MOISTURE CONTENT MEASURING METHOD AND APPARATUS

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Fig. 2.

Fig. 3.

\[ \frac{\ln \left( \frac{I_1}{I_2} \right)}{\ln \left( \frac{I_1}{I_2} \right)} = 0.64 \]

\[ \frac{\ln \left( \frac{I_1}{I_2} \right)}{\ln \left( \frac{I_1}{I_2} \right)} = 0.25 \]

% MOISTURE CONTENT (OVEN DRY BASIS)

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5 Claims

ABSTRACT OF THE DISCLOSURE

Methods and apparatus for determining the moisture content of relatively high moisture content materials such as green lumber are disclosed herein. The methods include passing X-rays of first and second known wavelengths through the material, detecting the intensity of the X-rays at the respective wavelengths after they have been passed through the material and comparing the ratios of the respective incident and transmitted intensities at the two wavelengths to thereby ascertain the moisture content of the material. The apparatus includes X-ray means adapted to direct first and second X-ray beams of first and second wavelengths through the material, X-ray detector means positioned to detect the beams after they have passed through the material, and analyzer means coupled with the detector means for providing signals representative of the quantity

\[ \frac{I_1}{I_2} = \frac{\lambda_2}{\lambda_1} \]

where \( I_1 \) and \( I_2 \) are respectively the incident and transmitted intensities at the wavelengths \( \lambda_1 \) and \( \lambda_2 \).

Background and summary of the invention

The present invention relates to an improved method and apparatus for determining the moisture content of materials and particularly for determining the moisture content of organic materials such as wood having a high moisture content.

Various devices and techniques have been developed for ascertaining the moisture content of organic materials such as wood, but in general the devices and techniques developed up to the present time have been relatively inaccurate when the moisture content of the material is high. Thus it is found that meters which depend essentially on measurement of the capacitance or the conductance of the material work well in the lower moisture ranges but the same become of limited value in determining the moisture content of materials such as green lumber having moisture contents of 30 to 200%. If a suitable method and apparatus were provided for determining the moisture content of organic materials such as green lumber having high moisture contents, it is seen that the drying of such lumber would be facilitated since the same could then be pre-sorted and grouped according to moisture content to thereby improve the effective utilization of drying facilities.

It is therefore an object of the present invention to provide a novel method of determining the moisture content of material. A more specific object of the present invention is to provide a novel method of determining the moisture content of organic materials such as wood. Another object of the present invention is to provide an improved method and apparatus for determining the moisture content of organic materials such as wood when the same has a relatively high moisture content. An additional object of the present invention is to provide an X-ray moisture gauge for determining the moisture content of wood when the moisture content thereof is greater than 30%. Another object of the present invention is to provide an improved method and apparatus for determining the moisture content of organic materials such as wood and wherein variations in the thickness of the material being subjected to investigation do not affect the determination of the moisture content thereof.

The present invention is based upon the fact that the absorption coefficient of oxygen varies more rapidly with the wavelength of an X-ray beam passing therethrough than does the absorption coefficient for carbon. Thus in the case of organic materials such as wood, wherein the oxygen content increases with the addition of moisture, while the carbon content thereof remains fixed, it can be shown that the moisture content of the wood can be accurately determined from data regarding the absorption of X-rays at known wavelengths absorbed by the moisture contained in the material, in accordance with the teachings of the present invention a plurality of X-ray beams at known wavelengths are passed through the material and then the absorbance of each beam at the known wavelengths is determined. The relative absorbance at the known wavelengths is then correlated to provide an accurate indication of the moisture content of the material. By using two separate wavelengths of a polychromatic beam and passing the same through a common volume of the material and then observing the changes in absorption at the two wavelengths, it is found that variations in the absorption caused by changes in the thickness or density of the wood are cancelled from the results and hence the determination of the moisture content is effectively independent of variations in the thickness or density of the material. Thus the teachings of the present invention are well suited for use in determining the moisture content of lumber passing a fixed monitoring station.

In accordance with one embodiment of the invention a polychromatic beam of X-rays is passed through the material and then detected by a suitable detector, such as a crystal of the type used in scintillation counters. Output signals from the detector are applied to a pulse height analyzer so that the absorbance of the beam at a pair of selected wavelengths can be ascertained. In another embodiment of the invention the two wavelengths in the polychromatic beam are effectively separated by a diffracting apparatus so that the output signals from first and second detectors positioned to receive only those X-rays of the selected wavelengths will be proportional to the intensity of the radiation at said respective wavelengths. The moisture content is then ascertained in each case by correlating the relative absorbance on the two wavelengths. The signals from the pulse height analyzer or from the separated detectors is readily processed by conventional data processing equipment so that a direct reading moisture indicator controlled by the data processing equipment is provided.

The above as well as additional advantages and objects of the present invention will be more clearly understood when read with reference to the accompanying drawings and wherein,

FIGURE 1 is a block diagram of one preferred embodiment of the invention making use of the teachings of the present method for determining the moisture content of lumber,

FIGURE 1A is a system similar to that of FIGURE 1 but including a movable filter in the path of the beam,

FIGURE 2 is a further block diagram of a modified embodiment of the invention making use of spectroscopy techniques to separate the two desired wavelengths, and

FIGURE 3 is a graph showing the linear relationship...
between moisture content and the data obtained by the apparatus of the present invention.

Referring now to the drawings there will be seen in FIGURE 1 an X-ray source 10 which for purpose of illustration is labeled as a polychromatic X-ray source adapted to provide a polychromatic beam of X-rays 11. Suitable collimators 12 may be used so that a pencil beam is directed through a sample of material shown as the wood 13. An X-ray detector shown as a scintillation type detector 14 is positioned in the path of the beam 11 passing through the wood 13. The output signals from the detector 14 are applied to a pulse height analyzer 15 having a signal output circuit 16A which can be coupled with a record plotter. In the embodiment of FIGURE 1 a suitable signal processing apparatus shown as a data processor 17 is connected to the pulse analyzer 15 to provide output signals for the direct control of a moisture indicator 18.

The method and apparatus described in FIGURE 1 are based on the fact that the mass absorption coefficient of water varies more rapidly with wavelengths than does the mass absorption coefficient for wood. It can be shown that the following ratio is linearly related to the moisture content of the material 13.

\[
\frac{I(\lambda_2)}{I(\lambda_1)} = \frac{\alpha_1}{\alpha_2}
\]

where \(I_1\) and \(I_2\) are the incident and transmitted intensities at wavelengths \(\lambda_1\) and \(\lambda_2\). While the system will work using a wide range of wavelength combinations, the linear relationship between moisture content and the above ratio is shown in FIGURE 3 for one case where \(\lambda_1 = 0.64\) A, and \(\lambda_2 = 0.25\) A. In practice the factors \(I_1\) are determined before use of the apparatus by reading the output when there is no material 13 between the X-ray source and the detector. This avoids any problem which might be encountered by changes in the system parameters between uses, and assures an accurate value for \(I_1\) at \(\lambda_1\) and \(\lambda_2\) in all cases. The values of \(I_1\) at \(\lambda_1\) and \(\lambda_2\) may or may not be equal. By first testing with two pieces of wood of known and different moisture contents, a straight line curve of moisture content versus the above ratio is readily ascertained. Then thorough the curve can be used with the ratios determined from readings of \(I_{1}\) and \(I_{2}\) at \(\lambda_1\) and \(\lambda_2\) to ascertain the moisture content of similar material. \(\lambda_1\) and \(\lambda_2\) may be varied for different applications, with longer wavelengths providing better sensitivity but having less penetrability. With the equipment of FIGURE 1 the data processor and pulse height analyzer together provide automatic means for determining the equivalent of the straight line curve and thus provide control of the indicator 18. The calibration of the indicator is readily established by readings from pieces of wood of known moisture contents. Once the equipment is adjusted the readings are then automatic.

It is of importance to note that the above ratio provides a result which is independent of the density of thickness of the wood since the same is based upon the ratio of carbon to oxygen in the material, and not upon absolute quantities of either. The actual intensity of the transmitted energy at each wavelength will of course vary in accordance with the quantity of material between the detector and the source, but since the data used is based upon a ratio of relative absorptions, the factors of thickness and density are effectively eliminated from the results. Since the differential in absorption is small, the apparatus has been found to work best at high moist content levels, as for example in the case of wood, in the range of 30% to 200% moisture content. As used in the lumber industry, the term moisture content refers to the ratio of the weight of the moisture in the wood to the weight of the same piece of wood after being oven dried. Thus if a piece of wood weighs two pounds before being oven dried and one pound after, it is said to have had a moisture content of 100%. Since green wood from the forest typically has a moisture content of 100% or more, the apparatus and method are well suited for pre-sorting lumber prior to kiln drying. Then by grouping the lumber according to moisture content the kilns can be more efficiently utilized.

The system of FIGURE 1A is similar to that of FIGURE 1 but in addition includes a movable filter 30 having sections 30A and 30B adapted for selective positioning in the path of the beam 11 to discriminate the different wavelengths. The filter 30 can be supported in various ways, as for example by being supported for rotation. In the embodiment shown the filter is carried by a connecting lever 31 connected to a filter drive apparatus 32 which operates to selectively position either section 30A or section 30B in the path of the beam. The drive 32 includes a solenoid actuator coupled with the lever 31, and is coupled electrically with a counter 34 by circuit 33. The arrangement is such that effective wavelengths are determined by the filter, with the output from the counter being correlated with the filter position so that \(\lambda_1\) and \(\lambda_2\) signals are identified for the signal processing equipment. The filter 30 can be constructed with the section 30A being a suitable metal foil and the section 30B merely being an opening to permit passage of the beam 11. In one system the X-ray tube voltage was adjusted to give a maximum output at an effective wavelength of 0.64 A, and an aluminum and/or lead foil was used to absorb the longer wavelengths to give an effective wavelength of 0.25 A.

In the embodiment of the invention illustrated in FIGURE 2, a diffraction member 20 which may be a grating or a suitable crystal is positioned in the path of the X-ray beam 11 so that the detectors 26 and 27 are selectively subjected to X-rays of two distinct wavelengths. The member 20 is preferably mounted on the head of a goniometer 21 so that the angles involved are accurately known and thus the two wavelengths known. The member 20 is moved between two settings for a given reading so that the detectors 26 and 27 will provide output signals proportional to the quantities 1 in the above equation, and in practice the crystal can be oscillated between the two settings to provide rapid and essentially continuous monitoring of the material shown as lumber 13. The data processor 28 is a computer adapted to automatically perform the above division to thereby provide output signals for direct control of the moisture meter 29. Calibration is achieved as for the apparatus of FIGURE 1. The apparatus of FIGURE 2 is especially advantageous when the selected \(\lambda_1\) and \(\lambda_2\) are very close in value.

Various other arrangements of components can be used for carrying out the teachings of the present invention merely by using apparatus for determining the intensities of the radiation at two distinct wavelengths.

While there are obvious advantages to using a system wherein the two beams of the two selected wavelengths pass through the identical volume of material under investigation, it should be noted that individual beams from separate sources positioned adjacent to each other can be used if the material is sufficiently homogeneous to preclude large errors from being introduced by virtue of the beams not passing through the identical material along identical paths. The use of two separate monochromatic sources removes any need for wavelength discrimination by the two detectors associated therewith.

As noted above, the ratio of the natural logarithms of the indicated intensity ratios provides an accurate basis for determining moisture content. It has also been discovered in practice that the ratio of the intensity ratios themselves (as contrasted to the logarithmic ratio thereof) also results in an essentially linear relationship in view of the small numbers involved.

While the invention has been described with reference to specific embodiments thereof, it is to be understood that those modifications which are obvious to a person
skilled in the art from the teachings hereof are to be encompassed by the following claims.

What is claimed is:

1. A method of determining the moisture content of wood and other organic material having moisture content substantially in the range above 30% comprising the steps of passing X-ray radiation of wavelengths \( \lambda_1 \) and \( \lambda_2 \) through said material; detecting the intensity of the radiation at wavelengths \( \lambda_1 \) and \( \lambda_2 \) which has passed through the material; computing the value of the quantity

\[
\frac{\ln \left( \frac{I_0}{I} \right) \lambda_1}{\ln \left( \frac{I_0}{I} \right) \lambda_2}
\]

where \( \frac{I_0}{I} \lambda_1 \) is the ratio of the intensity of the radiation at \( \lambda_1 \) before and after having passed through the material and \( \frac{I_0}{I} \lambda_2 \) is the ratio of the intensity of the radiation at \( \lambda_2 \) before and after having passed through the material; and comparing such computed value with similarly determined values for similar material of known moisture content.

2. A system for determining the moisture content of wood or other organic material comprising in combination: X-ray means adapted to direct first and second X-ray beams of first and second wavelengths through the material; X-ray detector means positioned to detect said beams after the same have passed through said material; and means coupled with said detector means for providing signals representative of the quantity

\[
\frac{\ln \left( \frac{I_0}{I} \right) \lambda_1}{\ln \left( \frac{I_0}{I} \right) \lambda_2}
\]

where \( \ln \) and I are respectively the incident and transmitted intensities at wavelengths \( \lambda_1 \) and \( \lambda_2 \).

3. Apparatus useful in determining the moisture content of high moisture content materials such as green lumber comprising in combination: X-ray means directing X-rays at wavelengths \( \lambda_1 \) and \( \lambda_2 \) through said material; signal means including detector means positioned for receipt of said X-rays passing through the material and providing first and second signals respectively proportional to the intensity of the X-rays at said wavelengths \( \lambda_1 \) and \( \lambda_2 \) passing through the material; moisture indicator means; and means connecting said indicator means with said detector means and providing to said indicator means signals proportional to the quantity

\[
\frac{\ln \left( \frac{I_0}{I} \right) \lambda_1}{\ln \left( \frac{I_0}{I} \right) \lambda_2}
\]

where \( I_0 \) and I are respectively the incident and transmitted intensities at wavelengths \( \lambda_2 \) and \( \lambda_2 \).

4. Apparatus as defined in claim 3 wherein said signal means includes a pulse height analyzer coupled with said detector means.

5. Apparatus as defined in claim 3 wherein said signal means includes a counter coupled with said detector means, filter means selectively positionable between said detector means and said X-ray means, and filter positioning means mechanically connected to said filter means and electrically coupled with said counter means.

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