Manfred Gläser and Wolfgang Jahnke, Potsdam, Marco Pütz, Alpen, and Matthias Mumme, Groß-Umstadt

Non-destructive Radiometric Density Determination within Round and Square Bales

The capacity of a round baler or square baler is mainly defined by the density distribution within the bales, in addition to other parameters. Up to now there was no way to asses this parameter non-invasively. For this reason radiometric density measuring, used already above the cross section of Compact Roller discs [1], was successfully tested with six round balers [2], within the framework of a comparative test with round and square balers.

Dr. rer. habil. Manfred Gläser has been working for the Leibniz Institute for Agricultural Engineering (ATB) Potsdam-Bornim until 1992.
Wolfgang Jahnke has been working as test engineer in the DLG Test Center Potsdam-Bornim until the 31. December 2004, and is since then working for the Bundesanstalt für Materialforschung und -prüfung Berlin (BAM).
Marco Pütz has been working as test engineer in the DLG Test Center until the 31. December 2005, and is since the working for Lemken, Alpen.
Matthias Mumme is working as test engineer for cultivation machinery, seeders and machinery for forage harvesting in the DLG Test Center in Groß-Umstadt; e-mail: *M.Mumme@dlg.org*

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Keywords

Square bale, round bale, radiometric density determination

The average density of square bales is, caused to the high part of dry substance, about 100 to 200 kg/m^3 wet mass for straw and hay and up to 600 kg/m^3 wet mass for silages. For the future, new developments of the baler manufacturers will bring us higher values for straw to optimise the maximum payload of transport vehicles. Densities for silages will not increase for easier handling and wrapping.

In pilot surveys, square bales have been scanned in 3 levels over the height and in distances of 20 cm in lengthwise. Round bales have been scanned in axial direction and several levels. The layer thickness was 70 to 120 cm. For the future, round bales shall also be scanned radially with layer thicknesses of up to 200 cm.

Preview

The radiometric density measurement is often used for the product- and quality assurance. Depending on different materials and layer thicknesses, different types of rays and energies are used to attain the maximum sensitivity.

Because of the nearly constant stoichiometric consistence, the effect of the herbal material on the ray-attenuation can be disregarded [2, pp. 107-110]. That means that the same mass attenuation coefficient counts for all herbal materials. The ray-attenuation is exponential, and can be evaluated as follows:

$$I = I0 \exp. (-\mu/\rho \cdot d)$$

The signs mean:
I: impulse rate with debilitating material
I0: impulse rate without debilitating material
μ/ρ: mass attenuation coefficient
d: grammage (= density • layer thickness)

Regards on the extremum show that a maximum sensitivity of the measurement is reached for $\mu/\rho \cdot d = 1$. With the defined grammage d in the direction of the radiography of a square bale:

$$150 \text{ kg/m}^3 \cdot 0.7 \text{ m} = 105 \text{ kg/m}^2$$

results for a maximum sensitivity, that means the range within the ray attenuation reacts with the highest sensitivity to a change of the density, a mass attenuation coefficient of about 0.0095 m^2/kg.

A comparison of radiometric density measurements adapted nuclides shows, that the mass attenuation coefficient for herbal materials of Cäsium-137 is clos to that value. For straw and hay, the experimental measured mass attenuation coefficient amounts $\mu/\rho = 0{,}00815$ m^2/kg [2, pp. 110].

That proves that gamma active Cäsium^{137} in closed form is the qualified nuclide for density measurements for round- and square bales. The gamma ray of that source has an energy of 662 keV and an activity of $2{,}8 \cdot 10^8$ Bq. That estimation is verified by Berthold-Technologies, Bad Wildbad [3]. For much higher grammages, the measuring sensitivity decreases, so that longer gate times will be necessary. Higher energetic nuclides would be able to show an increased sensitivity for higher grammages at lower gate times.

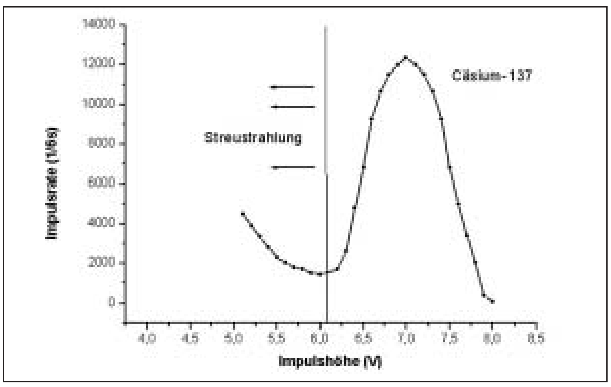

Fig. 1: Gamma energy spectrum of Caesium^{137} with discriminatory voltage of ~ 6 V

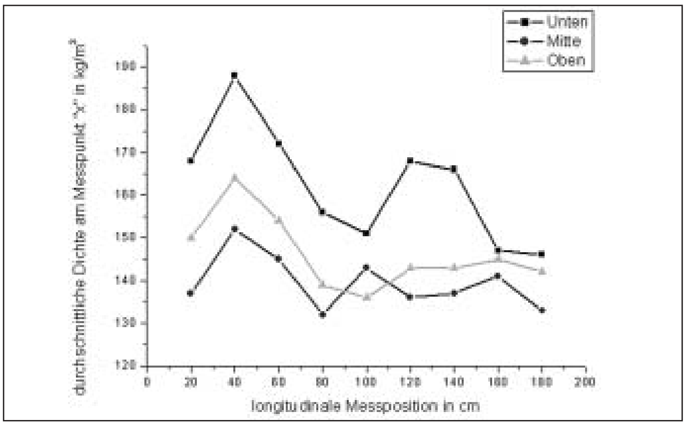

Fig. 2: Density allocation in three levels of a straw square bale

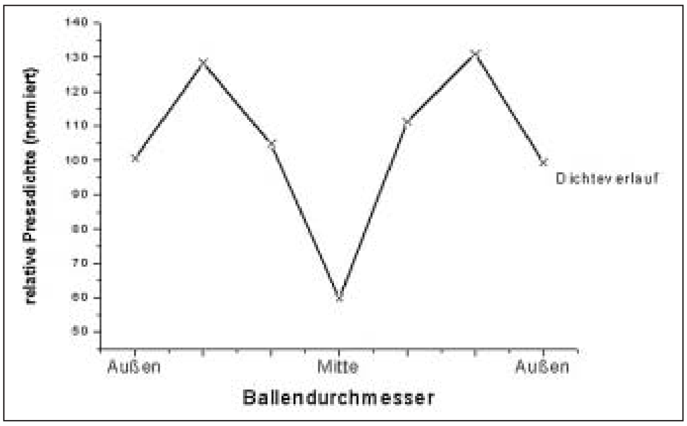

Fig. 3: Typical axial density allocation for a constant-room round bale (straw)

Calibration

The mass attenuation coefficient showed above is only valid for the radiation that reaches the detector directly. Scattered radiation and radiation from the surroundings distorts that legality. To eliminate the scattered radiation, the impulses of the low-energetic radiation are electronically disabled by a discriminator barrier, compared to those of direct radiation (*Fig. 1*).

The only unknown factor in the evaluation is the grammage d. Furthermore, it is possible to eliminate the scattered radiation, so that it is possible to measure the average density in the scanned area by using the differences between the impulse rates I and I0 and the layer thickness. Additionally, for each layer thickness a calibration graph by using two calibration pipes with known density is created.

Analysis of tests

By using the mass attenuation coefficient μ/ρ for herbal materials, especially for straw and hay, the layer thickness d, and furthermore after distraction of the zero-effect-impulse rates (I_{00} = 43/6 s) from the impulse rates of each position, the following relationship for calculating the density for each position results from the attenuation rule:

$$\rho = \frac{\ln(I_0 - I_{00}) - \ln(I - I_{00})}{0{,}00571} \quad [kg/m^3]$$

The calculated densities are shown in the following graphics (*Fig. 2 und 3*). It is obvious, that the density allocation in press direction shows gradients.

The comparison between the weighed and radiometric measured bale gives a validation for the high exactness (*Table 1*).

The small difference between both values allow the conclusion that the ascertained individual densities conform to the real densities.

Practical experiments

For round balers with variable press room, the new method was for the first-time utilized in the field during a machine-comparison [4].

The inner textures of these bales can be very different, and depends on the pressing technique and adjustment. It was found out that the density is lowest level in the core, while it increases up to the middle of the radius, and further on decreases to the outer edge (*Fig. 3*). The acquired data approved a good comparison of different round balers in terms of the density allocation.

Concluding remarks and outlook

The investigations have shown that the radiometric method is adapted for density measurements in round- and square bales and features the required sensitivity. This shows also the comparison of the average density of weighed and radiometrically ascertained bale densities.

Field test have supported the suitability of the method. A further rationalisation of the measurement will be attained with a new mobile test stand, which allows detecting the bale density by turning and canting in a second dimension. The measurement itself will be automated. That means the equipment measures and saves autonomously each measuring point, depending on the size of the bales. Furthermore, there will be a comprehensive graphical display enabled by image-guided software.

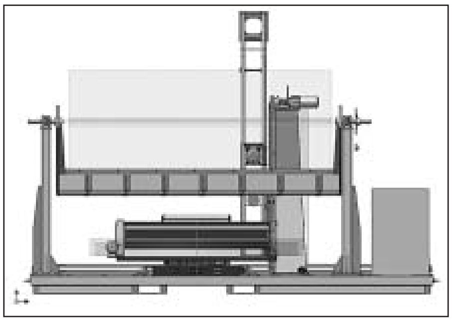

Fig. 4: Mobile density test stand of the DLG for bilateral irradiation of round and square bales

Type of material	Weighed average density kg/m³	radiometric average density kg/m³
Square bale hay	164.8	159
Square bale straw	115.4	116.8

Table 1: Average bale dendities determined by weighing and radio metrically measured

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