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In-line Measurement of Moisture Content of Wheat by Acoustic Method

Mehdi Lotfi[1*], Hosain Darvishi[2]

1. Department of Engineering, Islamabad-e Gharb Branch, Islamic Azad University, Islamabad Gharb, Iran
2. Department of Biosystems Engineering, Faculty of Agriculture; University of Kurdistan, Sanandaj; Iran

Corresponding author email: Mehdilofti@gmail.com

ABSTRACT: Moisture content has significant effects on most properties of agricultural products. Acoustic technique is a suitable method for moisture prediction of grains and seeds, because the impact sound of seeds with a impact surface is highly affected by moisture content. In this study, a acoustic device was used to determine the moisture content of wheat grains (12– 32% wet basis) to the sound spectrum generated by the fall of grains over a rigid surface of known characteristics (glass, wood and galvanize iron). A microphone, which is placed underneath the surface, receives sound waves generated by kernel impact and converts them to an electronic signal. The linear equations were proposed to describe the existing relationship between acoustic property and moisture content. Glass impact surface and 10 cm drop height selected as the suitable parameters for calibration of system. The moisture content of the samples was determined using standard oven method. Results show that the moisture content measured by using acoustic technique was highly correlated with the actual values ($R^2 \geq 0.95$).
Keywords: moisture content; acoustic; wheat; impact surface

INTRODUCTION

The amount of moisture in the grains is the most important factor influencing grain quality during harvest, process and storage. Accurate on-line estimation of moisture content of flowing grain is a fundamental requirement for the development of an efficient and reliable automatic control system for grain driers (Moura et al., 2013; Thibault and Duchesne, 2004). Present kinds of moisture meters are divided into 2 main classes, which are direct and the indirect method. Direct determination is based on some physical separation techniques like distillation, drying or chemical reactions producing gases like H_2 or C_2H_2, which are measured using specific techniques. Examples of direct methods include the chemical assays, drying technique, distillation, gravimetric analysis, microwave resonance, capacitance probes, electrical conductive and resistance measurement, near infrared spectroscopy, triboelectric probes, microwave and gamma ray densitometry (Mantanus et al., 2008; Liu et al., 2008; Gawande et al., 2003; Buschmuller et al., 2008). Generally, standard procedures for moisture determination are involved, requiring long hours of laboratory experiments and practices. Hence, they are not suitable for rapid on-line control and plant measurements.

In the area of grain moisture content detection, because of the high sensitivity and stability, capacitance sensor is widely used by most colleges and institutions (Liu et al., 2012). In general, higher moisture content results in higher dielectric constant and loss factor of some varieties of wheat (Nidhi et al., 2014). McKeown et al. (2012) reported that the moisture content of onion (8-91% wet basis) was linearly correlated with the dielectric constant at higher frequencies for the entire moisture range. Moura et al. (2012) studied the performance analysis of RF dielectric models for density-independent estimation of moisture content in sorghum. A method based on dielectric properties has been developed which allows continuous measurement of the moisture content (11.5 – 21.5% wet basis) of a stream of hard winter wheat to accuracy acceptable for normal grain drying operations (Berbert and Stenning, 1996). Kocsis et al. (2008) presented new on-line grain moisture measuring system for wheat (7– 29% wet basis) based on the microwave resonator technique. They reported that the standard deviation between the microwave-measured moisture content and the reference moisture content achieved was 0.51% wet basis for the whole moisture range. Determination of moisture content in wheat by near infrared diffuse reflectance spectrophotometer was studied by Law (1975).

The relationship between the electrical properties and moisture content of tea leaves was investigated within a frequency range from 10 Hz to 10 MHz (Mizukami et al., 2006). The acoustic method presented by Harrenstein and Brusewitz (1986). In this method kernels fell through the funnel outlet orifice onto a pile of kernels, and the impact sound was received by a microphone and was sent to a sound pressure level meter. Amoodeh et al. (2006) showed that the glass surface was the best surface contact in acoustic method. Mexas and Brusewitz (1987) showed that equivalent continuous sound level increased as temperature decreased below 25 ºC and cheat content affected the acoustic grain moisture meter reading by indicating up to 1% higher moisture content.

Wheat is popular crop produced in Iran and cultivated in considerably large areas. For wheat a moisture content value not exceeding 20% wet basis during purchase or sale and below 15% wet basis for storage is recommended. Their experiments indicated that the microphone should be as close to the source point as possible, in order to reduce the effects of outside noise and produce the highest equivalent continuous sound level value. The objective of this research was to study the relationships between moisture content of wheat and acoustic data obtained instrumentally.

MATERIALS AND METHODS

Wheat was selected as a representative grain due to its economical importance. However, this method can be used for measuring moisture content of other grains as well. The wheat grains used in the study were obtained from a wheat farm in Sanandaj, Kurdistan, Iran. Foreign material and broken kernels were separated from the wheat samples to eliminate their impact sound effects. The initial moisture content of the grain samples was determined using standard oven method at 103 ± 1 °C for 24 h, which was found to be 12 ± 0.6% (wet basis). The samples of the desired moisture contents were prepared by adding the amount of distilled water as calculated from the following relation (Coskun et al., 2006):

$$Q = \frac{W_i(M_f - M_i)}{100 - M_i} \qquad (1)$$

The samples were then poured into separate polyethylene bags and the bags sealed tightly. The samples were kept at 4 ºC in a refrigerator for a week to enable the moisture to distribute uniformly throughout the sample. Since the elastic property of the kernels is affected by temperature, this effect was eliminated by conducting all experiments at a constant temperature of 23 ºC. Before starting a test, the required quantity of the grain was taken out of the refrigerator and allowed to equilibrate to the room temperature for about 3 h. The six moisture contents (32.3, 28.5, 24.1, 18, 15.5, and 12% wet basis) selected were to cover the whole moisture content range of the wheat from harvesting to storage. All the experiments were replicated four times for each sample and the average values were reported.

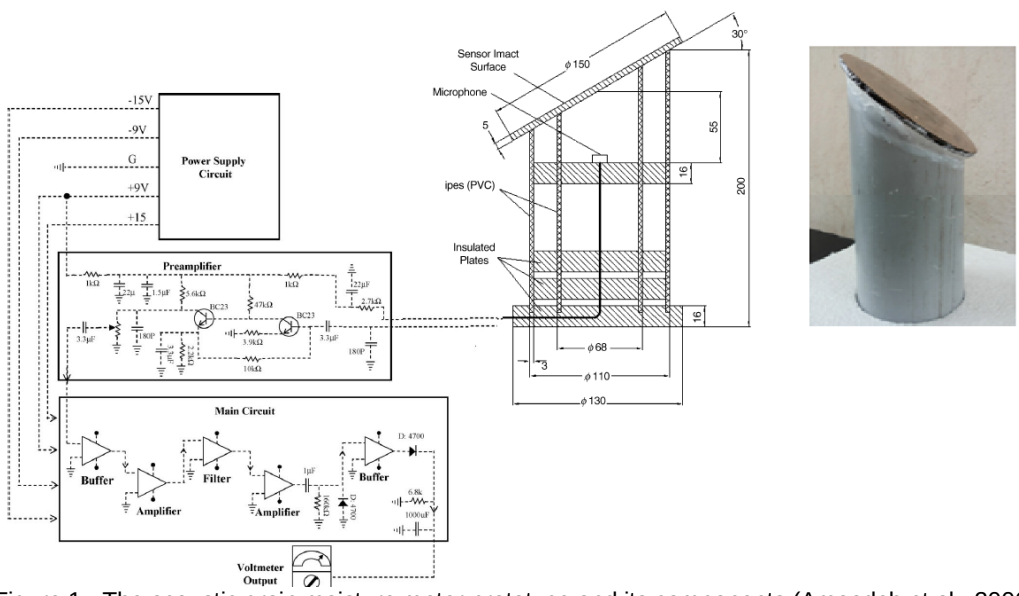

Figure 1 . The acoustic grain moisture meter prototype and its components (Amoodeh et al., 2006)

An acoustic grain moisture meter prototype was designed as shown in Figure 1. More explanation of instrument was presented by Amoodenh et al. (2006). Kernels, held in a 2 kg capacity funnel-shaped holding bin, fall on the inclined sensor surface upon opening the bin orifice. The discharged grain, with about 80 cm^3/s flow rate, is then collected in the collection bin. The microphone, placed under the impact surface, receives the impact sound and sends it to the electronic circuit. Output voltage of the electronic circuit, measured by a voltmeter, is proportional to the impact sound pressure level. Components of the designed sensor are illustrated in Figure. 1. The microphone was placed inside the insulated housing, which it distance from the center of the impact surface was 55 mm. Experiments were performed at three drop height of 5, 10, and 15 cm, and three Impact surfaces. Impact surfaces made of glass, galvanize iron and wood with 150 mm in diameter and 5mm in thickness was used. To prevent the accumulation of grains on the impact surface during the falling, the angle of the sensor surface was considered 30º (Amoodenh et al., 2006). A Lutron (Model Sl-4001) sound pressure level meter was used to measure environmental sound pressure.

RESULTS AND DISCUSSION

To evaluate the individual effect of independent variables on the output voltage, analysis of variance (ANOVA) table was constructed as shown in Table 1. Comparing F-values of the moisture content, drop height and type of impact surface showed that the effect of drop height on the output of acoustic moisture meter was higher (high F-value) than the effect of moisture content (low F-value).

Table 1. Analysis of variance for effect of M.C, H and type of impact surface on output of acoustic moisture meter

impact surface	Source	df	Mean Square	F
	M.C	5	6.5	221.4**
Glass	H	2	40.6	1376.9**
	H×M.C	10	0.25	8.405**
Galvanize iron	M.C	5	3.2	54.52**
	H	2	34.5	585.1**
	H×M.C	10	0.18	3.07**
Wood	M.C	5	0.22	2.16**
	H	2	0.87	8.57**
	H×M.C	10	0.11	1.13*

**Highly significant * Not significant

M.C and H are moisture content (%, wet basis) and drop height (cm)

The variation of output voltage with moisture content at different drop heights and types of impact surfaces are shown in Figures 2– 4. As depicted from Figures 2– 4, a decreasing trend in the output voltage was observed with the increase in moisture content. Also, output voltage increased with drop height under all moisture content. At all drop heights, the glass surface had the highest and wood surface had the lowest slope and coefficient of determination values. This result revealed that sensitivity and accuracy, to some extent, could have been affected by elastic properties of the glass surface. The glass sensor surface with a drop height of 10 cm had the highest accuracy and sensitivity to measure output voltage; therefore, this combination was selected for the final experiment. Multiple regression analysis showed that there is a linear relationship between dependent variable of the output voltage (V) and the independent variable of moisture content (M.C) for glass sensor surface with a drop height of 10 cm as follows:

$$V = 12.521 - 0.1203M.C \qquad R^2 = 0.975 \qquad (2)$$

For this moisture range, prototype calibration equation for the wheat grains is M.C = 102 – 8.102 V. The correlation between measured moisture content (oven method) and calculated moisture content by acoustic moisture meter is shown in Figure 5. As can be seen, the dots in Figure 5 are closely banding around at a 45º straight line (R^2 = 0.969) – a very good agreement between calculated and experimental data, which indicates that the image analyze method could adequately measure the length of fish.

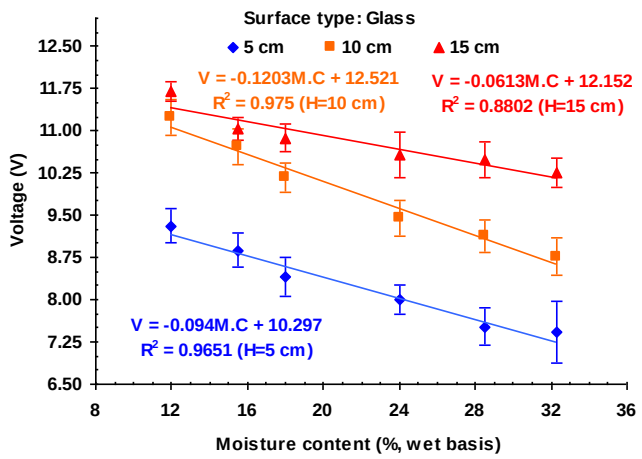

Figure 2. Variation of output voltage with moisture content for glass surface

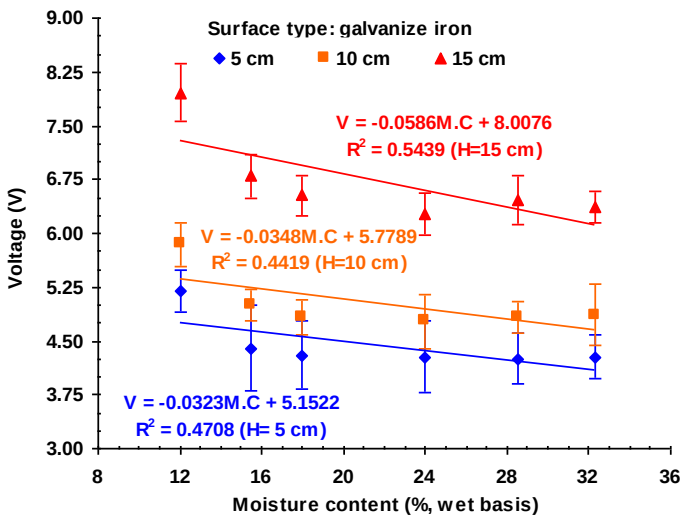

Figure 3. Variation of output voltage with moisture content for galvanize iron surface

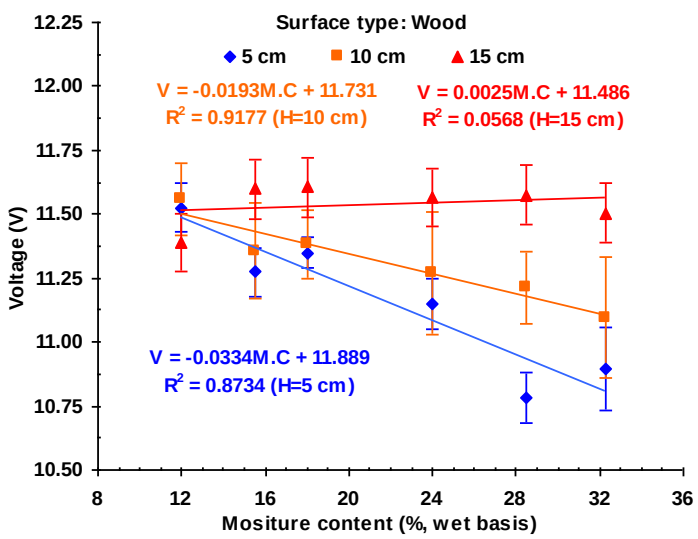

Figure 4. Variation of output voltage with moisture content for wood surface

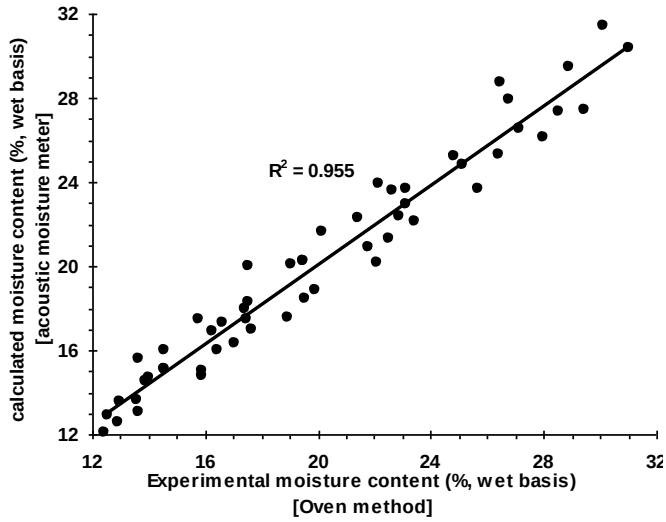

Figure 5. Comparison of experimental (oven method) and calculated moisture content by acoustic method

CONCLUSIONS

In this study, the elastic property of wheat was investigated as a function of moisture content. Linear regression was used to analyze the relationship between moisture content and sound spectrum generated by the fall of grains over a rigid surface. Through this method, the moisture content of wheat can be predicted reliably. For moisture content range of 12– 32.3% wet basis, prototype calibration equation for the wheat grains is M.C= $102 - 8.102 \times \text{Output voltage with } R^2 = 0.9750$.

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