바이오시스템공학 (*J. of Biosystems Eng.*)
Vol. 33, No. 6, pp. 410~415 (2008. 12)

토마토 패이스트 가공공정의 온라인 모니터링용 RF 센서의 활용 가능성

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Feasibility of RF Sensor Application for On-line Monitoring of Tomato Paste Processing

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Abstract

On-line monitoring of fresh tomato paste processing was done using two radio frequency (RF) sensors resonant at 85 and 110 MHz. Fresh tomato juice with soluble solid content of about 5 °Brix was evaporated up to 23 °Brix and diluted down to about 5 °Brix again with a pilot scale evaporator. The RF sensors were installed in a processing pipe and monitored. The pastes at a specific °Brix level were sampled and analyzed for physical properties such as soluble solid content and viscosity. The relationships between sensor outputs and measured physical properties were analyzed. Analysis results showed RF sensor is feasible to apply on-line monitoring of tomato paste processing.

Keywords : RF sensors, on-line monitoring, Tomato paste processing, Soluble solid content, Viscosity

1. INTRODUCTION

In the tomato processing industry, sauces and pastes manufactured from fresh tomatoes are sold according to their consistency as measured by a Bostwick index. For tomato products, Bostwick values may range from approximately 1 for pastes to over 10 for less viscous sauces. While the Bostwick measurement has proven to be adequate for quantifying the consistency of tomato pastes and many other food products, it epitomizes the shortcomings of off-line measurement regimens. Paste samples must be taken from the process stream and cooled to 20℃, the standard temperature at which Bostwick measurements are performed, before being loaded into the gated compartment. The user must then perform the 30 second test, repeating the measurement at least once due to the inherent imprecision of the Bostwick device. Since it requires to remove the entire paste sample and clean the device between repetitions is taken into account, obtaining an accurate Bostwick reading for a single batch of paste may take several minutes. Because the paste is simultaneously being concentrated in an evaporation process, its consistency can change significantly while off-line testing is taking place.

Effective on-line process control requires both precision and speed in order to achieve the desired product specifications. Ideally, sensor apparatus to monitor process variables should provide accurate data in real time to ensure that the necessary corrective measures can be taken. In the food processing industry, most process monitoring takes the form of off-line testing, which can be time consuming, labor intensive, and inaccurate. Due to the batch type characteristic in food production, the processing operator is often forced to

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This study was conducted by the research fund supported by Chonbuk National University. The article was submitted for publication on 2008-12-02, reviewed on 2008-12-05, and approved for publication by editorial board of KSAM on 2008-12-10. The authors are Seongmin Kim, Division of Bioresource Systems Engineering, Chonbuk National University, Korea, Casey Garvey, Quality & Innovation, ConAgra Foods, Inc., Thomas Leary, Department of Chemical Engineering, University of California, and Michael McCarthy, Department of Food Science & Technology, University of California, USA. Corresponding author: S. M. Kim, Division of Bioresource Systems Engineering, Chonbuk National University, Jeonju, Chonbuk, 561-756, Korea; Tel: +82-63-270-2613; Fax: +82-63-270-2620; E-mail: <smkim@chonbuk.ac.kr>.

choose between holding up a batch to verify product integrity via offline measurements and simply not performing the measurements. The demand for a probe that can perform the requisite measurements in situ then becomes self-evident.

In addition to the Bostwick index for consistency, tomato products are quantified according to their soluble sugars concentration, measured in the food industry as degree Brix. Typical Brix values for tomato concentrates range from 5 °Brix for juice from freshly ground tomatoes up to 32 °Brix for highly concentrated viscous pastes. To achieve maximum accuracy, Brix values should be measured on the serum from tomato concentrates using a refractometer. However, reasonable accuracy can be achieved by testing the tomato concentrate itself with an on-line refractometer. Thus, a correlation between Bostwick index and Brix value can be obtained. The problem with such a correlation is that tomato concentrates at a given Brix value (and temperature) can exhibit a wide range of viscosities, depending on the tomato variety from which the concentrate originates.

The ability to precisely determine the viscosity of a tomato concentrate during batch evaporation via an on-line, non-intrusive sensor offers a promising alternative to measurement techniques currently used in the food processing industry. Traditional bench-top rheological instruments, such as rotational and tube viscometers, are widely used in the food processing industry but suffer from fouling issues, therefore, not well-suited for continuous on-line operation. In many food applications, the presence of particles creates wall slip problems in tube viscometers (Cullen et al., 2000). This issue may be circumvented by collecting data from tube viscometers of different radii to obtain a slip coefficient as a function of shear stress at the wall. However, deviations from viscous flow may yield non-physical results (Steffe, 1996). Optical methods have shown a strong correlation between water-insoluble solids content and Bostwick value for dilute tomato concentrates, but the correlation is weaker for concentrated tomato pastes (Haley and Smith, 2003). Recent work on this subject has examined the feasibility of an ultrasonic Doppler velocimetry (UDV) technique to monitor tomato concentrate properties during evaporation (Choi et al., 2006). However, UDV techniques are sensitive to mechanical vibrations, making them less than ideal for an industrial setting where a more robust apparatus is required. More critically, penetration depth can be extremely limited for suspensions with high particle loadings, resulting in an incomplete velocity profile and direct contact with tomato juice is very bad.

In dielectric spectroscopy measurements, coaxial probe techniques are still widely used, with a number of commercial models available (Datta et al., 2005). However, they suffer several drawbacks, most critically the necessity of physical contact between the probe and the test material. This negates the possibility of using such probes on-line. Additionally, measurements performed by coaxial probe methods are susceptible to inaccuracy due to signal reflection from the sample holder if the field is not sufficiently attenuated in the sample itself (Nelson and Bartley, 2002). This may be an issue with low loss substances, such as food materials containing little water. Another disadvantage, at lower (radio) frequencies, is the accumulation of charge at the probe surface if an ionic substance is tested. This dielectric loss mechanism decreases with increasing frequency and is not significant at microwave frequencies (Ryynanen, 1994). Often, absolute calibration is not necessary, since the physical properties to be measured can be correlated to the network parameters rather than the actual dielectric values (King et al., 1996). Reflection resonance probes have been made in numerous shapes and sizes for a wide variety of applications, including portable units used for in situ determination of peat moss quality and snow pack wetness (Nyfors and Vainikainen, 1991). They have also been utilized on-line to monitor dynamic processes such as epoxy resin cures. In this application, the resonant frequency of the probe was shown to be closely correlated with resin viscosity (King et al., 1993).

The objective of this work was to employ reflection resonance probes operating in the radio frequency range for on-line monitoring of a tomato concentrate batch evaporation process by correlating the dielectric response of the tomato concentrate to its physical properties.

2. MATERIALS AND METHODS

A. Sample Preparation and Experimental Setup

A high viscosity paste type processing tomato variety, H9780, harvested at the beginning of September and October, 2006 in the middle of California area was used. Fresh, mature tomato fruits were ground into juice, and then processed through a 'hot break' during which it undergoes a rapid heat treatment at 104℃ to inactivate enzymes. After seeds and skin were screened out, the tomato juice was then placed under a vacuum of roughly 26.7 KPa for 30 seconds to remove air bubbles before being stored at 4℃ until loaded into the evaporator.

Batch evaporation of the tomato concentrate was done in a single stage tube and shell pilot-scale Rossi-type evaporator, which can produce commercial quality paste. The progress of the evaporation was monitored via an on-line refractometer (UR-20, Maselli Measurements, Stockton, CA, USA) to determine the Brix value of the concentrate for sampling points from the evaporator. The evaporation continued until the circulator pump began to cavitate due to the high viscosity of the tomato paste.

During the evaporation process, tomato concentrate was sampled at predetermined Brix values to perform the off-line physical property testing. Six Brix values were selected: the initial Brix value of the tomato juice, 7, 14, 16, 20, and the final maximum Brix value of the tomato concentrate. Once the final sample was taken, the tomato concentrate in the evaporator was gradually diluted back to its initial Brix value with deionized water, with sampling for off-line testing at the about same Brix values as during evaporation. Ultimately, each complete concentration and re-dilution trial provided 11 sampling points for off-line physical property measurements. Two experiments were performed with sensor A and B which resonant frequencies are 110 MHz and 85 MHz respectively. One experiment was utilized tomatoes harvested on September and RF sensor A, and the other was done with tomatoes harvested on October and RF sensor B.

Batch evaporation of the tomato concentrate was performed in a Rossi-type evaporator (Fig. 1). This consists of a cylindrical vessel connected to three pumps: a loading pump to feed the freshly ground tomatoes into the evaporator, a circulator pump (Wakkesha Model 024, Cherry-Burrell, Delavar, WI, USA) to continuously move the concentrate through a tube-and-shell heat exchanger (56×4.76 mm tubes with 38.1 mm OD SS sanitary pipe), and a vacuum pump (Model TRSC 40-100/C/F, Coker Pump and Equipment, Salida, CA, USA) to remove the evaporating water vapor from the concentrate. When fully loaded, the evaporator holds 35 L of tomato concentrate.

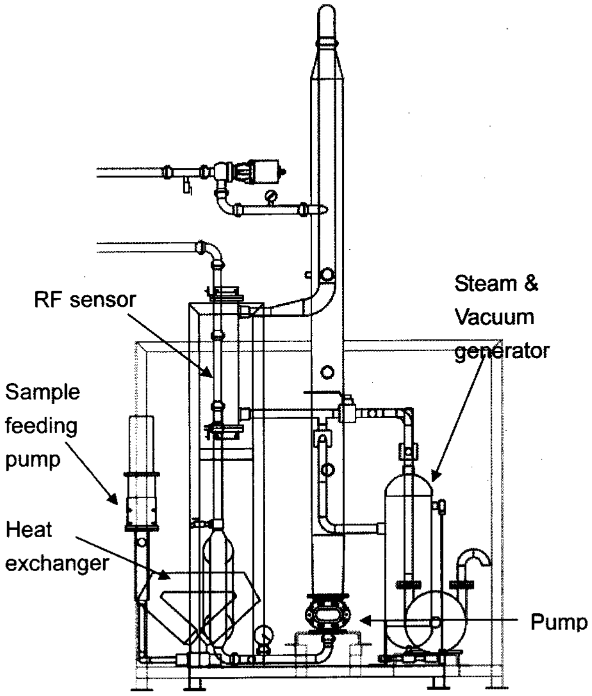

Fig. 1 Pilot scale Rossi-type evaporator.

B. Measurements of Physical and Rheological Properties

Soluble solids measurements were performed using a refractometer (RFM 320, Bellingham & Stanley Ltd., Tunbridge Wells, Kent, UK) to analyze the Brix of serum of the tomato concentrate. Three samples were taken from each sampling point and the total solids fraction recorded was the mean of the three tests. The apparent viscosity of the tomato concentrate samples was measured directly by a rotational viscometer (Viscotester VT24, Haake, Saddle Brook, NJ) using the infinite cup geometry. The tests were performed at approximately process temperature (50℃). The reading on the viscometer was converted to a viscosity value in centipoise using a calibration curve made from test fluids of known viscosity. This measurement was performed twice and averaged. Tomato concentrate samples were analyzed to determine the Bostwick index using a standard Bostwick consistometer (CSC Scientific, Inc., Fairfax, VA). The samples were cooled to 20℃ and loaded into the gated compartment.

Once the spring-loaded gate was opened, the distance the concentrate traveled in 30 seconds was measured to the nearest 0.1 cm. Each measurement was performed twice.

C. Dielectric Response Measurement

Measurements of the dielectric response of the tomato concentrate were performed on-line using two types of reflection resonance probes (Aspect Magnet Technologies Ltd., Ben Shemen, Israel) operating at different resonance frequencies connected to a network analyzer (Model 8753C 300 kHz - 3 GHz, Hewlett Packard, Palo Alto, CA, USA) and a laptop computer. The probe was mounted on the return line of the evaporator circulator pump, above the tube-and-shell heat exchanger and below the sampling port. LabVIEW software (National Instruments, Austin, TX, USA) controlled the probe via the network analyzer. The computer logged data files containing two reflection coefficient readings for each of the discrete frequencies at 46 second intervals. The resolutions of sensor A and B are 0.15 MHz and 0.1 MHz, respectively. Data files were time stamped to accurately correlate the network analysis measurements to off-line physical property testing on each sample. Analysis of the reflection coefficient data was performed using MATLAB (R2006b, MathWorks Inc., Natick, MA, USA). The resonance frequency f_r and the normalized impedance magnitude Z were calculated by following equations defined as:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

$$Z = \left|\frac{Z_L}{Z_0}\right| \tag{2}$$

where Z_L and f_r are the load impedance and resonance frequency of RF sensor circuit depicted in Fig. 2 and Z_0 is the characteristic impedance of the cable transmitting the electric current to the resonance probe. Impedance magnitude sum, which was derived from summing normalized impedance magnitude at the 4.5 MHz (Sensor A) and 3 MHz (Sensor B) swept frequency range around resonance frequency, was calculated and used it for analysis.

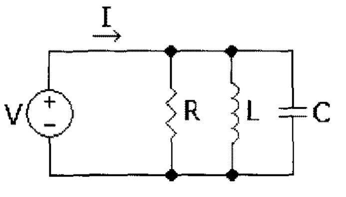

Fig. 2 Schematic diagram of RF sensor circuit.

3. RESULTS AND DISCUSSION

A. Correlation of Resonance Frequency to Physical Properties

The resonance frequency and magnitude of impedance, calculated from reflection coefficient data, of RF sensors were the two parameters with which correlations to physical properties were made. Because the probes were specifically designed for the tomato evaporation process, its resonant frequency was located approximately in the middle of the 30 MHz and 20 MHz swept frequency range for RF sensor A and B, respectively. The left side of Fig. 3 and Fig. 4 show the plots related to resonance frequency changes of RF sensor A and B during tomato concentrate processing, respectively. Although the resonance frequency clearly de-

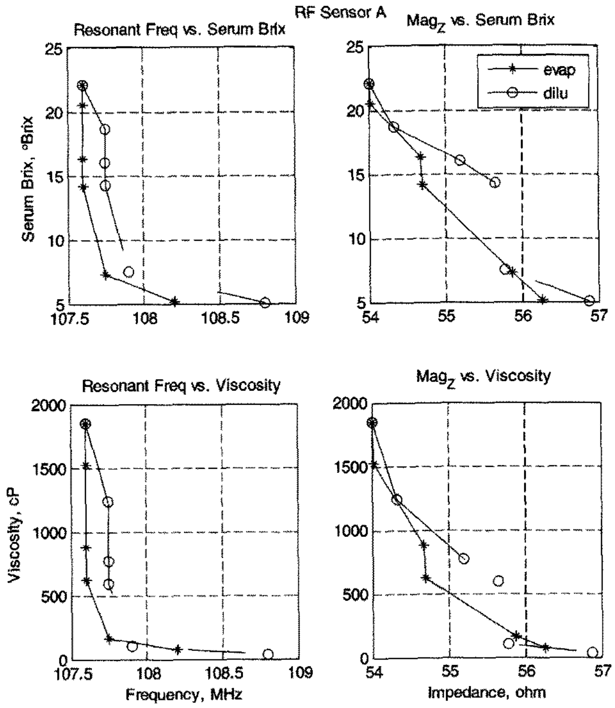

Fig. 3 Analysis plots for Sensor A. evap = evaporation, dilu = dilution, Resonant Freq = sensor resonance frequency, Mag$_Z$ = magnitude of impedance. Fig. 4 Analysis plots for Sensor B. evap = evaporation, dilu = dilution, Resonant Freq = sensor resonance frequency, Mag$_Z$ = magnitude of impedance.

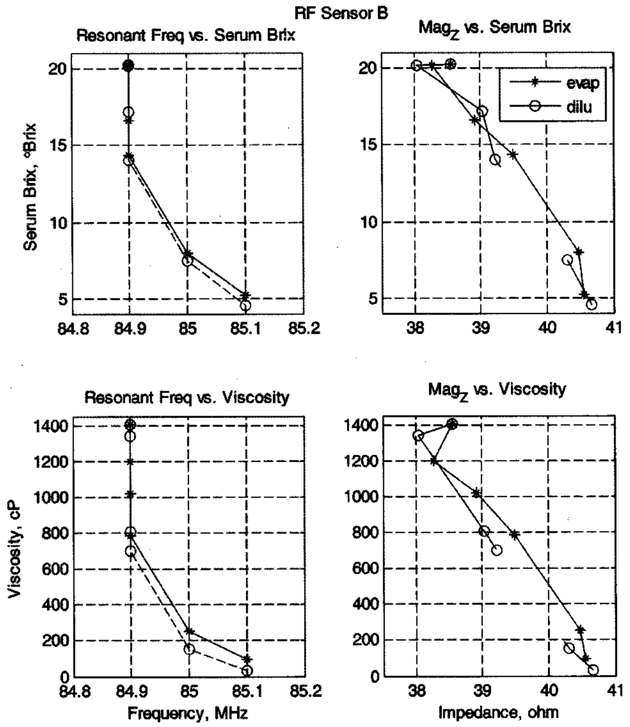

Fig. 4 Analysis plots for Sensor B. evap = evaporation, dilu = dilution, Resonant Freq = sensor resonance frequency, Mag$_Z$ = magnitude of impedance.

creases as the evaporation proceeds, the resolution of the probe is insufficient to distinguish among tomato concentrates at Brix values higher than 14 °Brix. Sensor A shows frequency upward shift in 0.15 ppm during dilution process whereas Sensor B doesn't show any frequency shift during evaporation and dilution process.

For ionic species such as Na and Cl to pure water are present in significant amounts, the capacitor in the tank circuit must be modeled in series with a resistive element, such that the resonance frequency of the circuit decreases as the effective resistance (inversely related to the conductance of the test material) decreases. This is the only mechanism by which a material whose dielectrically active component is being removed could exhibit a decreasing resonance frequency. At the highest Brix values, resonance frequency remains constant. This means no significant change in the mean state of the associated water is observed during this part of the evaporation process.

B. Correlation of Impedance to Physical Properties

The right side of Fig. 3 and Fig. 4 show the plots related to impedance changes of RF sensor A and B during tomato concentrate processing, respectively. Sensor A shows more changes in impedance magnitude sum than Sensor B. As the evaporation proceeded, the magnitude sums of sensor impedance usually decreased. It could be due to an increase in the material's dielectric loss factor as the ionic species present are concentrated during the evaporation. Therefore, one might expect that as the tomato concentrate changes from a 'liquid' sauce to a 'solid' paste, the mobility of its free ions is decreased and their contribution to signal loss is commensurately reduced.

C. Correlation of Viscosity and Soluble Solid Content

Fig. 5 shows a plot between viscosity and serum Brix of sampled concentrate of two experiments. The sample used for testing Sensor A is more homogeneous than one used for Sensor B. The important physical properties of the tomato concentrate are its viscosity and soluble solid content expressed as serum Brix. The ultimate goal of this project was to establish a meaningful correlation between these off-line measurements and the dielectric response of the tomato concentrate as measured by one or more parameters via on-line RF sensor. The resonance frequency ceased to change in response to the increasing viscosity of the tomato concentrate after 14 °Brix. However, the impedance magnitude sum decreased as the concentrate viscosity increased. Sensor B responds more linearly in about same range than Sensor A. Analysis showed RF sensor is feasible to apply on-line monitoring of tomato paste processing but needs more works to use it as an on-line sensor.

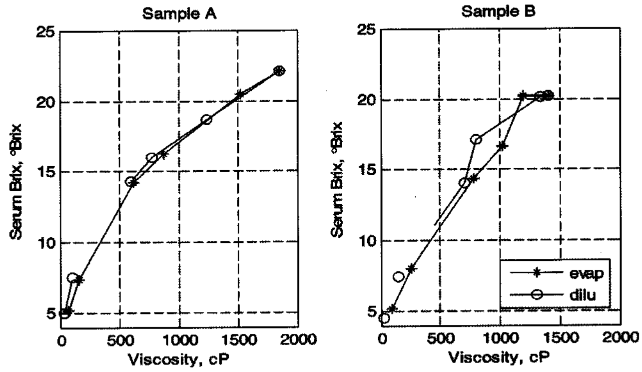

Fig. 5 Relation between viscosity and serum Brix of sampled concentrate of two experiments. A = harvested on September, B = harvested on October. evap = evaporation, dilu = dilution.

4. CONCLUSIONS

On-line monitoring of fresh tomato paste processing was done using two kinds of radio frequency (RF) sensors resonant at 85 and 110 MHz. Fresh tomato juice with soluble solid content of about 5 °Brix was evaporated up to 23 °Brix with a pilot scale evaporator. The RF sensors were installed in a processing pipe. The relationship between sensor outputs and measured physical properties demonstrate the potential for using a RF sensor for on-line tomato juice process control. Analysis results showed RF sensor is feasible to apply on-line monitoring of tomato paste processing.

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