



Temperature effects and compensation in ultrasonic concentration measurement of multicomponent mixture



Xiaobin Zhan, Yili Yang, Jian Liang, Tielin Shi, Xiwen Li*

State Key Laboratory of Digital Manufacturing Equipment and Technology, Huazhong University of Science and Technology, Wuhan 430074, China

ARTICLE INFO

Article history:

Received 24 April 2016

Received in revised form 25 October 2016

Accepted 26 October 2016

Available online 27 October 2016

Keywords:

Ultrasonic sensor

Temperature compensation

Concentration

Multicomponent mixture

Partial least squares

ABSTRACT

The ultrasonic technique has been successfully used to measure the concentrations of mixtures, but ultrasonic sensor is sensitive to the temperature of mixtures, which makes the ultrasonic concentration measurement very difficult. In this study, a novel ultrasonic method for compensating the temperature effects and measuring the concentrations of multicomponent mixtures comprising insoluble and soluble substances is proposed. At first, the temperature effects on the ultrasonic signals and ultrasonic concentration measurement of mixtures are investigated. Then, the stepwise temperature compensation (STC) model based on the synergy interval partial least squares (Si-PLS) model and linear interpolation as well as the global temperature compensation (GTC) model based on the Si-PLS model are separately established in combination with the ultrasonic spectra. The overall results indicate that the combination of ultrasonic spectra and temperature compensation models can compensate for the temperature effects effectively and measure the component concentrations of multicomponent mixtures in the range from 16 °C to 40 °C. The GTC model, with which the root mean square error of the prediction subset is 0.54 wt.%, is superior to the STC model, especially when the temperatures of samples are difficult to be acquired or have to be estimated from the ultrasonic spectra. The proposed method can broaden the application scope of ultrasonic concentration measurement, which makes it easier to monitor production process and product quality of multicomponent mixtures with one ultrasonic sensor only.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

In food, chemical and pharmaceutical industries, the multicomponent mixtures comprising insoluble and soluble substances have been widely used in such processes as mixing, suspension, crystallization, etc. Fast and accurate concentration measurements of multicomponent mixtures are of great significance for process control and quality management [1]. Owing to the advantages of stability and cost-effectiveness, the ultrasonic technique has found wide applications in online measurement of component concentrations of solutions and suspensions with high temporal and spatial resolutions [2].

Unfortunately, it is well known that the ultrasonic sensor is not only sensitive to the component concentrations but also respond to the temperature of mixtures [3,4], which makes the ultrasonic concentration measurement very difficult. For this reason, most ultrasonic measurements are often carried out with thermostated samples by using either water tanks or climate chambers [5,6].

However, in many industrial applications, the temperature of mixtures cannot be precisely controlled as desired. What's more, the changing temperatures are even required in some processes, e.g., crystal growth [7]. Thus, the application scope of ultrasonic technique in industrial processes is limited by the temperature effects. This is also a common problem in the measurements of industrial processes using the NIR spectrum [8] and the Raman spectrum [9], etc.

In order to measure the concentrations of mixtures using the ultrasonic technique in industrial processes, it is necessary to compensate the temperature effects on the ultrasonic signals [10]. Some researchers [11–13] established an empirical equation among concentration, ultrasonic features and temperature to eliminate the temperature effects and estimate the biomass concentrations. Huang et al. [14] measured the solid suspension concentrations at different temperatures using the linear functions of attenuation and temperature for concentration. Nevertheless, the empirical equations and linear functions were fit for two-component mixtures and limited by strong interactions among components if applied to the concentration measurement of multicomponent mixtures. Wang et al. [15] established a temperature compensating model based on the neural network to eliminate the temperature effects

* Corresponding author.

E-mail address: xiwenli@hust.edu.cn (X. Li).

on ultrasonic flow measurement, but the neural network had a disadvantage, that is, the available sample set should be considerably large for the purpose of effective training. Despite the fact that Krause et al. [16] combined the sub-models for different temperature points to build a unified model which could detect the concentrations of ternary solutions at different temperatures, it was required that the sub-models should have the same framework. So far, there is not an appropriate method to compensate for the temperature effects in measuring the concentrations of multicomponent mixtures which comprise insoluble and soluble substances.

The ultrasonic spectra transmitted through the multicomponent mixture contain sufficient information about the component concentrations. Unfortunately, it is very difficult to separate the mutually interfering effects of temperature and component concentrations on the ultrasonic spectra in multicomponent mixtures. The partial least squares (PLS) model is particularly suited for quantitative analysis of spectral data when the predictor matrix $\mathbf{X}$ has more variables than samples and/or when there is multicollinearity among $\mathbf{X}$ variables [17]. The full ultrasonic spectrum may contain useless information like noise which can worsen the model predictability [18]. The synergy interval PLS (Si-PLS) model is commonly used to search for all possible combinations of subintervals and find out the optimal spectral intervals that contribute to the maximal precision of models [19]. Therefore, the Si-PLS model is used as the basic technique for selecting the spectral subintervals and building the temperature compensation model in the study.

In the study, a novel technique for compensating the temperature effects and measuring the concentrations of multicomponent mixtures within the range from 16 °C to 40 °C is proposed through the combination of ultrasonic spectra and temperature compensation models based on the Si-PLS model. Though the establishment of temperature compensating model is time-consuming, the prediction of concentrations can be completed in a short time. The proposed method is advantageous owing to simplicity and easy implementation and makes it possible to carry out online monitoring for production process and product quality in multicomponent suspensions with one ultrasonic sensor only.

2. Materials and methods

2.1. Samples preparation

In the experiments, the multicomponent mixtures composed of pure water, TiO₂ (the poly-disperse particles with the mean size of 19 μm) and glucose are used instead of a specific industrial product. The component concentration represents the mass fraction of one component to the total mixture in this study.

The temperature points for calibration are selected in the range from 16 °C to 40 °C with an interval of 2 °C. At each temperature point, TiO₂ is prepared in 8 groups from 0 g to 210 g, with an interval of 30 g, and glucose is prepared in 13 groups from 0 g to 180 g, with an interval of 15 g, respectively. 600 g pure water is added into the possible combinations of TiO₂ and glucose to obtain 104 samples. These samples make up the calibration subset which is used to build the regression model.

The temperature points for prediction are selected in the range from 16 °C to 40 °C with an interval of 1 °C. Similarly, at each temperature point, TiO₂ is prepared in 5 groups from 0 g to 210 g, with an interval of 27 g between the first and second groups and 54 g from the second to fifth groups, and glucose is prepared in 7 groups from 0 g to 180 g, with an interval of 28 g, respectively. 600 g pure water is added into the possible combinations of TiO₂ and glucose to obtain 35 samples. These samples (the sample of pure water is

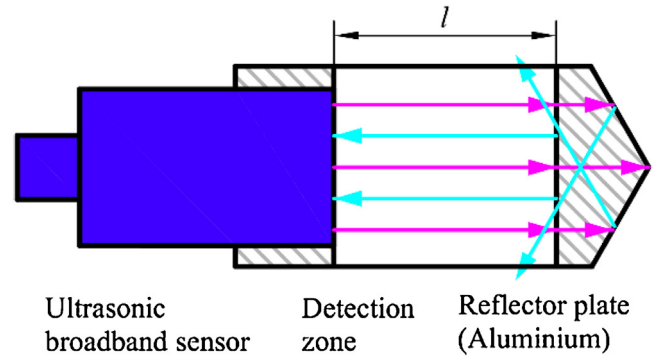


Fig. 1. The schematic diagram of broadband ultrasonic pulse-echo reflectometer.

excluded) constitute the prediction subset which is used to evaluate the model performance only.

2.2. Ultrasonic measurement system

The ultrasonic measurements are conducted using a broadband ultrasonic pulse-echo reflectometer (BUPR), as shown in Fig. 1. The arrangement of BUPR in samples is intrusive in nature but helpful to improve the signal strength of reflected echoes. Due to the invasive nature of measurements, the transducers are enclosed in a cylindrical housing to minimize the resistance of flows. The reflector plate is conical in order to prevent the echoes reflected by its outer surface from interfering those reflected by the inner surface.

The ultrasonic wave is transmitted into samples by an ultrasonic transducer (Olympus V306-SU, with the center frequency of 2.25 MHz), which is excited via an ultrasonic pulser/receiver (Olympus Models 5072 PR) at 100 Hz. The reflected echoes traveling through samples are received by the same sensor and detected with an oscilloscope at the sampling rate of 500 MHz. The samples and BUPR are contained in a flat-bottomed cylindrical tank, while the tank is immersed in a circulating thermostatic water bath to control the temperature of samples with the accuracy of ±0.1 °C. The samples are constantly stirred to ensure their homogeneity.

The first echo signals and temperatures of each sample are real-time acquired with an interval of 1 s after the samples become homogeneous and the temperatures become stable. The first echo signals of samples in the time domain are windowed over 5 μs. For each sample, 300 windowed signals and 300 temperature data are averaged at first, and then the averaged signals are zero-padded and mapped to the frequency domain using the fast Fourier transform (FFT) algorithm. The process is shown in Fig. 2.

The ultrasonic spectrum in the bandwidth of 1.76–3.28 MHz is chosen for further analysis because the signal-to-noise ratio (SNR) is sufficiently high in that range. In this paper, the phase velocity of a sample is derived from the ultrasonic velocity of water and the difference of the phase spectra between the sample and water via the following formula [20,21]:

$$v_s(k, T) = \frac{v_w(T)}{1 - \frac{v_w(T)}{4\pi l} (\theta_s(k, T) - \theta_w(k, T))} \quad (1)$$

where l is the length of acoustic path, $\theta_s(k, T)$ and $\theta_w(k, T)$ are the phase spectra of the sample and water at temperature T respectively, $v_w(T)$ is the ultrasonic velocity of water and assumed to be dispersionless and dependent on temperature T [22]. The attenuation spectrum of the sample is calibrated by measuring the amplitude spectrum of pure water at the same temperature and calculated with the equation below:

$$\alpha(f, T) = \frac{1}{2l} \ln \left(\frac{X_w(k, T)}{X_s(k, T)} \right) \quad (2)$$

Download English Version:

<https://daneshyari.com/en/article/5008507>

Download Persian Version:

<https://daneshyari.com/article/5008507>

[Daneshyari.com](https://daneshyari.com)