for determining the dry matter content of wood. It was challenging to identify the different techniques that have been tested over the years. Tests using dichromatic photon absorptiometry have shown good results.

For mills, this literature review provides an easily accessible source of research being done with various techniques. Currently, I am doing additional testing with the dichromatic photon absorptiometry method and so far, the results have been excellent.

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