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Determination of Water added in Raw Milk using Interdigital Capacitor Sensor

***Abstract**. This paper suggests that for water added in raw milk has been developed using Interdigital capacitor electrical conductance measurements, other than using conventional methods such as determination of specific gravity or of the freezing point temperature, and the compression on frozen samples. The system has been assembled and the experiments were conducted. The characteristics at 1 KHz, 10 KHz and 20±1 ℃ for all raw milk samples revealed a linear increase in conductance with increasing water content over the entire of water concentrations. Results shown that the capacitance value of the water added in raw milk were lower than the raw milk without added water. It also provides an opportunity for the development of a microcontroller-base low-cost sensing system.*

Streszczenie.** Do badan ia zawartości wody w mleku wykorzystano czujnik pojemnościowy. Badania przy różnych częstotliwościach wykazały że między przewodnością i dodatkiem wody jest liniowa zależność. Także między pojemnością a koncentracją mleka obowiązuje zależność liniowa.* ***Określania zawartości wody w mleku przy wykorzystaniu czujnika pojemnościowego

Keywords: Interdigital capacitor, raw milk, water added.
Słowa kluczowe: czujnik pojemnościowy, czystość mleka

Introduction

In the dairy industry, milk added can cause several significant problems, including economic losses, end products deterioration and a safety risk for consumers. Several standard techniques have been, therefore, applied to detect the water content in milk, using basic indicators like the freezing point of raw milk or the refraction of light when passing through whey after fats are removed. Nonetheless, these techniques require too much time and high expenditures. So, more effective instrumentation needs to be developed for the more rapid and more reliable detection.

Fundamental information about the electrical conduction behaviour of milk and other dairy products can be obtained from their data of electrical admittance over a wide range of frequencies (Lawton and Pething., 1993, Mucchetti et. al., 1994). Additionally, during the milking process, a change in conductivity may also trace mastitis (Nielen el. al., 1992). These imply that a single conductivity measurement does not provide sufficient information to establish the quality of milk.

The previous study involving milk showed that there were some changes in resistance value and electrical capacitance of raw milk when it is kept at a room temperature of 20 ℃. The observation was also conducted, together with changes of possible pH by applying parameters for rapid measurement and for predicting changes in the quality of raw milk soon after milking and until freezing (Żywica et al., 2000).

For measurement technologies, relative permittivity changes or capacitive changes are used as a factor for monitoring the environments and for measuring the material properties (Abu Al Aish et al,. 2010; Jusoh et al., 2011; Watanabe et al., 2009; Yeow et al., 2010).

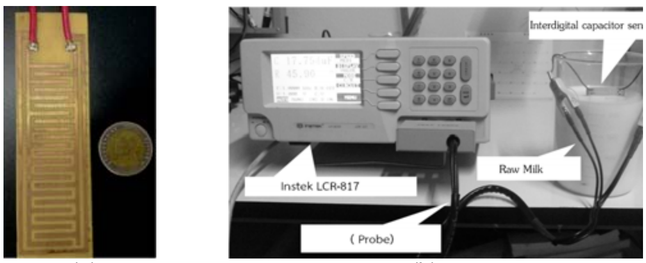
Among sensor technologies (Kim et al., 2010; Salvo et al., 2010; Sivaramakrishnan et al., 2010; Ye et al., 2011; Yu et al., 2011; Zhuang et al., 2011), interdigital capacitors are used for the evaluation of near-surface properties, such as conductivity, permeability, and permittivity of materials (Kim, 2008; Mukhopadhyay et al., 2007; Stojanovic et al., 2010; Zhang, 2010). The interdigital sensors have been used for estimation of properties of dielectric material for dairy products (Mukhopadhyay et al., 2006), humidity and gas sensors (Laville and Pellet, 2002). The applications of these sensors depend on both the characteristic of the particular sensor chosen and also on the characteristic of the material under test (MUT).

Therefore, this article has presented the results of the study and the effects of the levels of water added in raw milk which was one of the compositions to indicate properties of intensity and quality of raw milk by using Interdigital capacitor sensor. The study aimed at examining the correlation between the level of water added in raw milk and the thermal parameters of raw milk (electrical capacity and conductivity) and performing analyses by using a mathematical equation approach.

Material & Methods

Most of materials used in these experiments came from Mahasarakham Dairy farm Cooperative in Mahasarakham Province. Their acidity was a pH of 6.80. An Interdigital Sensor was used to test electrical conductivity and capacity. The sensing devices consisted of copper electrodes 20mm with a separation of 2 mm and N =24.

Electrical measurement tested electric conductivity by pouring raw milk into a beaker. Two electrodes were installed with wires which were connected to the PCB of the Interdigital Sensor (Figure 1a). Each electrode was connected to the power supply, and the system was measured with the GW instek LCR817



(a) (b)

Fig. 1. (a) Top view of an interdigital capacitor. (b) experiments setup

After that, in order to have raw milk at a temperature 20±1 ℃, the sample was allowed to reach room temperature. When the desired temperature had been reached, the parameter measurement process was started. The electric conductivity of raw milk, resistance(Z), and capacity(C) were measured with GW instek LCR817 at a voltage of 1V and a frequency between 1K-10KHz. For each sample, the measurements were repeated three times.

According to previous studies involving milk, juice, meat, paste, and sugar concentration and research report (

Banach et al., 2010, 2012; N. Angkawisittpan et al., 2012) it was useful in order to analyze electrical properties of milk (Marbook and petty, 2003b).

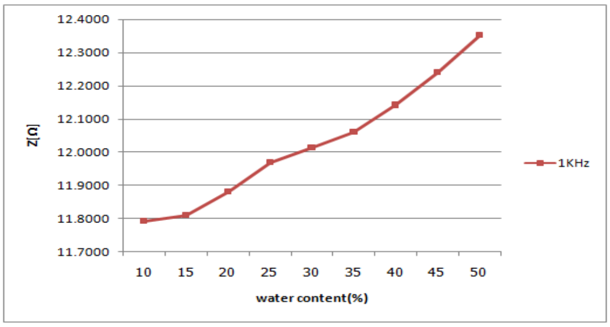
To examine the correlation between the parameters of raw milk and the amount of water added in raw milk, the correlation and linear regression were calculated by using a statistical analysis program.

Result & Discussion

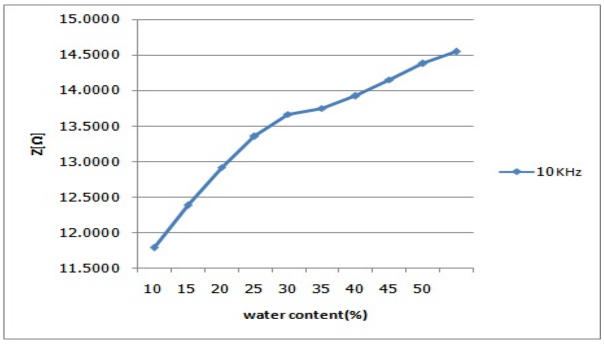
Changes in the parameters of resistance of raw milk

From the study, it can be seen that the values of the resistance of raw milk increased, together with water level in raw milk, regardless of the electrical frequency voltage measurement (f). By increasing the amount of water from 10% to 50% at a frequency of 1 KHz, a rise in the resistance value showed an increase from 11.77 Ω to 12.35Ω (Fig. 2a). At a frequency of 10 KHz, the resistance value showed an increase from 11.79 Ω to 14.55 Ω (Fig. 2b).

The correlation analysis of water added of raw milk in the changing functions of conductivity parameters (Z) of raw milk showed a significance of α = 0.000. The level of correlation of the coefficient was at 0.974 ≤ *r* ≤ 0.989, and the level of R-Square was between R^2= 0.948 (1KHz) and R^2= 0.978 (10KHz). The value of the mathematical correlation between the level of water added in raw milk and the value of electrical resistance can be explained by using regression y = ax±b with the whole electrical frequency voltage measurement (Table 1).



(a)



(b)

Fig. 2. Changes in resistance of raw milk that are affected by water added in raw milk and the frequency of Electrical voltage measurements (a) 1KHz (b) 10KHz)

Table 1. The correlation analysis of water added in raw milk (W) in regard to the changing function of resistance (Z) of raw milk

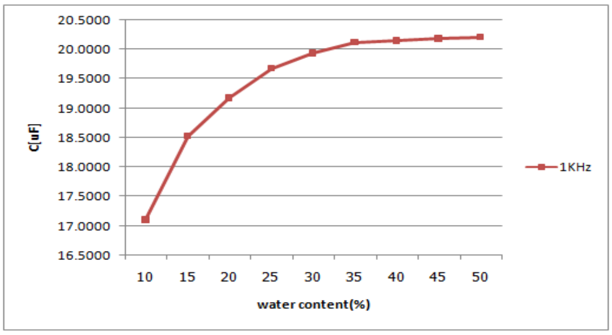
Frequency (Hz)	Measuring parameters	*r*	α	Regression equation
1000	Z	0.974	0.000	W = 0.2481 × Z+12.437
10000	Z	0.989	0.000	W = 0.0691×Z + 11.683

Note: W, water added; *r*, correlation coefficient; α, significance level, computed.

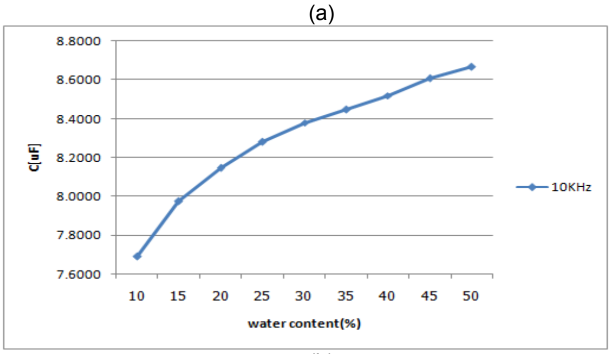
The trend above showed changes of the resistance of raw milk affected by the amount of water added in raw milk and the frequency of electrical power prescribed. Hence, in order to get a complete picture of the electrical properties of raw milk, it was created to examine the effects of the changes in the amounts of water added in raw milk that affect electrical capacity and are related to other things given water's ability to collect an electrical charge.

Changes in the electrical capacitance parameters of raw milk

The result of electrical capacity measurement (C) in raw milk showed that the increasing value of electrical capacity depends on the amount of water added in raw milk and the electrical frequency voltage (f). The level of water increased from 10% to 50% (Fig. 3a&3b). The result of electrical capacity measurement (C) showed an increase in the absolute value as the amount of water in raw milk increased, in regardless of the electrical voltage.



(a)



(b)

Fig. 3. Changes in the electrical capacity of raw milk that are affected by the amount of water added in raw milk and the electrical frequency voltage measurements (a) 1KHz (b) 10KHz)

Increasing the amount of water from 10% to 50% at the frequency 1KHz showed that the value of electrical capacity of raw milk(C) rose from 17.09 μF to 20.20 μF (Fig. 3a) and the value of electrical capacity (C) of raw milk increased from 7.69 μF to 8.66 μF at the frequency of 10KHz (Fig. 3b). When the measurement of electric power is at a frequency higher than1KHz; it can be seen that the value of electrical capacity (C) will respectively decrease.

Table 2. The correlation analysis of water added in raw milk (W) in changing the function of the electrical capacity (C) of raw milk

Frequency (Hz)	Measuring Parameter	*r*	α	Regression equation
1000	C	0.862	0.003	W = 0.3303 × C +17.79
10000	C	0.965	0.000	W = 0.1117 × C +7.742

Note: W, water added; *r*, correlation coefficient; α, significance level, computed.

The correlation analysis of water added in raw milk in changing the function of electrical capacity parameters (C) of raw milk showed its significance at α ≤ 0.003. The level of correlation of the coefficient was at 0.862 ≤ r ≤ 0.965, and the level of R-Square was between R^2= 0.743(1KHz) and R^2= 0.931 (10KHz). The value of the Mathematical correlation between water added in raw milk and the value of electrical capacitance can be explained by using the regression y=ax±b with the whole electrical frequency voltage measurement (Table 2).

The measurement of electrical conductivity (Z) and electrical capacity (C) in raw milk parameters revealed the relationship between those values and the water added of raw milk. The average changes in electrical conductivity parameters were between 10% to 50%, and were maintained at this level irregardless of the electrical frequency voltage measurements. Regarding the coefficients received from the relationship between changes in the parameters of electrical conductivity and the amounts of water added in raw milk, the specified equation was y=ax±b and ranged between 0.974 and 0.989, and the significance of data processing (invariant) was α = 0.000 (Fig. 2a & 2b, Table 1)

According to the observation, the correlation analysis of water added in raw milk in changing the function of the electrical capacity showed that the highest relation was between 0.862 ≤ r ≤ 0.989 ; 0.000 ≤ α ≤ 0.003. The successful process between the amount of water added in raw milk and the electrical capacity (C) showed that the specification of the amounts of water in raw milk was absolutely accurate (W). It was in line with the measurement of electrical capacity (C) and was calculated with the mathematical equation, W = aC+b, which specifies the relationship between the electrical capacitance (C) of raw milk and the amount of water added in the raw milk (Table 2).

The result of the measurement of electrical conductivity, resistance, and capacitance by using parameters has clearly revealed that changes in water added of raw milk affected changes in electrical conductivity and capacity.

After investigating a variety of factors such as temperature, acidity, and seasonal changes, the successful results have now been presented in a basic form. It was possible that these factors could affect the electrical properties of raw milk and a wide dimension of electrical frequency voltage measurements.

Conclusion

This paper is a report of a novel low-cost electronic system for water added determination in raw milk, in which an interdigital capacitor sensor is designed and fabricated and some experiments are conducted. The proposed electronic system incorporating the interdigital capacitor sensor responds very well to differing percentages of water added in raw milk. Results of the experiments show that, to obtain the fixed output voltage indicating between 10% and 50% water added, suitable frequencies of voltage source for the system should be between 1-10 kHz. In addition, there is a possibility of developing a novel low-cost sensing system using any microcontroller for the dairy, food and juice industries.

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