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Rapid determination of the moisture content of milk powder by microwave sensor

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ABSTRACT

A rapid method of determining the moisture content of milk powder by microwave sensor is investigated. Calibration models of milk powder moisture content are established using the linear least squares method. The results predicted by the microwave technique are compared with that determined by standard weighing method. It shows that the maximal measurement deviation was 0.2%, based on the microwave method, which provides an effective tool for determining the moisture content of milk powder in the dairy processing industry.

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1. Introduction

Whole milk powder (WMP) is a valuable product that is generally used by the consumer as a fresh milk substitute. In the manufacture of WMP, milk is subjected to a range of processes such as agitation, pumping, heating, concentration, homogenization and spray drying [1]. The moisture content of milk powder, which is a predominant factor determining the keeping quality of the product, and influences the cost of production, must be accurately controlled during the process of spray drying.

Residual moisture in milk powder can be determined by the drying oven method [2], with which the powder is dried at 102 ± 2 °C until constant mass is obtained, then the difference in weight (i.e. weight loss) is determined and the moisture is calculated in percent of the powder weight. However, this method is time consuming and not suitable for in-line measurement. In diary industry, infrared spectroscopy has been used as a powerful tool for in-line measuring the moisture content of milk powder for more than 20 years [3,4]. Besides, analysis of the water/moisture and fat content of dairy products using time-domain nuclear magnetic resonance (NMR) has been reported by Todt et al. [5]. The development of microwave sensors begun in the 1950s, when there was activity to develop better methods for the measurement of the permittivity and to study the relation between the permittivity and the physical properties of materials and mixtures [6–8]. Since microwave sensors see a very good contrast between water and most other materials, they are well suited for moisture content measurements [7]. Moisture measurement was also the first application of microwave sensors that was extensively studied [9]. It has been applied in many branches of industry [10–14]. However, to the best of our knowledge, few applications have been reported in the dairy industry except the pioneer work of Kress-Roger and Kent [15]. Microwave technology has some advantages in measuring moisture content of powder materials and food [7,16]. For example, the microwave sensors do not need mechanical contact with the object, and it is low price, as well as low power requirements;

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Table 1
The components of milk powder.

Components	Fat	Minerals	Protein	Lactose	Moisture
Content	⩾26%	4–4.5%	⩾Solids-non-fat 34%	⩾30%	⩽5%

compared with infrared spectroscopy, the measured results of microwave sensor represents a volume of the materials, not only the surface, since microwaves penetrate all materials except for metals; compared with NMR method, the microwave techniques are safe and environmental convenience. In this paper, the rapid determination of the moisture content of milk powder based on the resonant microwave sensor is investigated, and different calibration model for measuring the moisture content is established. The measurement deviation is analyzed and discussed in detail.

2. Experimental techniques

2.1. Materials

The experimental sample was whole milk powder, obtained from Dengchuan dairy Ltd. in the Yunnan province of China. The constituents of the sample are shown in Table 1.

Whole milk powder (typically 140 g in weight) was dried at 102 ± 2 °C for at least 2 h. The samples of milk powder were then divided into seven portions, each weighing 20 g. Samples with different moisture contents were obtained by adding different proportions of water to the dry powder. Finally, the moisture content of each sample is obtained by putting individual samples into the calibrated microwave sensor. The calibration was performed only once and was automatically stored in the device.

2.2. Measurement principle

The principles of cavity perturbation techniques have been studied by many researchers [16–18]. Let Q_0 and f_0 be the quality factor and resonance frequency of the cavity in the unperturbed condition, respectively, and Q and f the corresponding parameters of the cavity loaded with the sample. When a small sample is introduced in a cavity, it causes a frequency shift $\Delta\omega$, and the Q fact is changed accordingly. These quantities are given by [19,20]:

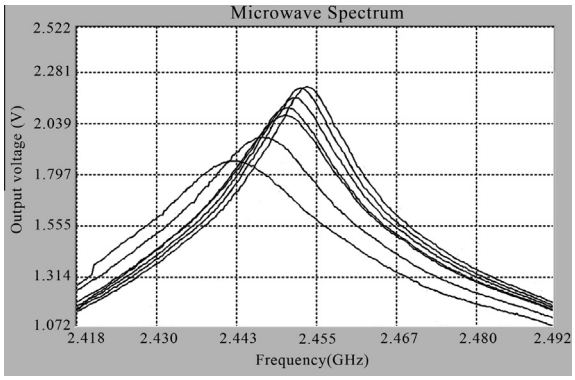

Fig. 2. Microwave spectrum of milk powder of different moisture contents.

$$\frac{\Delta\omega}{\omega} = -\omega_0(\varepsilon_r' - 1)\int_{ve} E_0^* \cdot E dv/4W \tag{1}$$

$$\frac{1}{Q} - \frac{1}{Q_0} = 2\varepsilon_0\varepsilon_r''\int_{ve} E_0^* \cdot E dv/4W, \tag{2}$$

where $W = \int_{ve}[(E_0^* \cdot D_0 + H_0^* \cdot B_0) + (E_0^* \cdot D_1 + H_0^* \cdot B_1)]dv$ and $\Delta\omega = f - f_0$, $f_0 = \omega_0/2\pi$. E_0^*, D_0, B_0 and H_0 are the fields in the unperturbed cavity, and D_1 and H_1 are the fields in the interior of the sample. V_c and V_e are the volumes of the cavity and the sample respectively, dv is the elemental volume.

In the vicinity of its resonance, the cavity can be modeled as a lumped element resonator. The transmission of power can therefore be described as:

$$|S_{21}|^2 = \frac{a}{b + (c - f)^2}, \tag{3}$$

where f is the normalized frequency; a, b and c are used as fitting parameters. This equation is a Lorentzian curve. The resonance frequency and the quality factor Q are $f_r = c$ and $Q = c/2\sqrt{b}$, which can be determined by stepping–sweeping the frequency. According to microwave network theory the cavity can be modeled by S-parameters, and $S_{21} = \frac{V_2^-}{V_1^+}\Big|_{V_2^+=0}$, where S_{21} is the forward transmission coefficient when the output port is terminated in a matched

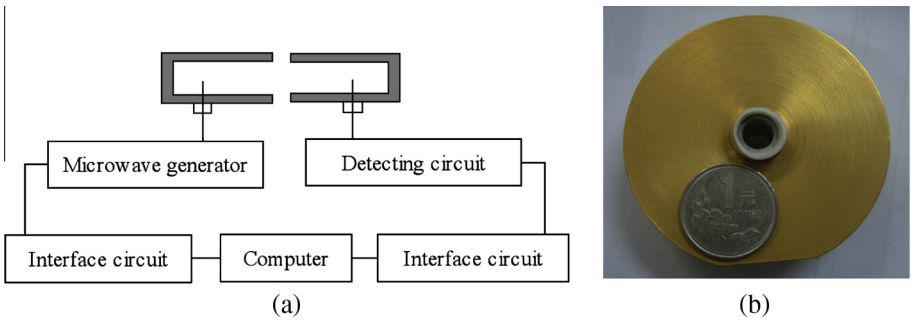

Fig. 1. (a) The structure diagram of the microwave sensor system for measuring the moisture content of milk powder. (b) A photograph of the microwave resonant cavity.

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