Simple measurement instrument of moisture content for Indonesia coffee powder based on capacitive sensor

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Abstract. Moisture content is one of the most important parameters for coffee commodity especially related to quality and taste. However, research on measurement instruments which capable to measure moisture content directly from a coffee sample is still very rare. Therefore, in the current study, this prototype is realized by utilized a capacitive sensor made from couple of copper plates to measure capacitive signal from the sample, which subsequently converted to a voltage signal by an oscillator and comparator, and then finally converted to the moisture content by a microcontroller which can be shown on an LCD screen. An accuracy testing is carried out by comparing the moisture content measured from the oven heating reference method and the prototype. The results show the average of measurement errors is 0.08 % and 0.22 % for coffee evaporated sample and coffee-water mixed sample respectively. Based on the maximum permissible error stated in OIML International Recommendation of R-059, this prototype meets the requirement of moisture meter of Class I.

1. Introduction

Coffee is a very popular beverage throughout the world [1–3] because it has delicious taste [4], pleasant aroma [5] dan several beneficial properties such as stimulant [1], antioxidant [6] and anticancer [3]. All those properties are determined from several stages of the manufacturing process i.e. sorting, cleaning and roasting the green coffee beans, grinding the roasted products, extraction of soluble coffee solids, pre-concentration of the coffee extract, and drying method to produce the coffee powder [4,7,8,9]. From all these stages, the drying method plays an important role in the coffee flavor formation through the formation of particular compounds related to the coffee’s taste and aroma [4,7,8,10]. Then, moisture content as the indicator of the drying stage plays significant roles for coffee bean and coffee powder quality [9, 11]. If the bean is too high in moisture, then it can be easy to deteriorate due to bacteria, mold or yeast, while in low moisture, the bean will become distorted that lowering its quality and taste [11]. Also, not only to the coffee bean, the moisture content also plays a significant role for coffee powder properties especially the solubility of the coffee powder [9].

Due to the importance to the coffee quality, several methods for measuring the moisture content have been developed such as oven or hot air heating method [9,11,12], P2O5 reference method [12], microwave [13], infrared spectroscopy [12], colour [11, 12], hardness and brittleness [11], and electronic meters [11, 14]. Among all those methods, moisture content measurement using the electronic meter
with the capacitive principle is the most widely used method due to the practical and fast measurement of the capacitive properties that related to physical and chemical properties of the material [11, 14, 15].

Developments of the electronic meter based on the capacitive principle for coffee were intensively studied starting from the dielectric property studies related to the coffee moisture until the making of electronic meter prototype [14, 16–18]. Studies of the capacitive property of coffee were started from findings of increasing dielectric value of coffee bean with the increase of moisture content and density [16]. An instrument to measure the dielectric value of the coffee bean was developed, but it was unable to measure moisture content directly and predict that moisture by a mathematical model [17]. An electronic meter was developed to measure the moisture content from the water activity and the electrical current, but it has a greater error at higher water activities [18]. Recently, an electronic meter was developed which capable to measure the moisture content of the coffee bean and directly shown the result using a capacitive sensor [14], but this instrument only can be used for certain coffee commodities. However, the electronic meter for coffee powder is currently not available. Therefore, the aim of this paper is the development of instrument that capable to measure the moisture content directly to coffee powder due to the high production of coffee bean (739.005 ton) and coffee powder (398.000 ton) in Indonesia [19], to fulfill the requirement in the Indonesia Quality Standard for coffee powder with 7% moisture content.

2. Experiment Method
This study is divided into two stages i.e. fabrication of the electronic systems for the coffee powder and testing of the meter with the reference method (oven). In the first stage, the electronic meter is designed based on the scheme shown in Figure 1. A pair of copper plates (10 × 10 cm²) with a 1 mm to 3 mm gap distance is used as the capacitive sensor to detect the dielectric value change when the coffee powder is placed between the plates [16, 20-23]. Then, the change of the capacitance value is converted to the frequency and voltage values in the Frequency Oscillation and Phase-Locked Loop module. The frequency oscillation module employs a hex inverter Schmitt Trigger logic gate of IC 74HC14 with resistor and capacitor components as the tuning series [24-26]. The oscillation frequency value is determined based on the equation [24, 25] that assigned f0 value as 250 kHz in the condition without the coffee powder. This value will change when the coffee powder as the dielectric material is placed between the plates. The Phase-Locked Loop module utilizes the IC 74HC4046 to convert the frequency value becomes the voltage value by comparing the frequency coming from the frequency oscillation module to the reference frequency stored in IC 74HC4046 [27,28]. Subsequently, the voltage value is converted to the moisture content by a microcontroller and shown on the LCD screen.

![Figure 1. Block diagram of electronic meter for measuring moisture content of the coffee powder](image-url)
The second stage is the testing of the electronic meter with the reference method [29, 30]. Coffee powder samples are prepared by two methods i.e. water vapor method and water mixing method to obtain several different moisture contents samples as required by the standard [29, 30]. Both methods utilize the Indonesia coffee powder brand “X”. In the first method, coffee powder samples are prepared by exposing three sets of 40 grams coffee powder samples above a water humidifier at three different exposure times i.e. 30 minutes, 60 minutes and 90 minutes. While at the second method, three sets of 40 grams coffee powder samples are mixed with three different water volumes i.e. 8 ml, 16 ml and 32 ml in a plastic bag. From each set of 40 grams of coffee powder sample, 25 grams sample divided into five containers was determined its moisture content by reference method, while the remaining 15 grams sample was measured its moisture content several times by the electronic meter. Then, the accuracy and precision of the electronic meter will be evaluated from the error, the standard deviation of difference (SDD) and standard deviation (SD) values as described in the standard [14,29,30].

3. Results and discussion
The result of the designed electronic meter is shown in Figure 2. An LCD screen and reset button are placed in the forepart of the electronic meter. A pair of copper plates as the capacitive sensor is placed on the top of the electronic meter that consists of the bottom copper plate with the feature like a drawer which facilitates the easiness to load and unload the sample horizontally, and the top copper plate that attached to threaded section to move up and down easily. Coffee powder sample is placed on the surface of the bottom copper plate (Figure 2), then covered with the top copper plate to form a complete capacitive sensor of parallel plates to measure any change of capacitance value of the sample then converted to moisture content as shown in Figure 3.

![Figure 2. Electronic meter when loaded by the sample.](image1)

![Figure 3. Example of a measurement result of moisture content for coffee powder sample.](image2)

The performance of electronic meter in measuring the moisture content of the coffee powder sample is evaluated by the reference method as described in the standard [29, 30]. Testing results using the first samples set are shown in Table 1. Moisture contents of the sample set as measured by the electronic meter are between 1.00 % and 2.60 % that close enough the reference method results at 0.96 % to 1.86 %. These results are quite accurate with an average error value of 0.08 % and an SDD value of 0.11 % that below the maximum permissible error (MPE) of 0.30 % and maximum SDD of 0.15 % for Class I
Table 2 shows the testing results of the second samples set which have wider measured moisture content range from 1.00 % to 10.60 % with an average error value of 0.21 % and SDD value of 0.07 % from correspondence reference method results. These results are also below MPE of 0.32 % and maximum SDD values of 0.16 % Class I electronic meter [29, 30]. This meter also shows a fairly precision with SD values of 0.17 % (the first samples) and 0.26 % (the second samples) that below SD maximum of 0.35 % [14].

To analyze the linearity between input and output in Table 1 and Table 2, then moisture content measured by electronic meter is plotted to reference method data. Plots are shown in Figure 4 and Figure 5. Linear regression at the first samples set yields correlation coefficient value (R) as 0.8448 (Figure 4) and 0.9781 (Figure 5).
that indicates a moderate linear correlation between output values in a narrow range of moisture content input of 1 to 2 %, then to increase the linearity, the electronic meter should increase the resolution [31]. A better linear correlation coefficient (R) value is achieved in the second samples set result (Figure 5) with R-value of 0.9781 which shows a stronger correlation between input and output at wider range of moisture content from 0.2 % to 10 % that similar to the moisture content range founded for coffee powder in the market [9,13,32], and therefore the designed electronic meter is suitable for measuring the moisture content of the coffee powder.

4. Conclusion
Electronic meter that capable to measure the moisture content of the coffee powder sample directly and show the measurement result on an LCD screen successfully fabricated from a pair of copper plates as the capacitive sensor, frequency oscillation and phase-locked loop modules, and microcontroller. The accuracy test with the reference method yields average error values and SDD values below the MPE and maximum SDD values of Class I electronic meter as required in the standard. Precision test results also show that SD values of the meter are still below of MPE values in the standard. Also, the linearity testing results indicate that the meter produces a fair linear output at the moisture content range of 0 – 10 % as the most widely founded moisture content of coffee powders in the market.

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